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Climate and Constructions

International Conference
24 and 25 October 2011, Karlsruhe, Germany

Competence Area “Earth and Environment”

Andreas Gerdes, Christoph Kottmeier, Andreas Wagner (eds.)

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edited by
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Preface

Climate impacts the construction sector in various ways. In this context, the construction sector includes not only construction chemistry, materials technology and building science, but also planning, construction techniques and urban climate.

The challenge is to identify which component is most vulnerable to changes in climate and how to respond to these changes. Many challenging questions are raised by scientists, policy makers, industry etc. For example, what do we know about climate change and its impacts on the construction sector? Which technologies are needed to respond to future climate conditions without neglecting ecological, social, and economical aspects? The conference establishes a platform to discuss scientific results in combination with practical examples, and therefore, contributes to an increased understanding of the two-way interaction between climate change and the construction sector.

The Karlsruhe Institute of Technology (KIT) is one of the leading research institutions in the technological sector. Its main focal points are research, teaching, and innovation. KIT is part of the Helmholtz Association and bundles its environmental research in the KIT Center "Climate and Environment", which supports the dialog at the conference.

Important contributions will be given by international experts in this field and will range from energetic interactions in the urban boundary layer to the life cycle management of building structures. Apart from these, also contributions on subjects like modelling of material behaviour or the production of low CO_2 building materials form part of the discussion. KIT would like to stimulate on the theme of Climate Change and Constructions.

Karlsruhe, October 2011

Prof. Andreas Wagner
Prof. Dr. Christoph Kottmeier
Prof. Dr. Andreas Gerdes

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Chapter 1: Building Science

Climate and Constructions
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Climate Mitigation and Adaptation in the Built Environment – Sticks, Carrots or Tambourines … Where to From Here?

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Abstract

Current trends point to a future where the population (and resource consumption) is continuing to grow, our resources are dwindling, and the economy is carbon-constrained (in both climate mitigation and adaptation modes – also known as a “low-carbon economy future”). Our built environment will continue to be an important, and even critical, factor in addressing these global and local challenges. This presentation will give an overview of the “glo-cal” challenges and a range of possible solutions, ranging from a focus on an individual building, or the building stock, or a jurisdiction (state or national). The alternative pathways forward will involve a combination of regulations (“sticks”), incentive schemes and market-based instruments (“carrots”), and stakeholder engagement, awareness and education (“tambourines”). Methods of assessing their effectiveness for climate mitigation and adaptation into the future will be presented. With the current greenhouse gas (GHG) concentration already in the atmosphere, even if further emissions are successfully mitigated within the next several decades, the changing climate will influence weather patterns, temperature and coastal environments, among other geophysical effects. Thus, the planning, design, construction and management of our built environment now demand that they contribute to both global GHG emissions reduction and local climate adaptation strategies. Key projects and examples will be cited. Time is very limited and the challenges are immense; thus, rapid rates of technological, industrial and market transformation are required. Aiming for efficiency (i.e. shortest path and best use of limited time and resources) and effectiveness (i.e. sustained change over time), a systems-based “tipping point” approach is advocated.

Climate and Constructions
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Climate Change and Sustainable Development - Consequences for Risk Assessment and Economic Valuation of Buildings

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Abstract

The construction and real estate industries are confronting a range of current challenges, which are closely associated with megatrends such as climate change, depletion of re-sources, demographic change, changes in types of living accommodation and living prefer-ences, urbanisation and globalisation. The focus of this contribution lies in the approach to climate change, which opens new opportunities and markets as well as creating additional risks. The construction and real estate industries contribute on the one hand to climate change, but on the other hand they are also heavily affected by its consequences. These industries are therefore pursuing a twin strategy. As regards the subject of climate change, this consists primarily of:

- Ensuring that a contribution is made to easing the burden on the environment and to limiting global warming through a reduction in the emissions of climate-related gases, which are caused by the manufacture, construction and use / operation of buildings and constructed assets (mitigation).
- Avoiding or overcoming the consequences of climate change, which have already begun and which will in future be felt even more strongly (adaptation).

There are also economic consequences of the nature and scope of the contribution, which buildings can make to increasing or easing the burden on the environment, as well as of the nature and scope of the ability of buildings to withstand the effects of climate change. In this contribution there will therefore be discussions about whether, and how, questions re-garding the approach to climate change can be incorporated into risk analysis and portfolio management in the real estate

industry, as well as about whether and how this has an impact on valuation and appreciation in value. This is classified into the subject area of the description and evaluation of the contribution, which real estate can make to sustainable development. Touched on here are also questions about the contribution, which can be made by buildings to the saving of resources, to the easing of the burden on the environment and to climate protection, while at the same time maintaining their functionality, durability and economic value.

1 Climate change from the view of the building and real estate industries

There have been discussions for some time now on the questions about the effects and con-sequences of climate change for the construction and real estate industries (e.g. [1], [2], [3), [4]). The analysis on this subject can be made from the perspective of one particular industry sector (e.g. [5], [6]) or from the specific view-point of one building or real estate company, or it can be made within the context of the further development of standardized and/or legal requirements (e.g. [7], [8]), or finally it can be made in connection with con-crete individual projects (planning, construction, transactions, financing, insurance). A par-ticular comparable starting point is firstly to incorporate the analysis on questions of climate change into those medium to long-term perspectives, which do however have immediate conse-quences for activities today.

Starting points and solutions for the integration of the strategies of climate change mitigation and adaptation, must however be developed specifically for the particu-lar level of activity (sector, company with building stocks, individual projects). It is important in this regard to in-tegrate the subject of climate change into the methods and instruments, which the relevant stakeholders use as the basis for making their decisions. The relevant groups of stakeholders in this regard are, inter alia, companies in the building industry, companies in the housing and real estate industries, financial institutions and insurers, real estate agents, valuers, standards organisations and legislators. Appropriate starting points for this integra-tion of the subject of climate change are decisions on location sites, planning deci-sions, decisions about sales transactions, and decisions on the financing and insu-ring of projects, including the drafting of the corresponding terms and conditions, and with this the questions on the future development of risk analysis, portfolio management and valuation.

The following contribution concentrates on these three methods and it also deals with ques-tions of the evaluation of sustainability. Building stocks and individual projects are also dealt with.

2 Consequences for risk analysis and valuation

Discussed below, primarily from the viewpoint of the housing and real estate indus-tries as well as of the financial and insurance institutions, are the consequences for risk analysis and valuation of an analysis on the subject of climate change for the building sector and building stock. This is conducted separately for the split subjects of mitigation and adaptation.

2.1 Subject area of Mitigation

It is well known that the building and real estate industries form a high proportion of the de-mands on resources and the consequent impact on the environment. The manufacture, erec-tion and use of buildings contribute to global warming and climate change, due to the emis-sions of climate-related gases caused by the use of energy. Similarly well known is the huge savings potential, which can be exploited by suitable measures, as long as the conditions of technical feasibility and economic viability are met.

The relationship to risk analysis and valuation has been to date predominantly indirect. The climate protection targets in the building sector are generally translated into increased de-mands on the energy efficiency in buildings. With the introduction in 2010 of the Property Valuation Act (ImmoWertV), it was clearly recognized in Germany that energy efficiency / energy performance was a factor influencing property values. Although energy efficiency is not precisely defined, it is accepted that, in addition to the energy requirement and the effi-ciency of the energy supply, this also includes the energy source and, as part of this, the type and scope of renewable energy. In this regard CO_2 emissions are already covered.

Concepts for 'net-zero-emission-buildings' are already being worked on in development, and in some individual countries, information about the property-related CO_2 emissions already forms part of the energy certificate which has to be provided in sales transactions.

It can clearly be established that to date any correlation between property risk and property value on the one hand and emission-related contribution to climate change on the other have been dealt with overwhelmingly by way of a 'detour' via energy efficiency. Increasingly how-ever companies are becoming interested in positive sustainability reports and small carbon footprints. This has consequences for their decisions with regard to the construction, purchase or renting of property - and in their consideration of individual projects as well as in the evaluation of complete stocks (industrial companies, housing companies, property funds). Buildings which have too high energy-related CO_2 emissions in their usage adversely affect the reputation and image of the building users. In this respect buildings with above average energy-related CO_2 emissions present an increased letting or marketing risk.

The CO_2 emissions in the life cycle and thereby the contribution to the greenhouse effect (GWP - Global warming potential) flow for example in Germany into the sustainability as-sessment of buildings. The result of this is starting to impact, at the very least indirectly, on the letting and marketing as well as on the value of property.

One can assume that in future buildings, which have a high energy consumption and above average emissions of climate-related gases, will have to suffer reductions in value. It is not yet possible to estimate whether, and how far, considerations about extending CO_2 carbon trading to buildings will impact on risk analysis and valuation.

A further opportunity for the real estate industry to provide for a reduction in unwanted effects on the (local) environment, is to contribute to the reduction of the 'urban heat island' effect in town and city centres. Besides initiatives and starting points associated with town planning, this can also involve for example measures such as the green landscaping of roofs and building facades.

2.2 Subject area of Adaptation

Climate change, which is already upon us and will probably become more pronounced, leads to very significant consequences for all types of buildings ([9], [10]). It needs to be analysed in every case what this involves at the particular site, and with what risks, and also whether, and how far, the building is suitable with its features and characteristics to face the outcome of climate change. The analysis of this subject of adapting to climate change leads therefore to consequences for the assessment of risks at locations and in projects, even within the framework of risk management for individual properties ([11], [12], [13]).

This analysis of risks at site locations is carried out within the framework of an analysis of both the macro and micro locations. It is recommended that not only the current situation with regard to the consequences of climate change is analysed, but that also the future trend of this development and its consequences are included. Up to now this has barely been ex-tended to the site analysis. It is therefore recommended that in future both the current situa-tion and the trend of the consequences of climate change are included in the site analysis, to the extent that this is sensible and meaningful for the particular location. Table 1 gives an overview of this.

Besides the analysis of the possible consequences of climate change on the location, the site analysis will also in future have to adopt building and organisational measures for precautions against these consequences. It will for example become a criterion of the site as to whether, and to what degree, preventative measures are planned in an appropriate case, for example high water levels and floods, and to what extent these can be implemented at any time- see Table 2.

Empirical analyses of the effects on property values of the consequences of climate change, which are associated with the environmental situation at the location, have concentrated to date on high water level occurrences and the risk of flooding (e.g. [14], [15], [16], [17]).

In those areas where the consequences of climate change lead to increased risks for a loca-tion, the buildings must be equipped with suitable features and characteristics to enable them to withstand these consequences. It is clear that there is a direct relationship between the environmental situation at the location and the features to be selected for the building project. In Table 3 there are suggestions given for the extension of the building features in the analysis of the property.

The results of the site and property analyses with regard to risks are of great interest to in-vestors, financiers and insurers alike. It is suggested that the site analysis and the property analysis, which up to now have been conducted comparatively separately from each other, should be combined more effectively. In particular it should be investigated and assessed, in those cases where there are

increased risks at the location, whether these risks can be offset by appropriate constructional solutions, and what measures in reserve are available if there is an intensification of the consequences of climate change. Here there is a correlation with the sustainability assessment, which similarly needs to include future developments and trends.
In the author's view, the approach to the climate temperature increase will be of great impor-tance to the real estate industry. Buildings with a poor heat defence in summer will present significant risk as regards letting and marketing, and this will have an impact on their value. Empirical analyses on this still require to be conducted and they are consequently being ac-tively encouraged.

Table 1: Suggestions for the extension of the site analysis - Section on environmental situation

Possible consequences of climate change with regard to the site analysis Features for the characterisation of the environmental situation (current state and trend)	*Effects / comments*
Sea level change	affects primarily coastal areas, where applicable, also the increase in risk of an ingress of surface water, or potentially the risk of the permanent loss of the plot of land
Change in the frequency and intensity of precipitation (rain, snow)	potentially the risk of increased snow loads on buildings
Change in the water table level	potentially increased risk of an ingress of ground water from the water table
Change in ground moisture level	potentially increased risk of subsidence
Change in the frequency and intensity of high water levels and floods	potentially increased risk of an ingress of surface water
Change in the frequency of extreme weather occurrences (storms, hailstones)	potentially increased risk of damage to roofs and fronts of buildings
Change in the risk of avalanches and landslides	potentially increased risk of damage to buildings and a potential increase in the risks to inhabitants
Changes in the average temperatures overall, or in winter/summer	potential reduction of energy requirements in winter (positive) potential increase in the heat load in summer, deterioration of heat comfort level in summer (negative)
Change in solar radiation	potential change in the solar radiation supply (positive for solar energy) potential increase in the demands on surface areas, quicker aging of building components

Table 2: Suggestions for the extension of the site analysis - Section on preventative measures

Possible consequences of climate change with regard to the site analysis Current state and trend of the environmental situation	*Relevant features of the location*
Sea level change	type and extent of the coastal high water defences
Change in the frequency and intensity of high water levels and floods	type and extent of the high water defences

Table 3: Suggestions for the extension of the building features

Possible consequences of climate change	*Relevant features of the building*
Sea level change	high water defences
Change in the frequency and intensity of precipitation (rain, snow)	stability against collapse, load-carrying capacity
Change in the water table level	stability against collapse, type and extent of the defences of the building against incoming ground water from the water table
Change in the ground moisture level	stability against collapse
Change in the frequency and intensity of high water levels and floods	stability against collapse, type and extent of the defences of the building against an ingress of surface water
Change in the frequency and intensity of extreme weather occurrences (storms, hailstones)	among other measures, **capacity of the roof covering and anchoring points to resist these occurrences.**
Change in the risk of avalanches and landslides	Stability against collapse
Changes in the average temperatures overall, or in winter/summer	among other measures, **heat defences in summer,** or type and extent of measures for ensuring thermal comfort in the summer
Change in solar radiation	Durability of liner sheets, sealant media and components which are exposed to solar radiation

In addition to carrying out a property analysis, it will be necessary for those companies with building stocks to integrate an assessment of the risks and consequences of climate change into their portfolio analysis. Real estate companies will therefore have to investigate whether any parts of their building stocks, and if so which, would be affected by, for example, rising sea levels.

3 Need for data, recommendations and experiences

The building and real estate industries require more and better information about the imme-diate and future consequences of climate change, so that they can integrate aspects of cli-mate change more effectively into their methods, instruments and decisions. There is a great interest in small-scale forecasts, which can be taken into consideration when for example site analyses or planning decisions are being made. This is a task for climate research. Helpful for this is the transfer of information contained in 'risk maps' - such as for example that con-tained in the CEDIM (Center for disaster management and risk reduction technology) Risk Explorer (http://www.cedim.de/riskexplorer.php). It would be de-sirable to provide this not only with the depiction of current risks but also with information about medium-term trends in developments.

Building on this, construction research can then develop suggestions for solutions, as well as analysing the costs, effectiveness and permanence of these solutions. An example of this is the handbook for High Water Defences for Property Protection and Building Precautions ([18]).

The real estate and financial industries must incorporate the fact and the dynamic of climate change much more effectively than to date into their methods and instruments, as well as those property features which are associated with climate change. This involves, inter alia, the description of location features and the environmental situation, as well as those features and characteristics to be considered in the description of the property, which present some type of reaction in its construction to the consequences of climate change. Starting points for this are considered in, inter alia, the real estate analysis of the VÖB (Bundesverband Öffentlicher Banken Deutschlands, http://www.voeb-service.de/v-ia).

Finally it is recommended that in the systems for evaluating the sustainability of buildings (see the DGNB under www.dgnb.de and the BNB under www.nachhaltigesbauen.de) there is greater focus than in the past on the interaction between on the one hand the current state and trends of environmental conditions at a location, and on the other hand the appropriate reactions in the building construction which bring about a capacity for greater resistance and permanence.

4 Outlook

In this paper it is made clear that, within the subject area of the description of the conse-quences of climate change and the overcoming of this, there is huge potential for cooperation between bodies in the areas of climate research, building research and research for the real estate industry. This cooperation needs to be expressly encouraged.

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Extention of the Heat Health Warning System by Indoor Heat Prediction

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Abstract

The German Weather Service (DWD) releases a heat warning, when the weather forecast provides a warm, humid, sunny, and windless weather condition during the next days. The heat stress is calculated by the so called Klima-Michel model. If the apparent air temperature exceeds ca. 32°C / 38°C, there is a strong / extreme heat stress. The smallest forecast area is each administrative district. As people (and especially the vulnerable population) stay most of the time indoors, the heat health warning system was extended by the prediction of heat stress in typical rooms. Therewith it is feasible to forecast the heat stress using a combination of the outdoor and indoor heat stress. The prediction for the indoor heat stress is based on the same weather forecast like the Heat Health Warning Systems (HHWS).and calculates the heat stress by the PMV-model (predicted mean vote).

Based on a sophisticated data analysis and simulation study, realistic but summer-critical living situations were defined and implemented in the building simulation program ESP-r. As the simulation runs especially for extreme weather conditions, a simplified building model cannot be used. Standardized input/output routines and an adaptive handover of start values provide for short run times for each forecast area. Good building designs and urban planning provide effective measures to reduce heat stress in cities. However, we have to also pay attention to the present building stock under climate change and a higher heat-wave risk. The extended German HHWS provide information for the emergency services to support the social assistants during heat waves.

1 Introduction

1.1 European heat wave forecast system

The adverse health effects of heat waves are largely preventable. The EuroHEAT project [1] recommends developing and implementing heat-health action plans at national and regional level in Europe, to prevent, react upon, and contain heat-related risks to health. A web-based system provides a heat-wave forecast, see Figure 1.

1.2 German weather alert and HHWS

The German HHWS [3] evaluates the heat stress based on the outdoor climate and releases a web-based warning, see Figure 2. The heat stress is expressed by the perceived temperature. This temperature is calculated by a heat balance model which takes the thermo physiological mechanisms between the human body and the atmosphere into account [4].

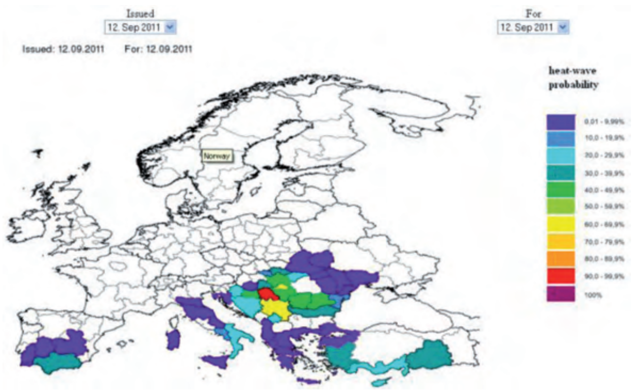

Figure 1: EuroHEAT. Heat wave forecast [2].

Figure 2: DWD weather alert [5].

1.3 Extension of the German HHWS

Elderly and handicapped people and small children are specifically affected by heat stress. As this vulnerable population stays most of the time indoors, the prediction of heat stress in typical rooms gives important information for the vulnerable population and social assistants.

In typical buildings without mechanical cooling or ventilation, the difference between the indoor environment and the prevailing weather in summer is mainly caused by the building fabric and the user behavior. The existing HHWS was extended by a thermal building model which predicts the room climate (i.e. air and radiant temperature, air change rate and relative humidity) based on the weather of the past days and the weather forecast for today and the next days [6].

The indoor heat-stress is defined by both the operative room temperature (i.e. arithmetic mean value of the air temperature and the area averaged surface temperature) and the predicted mean vote PMV [7] (i.e. combined factor which describes the physiological heat-stress) for a given metabolic rate (met) and clothing factor (clo).

2 Building typology and model validation

A crucial task is the definition of a realistic but summer-critical living situation. The building simulation model was developed in two steps:

- A cross-section analysis of the German building stock (residential buildings only) clearly revealed that apartment buildings from the 1970's comprise the most summer-critical living situations [8].
- A sophisticated monitoring campaign (weather and micro-climate monitoring, air change rate, air temperatures, inside and outside surface temperatures etc.) in a poorly insulated 1920's apartment on the attic floor in the city center of Freiburg, Germany, was used to validate a simulation model for critical living situations under realistic conditions (i.e. no user interaction, closed windows and no shading device), see

An abstracted building model was used for the prediction of operative room temperatures from 2007 to 2010. The prediction of indoor heat-stress ran independently from the HHWS. Good experience with the additional system encouraged the DWD to extend the existing HHWS. A redeveloped indoor heat prediction has been running together with the HHWS since April 2011. Both prediction systems share the same weather data and weather forecast.

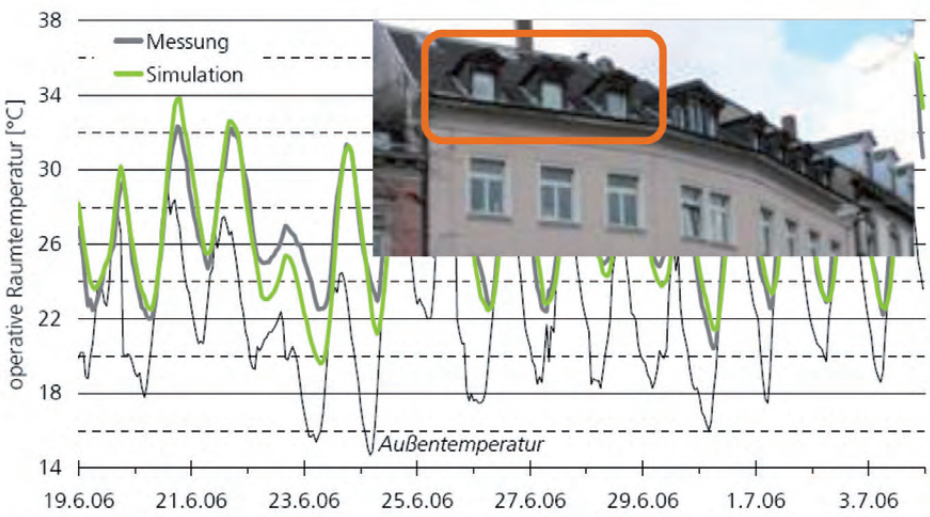

Figure 3: Validation of the simulation model for critical living situation in summer.

3 Building model database

Based on the existing simulation platform, a building model database according to the German building typology was set up for different geometries (living situation), fabric (building components), windows (solar heat gain and solar shading), ventilation (free cross ventilation), user profiles (attendance and internal heat gains), and user behavior with regard to window opening and solar control. The person is defined by the metabolic rate and the clothing for the calculation of the physiological heat-stress and the PMV, respectively. These data models can be chosen freely in order to compile the simulation model. However, there are some useless combinations for plausibility reasons. The reasonable combinations result in 972 simulation models. The simulation results can be evaluated with any combination of metabolic rate and clothing.

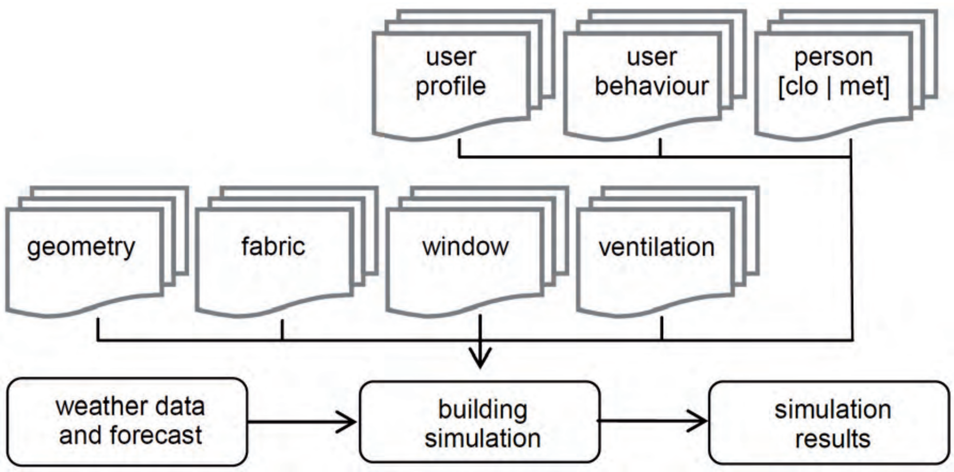

Figure 4: Database for set up of the building model.

4 Building simulation

4.1 Three prototypical simulation models

Three pre-compiled simulation models describe typical living environments and can be used favorably to check indoor heat stress in specific "standard" situations without any users' interaction and with active intervention:

- Vulnerable people at home: The WG model describes a typical apartment in a 1970's multi-family house with two 11.9 m²-rooms and a room height of 2.55 m. The double-glazed window has a curtain as solar shading device. The room is continually occupied. The active user closes the curtain during the day and opens the window if the outdoor temperature is below the indoor temperature.
- Lower-income family: The DG model describes a poorly insulated attic flat in a 1920's multi-family house with two 11.2 m²-rooms and a room height of 2.4 m. The double-glazed window has a roller blind as solar shading device. The room is unoccupied during the day. The active user closes the roller blind during the day and opens the window during the night.
- Vulnerable people in a nursery home: The PH model describes an apartment in a 1990's nursery home with two 14.2 m²-rooms and a room height of 2.8 m. The heat-protection window has external Venetian blinds as solar shading device. The room is continually occupied with some hours of extra occupancy. The Venetian blinds are controlled by solar radiation and the windows are opened according to a duty roster with additional rush airing in the morning.

Figure 5 shows clearly, that occupants can strongly influence the indoor room temperature by simple interventions. Furthermore, different buildings are characterized by different thermal behavior. These aspects result in heterogeneous room temperature trends:

- WG model: The thermal inertia of a 1970's building results in a moderate temperature fluctuation. Simple interventions reduce the room temperature by 4 to 5 K especially during the nights.
- DG model: The light-weight structure of a poorly insulated attic flat results in strong temperature fluctuation and high peak temperatures. Though simple interventions may reduce the room temperature by up to 10 K, the absolute room temperature remains very high during the day.
- PH model: New buildings with a high thermal inertia, good heat protection and large windows may act as a greenhouse where room temperatures stay high during day and night. On the other hand, passive cooling strategies (blind control and free ventilation) provide low room temperatures.

Each living situation has a specific summer-critical characteristic.

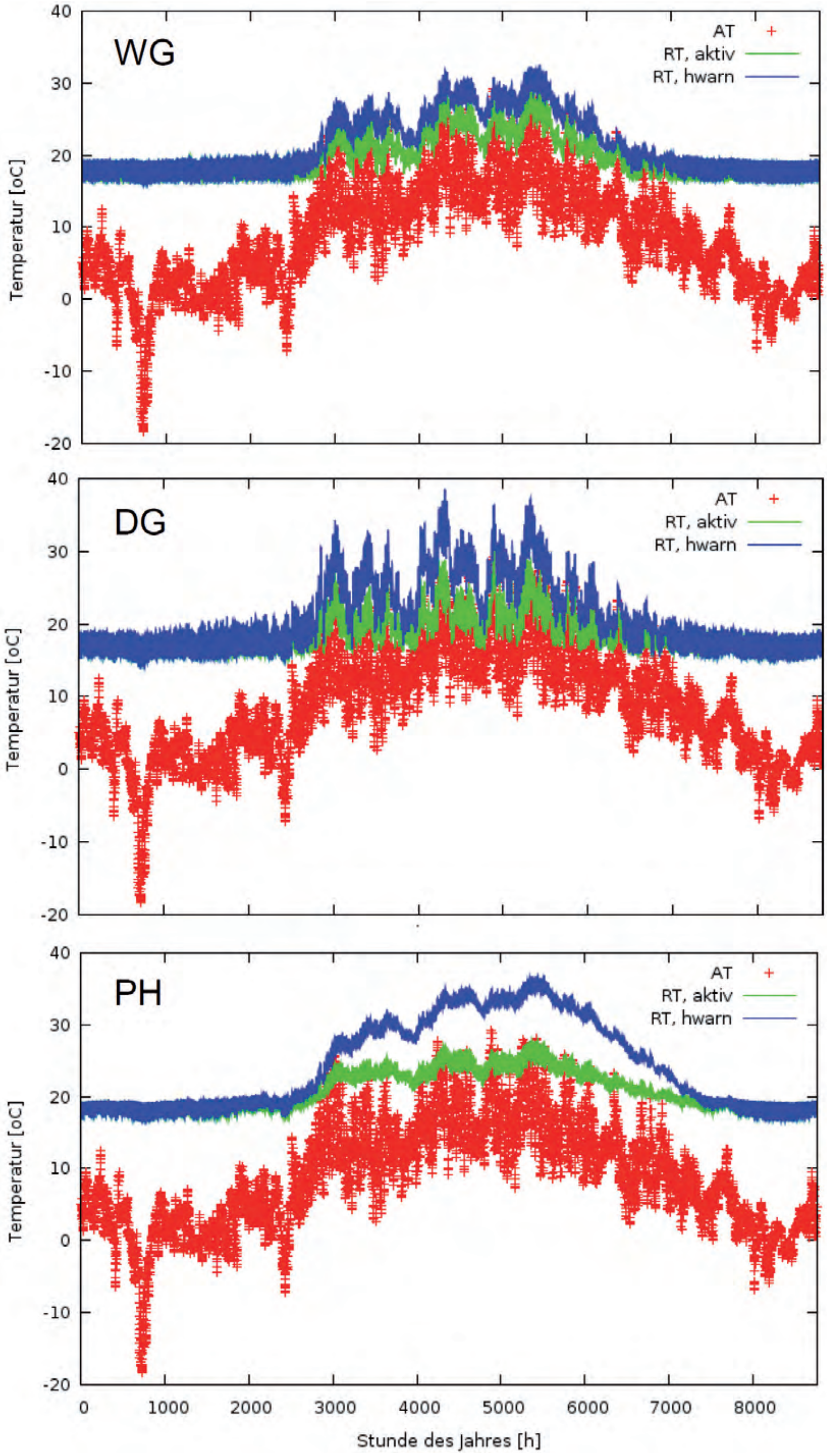

Figure 5: Three building models with / without active user behavior.

4.2 Statistical analysis of simulation results

A usable warning system must confidently predict the crucial situation but should not overestimate the risk. In this context, the heterogeneous temperature characteristics ask for a representative simulation model. Hence, the simulation results should be as realistic as possible and as stringent as necessary. The simulation models with active users' intervention provide a realistic overview of typical room temperatures in summer. Each temperature characteristic is shown as duration curve of operative room temperatures. The limitation on active user's intervention reduces the volume of 972 possible simulation models to 729 simulations. Figure 6 shows a statistical evaluation of 729 simulation runs with active user's intervention by the median and the standard deviation.

Additionally, the figure shows the duration curve of the WG simulation model with passive user and active user's intervention. The "active intervention" scenario is very similar to the median of all simulation runs and, hence, represents a typical living situation and can be used to evaluate the effect of urgent measures during a heat wave. The "warning scenario" is similar to the 84%-quantile of all simulation runs and, hence, represents a typical overheating situation and can be used to characterize the impact of a heat wave on the indoor environment. Thus, the simulation model confidently predicts the crucial situation but does not overestimate the risk.

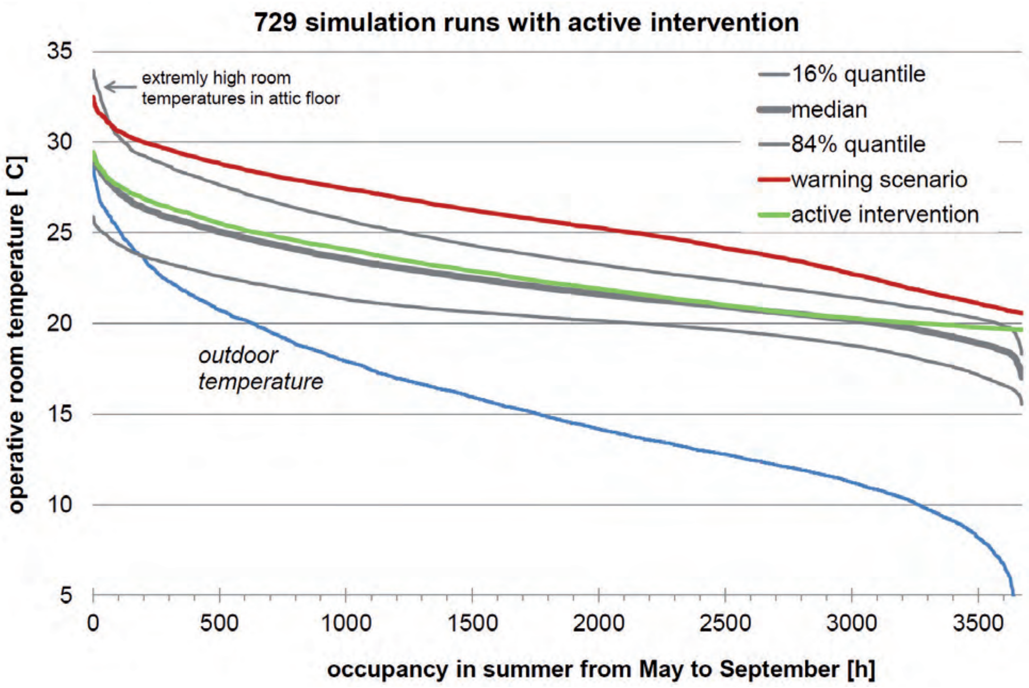

Figure 6: Statistical analysis of multiple parameter variation with active user behavior.

5 Procedure

Figure 7 shows the outline of the indoor-heat-prediction routine. For each German administrative district, the weather forecast is added to the existing weather data. The simulation model is run with passive user as "warning scenario" to predict the indoor heat-stress and with active user as "active intervention" to estimate the effect of urgent measures. The whole procedure can be run in parallel simulation mode to considerably reduce the simulation run time. The short run time allows for a feasible integration of the indoor heat prediction into the existing HHWS.

6 Application of the extended HHWS

First experiences with the extended HHWS clearly confirm the additional value of the predicted indoor heat stress. According to the statistical analysis in Chapter 4.2, the WG simulation model is used to predict the indoor heat stress. The algorithm runs daily for approx. 900 administrative districts in Germany. Figure 8 shows the heat stress according to a green/yellow/red scale. The indoor heat stress is perceived in some regions on the 1st day, is extremely strong during the 2nd day in many regions and decreases on the 3rd day.
Figure 9 shows that the indoor heat-stress prediction differs considerable form the outdoor heat-stress prediction: Up to an ambient air temperature of 25°C the indoor heat stress is stronger than the outdoor heat stress. At high ambient air temperatures, the heat stress might be lower indoors than outdoors. However, the indoor heat stress remains high during nights.

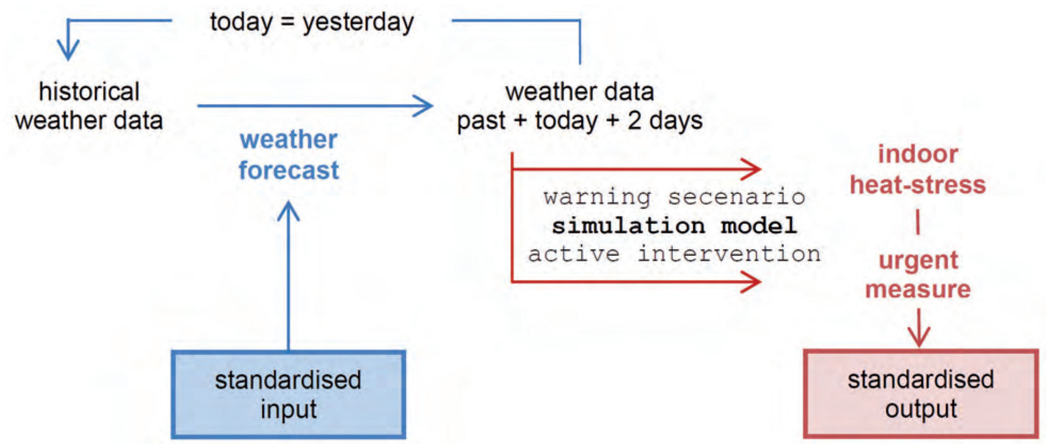

Figure 7: Procedure of the indoor heat prediction and integration into the HHWS based on standardized input/output data exchange.

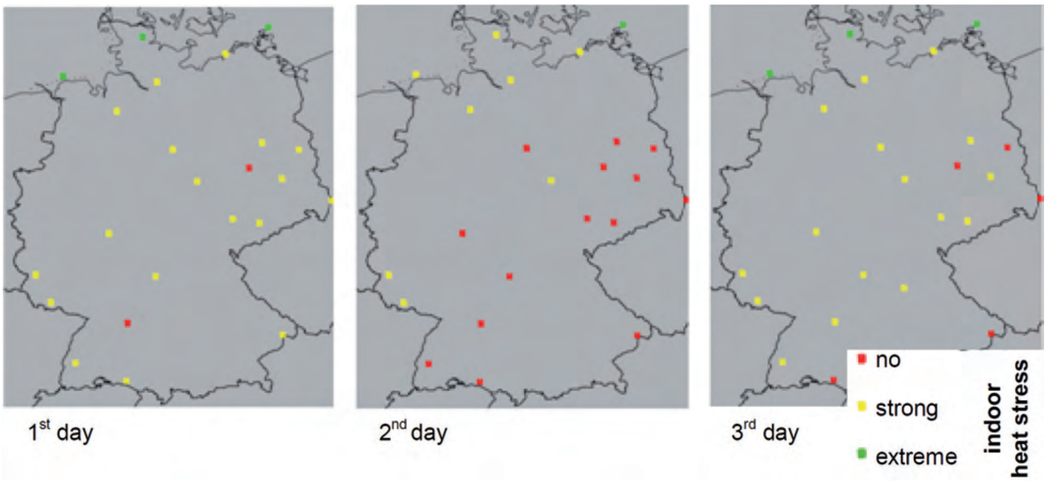

Figure 8: Indoor heat stress prediction for some selected administrative districts during a short heat wave.

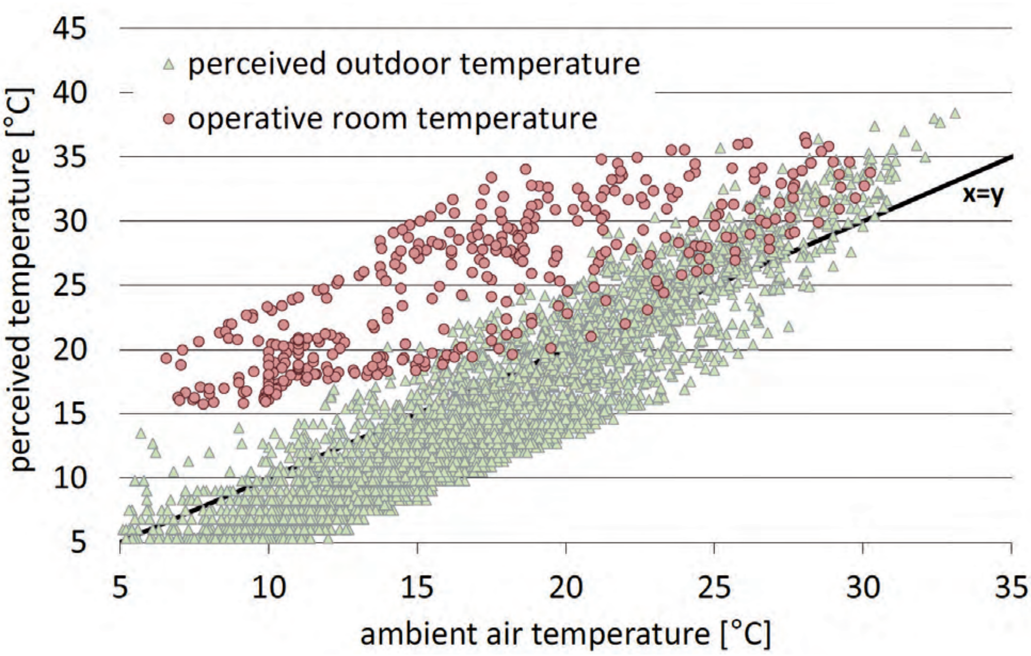

Figure 9: Comparison between the perceived outdoor temperature and the operative temperature for one region in terms of indoor and outdoor heat stress.

As the physiological heat-stress during the whole day is also strongly influenced by a feasible cooling-down effect in the night, a future criterion to determine the heat stress should take both the outdoor heat stress during the day (maximum) and the indoor heat stress during the night (minimum) into account.

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Openness to the Sky as Indicator for Daylighting Potential of Urban Office Buildings in a European Mid-Latitude Location

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Abstract

The vertical geometry of an urban structure expressed by the openness to sky of its surfaces (façades and streets) is decisive on the urban microclimate as well as on the building indoor climate: thermal and visual. The daylighting is one key issue regarding a climate sensitive and energy efficient building design. Maximising the use of natural daylight helps reduce the need for artificial light. This issue is particularly important in office building types where lighting may be one major reason for energy demand. The present paper reports on an extensive investigation which aims at understanding the dependences between urban geometry, urban microclimate, building construction and material properties on one side and the visual quality of indoor urban spaces on the other side. Extensive simulations are run in TRNSYS for an office building, centrally located in a canyon-like urban structure with 2 facades. The focus is put here on the "openness to the sky" as indicator of the "view of sky and sun" of indoor spaces at different heights. Therefore calculations are made for offices at 5 floors within the canyon to find out the importance of the vertical geometry. The following parameters are varied: canyon geometry (H/W), solar orientation, window ratio, thermal insulation, thermal inertia, light transmittance. Preliminary results are presented for a European mid-latitude location and the target metric D_{int} expresses a yearly daylighting potential in percentage. The window ratio, light transmittance, floor height and aspect ratio reveal to be the most decisive on D_{int} as well as their interactions.

1 Introduction

The present paper is one part of an extensive investigation, which partial results on thermal issues have been reported previously (see e.g. [1]). In this paper the focus is put on the issue of daylighting as this is usually less investigated than thermal aspects, especially with the urban context as boundary condition. Preliminary results are reported and discussed below.

2 Objectives

The present paper addresses the following issues:

- Which impact has the urban surroundings expressed with the vertical urban profile and solar orientation on the availability of daylight indoors?
- How does the vertical openness to the sky affect the visual quality of urban offices?
- Which urban, building and material describers are the most decisive in the availability of daylight indoors and in which combinations?

3 Method and Object of Study

The investigation was carried out with the building energy simulation programme TRNSYS [2]. Upstream, the air temperatures were adjusted to the urban context by means of the urban climate model TEB [3], (see [1]). Some complementary calculations were added in TRNSYS to account for the short-wave irradiation in-canyon. Moreover, the urban configuration affects the potential for daylight inside the canyon depending on its depth because of limited sky view and internal reflections. Hence, the outdoor illuminance has also been adjusted in the TRNSYS simulations by considering the location of each office zone in relation to its height above ground (Figure 1).

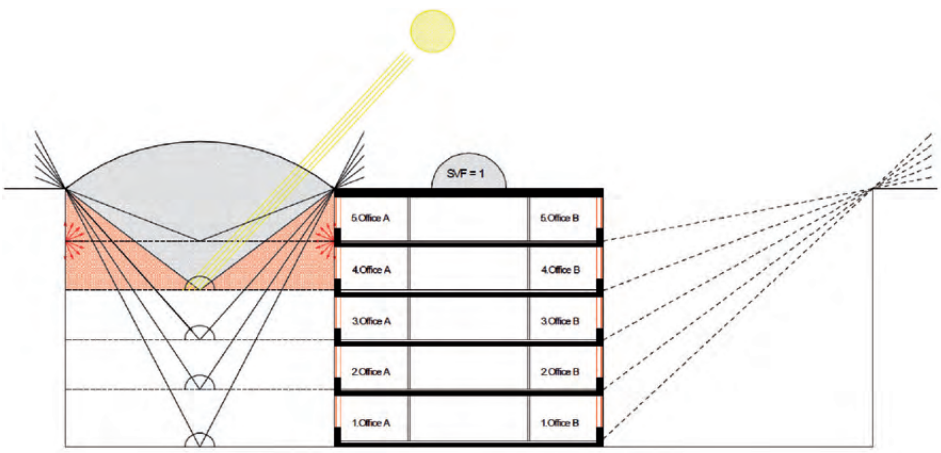

Figure 1: The urban structure and building as simulated with TEB and with TRNSYS

The outdoor illuminance E_{ext} can be deduced with good approximation from the global solar radiation received at horizontal surface G_h with the assumption that 1 W = 110 lumen (1 lux = 1lm m^{-2}) as follows: E_{ext} (in lux) = G_h / 110. The indoor illuminance is given by $E_{int} = DF \cdot E_{ext}$, where the daylighting factors DF of the offices (function of the geometric and optical surface properties: opaque, glazing) have been determined by RELUX software [4]. The lowest limit for switching on the artificial light was set at an indoor illuminance of 500 Lux, whereas daylight was assumed if 700 Lux or more were available. A shading control was also set in TRNSYS for thermal purposes and this obviously influences the availability of daylight indoors as well. The shading devices keep 75% of the undesired solar radiation away. A standard office building adapted from [5] and located within an urban structure was investigated. It consists of 5 stories with 2 external facades and hence 10 offices with external exposure (Figure 1).

Several factors play a role in the daylighting availability patterns:

- Climatic: site-related global solar radiation (from test reference year [6])
- Urban: the view of sky versus proportion of surrounding walls, the incanyon solar reflections, solar orientation of the facade,
- Building/office: exposure of office given by its height above ground, window ratio, daylight transmittance, shading devices, etc.

These factors being combined and sometimes in conflict (e.g. shading is positive for preventing overheating but negative regarding daylight), it is difficult to intuitively predict their combined impact.

As shown in Table 1, the urban structure density and orientations were varied as well as the building construction. The 3-steps equidistant variation was chosen for DOE statistical analysis purposes.

Table 1: Urban, building and material properties varied in the simulation runs

Coded form →		-1	0	1
urban context				
A	Aspect ratio H/W	0.2	1	1.8
B	solar orientation	NS	NESW	EW
Building construction				
C	window ratio	30%	60%	90%
D	thermal insulation U_{wall}; U_{window}; U_{roof}	0.15; 0.7; 0.10	0.40; 1.4; 0.35	0.65; 2.1; 0.60
T	light transmission	0.625	0.706	0.786
G	solar heat gain coef.	0.407	0.589	0.702
E	thermal inertia	Light-weighted construction	-	massive construction
V	floor level	1 (ground level)	3 (middle height)	5 (last floor)
climate				
F	climate	Mannheim: 49.31°N		

4 Results

The daylighting values Dint (%) reported below express a frequency, i.e. the percentage of time of year where only daylight was necessary in the offices (set as equal to or higher than 700 Lux). These values where converted from the artificial light demand as prognosticated by TRNSYS and from the lighting settings assumed (power of lighting appliances).
Figure 2 shows the yearly daylighting potential for all case studies in dependence with A, B, C, T, and V (E parameter is not relevant here).
The daylighting potential Dint ranges between a minimum of 2.9 % and 60.1 %. The mimimal values of Dint (< 5 %) occur for the following combinations: A (all steps), B (-1, NS orientation), C (-1, low window ratio), T (-1 or 0, low to medium light transmittance), and V (1, top floor), the latter criterion likely due to shading devices in use due to high solar exposure. The maximum values of Dint (> 55 %) were found for the following combinations: A (-1, shallow urban canyon), B (all steps, yet mostly -1), C (0 or 1, medium to largely glazed), T (0 or 1, medium to high light transmittance) and V (mostly -1, yet other cases possible).
The following observations can be made to Figure 2:

- The potential use of daylight decreases with higher aspect ratios H/W, in particular for largely glazed facades.
- The NS orientation is better than EW for the lowest floors whereas the trend is reversed at the highest one and the difference is less marked at canyon mid-height.
- The daylight increases with increased window ratio C. The difference in daylighting is however less marked between C = 0 and C= 1 than between C equal to -1 and 0. The window ratio impact is also more visible at the highest floor than at ground level.
- As expected, the importance of the light transmittance T is more visible as the window ratio increases.
- In a vertical comparison between the floors 1, 3 and 5, the highest floor which is most exposed is obviously more easily daylit than the ground-floor.

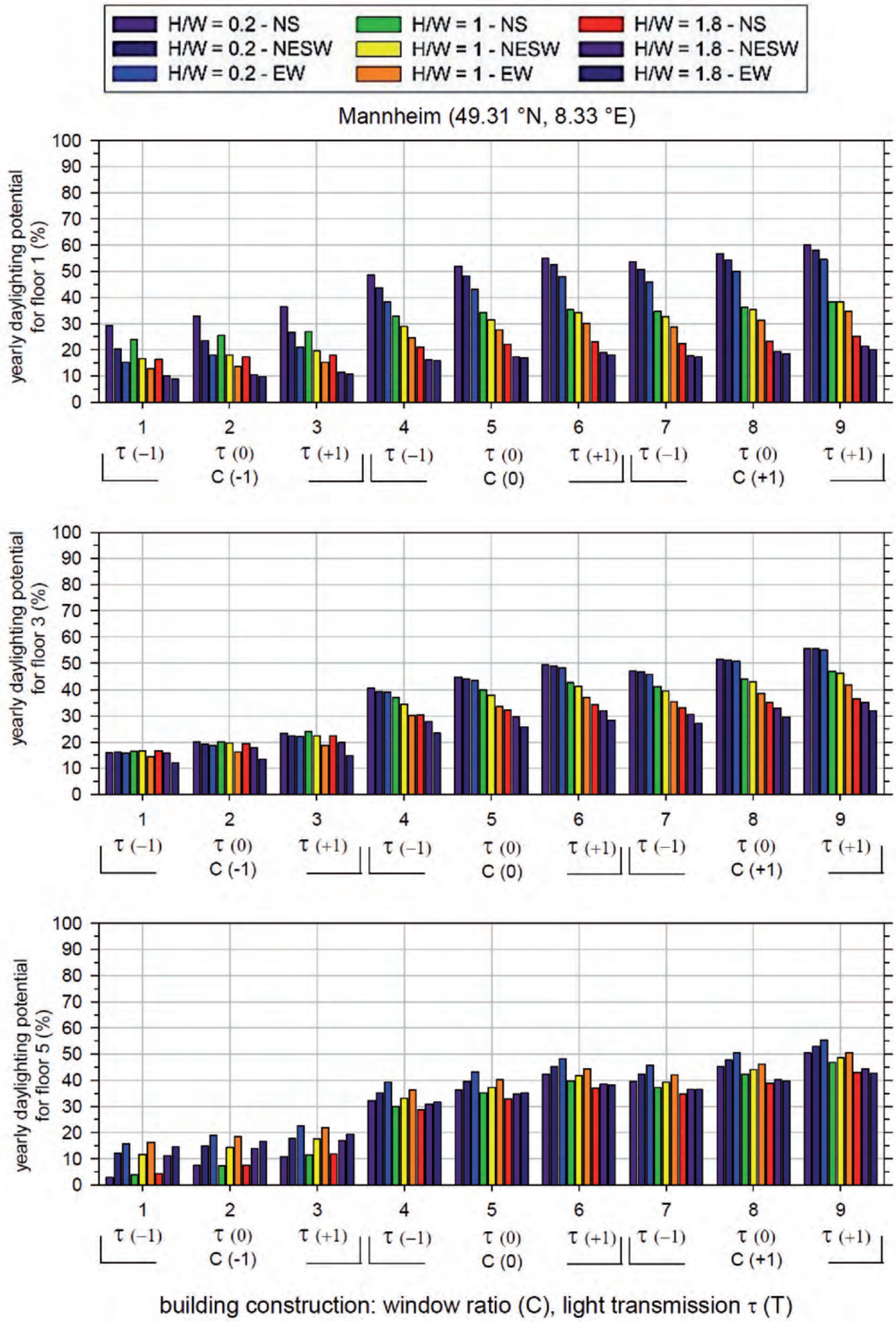

Figure 2: Daylight potential use as yearly percentage for Manheim in dependence with urban, building and optical properties

A statistical analysis provided a quantitative prognosis of the impact of each parameter (main effect) as well as the most relevant double interactions.

The provisional whole model found is as follows:

$Y = - 7.272*A - 2.025*B + 11.885*C + 3.152*T + 3.474*V - 6.821*C^2 - 1.959*V^2 - 0.402*A*B - 3.703*A*C + 1.999*A*C^2 - 0.921*A*T + 4.965*A*V - 0.927*V*A^2 + 3.544*B*V - 0.683*V*B^2 + 0.420*C*T + 3.234*C*V - 1.842*V*C^2 + 0.842*T*V - 1.493*A*V^2 + 1.629*B*V^2 + 36.859$

The resulting statistical model is provided with a coefficient of determination R^2 equals to 0.982 %. The additional variance when considering adjusted R^2 to explanatory terms is insignificant (0.981). This reveals that the proportion of data consistency is high and this statistical model is most probably to predict these interdependences with confidence. The mean value equals 31.005 and the standard deviation amounts 13.391.

The graphs in Figure 3 express the partial mathematical model for only one pair of parameters in each case and can shortly be commented as follows:

- The window ratio C is the most decisive parameter, with a non-linear-shape (quadratic) and is relevant in combination with all other factors. Daylight increases with increased window ratio C.
- The impact of the aspect ratio A is found to be linear in combination with B, C, T and almost linear with V. Daylight decreases with increased A.

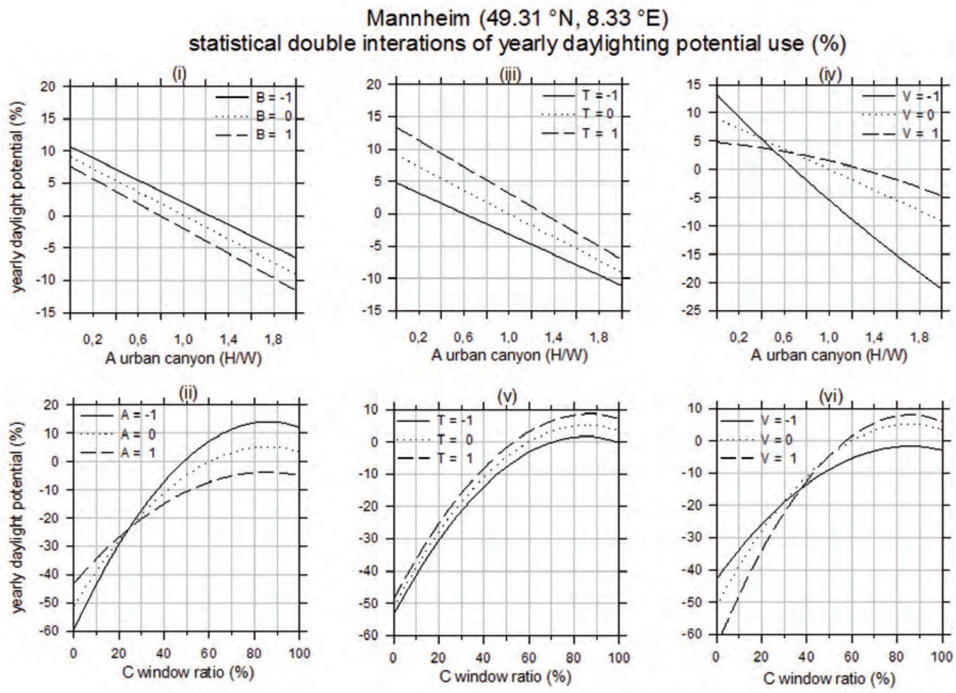

Figure 3: Statistical main effects and double interactions of most relevant parameters' combinations in relation to daylighting

Figure 4 shows the daylighting potential for some relevant combinations as absolute values according to the statistical model given above (all other parameters are set to 0). The cases V = -1 and V =1 are put side by side for further comparison in relation to the openness to sky.

a) A * B: Increasing the aspect ratio leads to less daylight at ground level with insignificant role of B. At top floor, the daylight is around 35 - 40 % almost regardless of B.

b) A * C: Increasing the aspect ratio A has a minimal effect for very low window ratio values. As C becomes higher (> 20 %) its impact becomes evident with a maximum effect of A visible around C = 80 % with Dint around 50 % for shallow canyons and 20 % for A = 1.8. The pattern is similar for both floor heights but with lower values of Dint for V = 1 which are smaller in magnitude. Beyond C = 80% the daylight potential diminishes likely because of more shading requirements.

c) A * T: The aspect ratio is more decisive for the ground floor where minimum daylighting occurs for deep streets and very low light transmittance T, whereas maximum daylighting occurs for shallow canyons and high transmittance T. With increasing floor height above ground, the aspect ratio becomes less important as the openness to sky increases.

d) C * T: Low window ratios combined with low light transmittance lead to lack of sufficient daylight so that artificial light must be switch on. Maximum daylight potential is visible at highest C and T values, whereas the ground floor experiences around 10 - 20 % lower frequency.

e) B * T: The impact of the solar orientation is slightly higher for ground level due to less sky view, yet B remains relatively of small relevance. The light transmission coefficient T is visibly more decisive at higher floor levels than near ground.

f) B * C: Largely glazed façades lead to the highest daylighting potential almost irrespective of the solar orientation B, even though NS seems slightly more advantageous at ground level and EW at top floor. At ground level, the daylighting is about 10 % less.

The cases (g), (h), (i) are shown in one pattern as the openness to sky is given on the y axis. The combination A * V reveals that the aspect ratio is more decisive at ground level with a D_{int} variation range of up to 25 %. In the combination C * V, the floor height gets more decisive when the window ratio dominates the façade. In conjunction with T, the floor describer V is less important.

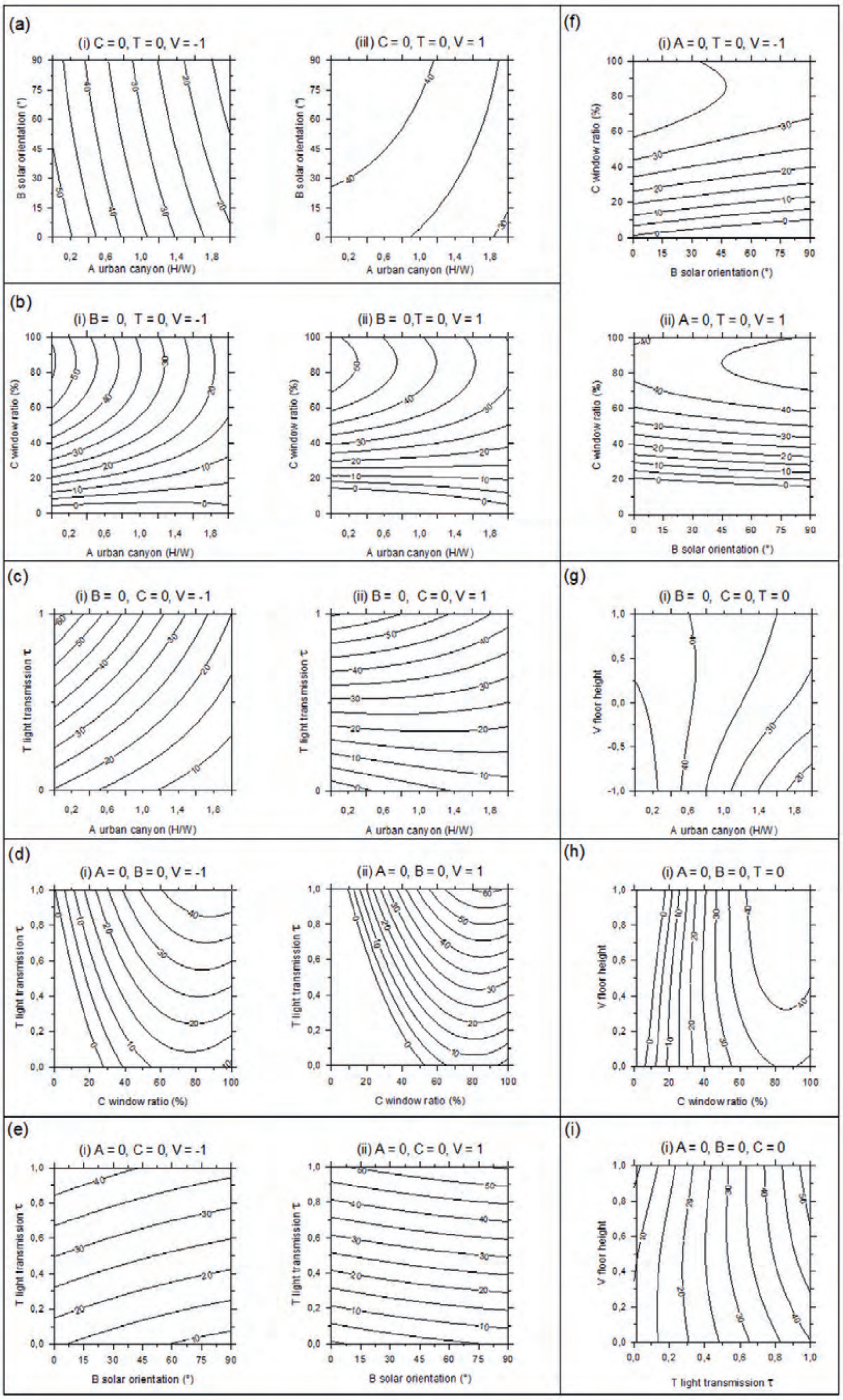

Figure 4: A selection of typical daylighting patterns for parameter pairs as provided by the statistical analysis

5 Conclusion

This study points out the importance of urban, building and material properties in the potential availability of daylight in offices. The results discussed are preliminary findings. They rely on the relatively simple assumptions of the changes in solar radiation and outdoor illumninace due to the urban structure. This study highlights the complexity of this issue and suggests the necessity of more field measurements to help gain more knowledge on these "urban daylighting".

It is also expected that these effects are different for other climate types and latitudes. This issue is currently being analysed comparatively for subtropical locations.

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The Role of Climate in Shaping Architectural & Urban Typologies: Arab Region

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Abstract

Arabic architecture & urbanism provides genuine climatic solutions as far as sustainability is concerned. Located in arid and semi-arid environments, this architecture has generated peculiar building envelopes that meet not only the social codes relevant to Arabic culture but also the contextual variables of topography, climate and energy use. The building is a microcosm within the macrocosm of the intricate urban fabric of the city (madina). The morphology of the city has evolved to foster an empirical sustainability that derives its engine from a particular spatial organization that optimizes use of energy: harnesses cool air, explores water sources, creates ecological realms (green courtyards), and provides highly insulated buildings within protected compact blocks. In addition to the design features as well as optimization of use of space, the use of organic materials made this architecture a living one as it has a metabolism that inventively performs under severe climatic changes in order to preserve a permanent thermal comfort at the level of the city as well as at the level of a single building. This paper traces some of the urban and architectural planning and design techniques through devised climatic solutions in mainly the UAE and Morocco. It examines the empirical sustainability of historic built environments, and offers some lessons from the past that can be explored in making contemporary buildings and cities.

1 Introduction

Sustainability is currently a common term among professionals in all fields with one common goal - how to optimize the use of natural resources in a time of high consumerism and energy waste. However, notwithstanding the global effort to make sustainability an intrinsic part of national policies, it is yet perceived as a resolution to post destructive rapid urban development. While sustainability ought to be an integrated part of the planning process in order to minimize a priori the future negative impacts of human activities, historic cities and buildings could provide yet genuine scenarios of embedded durability mechanisms.

The conventional urban sustainability often starts with indicators or footprint analysis of the status quo of unsustainability. These indicators are geared toward improving performance of the current unsustainable built environment, and not envisaged to project or achieve grassroots sustainability. This leads to an arsenal of technical solutions for partial sustainability issues with rare reflection upon an integrated holistic sustainable urban metabolism.

In order to establish this shift of the sustainability paradigm, a balanced urban metabolism based on ideal energy harnessing and use is to be found. The pre-industrial urban and architectural settings, if seen through this lens, could present past and future sustainability scenarios for how an organic built environment performs. As far as climate is concerned, these pre-industrial settings provided ideal indoor and outdoor thermal comfort with less energy consumption and pollution. Despite the fact that modern urbanism has augmented significantly thermal comfort due to industrialization and technological advancement, its rate of energy use as well as subsequent pollution is rather alarming.

The Middle Eastern and North African region constitutes a key example for studying the pre-industrial sustainable urban metabolisms devised to face the harsh desert climate vis-à-vis its current modern urban environment, which is one of the most polluting and energy abusive in the world due to oil discovery - particularly in the Gulf States. These States have one of the highest per capita carbon footprints in the world [1]. Nonetheless, these States were in the past the most hash environments for living due their desert climates, and presented some pioneering pre-industrial sustainability techniques.

The UAE and Morocco are selected to present the influence of climate on constructions in mainly historic contexts and with potential projections to the current ones. The two represent two distant regions of the Arabic world yet are similar partly because of their climate and culture.

2 Historic urban geometry and climate considerations

The first glimpse of a historic Arabic city (madina) map would reveal that its urban layout is not ordinary (Fig. 1). It is a compact urban fabric with a street pattern that is very irregular and unorthogonal. When viewed through a modern planning lens, this organic urban structure may look obsolete and out of fashion, but it has proven

Figure 1: Photo1: Arial view of the historic urban geometry of Fez madina (Source: author)

its efficiency in hot climates, where urban geometry plays a key role in maintaining thermal comfort. The madina's very deep street canyons give good protection during the long hot summer period and provide shade for pedestrians during the warmest part of the day [2].

In order to gain a deeper understanding on the role of the madina's urban geometry on thermal balance, it is important to present how its urban structure works at the macro and micro levels.

2.1 The macro urban geometry

2.1.1 Site and topography

As the madina is often located in desert climates, the most strategic element for its foundation is its site selection and topography. The interaction between its macro urban geometry with the nature of its topographical location engendered a typical manmade ecological realm, encapsulated within surrounding massive walls with limited access (gates). This is a major first strategic urban techniques providing insulation from the severe Saharan winds and storms. The peripheral part around the walls played the role of a buffer zone with its hinterland.

Figure 2: Photo 2 and 3: The sloppy site of Chefchaouen on the left and the water-flow directed street pattern (Source: author)

However, not all madinas are located in desert territories. As an example, Chefchaouen, a Moroccan madina, located at a high altitude in the Atlas Mountains. This generated a new urban rule that took into consideration the flow of rainwater and snow: the right of flowing, *haqq assayalan*. This generated an urban pattern of radial canyons that descend a steep slope in order to facilitate the flow of water (to avoid sudden flooding in between buildings) and ease the air movement (to allow warmer air to ascend through its alleys from the below valley). Thus, its macro urban geometry primarily evolved to meet environmental conditions (Figure 2).

2.1.2 Neighborhood structure

The quintessential urban unit in the madina was the neighborhood. The distribution of neighborhoods and their layout is a major trigger to achieve residential thermal comfort. The urban geometry of the residential neighborhood consists of introvert physical territories linked through a hierarchical street pattern. This introversion permitted the creation of comfortable climatic islands with less exposure to direct sunlight or severe winds. The more residential the neighborhood, the more compact in order to increase the shaded spaces versus the exposed ones (Fig. 3).

2.1.3 Macro street pattern

The temperature changes significantly when moving from a commercial wide street to gradually penetrate the residential alleyways. The non-directionality and non-rectilinearity of the macro street pattern spawns a continuous airflow that circulates through the whole curvilinear urban tissue. During summer, this generates a momentum of cool breezes that are closely felt by the residents of the madina. This is due mainly to the ratio between the height of buildings vis-à-vis the width of the street that controls the airflow as well as the wind movement. The macro street pattern plays the role of wind catcher before diffusing through the narrow alleys of residential clusters. This applies to the large madinas with a large built territory.

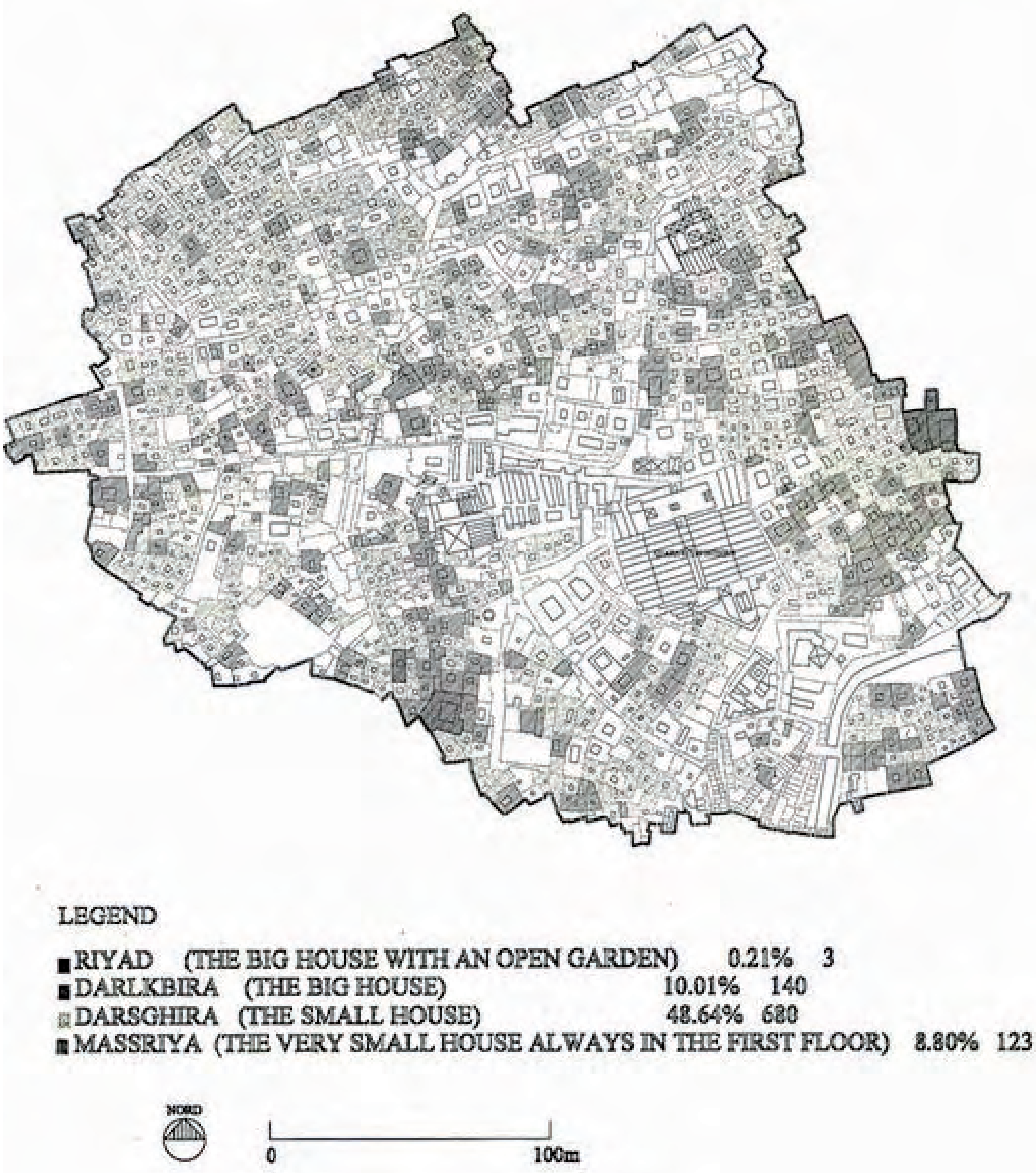

Figure 3: The largest neighborhood in the madina of Fez showing the dense urban fabric and street pattern (Source: authorValidtion in summer.

2.2 The micro urban geometry

2.2.1 Building clusters

Building clusters consist of a group of buildings surrounding a dead-end alley. All entrances are connected to the same alley. This is often found in residential units that need semi-public and semi-private space. In order to close the dead-end alley, all houses are adjacent to each other without leaving any gap and in some cases they may share the same carrying external wall. This overlapped architectural typology has a major impact on how climate works. Neighboring walls hide all the facades of the single house, and the only remaining façade is that of the terrace. This minimizes to maximum the exposure of the house to the external climatic changes, and produces a noticeably comfortable internal microclimate. The juxtaposed neighboring walls built out of bricks, lime and stone considerably preserve the coolness of the night during the long summer days (Figure 4).

However, this urban geometry may not be sufficient in very hot climate with meager winds such as in the UAE. This explains the extra measures to catch more wind and generate more airflow inside the urban historic urban fabric. These vary from a place to another depending on how far the city is located to the coastal line. The two measures I have deduced through my field study of Old Sharjah and Shindagha in Dubai are as follows. The first is to direct the urban geometry by facilitating the wind flow through the urban tissue with almost rectilinear streets that traverse the body of the madina (Figure 5). The second is to add additional wind catchers in the top of building (wind towers) to catch any airflow in the times of severe weather (Fig. 6). The second measure seems to work in the Gulf countries through the large number of wind towers in every historic city. Nevertheless, further research is needed in order to determine how efficient these structures are in both bringing the air in and circulating it through the internal space of historic houses..

Figure 4: The residential building cluster of Sbaae Louyat alley in the madina of Fez (Source: author)

Figure 5: A reconstructed map of old Sharjah shows the directed street pattern to sea (Source: author)

Figure 6: An example of a wind tower toping the left part of the building in old Sharjah (Source: author)

2.2.2 Alley and street canyon

The airflow through the narrow streets of the madina is augmented by the blank surfaces of facades that present minimum openings because of privacy. The opaque surfaces with highly insulating organic materials generate an ideal micro-climate especially when temperature reaches almost 50 degrees Celsius.

According to a research conducted by Lund University in collaboration with Moroccan National Laboratory for Tests and Studies (LPEE) for the street canyons in the madina of Fez, the air temperature differs considerably between modern and traditional neighborhoods (Figure 7). During the summer, the traditional street or alley is 2-4°C warmer in the coolest part of the day than a modern one, but during the hottest time of the day the traditional is around 10°C cooler [3].

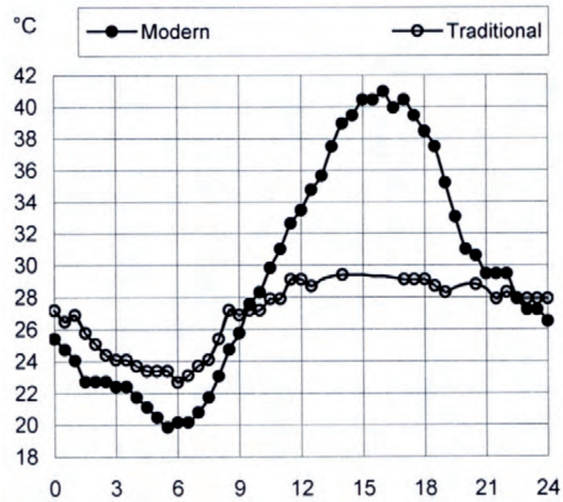

Figure 7: Air temperatures in the modern versus traditional street neighborhood on a typical hot summer day (Source: [3])

This significant drop of temperature between the outside and the inside of the madina scientifically proves that its street pattern as well as its dense fabric is made to ensure a balanced thermal comfort in a hot and dry climate through passive means. Accordingly, Hassan Fathy, a vehement advocator of vernacular form in the Arab world, stated the following:

"By simple analysis it becomes quiet understandable how such a pattern came to be universally adopted by the Arabs. It is only natural for anybody experiencing the severe climate of the desert to seek shade by narrowing and properly orienting the street, to avoid the hot desert winds by making the streets winding, with closed vistas." [4]

This statement presents a sense of judgment among architects based on practice and design, but yet scientific research and experimentation ought to be further conducted in order to prove more evidence about the reliability of any typological architectural or urban form.

2.2.3 Courtyard house

Moving from the alley the transition to the inner zone of houses is made through a careful bent-entrance that filtrates and intensifies the airflow entering to the central courtyard. Meant first to avoid the direct visual contact between inside and outside the house for reasons of privacy, the bent-entrance is a very shaded passage that is often cooler during the whole day (Figure 8).

Protected by masonry walls with minimum exposure to light, this twisted channel plays the role of a cooling system when air circulates between the alley and the courtyard. The central courtyard consists most of the time of vegetation and running fountains (Figure 9). Therefore, the series of courtyards within a dead-end alley that assembles a limited number of individual houses has an important effect on the microclimate of a whole neighborhood. The continuous airflows created by the dense masses and the limited exposure to the hash climate of the desert generates an ideal ecological environment for residents.

The courtyard house typology passively regulates temperature cycle between night (cooler temperature) and day (warmer temperature) in order to enhance the overall thermal performance (Figure 10). The high thermal mass of a courtyard preserves the heat of the day to regulate the coolness of the night and vice versa. "By maximizing the surface to volume ratio, the courtyard acts as heat sink and therefore, limits extreme temperature stress, and re-radiates this heat indoor as well as to the night sky." [5].

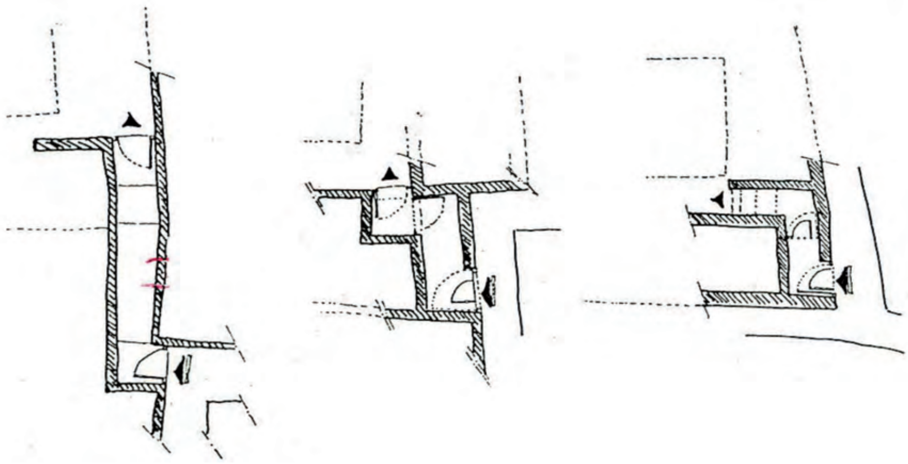

Figure 8: Different types of bent entrances in the madina of Fez (Drawings by author) .

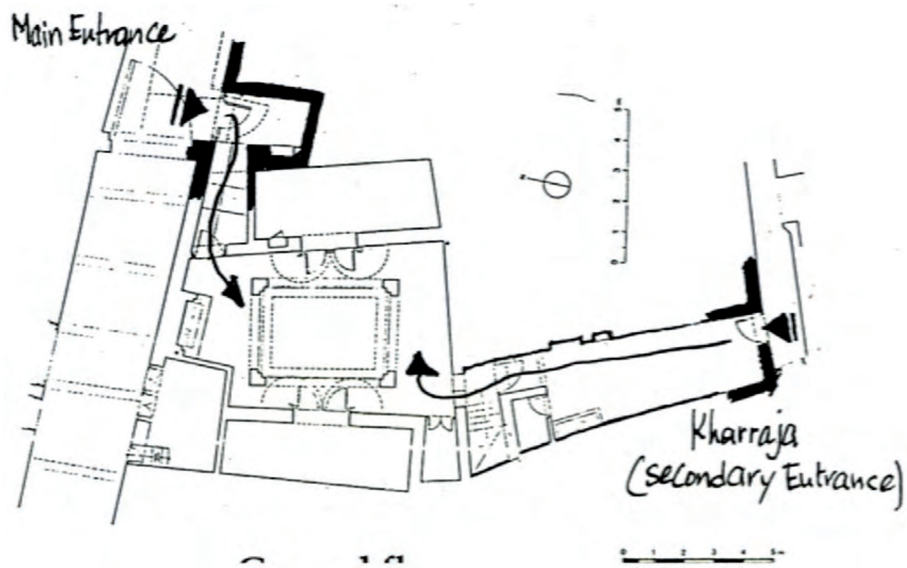

Figure 9: Air movement between the alley and the courtyard space (Drawing by author)

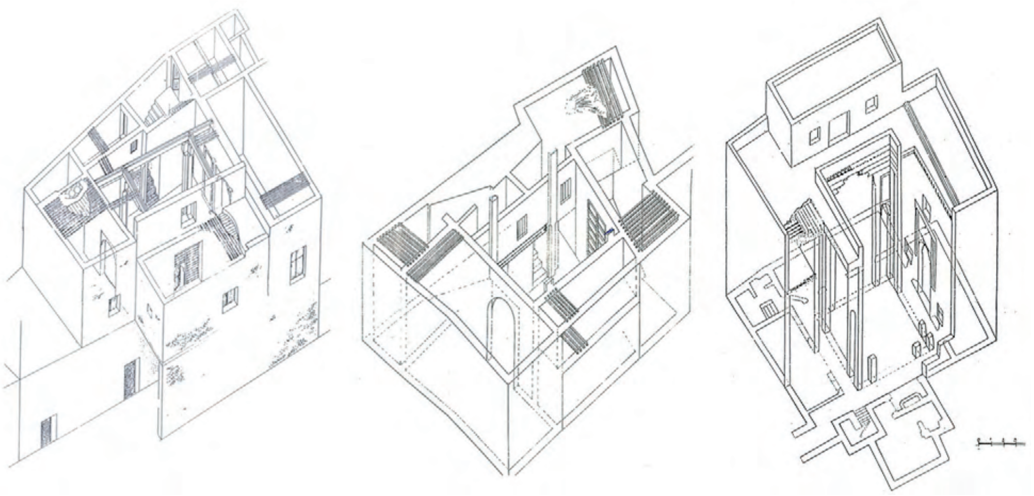

Figure 10: Different courtyard-house typologies with different thermal masses (Drawings by author)

3 Environmental lessons from the past

3.1 Current built environment crisis

The previous short examples, through field study observations, on how a madina, neighborhood, and house work to regulate the microclimate, proves that architecture in the Arab region evolved through centuries in one of the hottest climates with a continuous pursuit for an effective thermal response. The master builders sought ingenious passive energy means in order to reach a sustainable built environment (Figure 11). The typology of buildings was shaped closely by the climatic features, and generated henceforth a reach portfolio of forms, proportions, symbols, envelopes and so forth.

Nevertheless, the current built environment in the Arab region has reached a crisis stage in terms how the methods of building cope with the severe climate. The complete change from the traditional to fully a modern way of building has changed buildings into static boxes with one of the highest energy consumption in the world. For example, the UAE electricity consumption shifted from 5.5 billion kilowatt/hour (kWh) in 1980 to about 36 billion kWh in the year 2000 [6]. This represents an average annual growth rate of 10%, far above the 3% world average. Modern tall glazed buildings have taken over cityscapes and historic passive buildings have become but obsolete heritage (Figure 12).

Figure 11: An example of a living craftsman in Morocco educating a younger generation on organic building techniques (Source: author)

Figure 12: The old neighborhood of Sharjah invaded by tall buildings since 1970

3.2 Toward a climate-conscious urban geometry

As most sustainability expertise invests in remedial techniques to reduce the energy at the level of a building, the urban geometries of UAE cities ought to be revisited in order to create ideal thermal performance indoors and outdoors. Despite the hasty urbanization in the Gulf States that generated islands of iconic buildings seemingly parachuted, the future planning step is to improve its urban geometries in order to meet sustainability standards.

Urban planning and urban design regulations should include measures for seeking passive thermal comfort by orienting the urban geometry of cities. This can be attained by clear guidelines such as the following:

- Increasing shaded territory to encourage community-walking distances.
- Opting for more compact urban design elements that reduce the surface heat.
- Integrating the green landscape within residential complexes.
- Seeking more separation between heavy vehicular roads and communal ones.
- Orienting tall buildings to not obstruct the circulation of airflows.
- Applying more light-colored surfaces on the horizontal and vertical levels.
- Creating more shaded walking areas between tall buildings.
- Designing buildings with larger surface areas and high thermal mass.
- Creating urban courtyards that allow groups of buildings to have a thermal sink.
- Aiming at ideal built proportions (surface to volume ratio, shadow density, daylight distribution and so forth).
- Planning future urban contexts that alleviate the abusive use of air conditioning.

This mutation of urban geometry from a dispersed urban pattern to a more climate-conscious one cannot be achieved without continuous thermal simulation of the current urban fabric in order to assess its thermal performance and identify the environmental variables of interest. This will help architects and planners to seek suitable urban forms that includes surface to volume ratios, shadow densities, daylight accessibility and view factors from the city to the sky. In addition, the "urban heat island" a phenomenon that refers to the increase of temperature in an urban context when compared with its rural surrounding is a major indicator for planners and architects to design environmentally conscious urban and architectural forms.

4 Conclusion

This paper attempts to underline the fact that the historic built environment in the Arab world is a key reference in terms on how vernacular buildings were adapted to hot and dry climate. The ingenious methods applied by master builders, though might present numerous defects for lack of modern experimentation, capitalizes centuries of lessons on how to address the integrated climatic mechanism in buildings.

As demonstrated in the above examples driven from Morocco and UAE, the typology of buildings and urban geometry is an integral part of environmental design. The dense urban geometry has proven its thermal efficiency. Despite its increased heat island, the thermal comfort is improved significantly through high shade density. In addition to this typical urban geometry, another structural element is at play, the courtyard. Being the heart of an Arab house for its ecological dimension (water, air, and vegetation), the courtyard not only answers the need for privacy but also proves that it is an environmentally responsive building form. Therefore, both the macro urban geometry and the micro building typology are crucial for future thermal responsive urban planning and design in the Arab world, in particular the Gulf region.

In order to deduce practical applications from pre-industrial settings for designing climate-guided architectural and urban forms, further scientific research is needed. Nevertheless, it is important to alarm that emulating the vernacular form of the past may not provide a whole answer to resolve the crisis of the current built environment that is more complex in terms of size, proportion, function, and technology. Thus, this paper is neither a blind apology of past forms nor a sheer denial of modern ones. It meant primordially to awaken the creativity of scientists and designers alike on how our built environment could be contemporary, but yet authentic as far as climate is concerned.

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51–60 (2011)

OPTIShade: Potentials in Optimization of Passive Climate Protection for Buildings

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Abstract

Solar protection of buildings by fixed shading devices has the potential to increase user comfort and energy efficiency simultaneously. This is especially true for existing buildings not equipped with cooling facilities. Due to the inflexibility of these elements their correct design is essential. This paper discusses different methodologies for the ideal dimensioning of such elements and proposes the new method "OPTIShade". The method uses mathematical optimization strategies in building simulation. Basis for these simulations is EnergyPlus and Radiance, in addition to the generic optimization tool GenOpt. Using a ray tracing software tool will allow for angle selective materials and shading objects in the simulation. The search for a suitable optimization algorithm has been conducted successfully. First tests of the general method have shown its potential for the improvement of static shading design.

1 Introduction

About 37% of the German national primary energy use is consumed within buildings. This causes about 45% of the national carbon emissions. Besides immediate emissions from burning fossil fuels on site, nearly half of the emissions occur indirectly due to the use of electricity. A substantial amount of this usage is related to cooling measures.

The forecast changes in climate have an immediate influence on the design of buildings and building services. The requirements toward the energy efficiency of buildings are increasing. Due to rising temperatures, the reduc-tion of summer heat loads will become a more prominent factor in the tem-pering of especially office buildings [1].

In addition to reducing internal loads, angular selective fixed shading devic-es are an appropriate measure for reducing summer external loads. They are independent of control mechanisms and/or user behavior and are therefore more robust energetically and more predictable when dimension-ing building services as opposed to moveable shading. By cutting direct sunlight from the workspace, the user might more often remain in visual contact to the outside, as additional moveable glare protection devices might not be used so intensively. A disadvantage is the reduced field of view to the ambient sky, resulting in decreased daylighting and the reduction of winterly passive solar gains resulting in increased heating demand.

Static exterior shading is a strong graphical architectural element. It invariantly defines facades and offers high design potential. Yet it needs a precise interpretation, because of its consequences for the indoor climate and energy consumption. The consideration of the building envelope is an essential factor to minimize the energy demand for cooling, heating and artificial lighting. Solar protection plays a decisive role in the interaction of these factors [2].

This paper discusses methods for the calculation of shading elements and concludes with the presentation of a proposed tool for their optimization and shape generation.

1.1 Fundamentals

Static shading devices have been a common instrument in building design to control the amount of solar radiation entering the building. Prominent examples are the "brise soleil" of Le Corbusier or the horizontal concrete louvers on the Copan building in Sao Paulo by Oscar Niemeyer Figure 1.

They have a strong architectural quality and prove the acknowledgment of the designers for shading necessities.

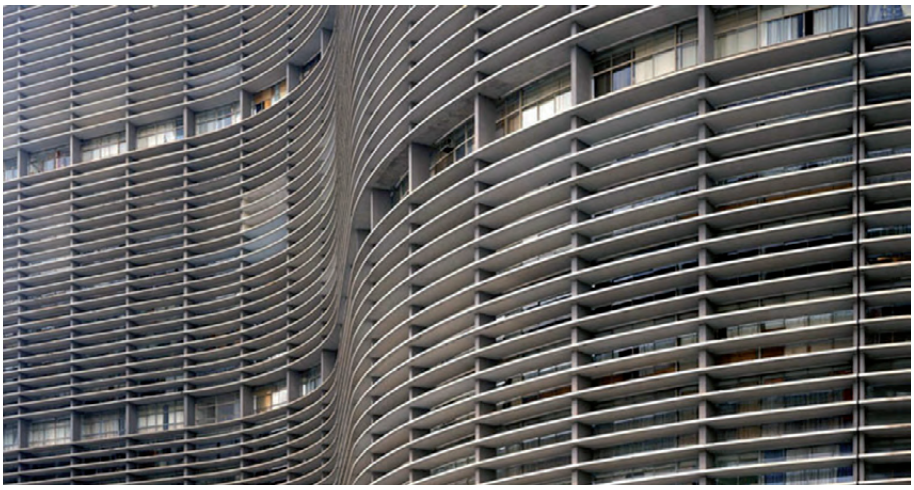

Figure 1: A superimposed screen of horizontal concrete louvers on the north facing façade of the Copan Building in Sao Paulo by Oscar Niemeyer

1.2 Design Methodology

The tools for the design of shading elements can roughly be classified into two groups based on:

- solar geometry ("cut-off")
- summation of solar irradiation

1.3 Cut-Off Methods

Substantial analyses of shading strategies and methodologies for sizing were published by Olgyay [3] in 1957. The described method takes both the local temperature and the solar geometry into account. Further geometry based methods have been proposed by ie. Mazria [4], Etzion [5] or Marsh [6]. The common basis for these approaches is defining annual periods in which it is desirable for a defined window surface to be fully shaded from direct solar gains, defining "cut-off" dates and hours. As a second step, the shaping of an element which will provide full shading of the window during this period is assisted. The precise definition of these "cut off" dates and hours is essential and require an understanding of the local climate and shading necessity. Not all tools provide guides in this respect. The incorrect definition can lead to extremely large shading elements. This can be a result of low solar altitudes during the beginning and the end of day and for locations which are distant from the equator.

The selected annual shading period in Figure 2 is the 10th April - 1st September. The daily shading period for the eastern window is 8:00-12:00 (4h), 12:00-18:00 (6h) for the west oriented window. The eastern overhang projects approx. 4m the west oriented projects approximately 31m. The extreme western overhang results from shading until late afternoon. The image demonstrates the problematic of correct "cut-off" definition in obvious exaggeration.

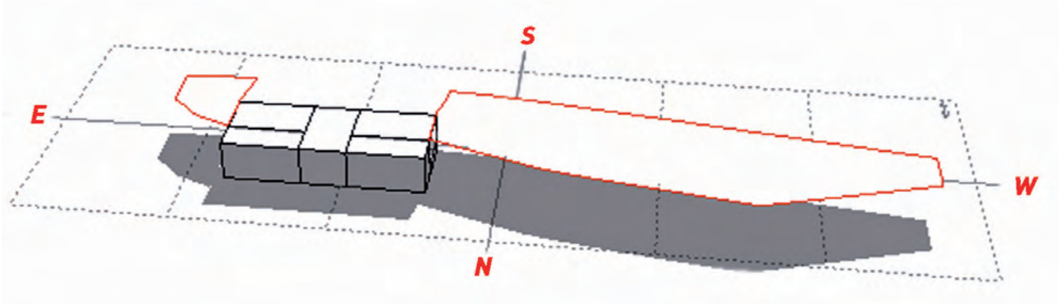

Figure 2: Overhangs derived from "cut-off" date method by Marsh [6] for an east (left in the image) and west orientated (right) window (width 2m, height 3m) in Stockholm, Sweden.

Even when cut-off periods are based on local climate data, the potential for overshading is high [7]. The periods of total shading are preceded and followed by periods of partial shading with varying percentages of shaded window surface. These effects are not taken into account. The methods rely only on the definition of shading for overheated periods, thus neglecting periods with solar demand. The consequences being a demand for heating even though solar gains might be available. Shading must be considered on an annual scale.

1.4 Irradiation based methods

Advances in computation have increased possibilities in fields of building simulation and design. One strategy for the design of static shading based on simulation of solar irradiation is the "Cellular Method" by Kaftan [7]. A rectangular simulation grid is defined above a window at a given height. The simulation is conducted in three roughly described steps:

1. Each cell of the grid is checked for its shading relevance
2. Passing direct solar radiation is summarized in each relevant cell
3. The need for shading or solar gains is derived from indoor climate

User comfort and energy saving are therefore accounted for. The computa-tional tool to this method "Optimal Shading Form" (OS-Form) is based on MS Excel spreadsheets. It relies on manual input from building simulation tools and has no graphical user interface. It has since been implemented into the Software Ecotect as a plug-in [8]. The plug-in no longer restricts the initial shape and can consider free-form surfaces.

A further tool based on and extending this concept in its precision is "Shaderade" [9]. Cell conditions can also be calculated for exterior three-dimensional uniformly spaced grids of arbitrary shape.

1.5 Limitations

The cellular method described is presently a most comprehensive approach to shading design. Incorporating indoor comfort criteria, local climate, building data and energy demand for cooling and heating into the estimation. The method relies on shading to be absent in each individual cell during the calculation. Shading a relevant cell however influences the necessity for shading in every other cell of the grid. The more relevant cells are opaque, the fewer cells are needed for shading. The neglect of this interaction will most lekely predict larger shading elements than necessary.

A common approach for shade designers to increase daylighting is to propose elements that are translucent. These can be made of light scattering materials or structures like grids with angular selective transmission proper-ties already given by the material. These material typologies are yet unaccounted for.

2 OPTIShade

2.1 Introduction

Occupant comfort and respectively occupant performance is dependent on multiple factors. Shading not only influences the indoor thermal conditions, but also influences the amount and quality of daylight entering the building interior. Therefore, when designing shading, thermal considerations must be weighed against the potential reductions in daylighting and the effect on artificial lighting. Taking the limitations of existing methods into account, a new method for the design of optimized shading elements is proposed. The proposed method is based on the simulation of heating and cooling energy and daylighting using validated building simulation tools and optimization procedures. It might also be applied to optimize the times of visual contact to the outside. The proposed method begins with an individually defined shading form and modifies its shape and/or extent until a defined optimum is achieved.

The tool OPTIShade is currently under development, employing EnergyPlus as the dynamic thermal building simulation engine. Integrating three-dimensional angular selective shading structures into the model requires ray tracing capabilities beyond those of EnergyPlus. The light simulation program Radiance can simulate Complex Fenestration Systems (CFS) and deliver the input data for EnergyPlus [10]. The combination of both tools into one simulation model will make it possible to evaluate and generate translucent shading elements with a diverse selection of material qualities and surfaces geometries.

2.2 Optimization vs. Parametric studies

Building simulation is time consuming due the work necessary to define the model and to run the simulation. To achieve a desired optimum, multiple runs are usually required. The planner has to interpret the results and rede-fine the parameters, not necessarily certain which will influence the simula-tion in the desired manner.

These Parametric studies can be automated. A java based tool that offers the exploration of alternative design options in EnergyPlus is jEPlus [11]. The designer has the advantage of setting up the simulation problem once and defining the parameters to be varied. These parameters can be con-secutive and will then result in a tree structure with varying branches defin-ing simulation paths based on the results of preliminary equations in EnergyPlus. The method automates and thus speeds up the process of multiple simulation runs. The exact numerically defined steps for each singular equation are required from the planner/programmer. This means there are as many simulations as the planner has defined parameter variations.The planner must assume the amount of variations of a parameter needed and the ideal step. The interaction of different building components in the simu-lation of building energy demand makes this a complex task. The more complex a simulation problem, the more complex the setup of an auto-mated parametric model will be.

A different approach is mathematical optimization. Optimisation is the proc-ess of minimizing (or maximizing) objective functions by automated varying of single or multiple parameters. The program GenOpt [12] was developed to facilitate optimization in building simulation. GenOpt launches the simula-tion program with input files based on a template supplied by the user. The program then reads the function value from the result file and iteratively generates new input parameter values until the maximum or minimum of the function is achieved or the defined amount of maximum runs is reached. It is essential to select an optimization algorithm that works effi-ciently on a particular problem. There is no general algorithm for all mathematical problems. GenOpt has mainly been developed for single-criteria optimization, but can be extended to multi-criteria optimization. This has lead to the choice of GenOpt as an integral part of OPTIShade.

2.3 EnergyPlus Model

EnergyPlus offers two basic shading typologies, detached or attached.

The majority of shading typologies listed in Table 1 are assumed by the software as a rectangular surface defined by two vertices distant to the building and two vertices on the building skin. The suffix "Detailed" implies that the element has an unlimited number of vertices allowing for more complex geometries.

The "Shading:Building:Detailed" model provides the most potential for op-timized shading:

- It can shade more than one surface
- An unlimited amount of vertices can be applied
- There is no connection to the building necessary
- If defined by relative coordinates it remains relative to the building geometry

Testing was conducted on a single-zone model created in DesignBuilder, a commercial software user interface for EnergyPlus and exported as an IDF file. The opaque shading element was added to the model in the EnergyPlus IDF-Editor. The model is based on a testing facility in Wuppertal and is assumed as unconditioned. The building is highly insulated. The window is south facing and is equipped with solar protective triple glazing. .

Table 1: Typologies of shading elements in EnergyPlus.

Shading:Site Shading:Building Shading:Site:Detailed Shading:Building:Detailed	Detached: Shading elements that are not connected to the buil-ding, ie. other buildings, trees, etc. Shading of multiple surfaces.
Shading:Overhang Shading:Overhang:Projection Shading:Fin Shading:Fin:Projection Shading:Zone:Detailed	Attached: Horizontal or vertical projections attached to the buil-ding. Shading a specific window or object.

Table 2: Definition of the test model properties

Location	51,26°N; 7,166°E
Weather file	DEU_Dusseldorf_IWEC, ASHRAE
Window Glazing (triple glazing)	U-value < 1,1W/(m² K), g-value 34%, light transmission 66%
Walls (adiabatic)	U-value 0,19 W/m²K
Roof	U-Value 0,21W/m²K
Floor	U-Value 0,05W/m²K
Heating Setpoint / Cooling Setpoint	21°C / 24°C
Lighting Load	17 W/m²
Office Equipment Load	9 W/m²
People Load	0.0538 m^{-1}
Target Illuminance	500 lux
Natural Ventilation	On

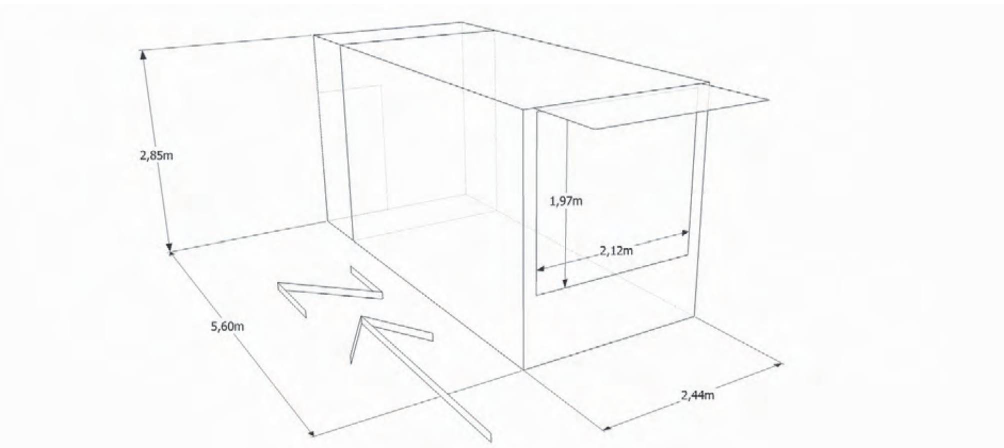

Figure 3: Single-zone model of a test room facility at the Universit of Wuppertal.

The annual source energy demand is based on the function (1) described by Wetter [12]. The optimization is done using the Hooke Jeeves algorithm:

$$f(x) = E_{tot}(x) = (Q_{heat}(x)/\eta_{heat}) + (Q_{cool}(x)/\eta_{cool}) + 3E_{lights}(x) \qquad (1)$$

$Q_{heat}(x)$ and $Q_{cool}(x)$ are the zones yearly heating and cooling load, $E_{lights}(x)$ is the zones electrical consumption for lighting. η_{heat} and η_{cool} are plant efficiencies, $E_{lights}(x)$ is weighted by factor 3 to convert the results from site to source energy. The simulation was based on the variation of only one parameter, shading depth. Simulations of shading elements with more individual variable vertices have proven to be more complex. The vertices are handled consecutively, not necessarily leading to the desired minimum.

3 Conclusions

The first results from the suggested method for the generation of optimized shading have so far been promising. The objective function will be adapted to user comfort according to DIN EN 15251:2007. This is especially relevant for existing buildings without cooling devices. Visual contact the exterior will be considered as an additional aspect.

The work on OPTIshade is currently ongoing. An optimization algorithm has been found to address the multi-criteria problem and simultaneously reduce the necessary computational time. The MOEA/D algorithm [13] (Multiobjective Evolutionary Algorithm based on Decomposition) uses approximation methods to narrow the problem before the optimization is initiated. Further work is to be conducted on the integration of Radiance into the simulation process. .

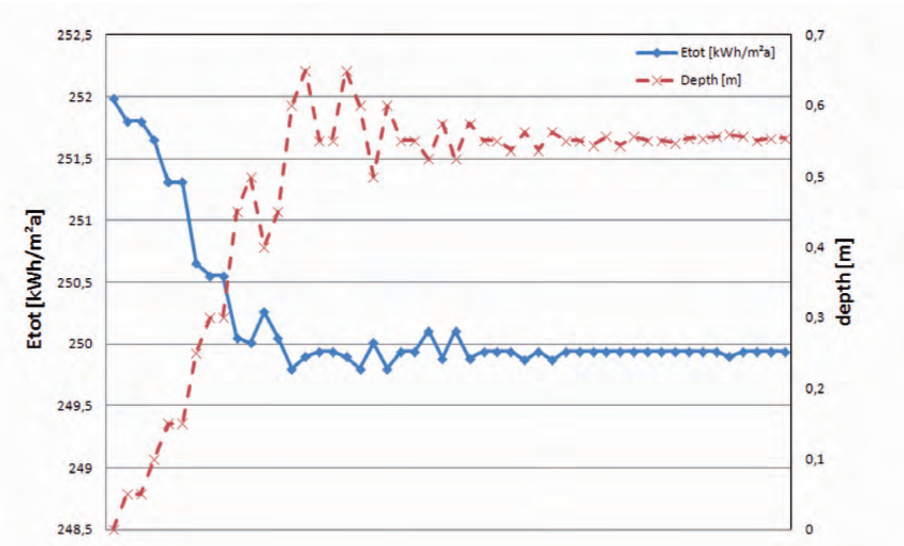

Figure 4: Iteration sequence using the Hooke-Jeeves algorithm.

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Urban Strategies on Climate Change

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Abstract

The research project 'Inner Urban Development versus Climate Comfort in the Region of Karlsruhe' looks into the possible contradiction of the mitigation and adaptation in urban development. While a highly dense and compact city is desirable regarding to climate protection, it can lead to problems in terms of climate adaption (urban heat phenomenon). The focus of research lies on experimental urban planning studies in three different areas in the city and in the region of Karlsruhe: New buildings are added to increase density while green space structures are modified to support climate benefits in the spatial context. The intention is to combine both aspects of adaptation and mitigation in inner urban development, to find out optimal proportions between building typology and green development to enhance the local climate situation during summer periods and to find conceptual approaches for a climate-friendly city. Based on the climate model of the greater city area the design alternatives will be compared by analysing climatic benefits of specific measures. As a result recommendations for an adapted inner urban development and climate-proof planning are expected.

1 Focus Areas

To get a spectrum of possible climate-friendly urban layouts three different areas with different urban and natural, spatial and contextual, structural and climatic conditions have been chosen.
For the different locations (inner city, town centre and periphery) specific tasks of inner urban development (residential or business) have been defined reflecting realistic inner urban development demands and potentials:

Karlsruhe: Durlacher Allee, Oststadt district (Figure 3) and
Stutensee: Ortsmitte Blankenloch (Figure 5)

- redensification of existent development (residential)

Karlsruhe: Durlacher Allee, district Gleisbauhof (Figure 3)

- conversion of derelicted land (business)

Ettlingen: Neuwiesen (Figure 4)

- redevelopment from scratch (residential)

To every focus area two different urban layouts had been designed with same levels of density in order to easily compare design-based consequences.

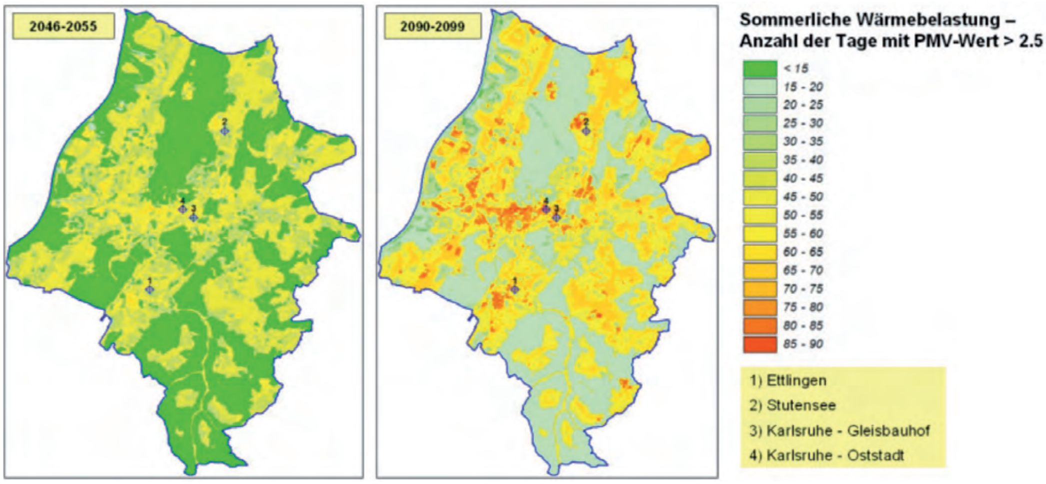

Figure 1: Increase of number of days with summer heat stress in the region of Karlsruhe for the years 2046-2055 and 2090-2099 (climate model projected with ENVELOPE based on the regional CLM-Data (SRES-Szenarios A1B) - Deutschland-modell

Figure 2: Location of focus areas: (1) Karlsruhe: Durlacher Allee (inner city, Oststadt and Messplatz + Gleisbauhof); (2) Ettlingen: Neuwiesen (periphery); (3) Stutensee: Ortsmitte Blankenloch (town centre)

2 Design Process

2.1 Objectives

The experimental designs attempt to optimise the relations between location, quarter and context, urbanistic and free space structure, between house and garden, green space network, air lanes and flow conditions.

The climate-conscious redensification and the development in parallel of mitigating and adaptating urban strategies (to promote synergies and avoid contradictions) are based upon the reflection of the spatial and climatic conditions and the aforementioned correlations.
The design is supposed to bring on positive climate conditions inside the district as well as to its proximal environment. Cold air currents are to stream freely by developing fitting building or free space typologies.

2.2 Method

General suggestions of measures have been derived from the evaluation of the climate model. Solutions reflecting the urban context and taking the landscape into consideration have been developed. Building and green-space typologies and uses correspond to the specific situation.,

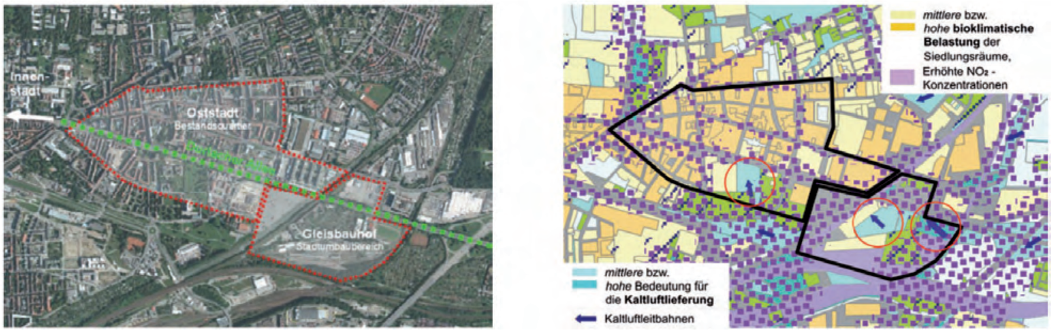

Figure 3: Focus area I: Karlsruhe: Durlacher Allee, aerial view + climate evaluation map (districts Oststadt and Messplatz + Gleisbauhof)

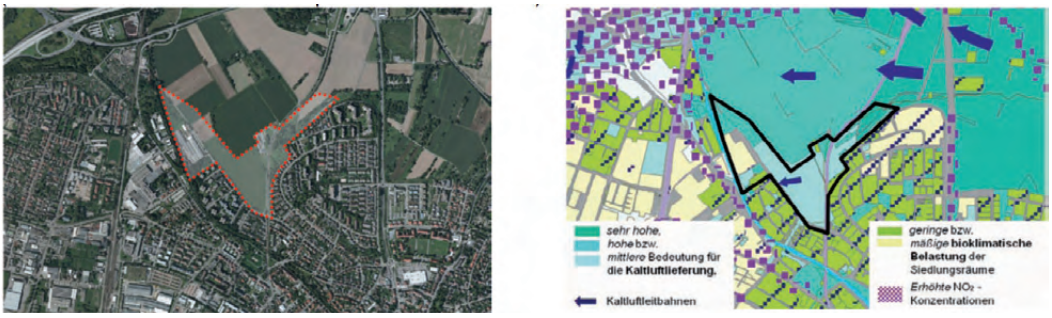

Figure 4: Focus area II: Ettlingen: Neuwiesen, aerial view + climate evaluation map

Figure 5: Focus area III: Stutensee: Ortsmitte Blankenloch, aerial view + climate evaluation map

Energetic aspects and strategies for climate protection (interior development and compactenergy-efficient building typologies, good lighting conditions and natural air circulation) were taken into consideration as well as climate adaptation (green space development and air circulation, shadowing and development of resilient, adaptable spatial structures, i.e. in case of heavy rain or heat).

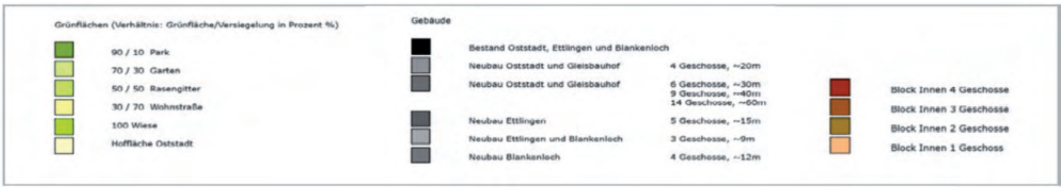

Figure 6: Key for focus design projects

2.3 Expectations

The analysis will show which kind of green space and building structures are to be recommended for the communities, i.e. where shadowing trees or green corridors should be located to be climatically effective.

3 Description of Designs

3.1 System of Layers and Colours for Preparation of Climate Analysis

As a preparation for the climate analysis a simple classification system has been developed to show the different grades of sealed surfaces. This system is valid for all concept alternatives. It also provides information on the respective building heights as well as descriptions of roof surfaces (green/grey) and facade surfaces (green/perforated).

3.2 Karlsruhe: Durlacher Allee (with districts Oststadt/Messeplatz and Gleisbauhof)

3.2.1 Option I, Oststadt district - 'Green Courtyards' and Messeplatz and Gleisbauhof district (FAR 3.0) - 'Hybrid Buildings on Green Space'

In the Oststadt district the courtyards will be largely cored, surfaces unsealed and the green space quota raised. Individual existent buildings will be preserved and, where possible, heightened by one or two storeys.

In the Messeplatz and Gleisbauhof district freestanding hybrid buildings (up to 60 m height) with low ground coverage are proposed to offer space for air circulation inside the district and up to Durlacher Allee in case of a persistent inversion layer.

3.2.2 Option II, Oststadt district, Messeplatz district and Gleisbauhof (FAR 3.0) - 'Pocket Parks'

In the Oststadt district a small district park as well as a number of pocket parks adjoining the Durlacher Allee are established to set up a network of green spaces in order to improve air circulation inside the district and along the cool air lane of Durlacher Allee. Subsidiary buildings inside the courtyards remain unchanged.

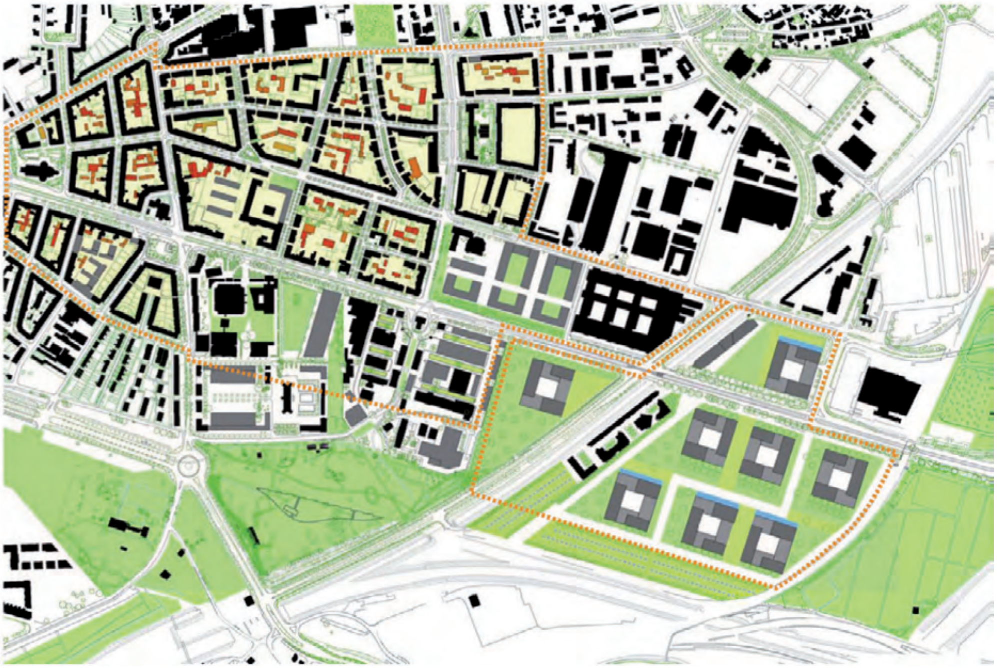

Figure 7: Overview Option I 'Green Courtyards' + 'Hybrid Buildings on Green Space'

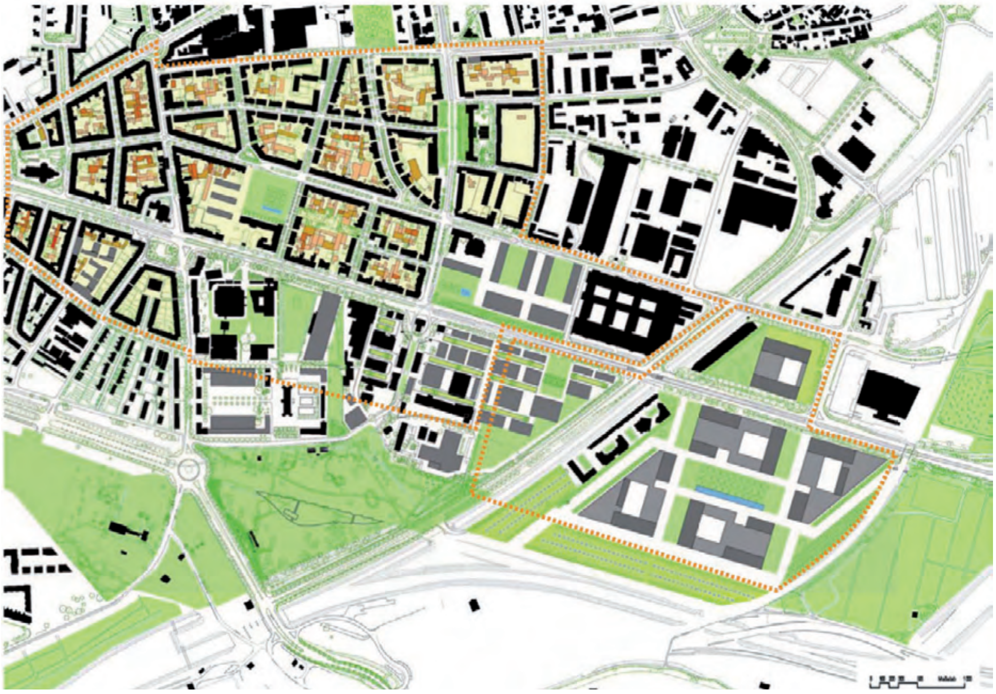

Figure 8: Overview Option II 'Pocket Parks'

In the Messplatz and Gleisbauhof district the design envisions the development of a business (up to 30 m height) district with a common green core with trees and an adjoining water expanse for an improved climate condition. Boundary and entrance areas will be kept free for incoming cold air currents during tropical nights. The pocket-like free spaces are meadows without trees to let fresh air through.

3.2.3 Differences and similarities of the various options

The main difference in the concept design of 'Hybrid Buildings on Green Space' and 'Pocket Parks' is their diverging approach to spatial expression: The hybrid buildings form single objects on free-flowing green space while in the second option the green space is enclosed in block structures.

Both options I and II for this district reach about the same floor-area-ratio accounts. Option I with its low ground coverage enables a resilient, well ventilated spatial structure while it is the green core in option II that causes positive climatic effects.

3.3 Ettlingen: Neuwiesen

3.3.1 Option I - 'Green Chute' (FAR 1.2)

A 'green chute' leads fresh air currents to the inner city in tropical nights. The three-to-five-storey residential buildings centre on the western part of the field near the river Alb. They are made up of south-east facing continuous rows of houses parallel to the natural air circulation and at right angles to the river Alb.

Preliminary Results:

The new development and complementary green structures cause cooling effects on the garden sides but hot spots inside the narrow treeless residential streets during the day. Air circulation towards the existing quarters is improved by aligning the new development with the natural air current. As a means to reduce hot spots streets can be broadened and trees can be planted. The layout of the new structure supports air flow in two directions; one being the natural air current and another being the 'chute' which leads towards the city.

3.3.2 Option II - 'Green Air Lanes' (FAR 1.2)

On the eastern and western edges garden space is used as buffer zone along the train tracks and along the river Alb. Air lanes are left open for circulation to the left and right of the buildings on the central field.

Preliminary Results:

The shading effects of the new development and complementary green structures reduce overheating of the field on hot summer days. Heat stress during tropical nights does not occur more frequently within the adjoining quarters or inside the new development. Optionally the green north-south lane can be broadened to lead fresh air currents towards the inner city.

Figure 9: Option I - 'Green Chute'

Figure 10: Option II - 'Green Air Lanes'

3.3.3 Comparison of the options Ettlingen-Neuwiesen

Main differences between the two options are the distribution of free space and the scatter of volumes in space.

3.4 Stutensee: Ortsmitte Blankenloch

3.4.1 Option I - 'Green Courtyards'

The single family houses and apartments surrounding the large gardens will be heightened by one storey and complemented by three-storey apartment buildings in the first and second row. Main goal of this concept is the preservation of the ample garden space inside the 'courtyards'.

3.4.2 Option II - 'Third Row'

The existent development is only occasionally complemented by four-storey apartment buildings. Subsidiary buildings in the second row will be preserved. The interior of the existing ensemble is complemented by three-storey houses with central residential streets as common space and private yards to the backsides.

3.4.3 Comparison of the options Stutensee - Ortsmitte Blankenloch

Both options try at an agreeable redensification of the existent development, reaching the same level of total floor area. Above all it is the green core in option I that causes positive climatic effects.

Figure 11: Option I - 'Green Courtyards'

Figure 12: Option II - 'Third Row'

4 Conclusion

The site-specific, well-balanced correlation between building and free space typology is essential for achieving positive climate-adaptive and climate-protective effects. The right measure of urban redensification and green space development is one of the most significant tasks in the context of urban strategies on climate change towards a climate-friendly city.

Project Management

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Chapter 2: Construction Chemistry

Climate and Constructions
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Modern Transport Infrastructure

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Abstract

In most cases, discussions with infrastructure authorities lead to the same result: “We don’t want to spend our money for infrastructure management, we rather use the money for the required maintenance measures”. Subsequent questioning about how this required maintenance is determined mostly shows that the decision is based on short term considerations but doesn’t include criteria like sustainability or long-term conservation of value. It should be generally agreed that a proper transport infrastructure is one of the important conditions for economic growth, social life and the distribution of goods, foods and other services. As a solution, infrastructure management methods were developed. A central issue within these methods is the prediction of material behavior under different conditions. This paper shows that present management systems can help to find good strategic decisions for the maintenance of future transport infrastructure. Taking into consideration the immense asset values of transport infrastructure, well-based decisions are absolutely necessary to achieve economic and social stability. But this management system needs further development due to climate chance and understanding materials behavior. This task can be solved in teamwork between civil engineers, natural scientists and the management. The future work should concentrate on material behavior and prediction models as the most important parts for the reliable functioning of a strategic management system for R&B-Work. The work should comprehend the following fields:

Which material properties and data will lead to better behavior models?

- Which characteristics of transport infrastructure can be reliably predicted?
- Which R&B-Work Types can be used in accordance to the actual conditions, and how can these be modified?
- What are the long term effects of defined M&R Work Types?

1 Introduction

In most cases, discussions with infrastructure authorities lead to the same result: “We don’t want to spend our money for infrastructure management, we rather use the money for the required maintenance measures”. Subsequent questioning about how this required maintenance is determined mostly shows that the decision is based on short term considerations but doesn’t include criteria like sustainability or long-term conservation of value. However, the transport infrastructure is constantly deteriorated by traffic load, climate conditions, etc. Ultimately, the long-term conservation of value of the transport infrastructure is at risk unless modern management methods for infrastructure maintenance are applied. These management methods are based on teamwork between engineers, natural scientists and the management. A central issue within these management methods is the prediction of material behavior under different conditions. This allows to choose between different maintenance methods, depending on their sustainability.

If this is disregarded, we will experience an effect which is described by M.Y. Sahin as “Pay now, or pay much more later”. Infrastructure needs to be managed, not just maintained. Although it is difficult to change the way we do business, it will be more difficult to explain to future generations how we failed to manage our resources and preserve our infrastructure [1]. In fact, the infrastructure asset deteriorates dramatically if we use the wrong techniques or make the wrong decisions using inexact calculation methods, as can be shown clearly by a lifetime calculation. The damage in monetary terms will increase rapidly to such an extent that one generation will not be able to cope with it.

In the past, several management approaches were developed to solve the decision problem. The solutions used today are important factors, but they can’t give a wide-ranging solution. For example, the German system for pavement management is based on an engineer’s view. But future systems need a comprehensive solution taking into account more basic and technical knowledge from different fields like natural sciences and economics.

So the objective of this paper is to show, (1) how large the impact of infrastructure on economic, environmental and social life is, (2) how large the asset value of public infrastructure is, (3) which management approaches are existing currently, (4) how we can improve these management approaches in view of a teamwork between engineers, natural scientists and managers and finally, (5) where the important fields for future work and research within these systems lie, especially in the case of natural sciences like construction chemistry.

2 The Significance of transport infrastructure

Transport infrastructure can be divided into the railway network, the road network, airports, waterways, and seaports. In a broader sense, we define also transport systems for energy, like pipelines or electrical power lines, as transport infrastructure. It should be generally agreed that a proper transport infrastructure is one of the important conditions for economic growth, social life and the distribution of goods, foods and other services. Lack of access to the transport infrastructure is considered as one handicap to overcome poverty in developing countries [2], an insufficient transport infrastructure is an obstacle for homogenous living conditions at a reasonable quality standard in industrial countries. Further to the big industrial transport volumes, some very simple transport tasks exist, like the access to education, the access to health care or the supply with aliments as basic tasks for social life.

Within the present paper, quality standards are not an issue, those must be determined in addition to local requirements. The basic problem is quite simple. The construction of transport infrastructure is very expensive, transport infrastructure is subject to a steady deterioration, by means of proper maintenance the deterioration can be corrected, which also requires a lot of money. In order to handle this problem, economic, technical and environmental restrictions must be taken into account.

To give an example: a road network consists of pavements, engineering structures and further equipment for safety and traffic signs. Pavements are divided in asphalt and concrete constructions, engineering structures are tunnels and bridges. Bridges can be constructed as steel or reinforced concrete bridges. Every part has its own lifetime behavior and many parts are strongly influenced by climate conditions. At this point it becomes obvious that any serious management system needs a deep understanding of the particular part of the construction, otherwise it won't be able to calculate any lifetime behavior model, which is the essential base for every management decision.

A brief view of the German road network shows an overall network length of 688,243 km [3], as seen in figure 1. The federal network part consists of interstates and federal roads, this means 52,921 km network length and covers an area of 613.6 km². In this networks, there are 38,782 bridges, consisting of 50,198 parts,

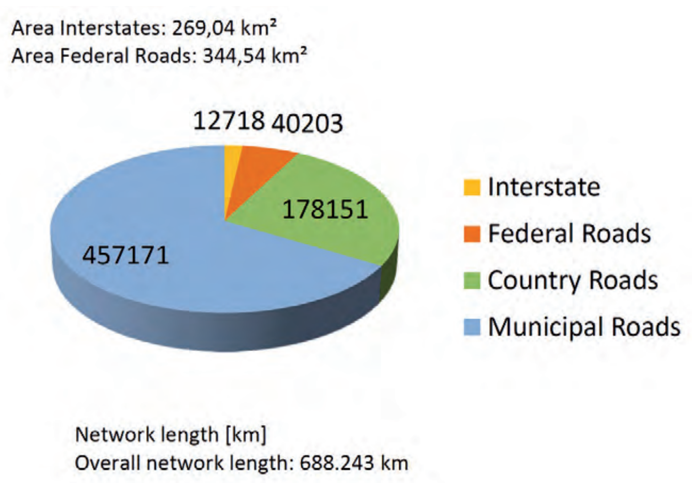

Figure 1: Length of the German road network

which cover an area of 29,6 Mio m², the length is 2,058 km [4]. The overall asset value (new construction value) for the federal part of the road network is fixed by the Federal highway agency at approximately 230 Mrd. EUR. The actual asset value can be calculated at approximately 160 Mrd. EUR. The annual requirements for maintenance are very difficult to determine, as different sources give different amounts. In [5] for example, an annual amount of 5.6 Mrd EUR for the federal road network is reported. The exact amount is not important; but the given range is in a reliable scale. So the problem is obvious, wrong calculation models lead to wrong management decisions and then to economic failure.

3 Lifetime and asset management considerations

In order to get reliable calculation models for material behavior it is necessary to characterize the factors for deterioration. Transport infrastructure is designed with a theoretical lifetime, roads and bridges are for economic reasons constructed to fail. In Germany, the road engineers assume a design lifetime of 30 years. In fact, every layer has its own theoretical lifetime, which differs sometimes significantly from this. There are three different main factors, which are to some degree interdependent:

- Type of layer and specific material characteristics
- Traffic Load
- Climate Conditions

The design problem can be solved quite well with materials testing, but there must be some estimates. One is the traffic load: if there is more traffic, the lifetime is shorter and vice versa. Another are climate conditions, there must be knowledge about highest and lowest temperature and also data about humidity, which is included in the calculated lifetime. An unexpected variability of climate conditions will lead to a very complex change in material behavior, influencing existing structures, maintenance measures as well as new structures.

4 Actual management solutions

For the federal road network, two different systems are developed. For the pavements, a Pavement Management System (PMS) has been in use since ten years now, for the bridges a quite similar Bridge Management System (BMS) was developed. A good overview to the PMS is given in [6], descriptions of the BMS are given in [7]. The exemplary examination of the PMS will give an understanding of the system performance and also of the technical problems which need to be solved in general and especially with regard to climate chance.

The principle of the system is divided into two parts, first a project level management (operational approach) and secondly a network level management (strategic approach) [8]. The targets of these two approaches are shown in figure 2.

This shows that a useful approach for a transport infrastructure management system should follow the ideas which are outlined in the strategic approach. The strategic approach can give conclusion to the quality of different management strategies but the calculation model have to base on a lifetime prediction model. In figure 3 it is detailed how the German PMS solves this task.

All model calculations are based on a fixed data base. Two data types are very important, first the pavement condition assessment based on the surface characteristics like evenness, skid resistance and different surface damages, secondly on structural pavement data which represent the bearing capacity. In the next step we want to find homogenous sections, which have a comparable structural and surface condition. These sections are the base for Rehabilitation & Maintenance (R&M) work planning. The pavement condition prediction provides the information when R&M work will be required in a defined section. I Depending on the section

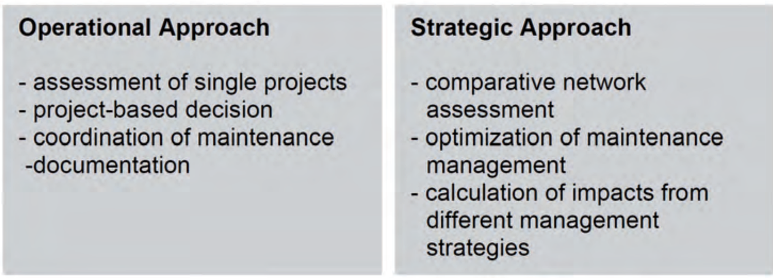

Figure 2: Project level and network level management

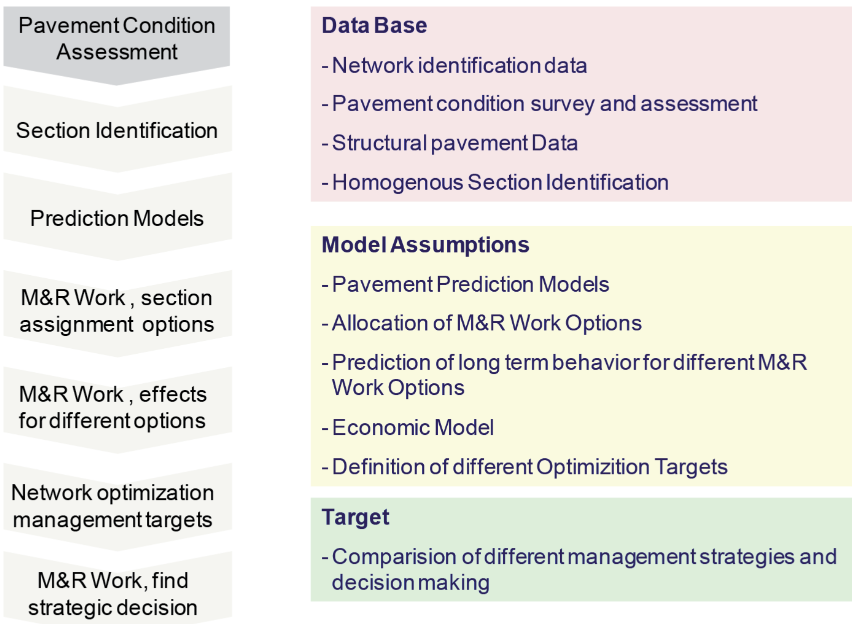

Figure 3: Strategic approach of German PMS

condition it is possible to assign more than one possible R&M work variants. This is the base for any further optimization. One of the important points is modeling the behavior of a section after a defined R&M work variant. There are the following management targets for the optimization:

- How much money per year is required for a defined quality level?
- How much money per year is required to keep the asset value?
- Which strategy is the best for a given budget?
- What will be happen with the network in the future, if there is not enough money

The answers will be a good base for management decision making, if all model assumptions are well defined and working. Figure 4 shows an example for overall results in a road network.

The results can be read very easily, the two lower rows show the predicted future condition chance per year. Blue color means a very good condition, yellow color means a bad, but usable condition, red color means that immediate R&M work is required. In this case it was possible to show a huge structural damage in the network, which can't be solved within the given budget.

This approach is state of the art and very useful for decision making. But these results are good only if the database is valid and if the model assumptions are sound. They represent the current knowledge of civil engineers and scientists as a result of over 20 years research. Anyhow, there is the question, what can be done better.

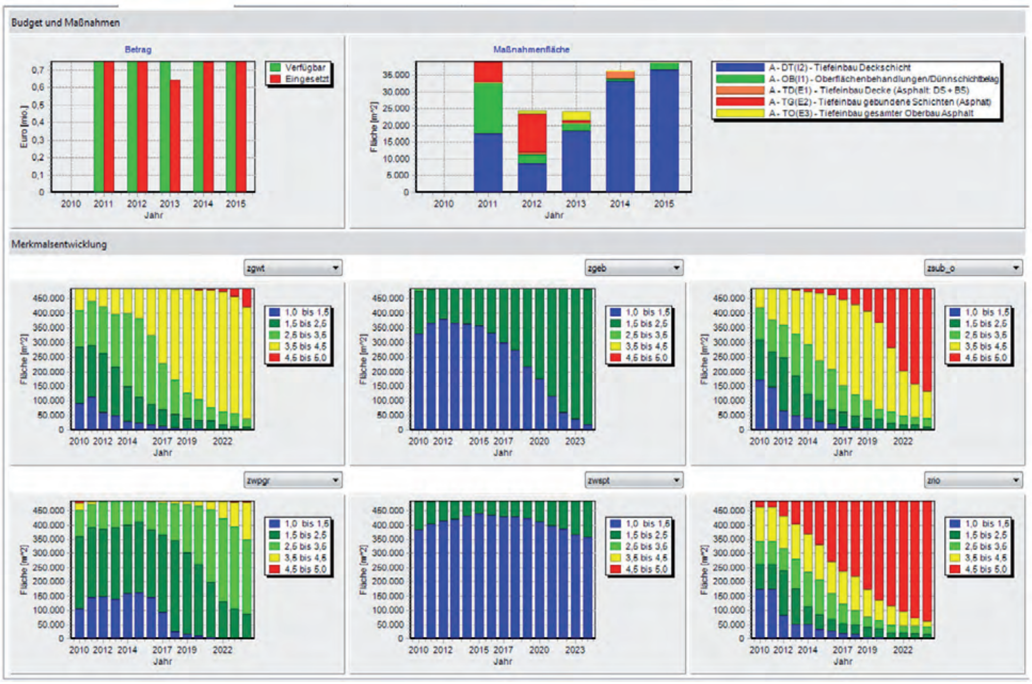

Figure 4: Example, overall results of German PMS

5 Future infrastructure management system solutions

Within a critical discussion of the German PMS, it can be stressed that the general system is suitable. In other countries within the European community or in North America similar solutions are established. At first view it could be a model for other parts of the transport infrastructure system. But there are some further basic questions about the database and the model assumptions, which can be formulated as different requirements for future development. Basically the management system is based on understanding material properties and their behavior under different loads like traffic and climate. So it is obvious that the model core needs excellent knowledge from engineers and natural scientists. All model calculations in the past led to the result that the biggest influence on the calculation results comes from modeling the materials behavior. Future work should be focused on this point.

The first requirement is the influence of climate change. The current prediction models represent the past climate dates and won't allow calculations with, for example, increasing annual temperature. For both methods, asphalt and concrete, different temperatures will lead to a reduced lifetime, even if different technical reasons are responsible for this. In addition to this, the building process can be influenced in a way that lifetime is reduced. For this reason it is necessary to calibrate the prediction models or to find a completely new approach. It is planned to test one approach based on data mining techniques. The effort of data mining lies in considering all available data instead of the actual reduced data set.

The second requirement is a better understanding of material behavior. Current tests use only surface data at a given point of time, when the damage is visible. Weak spots can't be detected. On one hand is there an influence of the prediction model, on the other hand can this lead to a wrong decision for R&M-Work Types. There is a need for better assessment and modeling methods for material behavior.

The third requirement is the development of R&M-Work Types, which are aligned to a special case. There are applications for bridge repair based on chemistry expertise combined with conventional materials testing. It is also possible to do this in the same way for concrete or asphalt pavements. In the case of asphalt pavements, considerable problems exist considering the bitumen quality. The quality requirements are based only on physical properties. It should be tested if chemical analyses can lead to a better performance prediction for asphalt pavements. Due to the fact that temperature strongly influences the behavior of asphalt pavements, this is a very important point for future work.

The fourth requirement is to some extent linked to the third requirement; it deals with the methods for condition survey. If there is a possibility for better materials models, there is even a need for further survey methods. In this context it should be discussed which data should be collected in addition to the existing data sets, especially climate data.

6 Conclusions

This paper shows that present management systems can help to find good strategic decisions for the maintenance of future transport infrastructure. Taking into consideration the immense asset values of transport infrastructure, well-based decisions are absolutely necessary to achieve economic and social stability. But this management system needs further development due to climate chance and understanding materials behavior. This task can be solved in teamwork between civil engineers, natural scientists and the management. The future work should concentrate on material behavior and prediction models as the most important parts for the reliable functioning of a strategic management system for R&B-Work. The work should comprehend the following fields:

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- Which R&B-Work Types can be used in accordance to the actual conditions, and how can these be modified?
- What are the long term effects of defined M&R Work Types?

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Computational Chemistry for the Investigation of Water Repellent Agents

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Abstract

The climate change results in new challenges. Certainly the construction trade is one of them. The existing buildings and infrastructure are exposed to altered environmental conditions. This makes often further treatment and protection for the buildings and infrastrucure necessary. One way to protect especially cementitious material is the treatment with water repellent agents. These agents are applied onto the surface. They are transported through capillary suction into the material and several reactions take place. The processes whilst the transport and the interactions are not declared till now. But for a directed improvement of the existing agents the knowledge of the molecular processes is very important. Usually agents are improved through empirical trying, so new methods have to be considered. One can be the computational chemistry, which offers new ways for examination of molecular processes. In the following for the example of the water repellent agents this is shown.

1 Introduction

Not only the climate change itself but also the consequences are subject of research activities. One sector which is in strong interdependency with the climate is the construction trade. First of all the existing buildings and infrastructure are exposed to the changing climate conditions. Second the construction phase has to be adapted to the revised conditions. And third is the release of climate-relevant gases, especially the carbondioxide-emission whilst the cement-production, one of the possible reasons for the climate change.

To improve the resistance against changed conditions, buildings and infrastructure can be treated with protecting agents. For example cementitious material is treated with water repellent agents to prevent the intrusion of water and especially chloride-solutions, which are part of thaw-salts. If winters get colder or/and longer more thaw-salts are sprayed on streets. The chlorides intrude into the covercrete and migrate to the reinforcement. There corrosion-processes triggered through the chlorides start. The intrusion and migration can be avoided through the water repellent treatment of the concrete. Concrete is a very complex system, consisting of several parts like e.g. aggregate and hardened cement stone. An important part of the hardened cement stone on the other hand is the calcium-silicate-hydrate-, CSH-gel. Unfortunately the chemical properties are rarely examined and experimental hardly accessible, but the CSH-Gel interacts with water repellent agents.

In the following the example of the investigation of water repellent agents with the methods of computational chemistry to elucidate the molecular processes is shown. This is a rather new approach in the construction trade. In the following some experimental results and their interpretation in the combination with molecular modelling methods are presented.

1.1 Alkyltriethoxysilanes

1.1.1 Introductory remarks

Silicon organic compounds, especially alkyltriethoxysilanes, ATES are used to protect cement based materials from the intrusion of water and therein solved substances. They are applied on the surface and transported into the material through capillary suction. Whilst this transport process the ATES follow a complex reaction mechanism, called polycondensation. About these mechanisms less is known, because they are experimental hardly accessible. Interactions between the mineral surface and the ATES are little accessible through experimental investigations, too. One way to interpret experimental investigations is to use molecular modelling methods.

1.1.2 Polycondensation

The polycondensation of ATES, consists of two partial reaction, first a hydrolysis, followed by a condensation. Both are nucleophilic substitutions and proceed depending on reaction conditions simultaneously and competitively. The polycondensation is strongly influenced by factors such as concentration, pH and temperature [1].

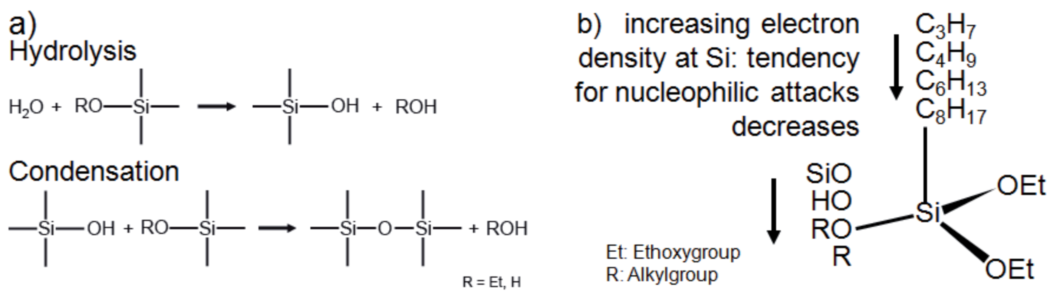

Figure 1: a) Hydrolysis and condensation of polycondensation of ATES, b) tendencies for nucleophilic attacks of alkylalkoxysilanes (/2/, S. 123, modified)

Nucleophilic substitutions start with a nucleophilic attack of a electron pair at the lowest unoccupied molecular orbital, LUMO. The tendency for nucleophilic attacks at the Si-atom increases, the more electron-pulling groups are attached and the better accessible the LUMO is [2] (Figure 1).

1.1.3 Interactions of ATES with Cementitious Material

Cementitious material itself is not only porous, which allows the intrusion of water and solutions, additionally it is reactive.

Unfortunately the chemical properties of the Calcium-Silicate-Hydrate-, CSH-Gel, the main constituent of the hardened cement paste, are rarely investigated. There are depending on the hydration conditions and on the composition of the alkaline pore solution more or less deprotonated silanolgroups on the surface [3, 4].

In an alkaline environment the attack of a deprotonized silanol on a hydrolyzed compound is the rate determining step for polycondensation. The acidity of the OH-groups increases with growing silane-oligomer size. For this reason the condensation of silane-oligomers occurs preferentially with monomers [1, 2]. So there can be expected an influence of the mineral material on the polycondensation of the ATES. From other investigations, it is known, that milled cement stone added to an alkaline solution of ATES retards the ethanol release [5].

Not only the chemical properties of the cementitious material, also the mechanism of the polycondensation are experimental hardly accessible, this applies also for their interactions. One way to get explanations for the processes, is the use of computational chemistry in addition to the experimental investigations.

1.2 Computational Chemistry

Apart from the force field methods, computational chemistry bases upon quantum mechanical concepts. Experimental unaccessible processes can be examined with these methods, but as with any modelling method found results, the modelling results have to be treated with regard to the validity of the used modelling method. This is just a very short summary of some principles. For a deeper insight and the mathematical basics it is referred e.g to [6].

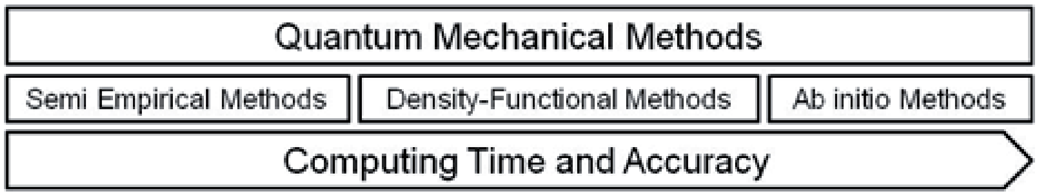

Figure 2: Overview Computational Chemistry-Methods.

Fundamental of all quantum mechanical methods is the so called Schrödinger equation, which is analytically unsolvable. One of the main problems of all modelling methods is the calculation of the electron-correlation, this means the dependence of the energy of each single electron of all others at any point of time. Mathematical this results in a so called many-body-wavefunction. Therefore for the different methods simplifications are adopted. An overview of the methods can be found in Figure 1.

The Hartree-Fock-, HF-method is used to get the solutions for the many-body problem. The many-body-wavefunction is written as a product of one-electron-wavefunctions. The wavefunctions are build through a linear combination of atomic orbitals, LCAO. These orbitals are approximated through Slater- or Gauss-type-functions. The HF-formalism to solve the wavefunctions leads to a multitude of integrals [6].

The semi-empirical methods use experimental determined parameters in the Hartree-Fock-equations and only distinguish between the inner (so-called core) and valence electrons. Semi-empirical parameters are continuously improved and adapted to experimental data. These models can handle large molecules and yield for parametrised atoms good results. With density functional methods, the energy of a system is calculated as function of the electron density, not as a function of the coordinates of electrons. Thus the complexity of the mathematical problem is reduced, because fewer equations are required [6].

2 Methods

2.1 Gas-Sorption

2.1.1 Fundamentals

Through the sorption of gases (mostly nitrogen or noble gases), the Brunauer-Emmet-Teller-, BET-method can be used to determine the specific surface area, SSA and pore size distribution of grained and porous materials. The sorbed volume of the gas is measured as a function of the pressure at constant temperature. Basic assumption of the method is, that the interaction between the sorbed molecules is small and of the same magnitude as the bonding energy at the surface. So, several layers can be sorbed and each layer can be described as a Langmuir-isotherm: the sorption-velocity is proportional to the pressure and the

amount of free-sorption sites while the desorption-velocity is proportional to the number of occupied sites [7, 8].
The measured isotherms are the base for all subsequent evaluation methods such as BET, Barrett-Joyner-Halenda-, BJH- or Non-Local-Density-Functional-Theory NLDFT.

2.1.2 NLDFT-Analysis

To obtain pore size distributions, the isotherms are usually analysed with the classical BJH-method. While for the Quantachrome-software, a more advanced method is available, the so called NLDFT-methods. Thess methods consider characteristics of certain surfaces like SiO_2 or carbon.
Therefore theoretical isotherms with respect to the desorption branch and defined surface properties for a set of pore sizes are calculated and compared to the measured ones. This comparison results in a so called fitting error which reflects the match of the experimental and calculated isotherm. This offers a possibility to account for surface characteristics and properties, which is impossible with the conventional BJH-method [9 - 11].
The NLDFT-modelling is done with the Quantachrome-software. The „N_2 @ 77 K on silica (cylindric pore, NLDFT, equilibrium model)"- and the „N_2 @ 77 K on carbon (cylindric pore, NLDFT, equilibrium model)"-kernel are used. With these kernels a theoretic N_2-sorption in a cylindric pore-system at 77 K on either a silica- or a carbon-surface is calculated with NLDFT-methods. Desorption-branches of isotherms for different pore size distributions with a silica- or a carbon-surface are deposited in the Quantachrome-software. The technical term for a set of calculated isotherms is "kernel" [12].

2.2 Computational Chemistry

The DFT can be used to calculate the electrostatic potential from the charge distribution. With the used software, called "ADF®" from SCM [13], this is done for the siliciumatoms to estimate the tendency for a nucleophilic attack.
The method calculates the charges in three steps. Initially, the total density is split off into atomic densities. The atomic densities are used to define atomic multipoles. Then the atomic multipoles are reflected through an exact distribution of charges over all atoms. This method reproduces the atomic charges in a better way than other ones [14].

3 Results

3.1 Modelling of the Polycondensation

3.1.1 Atomic charges

For the calculation the monomers whilst the hydrolysis, the triethoxy-, diethoxy-, monoethoxy- and trihydroxysilane are geometrie optimised. For this procedure

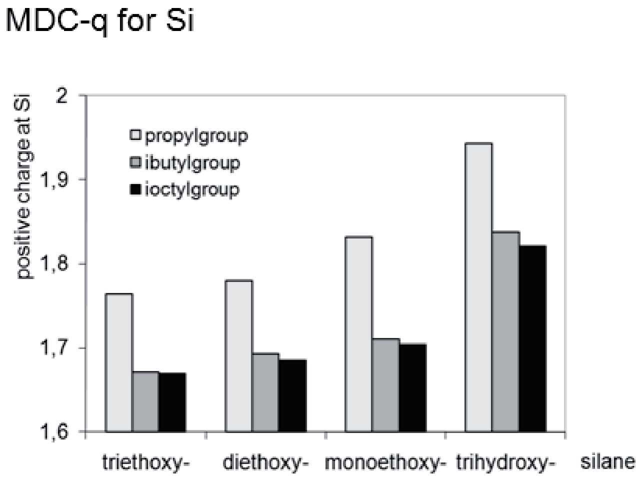

Figure 3: Positive charge at Si from MDC-q calculations /14/

generalized gradient approximation functional (PW91) and a split valence basis set with polarization functions (TZ2P) is used. The atomic charges of Si for these monomers are calculated and depictured in Figure 3.

The atomic charge at the Si-Atom increases with advancing hydrolysis degree. The triethoxysilane has the lowest, the trihydroxysilane the highest atomic charge. At a certain hydrolysis degree, the Si of the propylsilane has always the highest atomic charge.

3.1.2 Lowest Unoccupied Molecular Orbitals

To estimate the accessibility of the LUMOs, the monomers of the triethoxy-, diethoxy-, monoethoxy- and trihydroxysilane are geometry-optimised with a generalized gradient approximation functional (PW91) and a split valence basis set with polarization functions (TZ2P). Then the molecular surface and the surface of the LUMOs are calculated and depictured in Figure 4.

For the propylsilanes the LUMOs are bigger and better accessible than for the ibutyl- and ioctylsilanemonomers, where they are more covered through the molecular surface..

3.2 Nitrogen-Sorption-Measurement

3.2.1 Introductory remarks

The BET-examinations are carried out with an "Autosorb 1 MP" from Quantachrome. Samples are dried at 313 K till constant weight. Temperature for measurement is 77 K with liquid N_2

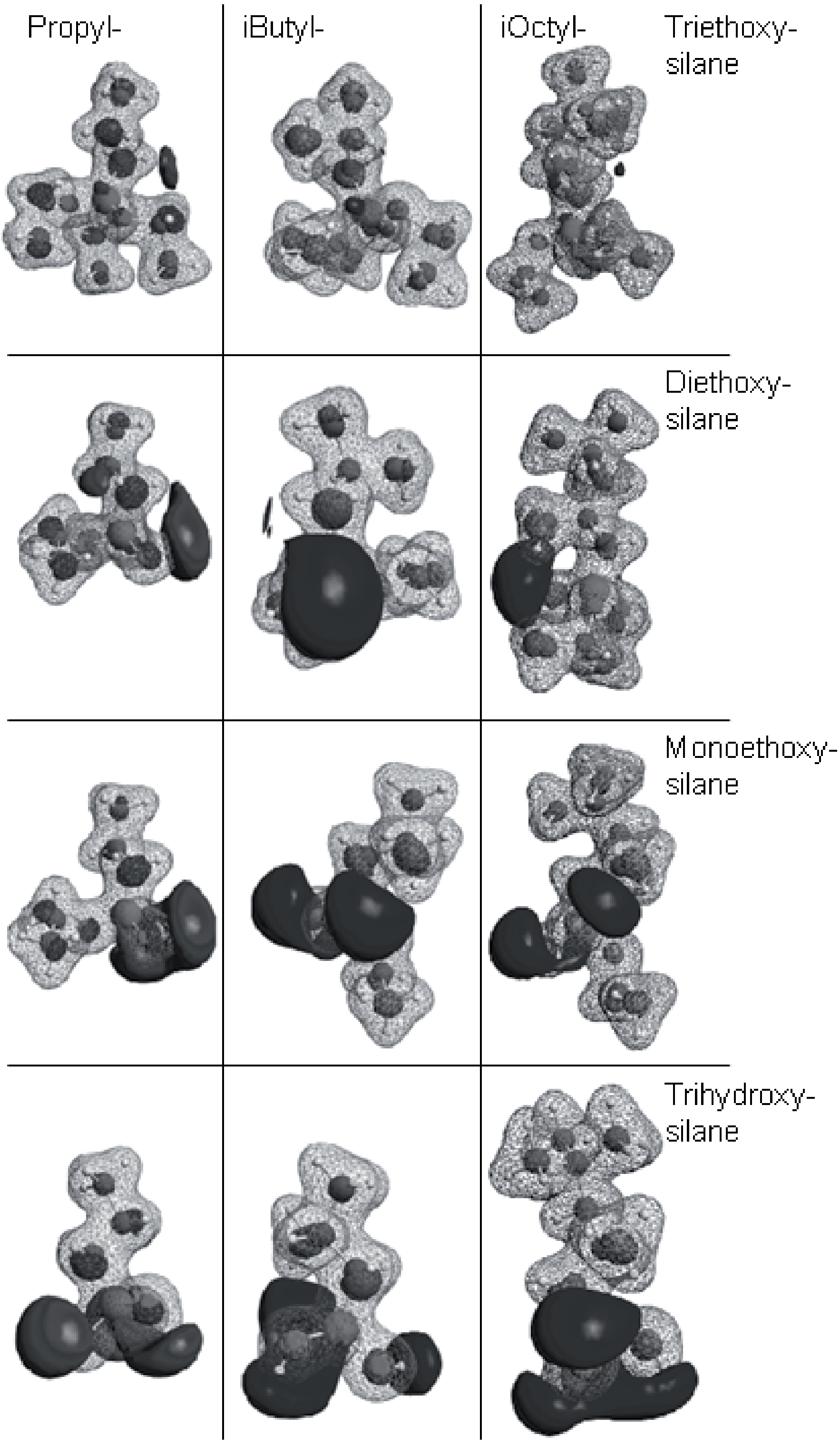

Figure 4: Molecular surface and lowest unoccupied molecular surface (LUMO) of the silane-species whilst hydrolysis

Table 1: Specific Surface Area [m2/g] and fitting error in % of untreated, with PTES, iBTES and iOTES treated cement stone

	untreated cement stone		**with PTES treated cement stone**		**with iBTES treated cement stone**		**with iOTES treated cement stone**	
SSA [m2/g]	10		42		32		10	
fitting errror [%]	silica	carbon	silica	carbon	silica	carbon	silica	carbon
	0,8	1,5	1,4	1,8	4,2	2,9	7,1	5,5

3.2.2 Specific Surface Area

In Table 1 the Specific Surface Area, SSA is listed. For the tested materials, the PTES-treated-sample shows the highest N_2-Sorption, smaller is the SSA for the iBTES-treated-sample and smallest for the untreated and iOTES-treated-sample. The latter show the same size of SSA.

3.2.3 Fitting Error

In Table 1 the fitting error in % for the analysis with the two kernels is listed. The fitting error from the analysis of the „N_2 @ 77 K on silica“-kernel is designated as "silica", from the analysis of the „N_2 @ 77 K on carbon“-kernel as "carbon".

For the untreated and with PTES-treated cement stone the „silica“-fitting error is the smaller one, for the iBTES- and iOTES-treated cement stone the „carbon“-fitting error. This means, the calculated desorption-branch of the isotherm with the „N_2 @ 77 K on silica“-kernel fits better to the measured one for the untreated and with PTES-treated cement stone and the calculated desorption-branch of the isotherm with the „N_2 @ 77 K on carbon“-kernel fits better to the measured one for the iBTES- and iOTES-treated cement stone.

4 Discussion

4.1 Reaction Rate of the Hydrolysis

The initial reaction, the hydrolysis starts with a nucleophilic attack on a Si-atom. The positiver the charge at the Si-atom the easier the attack takes place. The MDC-q-charges at the Si-atoms of the silane-monomers explain the fast hydrolysis of the propylsilane. The reaction rate of the ibutyl- and ioctylsilane should be almost the same, because the charges of the ibutylsilane Si-atoms are only slightly higher. Here sterical factors of the different alkylgroups at the Si-atoms have to be considered. For the ioctylsilane-monomers the access to the LUMOs is more hindered than for the ibutylsilane-monomers.

The experimental results show a fast ethanol release for PTES (97% after 1h) and a slow one (98% after 198h) for iOTES in pure alkaline (pH=12,6) solution /6/. The modelling delivers electronic and sterical factors for the explanation of the different reaction rates for the alkylsilanes.

4.2 Characteristics of the Untreated and Treated Samples

In this case, the fitting error is used to describe the surface characteristics. The basic assumption is, that the closer the calculated model-surface approaches the experimental values, the smaller the fitting error should be. The carbon-analysis fitting error should be smaller in case the mineral surface is covered with silane-oligomers of which the alkylgroups protrude into the pore space. In this way the mineral surface loses its silica-characteristics and attains carbon ones. For cement stone, the carbon-characteristics of the surface increase with increasing size of the alkylgroup of the silane.

The SSA of the PTES-treated is much bigger than that of the untreated cement stone, but the fitting error of the „silica"-analysis is the smaller one. This means the PTES-treated sample shows still silica-characteristics. The propylsilane-oligomers are packed with distance inbetween. So the N_2-molecules can probe both, the mineral surface and the polymer, which would explain the bigger SSA. This could arise from interactions of big propylsilane-oligomers, which are formed through a fast built-up of the propylsilane-oligomers.

The coverage of the pore-surface with the iOTES-oligomers is closely-packed, don't let the N_2-molecules pass to the mineral surface. The slower polycondensation of the iOTES could lead to the interaction with the surface of short oligomer chains which can be packed closer. These smaller oligomer-chains can be arranged close together, patterning the original surface. The SSAs of the untreated and with iOTES treated samples are almost the same. This supports the assumption of a rather close, tight packing of the silane oligomer on the surface.

5 Outlook

With the support of computational chemistry, some of the experimental data can be explained qualitatively at the molecular level. Quantitative considerations are more difficult, because of the lack of the exact reaction-mechanism of the polycondensation. Additionally, if the polycondensation of the ATES in cement based materials is examined, the CSH-gel, the main part of hardened cement paste, the formation with exact atomic postions is unknown. There are several approaches to overcome this deficit. The hardened cement paste is considered as a relative of crystalline material like tobermorite or jennite (e.g. [15 - 18]). The modelling of such structures is rather computer-costly, so that the modelling of interactions with complex additional substances at the interface are very difficult. Another way for the modelling at interfaces is the representation of the solid surface as cluster with similar properties [15, 16], which is less complex.

Hence computational chemistry is a manifold applicable instrument to support investigations in experimental hardly accessible systems and offers a tool to identify the important factors at the molecular level. With the knowledge of this factors, it is possible to exert influence on the reaction-process by the modification of the ATES. This is helpful when deciding on the application of additives and could help to develop "tailor-made" agents. First considerations could be done at the computer instead of the laboratory and would accelerate the way to a technical usable product.

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Impact of Climate Change on the Performance of Building Materials Laden with Salt Mixtures

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Abstract

It is well-known that soluble salts present in building materials can cause damage, mainly by producing stresses in the substrate. A lot of research has been done in the past concerning the behaviour of salts in built constructions. However, most studies include single salts, of which the deliquescence points are well documented while in situ one mostly finds complex salt mixtures, which makes the conservation strategy much more intricate. The environmental conditions to minimise damage of salt laden porous building materials can be modelled using a computer program ECOS capable of predicting the crystallization behaviour of salt mixtures. To use the model data of quantitative salt analyses are required as input. The program is then able to predict from a thermodynamic point of view which minerals will exist in the solid state under specified climatic conditions. This enables the user to determine 'safe' ranges of relative humidity and temperature in which phase transitions are kept to a minimum and predict the impact of climate change on the behaviour of the performance of building materials laden with a particular salt mixture. In this article, results are discussed of two historical built constructions of which the building materials were subjected to the experimental determination of the salt content in the framework of a proper rehabilitation and a prediction of the behaviour of the salt mixture related to the climate.

1 Introduction

Salts are commonly found in the stones of monuments, especially in urban, industrial and marine environments. Crystallization of salts is recognized to be a major factor of the degradation of porous materials in built heritage. There is an overwhelming literature on the simulation of salt damage effects. Since the early reports on the pressure generated by growing crystals, several models and equations have been developed that allow the evaluation of the crystallization pressures exerted by crystals growing in a pore [1 - 4]. Several researchers derived independently equations for the calculations of crystallization pressures considering the degree of supersaturation of the solutions. However, despite these efforts, the processes and pathways of salt damage are still incompletely understood.

In the absence of a liquid moisture source, such as rain water penetration, capillary rising damp and condensation, crystal growth in a porous material is the result of a phase transition reaction induced by changes in temperature or relative humidity (RH) [5,6]. Hence, unfavourable environmental conditions may cause repeated cycles of deliquescence-crystallization or hydration-dehydration, which can lead to the decay of building materials. RH-X-Ray diffraction measurements [7] to examine deliquescence reactions using glass fibres loaded with sodium chloride revealed that quite short-time variations of relative humidity, e.g. the typical daily variation of ambient relative humidity, may be sufficient to cause dissolution of crystalline salts in the pore space close to the surface [8]. A subsequent decrease in relative humidity may cause crystallization and the generation of stress in the materials. Much longer reaction times may be necessary for the deliquescence of salt crystals in greater depths of porous materials. This implies that the dynamics of deliquescence-crystallization cycles in building materials is strongly affected by both frequency and amplitude of the humidity variation as well as the moisture exchange properties between the material and the environment.

A recent research on the probable evolution of salt weathering during the 21st century in Europe based on climate data to predict the number of salt transitions under past, present and future climate projections revealed an overall increase in phase transitions [9]. The calculations are based on the number of times the RH in two successive days crosses the critical RH of sodium chloride transition, 75 %, on one hand, and the number of days that tenardite could convert to mirabilite, on the other hand.

However, situations get more complicated if one passes from single salts, of which the deliquescence points are well documented [10], to real practice situations. An inventory of the type of cations and anions in almost 1000 samples taken from Belgian historic buildings proved that building materials seldom contain one particular type of salt, but rather a complex mixture of ions. Recent research has shown that threshold values of salt contents up to which no damage is obtained, resulting from salt crystallization tests on samples contaminated with single salts, generally are no longer valid in case of combination with other types of salts. In fact, the prediction of the behaviour of salts in a mixture is complex partly due to the formation of double salts [11, 12].

Preventive conservation can be defined as all indirect actions aimed at increasing the life expectance of objects and collections which requires the assessment of deterioration agents and the environmental context. The term covers all cultural heritage, be it movable or immovable, and aims to keep an object in a preferred state where minimum damage and/or deterioration occurs, as well as addressing the assessment and management of potential risks.

The assessment of the critical environmental conditions of salt laden porous building materials, and hence potential risks of salt damage, requires the knowledge of the thermodynamics of the relevant phase transition reactions [13]. In the framework of a research project funded by the European Commission, a computer program ECOS (Environmental Control of Salts) was developed capable of predicting the crystallization behaviour of salt mixtures as a tool to predict environmental conditions to minimise salt damage [14 - 17]. To use the model, the concentration of a range of ions that are present in an aqueous extract of the salt contaminated material in question is required as input. The program is then able to predict from a thermodynamic point of view which minerals will exist in the solid state under specified conditions of relative humidity and temperature. This enables the user to determine 'safe' ranges of relative humidity and temperature in which phase transitions are kept to a minimum on one hand and predict the impact of climate change on the performance of building materials laden with a particular salt mixture on the other hand.

In this article, the results of two case studies dealing with the experimental determination of the salt content of building materials in the framework of a proper rehabilitation and the prediction of the behaviour of the salt mixture using ECOS-model are discussed.

2 Case studies – environmental assessment

2.1 Introduction

Environmental assessment [18] includes a survey of sources of liquid water, measurement and analysis of moisture and salts combined with the environmental monitoring aiming for an environmental management and modification. The word "environmental control" is more useful for indoor objects and museums, whereas in the case of historical buildings and outdoor objects it is more realistic to aim for a beneficial environmental modification. The environmental assessment implies knowledge on the behaviour of the salt mixture contaminating the building materials, in relation to the climate monitoring as to interpret salt damage in practice. It is assumed that due to its low solubility, gypsum will not contribute significantly to crystallization damage.

2.2 Farm at Opvelp (Figure 1)

The farm in the rural environment of Flanders, Opvelp, is one of the numerous examples where the composition and properties of building materials are not necessarily in favour of architectural rehabilitation concepts. Typically for such restoration projects is the transformation of former stables into offices, meeting rooms or restaurants. But has one ever considered whether this is in agreement with the properties of the built materials, more specific the salt contamination?

A systematic pre-investigation was carried out as to evaluate the salt contamination of brickwork as a function of the architectural concept and the history of this farm. A visual inspection was carried out prior to the selection of 10 zones for sampling on the interior part of brick facades. In this article, only some examples are presented.

Figure 2 presents the crystallization sequence of the soluble salts present in the mortar within zone I situated at the front and inside part of the farm (marked in red in Figure 1). It can be concluded that in case of decreasing RH, crystallization of sodium chloride starts at 52% RH. It could be noticed that a constant amount of sodium chloride of 0.6 g% is detected till a depth of at least 5 cm. From 32% RH on, calcium and potassium nitrate start to crystallize. The discrepancy of the RH at which single salts crystallize in the salt mixture compared to the value as pure salt [10] can be noticed. For this zone, a relative humidity above 52 % is recommended as environmental modification.

Zone V is located at the front and outside part of the farm, at a few meters from zone I. The salt contamination is as such that in case of drying sodium chloride crystallizes from 70% RH (Figure 3). Further drying results in a further crystallization of this salt. From 34 % RH on, calcium nitrate will be deposited, and the double-salt potassium-magnesium sulphate at 31%. For this area, little or no damage will occur in case the RH remains above 70 % at 20°C. However, such high values of RH are not in agreement with comfortable climate conditions for people.

Zone IX is located at the back and inside part of the farm in a part where the architect plans the installation of a swimming pool. From a thermodynamical point of view, potassium nitrate, being present at a content of 4,5 w%, starts to crystallize at a high RH (92 %) (Figure 4).Furthermore, a plateau of relative safe conditions between 60 and 90 % RH can be observed, where the total volume of salts is steady. Ideally, the RH should constantly be above 93 % or between 60 and 90 %. It is questionable whether this climate is in agreement with that of a room in which a swimming pool will be installed.

2.3 C-Mines in Winterslag (Genk)

The eastern part of Belgium, the Kempen, was during the 20th century known for its coal mine activities. One of the seven coal mines was located at Winterslag (Figure 5), active from 1917 till 1988. After a period of abundance, the entire mine site became the subject of stepwise rehabilitation projects. The ***C-mines*** comprise a unique industrial heritage and a witness of historical industrial activities typical for that region.

One complex of the C-mines was transformed into work shops and exposition rooms for a local designer/artist specialised in ceramics. The interior walls made in brickwork were decorated with a finishing layer principally composed of mineral

Figure 1: Farm at Opvelp.

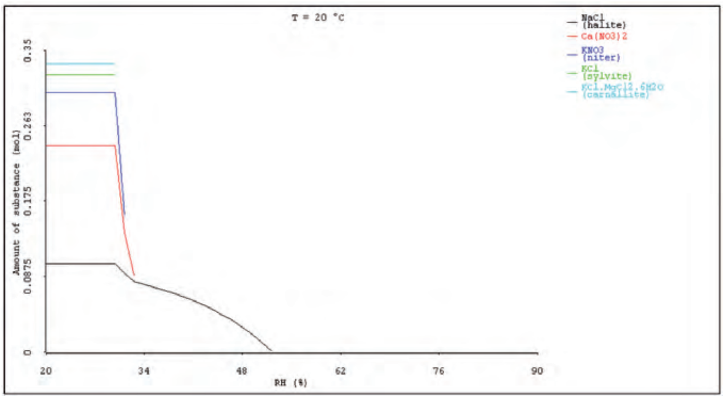

Figure 2: Crystallization sequence of soluble salts using ECOS (mortar, zone I, 110 cm height, 0-1 cm depth).

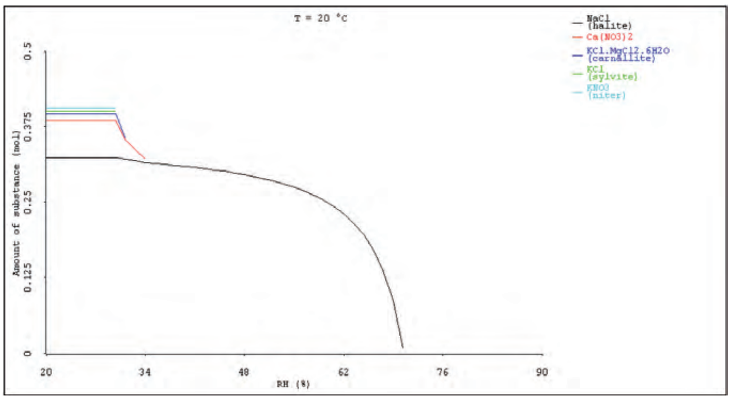

Figure 3: Crystallization sequence of soluble salts using ECOS (mortar, zone V, 127 cm height, 0-1 cm depth)

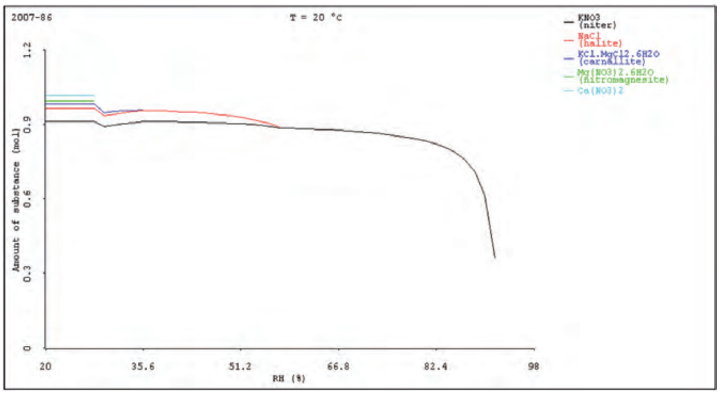

Figure 4: Crystallization sequence of soluble salts using ECOS (mortar, zone IX, 58 cm height, 0-1 cm depth).

compounds. However shortly after, damage occurred on several zones as illustrated in Figure 6. Salt analyses on mortar and brick samples revealed a high salt load, principally composed of sodium chloride. At the zone marked in Figure 6, its content was up to 7.5 w% for mortar while at least 1w% for the brick, crystallizing around 75% of RH (Figure 7). As a result of the high prevalence of sodium chloride in the salt mixture, its transition point approaches the value of the pure salt.

Since climate control of the rooms of this huge complex was for financial reasons not considered, nor technically possible since the activities of the artists' team working with mortars for the preparation of ceramics, it was advised to perform salt extractions as the salt content decreased in depth.

3 Conclusions

The use of the thermodynamic model ECOS to predict the behaviour of salt mixtures present in building materials is demonstrated for two case studies, a farm and an industrial built complex. The investigation aims to predict environmental conditions that would minimise salt damage to the brickwork.

It was shown that the crystallization of salts in a mixture generally takes place over a range of relative humidities and that individual minerals may crystallize out at relative humidities far lower than their equilibrium RH as a single salt. This was already demonstrated empirically in previous studies [19]. Moreover, depending on the architectural concept, construction phase, historical functionality and location, monumental constructions present variable salt loads even in adjacent locations.

Figure 5: Coalmines at Winterslag (http://nl.wikipedia.org/wiki/Steenkoolmijn_van_Winterslag)

Figure 6: Interior wall, damage on the finishing layer. The sampling place is marked in yellow.

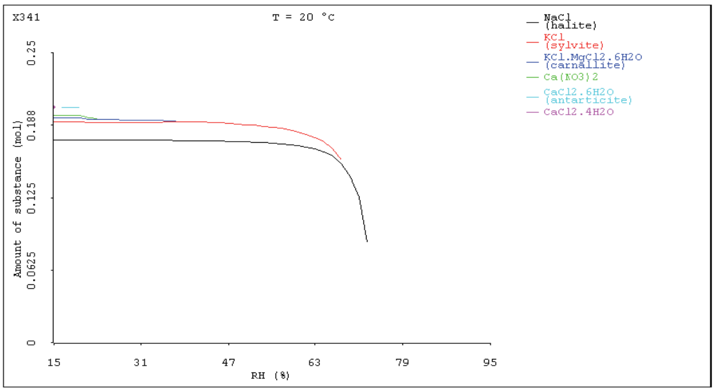

Figure 7: Crystallization sequence of soluble salts using ECOS of the outer 2 cm of the brick. The sampling place is marked in Figure 6

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Air Hardened Foam Concretes – A Multifunctional and Future Oriented Building Material

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Abstract

Saving energy is one of the most important challenge of today´s society. Therefore it is necessary to develop building materials that satisfy high requirements e. g. low need of primary energy and durability. One of these new innovative and multifunctional building material for construction purposes is chemical expanded and air hardened foam concrete. Foam concretes are building materials, which are well established for construction purposes. These foam concretes are divided into two groups: On the one hand the physically foamed concrete is mixed in fast rotating pug mill mixers by using foaming agents. This type of foam concrete cures under atmospheric conditions. On the other hand the autoclave aerated concrete is chemically foamed by adding aluminium powder. Afterwards it is cured into a saturated steam atmosphere. A new type of foam concrete was developed by combining chemical foaming and air curing in manufacturing processes. These air hardened foam concretes are innovative building materials with interesting properties - like low density combined with high strengths - which are partially superior to the conventional cellular concretes hardened in autoclaves. Thus air hardened foam concretes are sutainable and multifunctional materials that can be used as load bearing constructions with the additional effect of thermal insulation. Responsible for these properties is the pore size distribution of the macro-, meso- and micropores. Macropores are created by the reaction of aluminium powder in different volumes and with different particle sizes. However the microstructure of the cement matrix is affected by meso- and micropores. In addition the matrix of the hardened cement paste can be optimized by the specific use of chemical admixtures such as PCE-superplasticiser as well as polymer fibres.

1 Introduction

Buildings require energy during any period of the life cycle. The need of energy begins - as it is shown by the European Commission in Regener Report 2 [9] (Figure 1) - with the production of the building materials and construction of the buildings. After that the use and operation of buildings need energy as well. Finally there is also energy required for the buildings´ deconstruction.

The following paper deals with information about the benefits of multifunctional building materials. With the present-day constructions any material fulfils its specific task. Steel or concrete are used for load transfer but they do not achieve thermal insulation properties. For the heat insulation highly porous materials like plastic foams are necessary. Such constructions have energetic disadvantages because several different materials and components must be produced, assembled and finally also have to be disposed or recycled. One advantage of multifunctional building materials is that one component and of course one materials can fulfil different tasks in a modern building.

One multifunctional building material is mineral bound foam. These fine-grained concretes have a density ≤ 2.0 g/cm^3 and are classified as lightweight concretes. Some of them are applicable for load bearing constructions with thermal insulation properties at the same time. Thereby the use of this class of building materials requires less energy during the life cycle and supports the establishment of sustainable constructions and buildings. In this connection the highest benefits have the

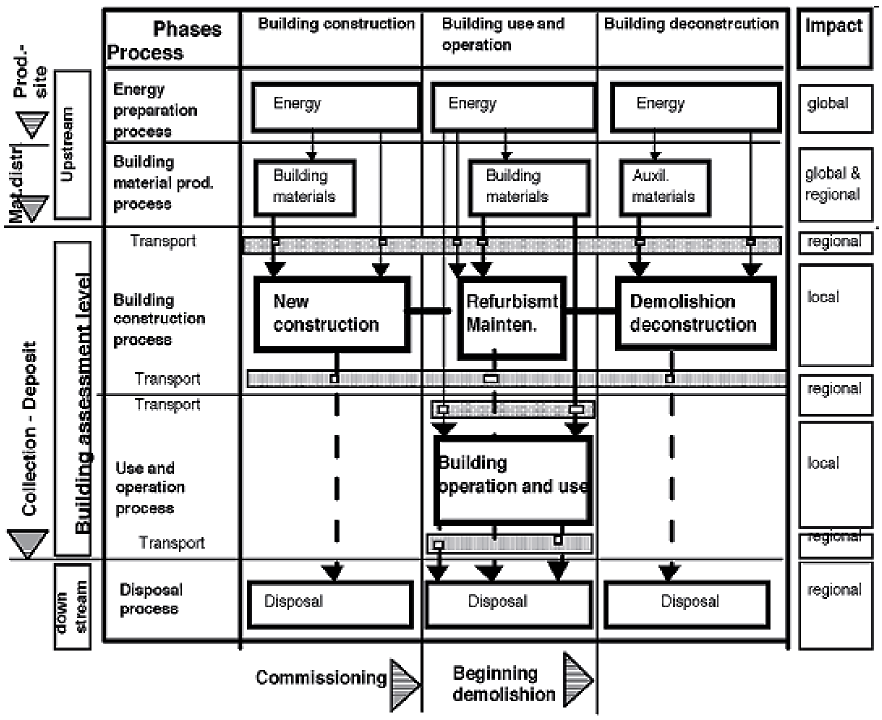

Figure 1: Energy demand of buildings (Regener Report 2 (1997)) [9]

new developed chemically expanded, air cured foam concretes which properties are described in the following.

Figure 2 shows the classification of mineral-bound foams according to the manufacturing process. The process of forming air voids in the fresh cement paste is significant. The methods of chemical expansion, as well as physical or mechanical foaming are well known and state of the art. Autoclaved aerated concrete based on a mortar with finely grounded, quartzitic sand, cement and/or lime and water to which a foaming agent, commonly aluminium powder, is added. The stable material is cured after remoulding in saturated steam atmosphere in autoclaves within a few hours and thereby receives its final properties [10].

Foam concretes are getting their structure by the use of foam which will be prepared in foam generators. These foams are carefully fold in the cement paste. Furthermore foam concretes can be generated by mixing a cement paste with a foaming agent in fast rotating pug mill mixers. The paste consists of the binder -usually cement [6], finely grounded quartzitic sand, water and foam generating admixtures. After moulding the foam, the concrete hardens under normal atmospheric conditions. During the mechanical foaming procedure, a foam agent is added to the mortar. Numerous voids are mechanically introduced by high-speed mixers. A relatively unstable foam with an irregular structure and undefined void structures will be developed.

In practice, a more usual manufacturing method is physical foaming. A pre-manufactured foam consisting of water and chemical admixture is mixed with the additional components. Under these conditions, a more stable and fine pored mortar will result.

In addition to the two established representatives of mineral bound foams, the possibility to produce chemical expanded, air cured, mineral bound foams, with mechanical properties which allow the use as construction building material has been established lately [7]. The physical-mechanically properties of this air cured foams - like density, compressive strength and thermal conductivity - are partially superior to the conventional cellular concretes hardened in autoclaves.

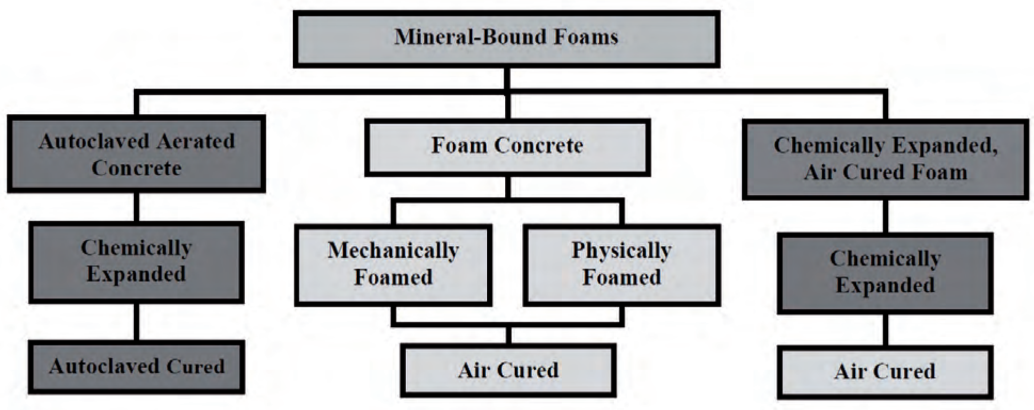

Figure 2: Classification of mineral-bound foams according to the manufacturing process

2 Advantages and Disadvantages of Structural Otimization

The structure of the cement paste matrix of this multifunctional air cured, mineral bound foams is optimized by the specific combination of the source material and adjusted to the particular task of the building material. Here the same principles can be applied which have been developed for high-strength and ultra-high performance concrete [1 - 5], e.g. by using chemical admixtures and additives, and at the same time reducing the water content. The total volume of air voids and its pore size distribution is controlled by the particle size distribution and the total amount of the expanding agent aluminium powder. Here often correlations with the used admixtures and additives arise which adversely affect the structure of the air voids. These correlations require special care to be taken with regard to the chosen source materials, especially in respect of the recipe composition.

In previous works [7, 8] the influence of structurally optimizing features on the properties of air cured, mineral bound foams could be quantified. The compressive strength at the age of 28 days of structurally optimized and not optimized foams is shown in figure 3. The increase of the compressive strength of mineral bound foams by reducing the water/cement ratio (w/c ratio) and the use of chemical admixtures and additives amounts to 15% - 20%, subject to the density. .

The same methods for the improvement of the structure have a significantly larger influence on the properties of pure hardened cement pastes, which were manufactured without foaming agents. A reduction of the w/c ratio from 0.60 to 0.35 and the simultaneous addition of 10% microsilica increases for example the compressive strength by 120 % [7].

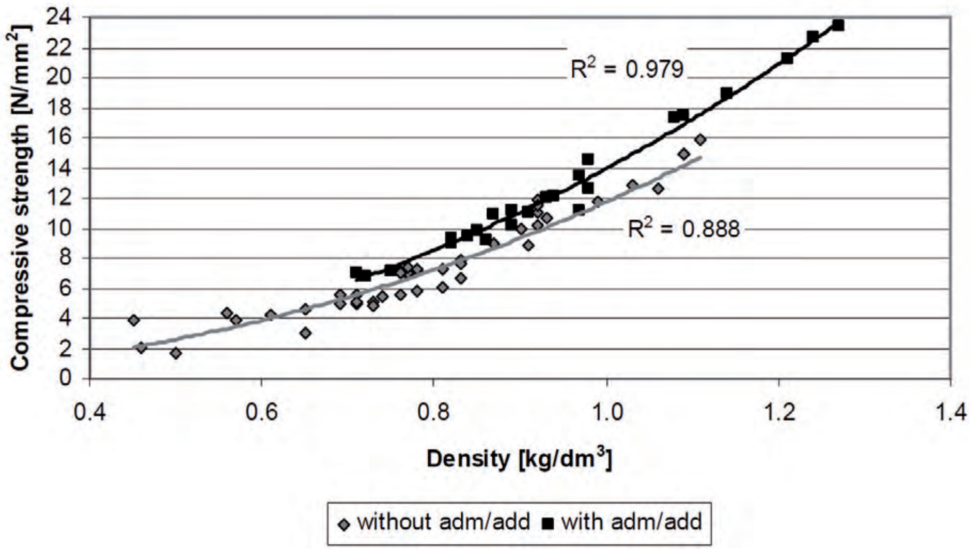

Figure 3: Compressive strengths (28 d) as a function of the density with and without the usage on admixtures (adm) and additives (add)

3 Influence of PCE-Superplasticizers

The structure of the hardened cement paste implies the spatial arrangement of the reaction products and the partly unfilled or with an aqueous solution filled areas: the pores. The pore area is composed in its entirety by the gel pores, the capillary pores and the air voids. The existing gel porosity and capillary porosity are primarily responsible for the characteristics of the microstructure.

In the following, the focus is directed toward the purposeful organization of the air void area, as well as the structure of micro pores.

The influence of the reduction of the w/c ratio and the simultaneous use of microsilica solidify and consolidate the microstructure of the hardened cement paste matrix. In Figure 4 a hardened cement paste is represented on the left side, which was manufactured without additives and admixtures and with the w/c ratio of 0.60. The right side of Figure 4 illustrates a foam concrete, which is manufactured with the w/c ratio of 0.35 and the use of PCE and microsilica. A clearly more consolidated and thus more denser structure is identifiable.

The approaches of concrete technology for improving the hardened cement paste structure, like, for example, the reduction of the w/c ratio and the use of PCE superplasticizers or fillers, often make the generation of an arranged air void area more difficult. With decreasing w/c ratios and simultaneous use of microsilica and super plasticizer, the average diameter of the air voids decreases and at the same time the number of air voids increases.Furthermore, the quantity of irregularly formed pores increase considerably (figure 5). The smaller the diameter of the pores are, the more regularly they are formed. Regularly formed air voids, however, increase the compressive strength with comparable densities. Pores with a cross section area of more than 1.0 mm^2 are irregular formed in large part. Otherwise the smaller pores with a cross section area smaller than 0.1 mm^2 are extensively consistently formed.

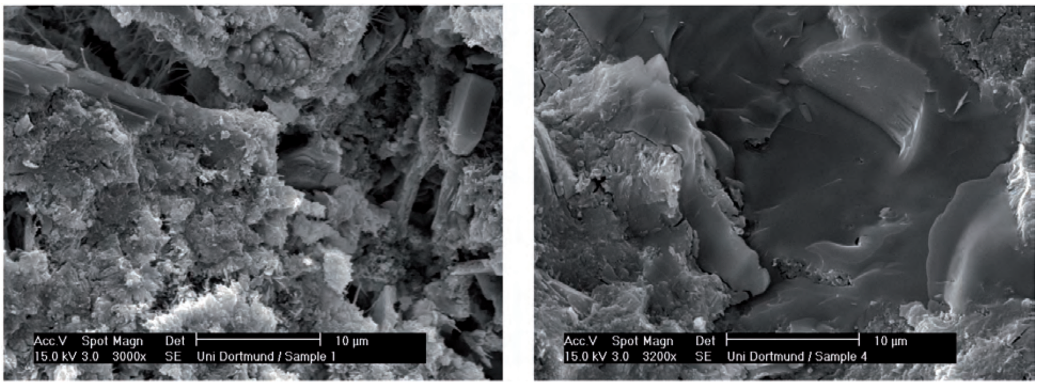

Figure 4: Microstructure of two foam concretes; left: w/c ratio = 0.60, without microsilica; right: w/c ratio = 0.35, microsilica content = 10 wt% of binder

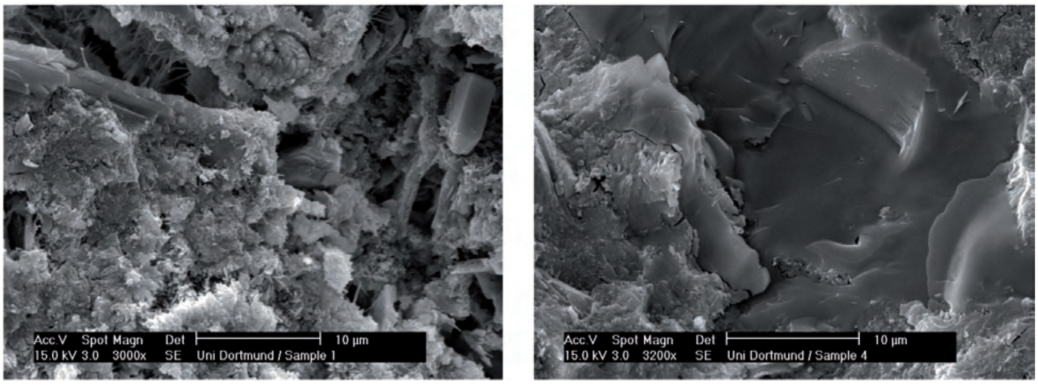

Figure 5: Air voids in two foam concretes: left: w/c ratio = 0.60, no microsilica, no superplasticizer right: w/c ratio = 0.40, microsilica content = 10%, superplasticizer content = 0.85 %r

4 Influence of Polypropylene Fibres

Using polypropylene fibres a different arrangement of the compulsory shrinkage cracks can be identified. The number of cracks increase but their widths decrease to be extensively invisible for the naked eye. Furthermore the fibre reinforcement enlarge the remaining bearing capacity of the foam concrete after the breakage. This remaining bearing capacity is to be needed, if during the transport and the assembly of precasted foam concrete elements unplanned tensile stresses occur. These stresses may be caused by impacts for example. The result of such impacts are cracks and break-outs. The remaining bearing capacity was tested on three-point bending test by using foam concrete prisms (40 x 40 x 160 mm^3). During this test the strain was continuously increased even after failure while the corresponding stress was recorded.

Figure 6 shows the bending tensile strengths of two fibre reinforced foam concrete prisms compared to one non-reinforced foam concrete. The concentration of fibres of 0.1 wt% and 0.3 wt% enlarges the bending tensile strength for more than 100 %. The amount of fibres is largely irrelevant. The bending tensile strength of each specimen is approximate and has a value of ca. 1.8 N/mm^2. But the foam concrete specimen with the higher amount of polypropylene fibres has also a clearly higher value of kinetic energy compared to the specimen with lower concentration of fibres.

The use of shorter fibres with a length of 3 mm do not cause an increase of the bending tensile strength compared to a similar fibre concentration with a fibre length of 6 mm.

This result was unexpected, because a similar concentration of fibres with a mottled length means that there is a doubled number of fibres in the foam concrete. Microscopical analyses have shown that longer fibres are in larger part in the air voids than shorter fibres. The parts of the fibres that are in the air voids do not

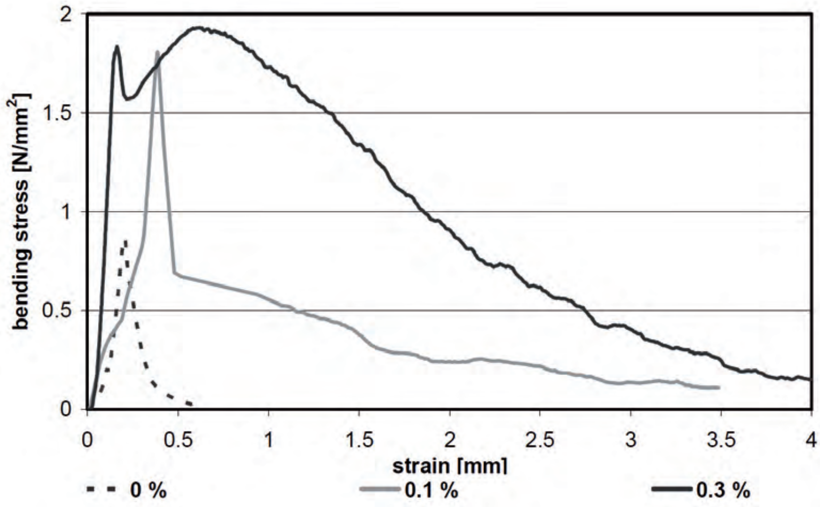

Figure 6: stress-strain curves of reinforced and non-reinforced foam concretes (density: 0.9 g/cm3; fibre length: 6 mm; fibre concentration: 0, 0.1, 0.3 wt%)

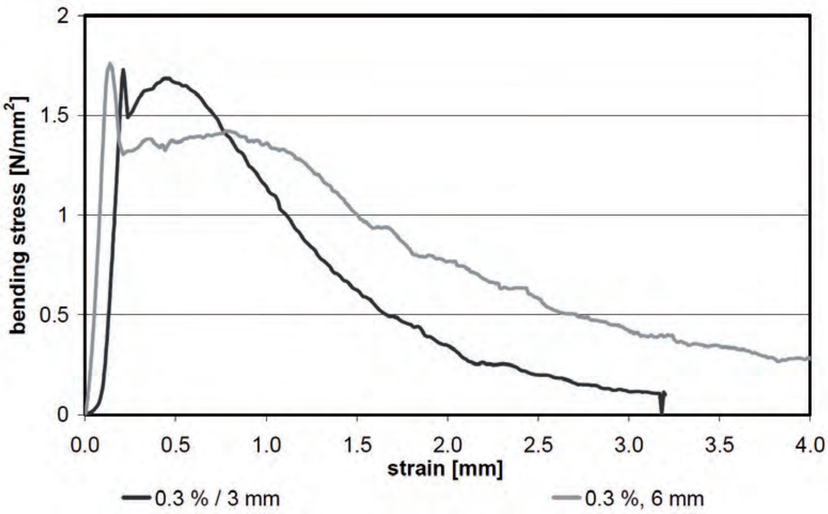

Figure 7: stress-strain curves of reinforced foam concretes (density: 0.8 g/cm3; fibre length: 3 mm, 6 mm; fibre concentration: 0.3 wt%)

have any relevance for the load bearing capacity. At the time of breaking the short fibres in the cement paste matrix are activated and transmit tensile stresses. This can be observed in Figure 7. The stress-strain curves show their culmination at the breaking tension. After this point there is a distinctly and visibly stress drop. The specimen which is reinforced with short fibres (3 mm) has a lower stress drop than the specimen which is reinforced with long fibres (6 mm).

5 Conclusions

It is possible to create chemical expanded and air cured foam concretes which have high strengths as well as high insulation properties. The mechanical properties of these multifunctional building material for construction purposes can distinctly be improved by the specific use of microsilica as well as superplasticizers and fibre reinforcement.

The reduction of the w/c ratio and the simultaneous use of microsilica lead to a optimized cement paste matrix and a stiffer mortar consistency. To get a workable consistency the use of a high-potency superplasticizer is necessary. But the rheology of the stiff mortar is influenced by the use of superplasticizer in such a way, that the building of unequally shaped air voids, which occur during the chemical expansion, is encouraged. These irregularly formed air voids negatively affect the features (e.g. compressive strength) of the hardened foam concrete, because the load transmission within the cement paste matrix is disturbed. The more superplasticizer is used the more irregularly formed air voids occur.

It was observed that the size of the air voids plays a decisive role. The bigger the air voids the more irregularities occur.

It can be stated that mineral-bound foams, which should have increased compressive strengths, must be adjusted in such a way that they preferably possess as few air voids as possible, with a cross-section area of more than 1.0 mm^2, because the larger air voids are in general more irregular formed than smaller air voids. Independent of the mortar recipe, air voids with a cross-section area smaller than 0.1 mm^2 are extensively consistently formed.

The use of polypropylene fibre reinforcement increases the bending tensile strength and decreases the widths of shrinkage cracks. There is a significant increase of bending tensile strength even with a fibre concentration of 0.1 wt%. A higher amount of fibres does not cause a further increase of strengths. With fibre reinforcements the risk of breakage of precasted foam concrete elements during the assembly can be minimized.

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Gypsum – the Future of a Traditional Material

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Abstract

Natural gypsum alabaster is in use as a building material or for sculptures since the ancient Greeks and the Romans. In the Middle Ages people started to synthesise hemihydrate from natural gypsum by heating. Nowadays most gypsum which is used to produce hemihydrate is a byproduct from various technical processes. The largest amount of byproduct gypsum is from the flue gas desulfurization. To obtain an active binder from this dihydrate, a hemihydrate or anhydrite has to be created. Therefore the dihydrate has to be heated about 130°C to obtain hemihydrate. To create cement clinker a temperature of 1400°C or higher is necessary, the energy consumption for clinker is much higher than for hemihydrate. Nowadays one of the largest fields of application for gypsum based binders is gypsum plaster board, which could be recycled much easier than cement based constructions. Printing of gypsum constructions is also possible and will be improved.

1 Properties of gypsum

Gypsum has a eudermic pH-value. It regulates the room climate. Because of its porosity it is able to adsorb water and evaporate it that way that the humidity is nearly constant. Depending on the type of gypsum the equilibrium moisture content is between 45% and 90% and it is reached very fast.

Gypsum is also a good heat reservoir. If gypsum is exposed to fire first the physical bounded water and the chemical bounded water has to be evaporated before a temperature increase is possible. For this reason gypsum has very good fire-retarding properties. Gypsum products can be recycled with small energy.

The hemihydrate reacts with water to gypsum. This process can be influenced with additives to reach a certain reacting time. During the early part of the hardening time the product could be formed in nearly any shape.

Unfortunately the flexible and compressive strength of gypsum is decreasing very much when it gets wet. So it is normally used for interior work like gypsum plaster board or stucco. A contact of combined gypsum and cement made constructions with water should be avoided because of the creation of ettringite as a structure damaging salt.

Gypsum was already mentioned as a mineral in the cuneiform script from the Assyrians and used as mortar in the Egyptian Pyramids. In the ancient Greece it was used as a construction material. The burning process was described by Theophrastus around 400 B.C. and the knowledge about this material was adapted by the Roman Empire where it was also used as stucco for example. Unfortunately this knowledge was nearly lost after the Roman Empire and was reinvented in the 14^{th} century. In baroque and rococo gypsum was used for great pargetting. There are also buildings of natural gypsum known from history. Today calcium sulphate based binders are used for plaster board, floor pavement, pargetting or smoothing cement in building industries. They are also used in the ceramic industry or dental technology as casting material. Gypsum is furthermore used in animal food or in breweries as filter material. Calcium sulphates were still used in cement as a retarding agent for the reaction of $Ca_3Al_2O_3$. Printing of gypsum made structures is also possible with 3D-printing.

The process of working with calcium sulphate based binders consists of two steps. It starts with Calcium sulphate-dihydrate ($CaSO_4 \cdot 2H_2O$) which is also known as gypsum or its mineral name selenite. This dihydrate is heated to 180°C to get hemihydrate ($CaSO_4 \cdot 0{,}5H_2O$ with the mineral name bassanite) or up to 240°C and higher to get anhydrite ($CaSO_4$). Anhydrite and hemihydrate are mixed with water and, in case of anhydrite, an accelerator they react to dihydrate or gypsum stone (Equation 1).

Equation 1:

$$2\ CaSO_4 \cdot 0{,}5H_2O + 3\ H_2O \rightarrow 2\ CaSO_4 \cdot 2H_2O$$

The water is necessary for the reaction but normally more water is added to the hemihydrate than is bounded by the dihydrate to get an appropriate stiffness.

This extra amount of water influences the strength and the porosity of the obtained gypsum. These two processes will be described in detail below.

Dehydration:

The dehydration is beside the transport of raw material and binder and the depletion of the raw material an energy consumptive process by using calcium sulphate based binders as building material. If natural gypsum is used the energy consumption of the raw material is comparable to that of the raw materials for cement. But if byproduct gypsum like FGD-gypsum or gypsum from the citric acid production is used this energy is lower. To create cement a temperature of 1400°C and for hemihydrate 180°C is used. Both could be synthesised in a rotary kiln. This hemihydrate or anhydrite is called the beta-modification. The creation of hemihydrate out of dihydrate could also be performed in different autoclave processes. One process is done in water steam autoclaves or in water with additives at 110°C to 140°C. In this case larger hemihydrate crystals could be obtained, called alpha-hemihydrate. This alpha-hemihydrate reacts with water to gypsum stone with higher strengths than, created from beta-hemihydrate.

The burning process was observed by optical microscopy and thermal analysis. It could be pointed out that the dehydration starts at lower temperatures than technically used, but the dehydration process is faster at higher temperature. The dehydration starts at imperfect sites on the gypsum crystals and the crystals brake down to small hemihydrate corns with a high surface. The surface of alpha-hemihydrate is smaller. Because of this it reacts slower. A Picture made by optical microscopy is given in figure 1, figure 2 shows an image from scanning electron microscopy (SEM).

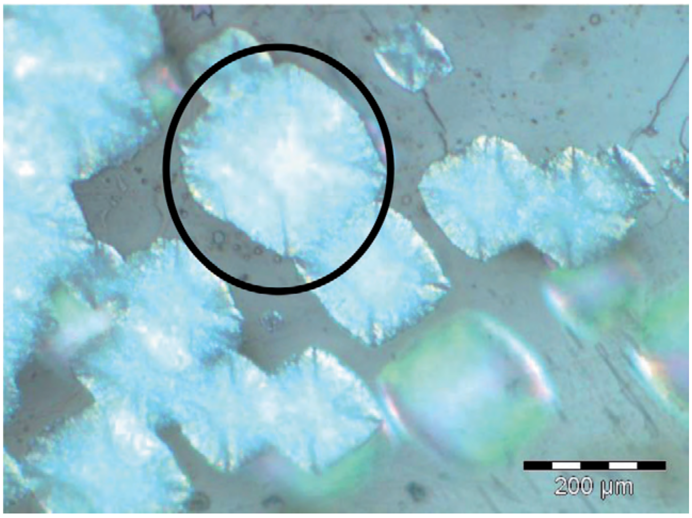

Figure 1: Dihydrate 300 minutes at 95°C, hemihydrate: black circle

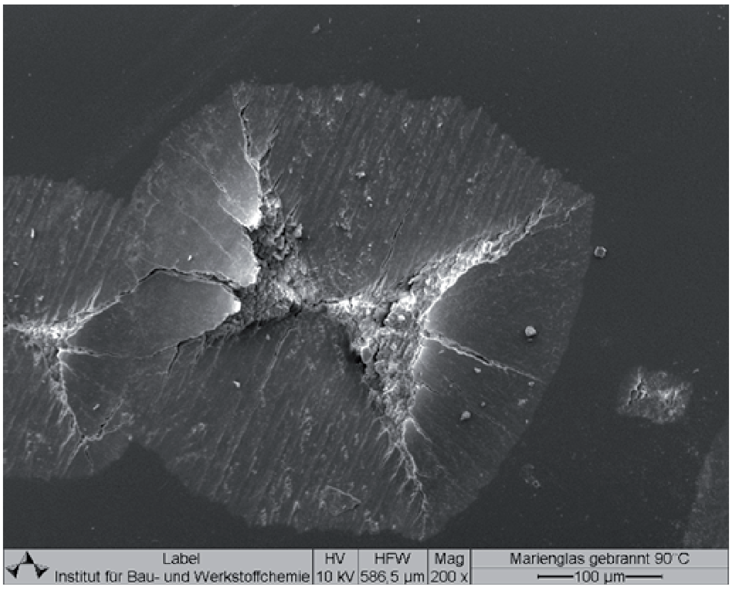

Figure 2: Dihydrate 800 minutes at 90°C

The production of different inorganic binders is normally comparable to each other and consists of three steps. First step is the mining or creation of the base material. In case of calcium sulphate based binders this base material is natural gypsum or byproduct gypsum. For burnt lime limestone was to be mined and for cement clinker a mixture of sand, limestone and clay minerals is necessary. The next step is the burning process, which could be produced with different kiln types. The energy which is necessary for the burning processes is given in figure 3.

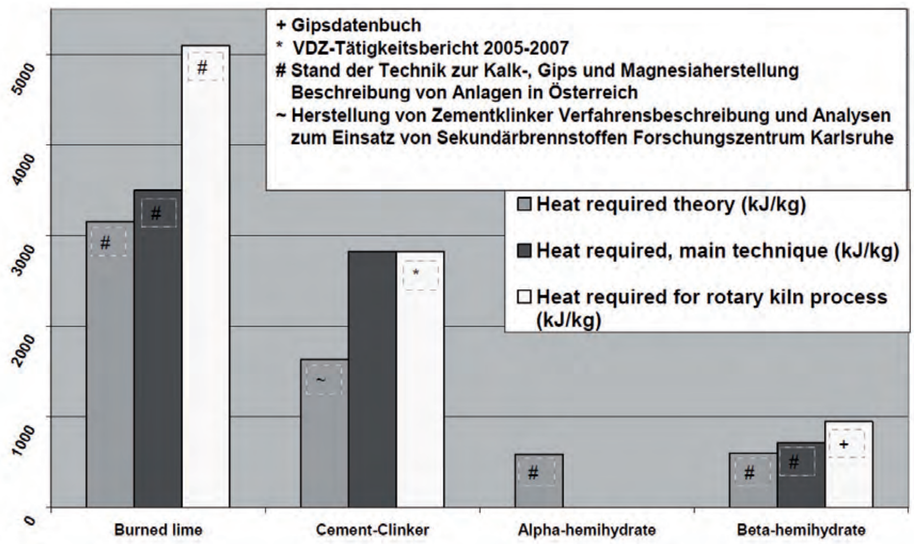

Figure 3: Heat required for the burning process of different inorganic binders

The rotary kiln is technically used for the production of any mentioned inorganic binder system. For cement it is the common method for gypsum or limestone other furnace types are normally in use.
The third step is the grinding process. The intensity of this process also influences some technical properties like reaction time and flexual- and compressive strength.
For application these binding materials are mixed with water and they react to a stone like material. In the case of lime first calcium hydroxide is created, which later reacts with carbon dioxide to calcium carbonate (Equation 3).

Equation 2: Reaction of calcium oxide with water

$CaO + H_2O \rightarrow Ca(OH)_2$

Equation 3: Reaction of calcium hydroxide with Carbon dioxide

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

Hemihydrate is solved in water and a supersaturated solution is formed. Out of this solution dihydrate crystals are obtained, because hemihydrate is more soluble in water than dihydrate at the relevant temperature range. At a higher temperature the created dihydrate crystals grow longer, the expansion during hydration is higher. This reaction was also observed by optical microscopy. Figure 4 was taken at the start of the reaction and figure 5 at the end. The results are also given in a short film.
This needle like structures felt. This is one reason for the resulting strength of the gypsum stone.

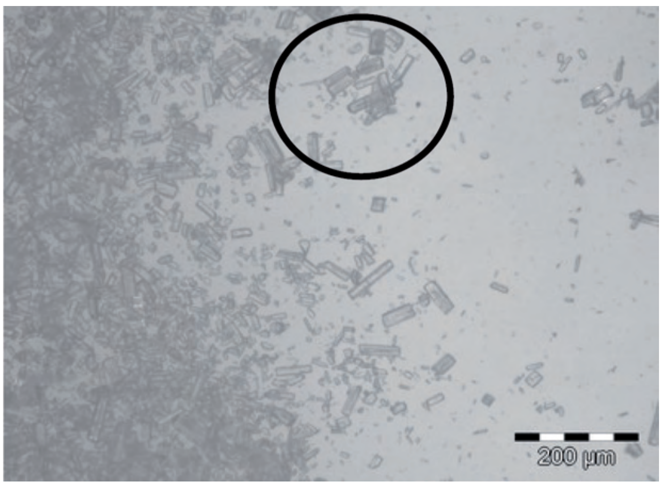

Figure 4: Alpha-Hemihydrate in water; 1 minute after water addition; hemihydrate for example black circle

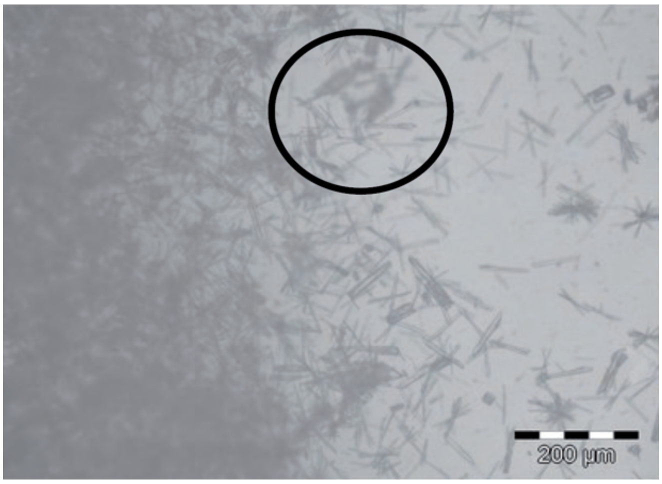

Figure 5: Alpha-Hemihydrate in water; 120 minutes after water addition; dihydrate for example black circle

2 Results

Gypsum is a very good building material for any interior work. The energy which is necessary for the production of calcium sulphate based binders is low compared to other inorganic binders and especially compared with polymers or metals and is comparable to wood (Figure 6).

The recycling of gypsum based products is easy and its technical properties are very good. Most of the technical properties can be regulated by different additives. FGD-gypsum is created by cleaning flue gas from polluting SO_3 and so it is also useful for environment.

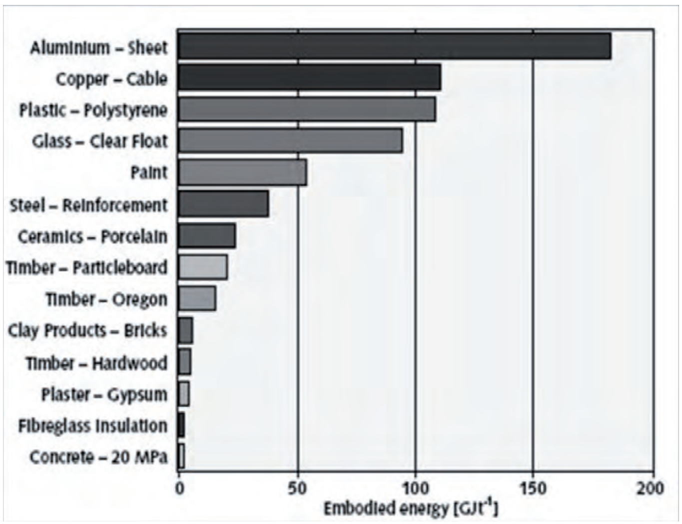

Figure 6: The embodied energy of building materials (J. Harrison, ZKG Intern. 2006)

Joos de Momper (1564-1635), Autumn

Chapter 3: Urban Climate

Climate and Constructions
International Conference, October 24-25, 2011, Karlsruhe, Germany
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Radiative and Derived Thermal Properties of Urban Surface Materials Using APEX Imaging Spectroscopy Data

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Abstract

In the frame of the urban climate module of the HyperSwissNet-project, the city of Basel, Switzerland, was scanned with the imaging spectrometer APEX in June 2010. APEX measures reflected radiation in 313 spectral bands in the range 380 to 2500 nm. Data pre-processing includes radiometric calibration, atmospheric and geometric correction resulting in georectified spectral reflectance data covering an area of 3 x 5 km^2. The Spectral Angle Mapper (SAM) classifier was used to separate surface materials. Broadband albedo was calculated from spectral reflectance data considering the ratio of direct to diffuse incoming radiation, the respective spectral weighting functions and the local horizon. The combination of surface material map and broadband albedo map with a high resolution (1x1 m^2) building model allows for a detailed analysis of the radiation properties of urban surfaces, including effects of inclined surfaces, street canyons and shadows. The thermal properties of surface material classes combined with surface brightness temperatures provide a new high resolution data base for the estimation of the heat storage term in the urban energy balance.

1 Introduction

High resolution imaging spectroscopy data from airborne hyperspectral sensors provide a new source for applications in urban climatology such as urban surface material classification, analysis of “urban green” and the link between building energy consumption and urban climate. However, few studies exist that combine the new data source with classical urban micrometeorology, instead, many studies focus on methodological issues [e.g. 1,2,3] and on vegetation dynamics, the designated classical field of imaging spectroscopy.

In contrary to natural ecosystems a large amount of additional information is usually available for urban environments from city authorities. In this study we make use of a high resolution and highly detailed digital building model. In combination with the spectral/broadband albedo and urban surface classification derived from hyperspectral data and the permanent monitoring of energy and trace gas fluxes at the Basel flux tower, we show how urban microclimate is influenced by urban geometry and surface materials.

Broadband albedo, i.e. the percentage of incident shortwave radiation reflected by a horizontal surface, is an essential property of urban surface materials with high impact on the heat balance of urban (micro)climates. This implies consequences for building energy applications as increased albedo has the potential to reduce the heat storage of buildings and roads and the exchange of sensible heat from the urban surface to the urban atmosphere during daytime. This in turn could significantly reduce the nightly urban heat island (UHI). Similarly spatially explicit knowledge of the thermal properties of urban surface materials, e.g. heat conductance, heat capacity and thermal emissivity, may improve the estimation of the heat storage term, which is the most uncertain term in the urban energy budget and difficult to measure. Imaging spectroscopy allows gathering such information with a high accuracy and high spatial resolution and thus provides a valuable extension to permanent meteorological measurements and flux towers in cities, which provide data of high temporal, but poor spatial resolution.

2 Experimental Setup and Site Description

In the frame of the urban climate module of the HyperSwissNet-project [4], the city of Basel, Switzerland, was scanned with the imaging spectrometer APEX (Airborne Prism EXperiment) on 26th June 2010, between 1111 and 1119 UTC, i.e. close to maximum sun elevation. In the applied data acquisition mode, APEX measures reflected radiances from the earth’s surface in up to 313 spectral bands in the wavelength range from 380 to 2500 nm. The sensor has a spectral sampling interval of 0.5 to 15 nm and a spectral resolution of 0.6 to 18 nm. The push-broom system collects 1000 spatial pixel in one scan line. Compared to other hyperspectral sensors like e.g. HyMap, APEX has a relatively small instantaneous field of view (IFOV) of 28°. Flight altitude was kept constant at 3500 m a.s.l., therefore the raw data resolution was about 1.65 x 1.65 m^2, slightly dependent of the height of

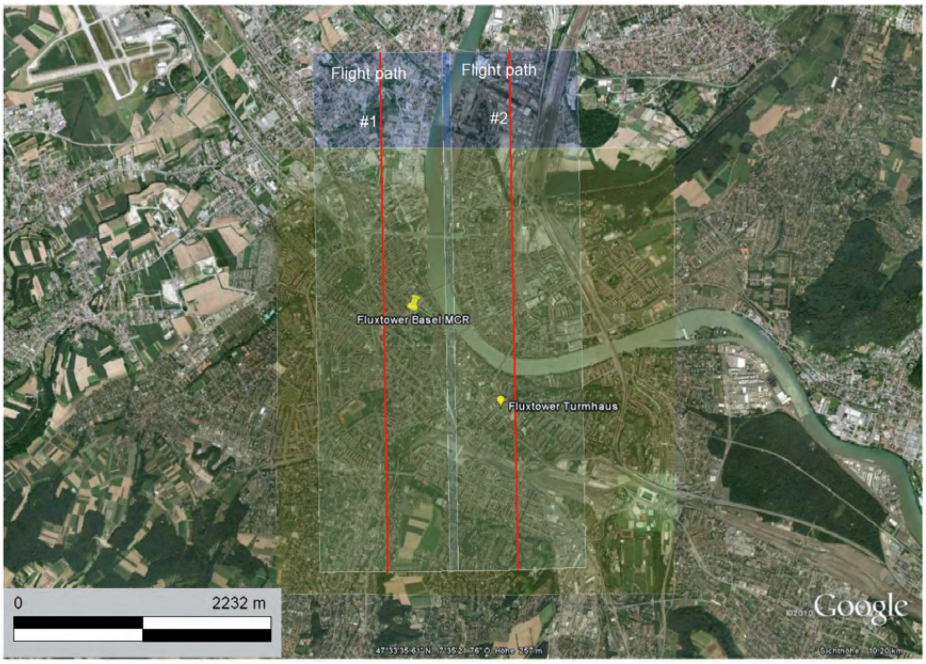

Figure 1: The city of Basel and the area covered by APEX overflights (blue), nadir-lines in red. 3D surface and building model is available for the yellow area. Yellow markers indicate the flux tower locations.

the underlying terrain. The technical specifications of the sensor are described in detail in [5]. The APEX data cover an area of about 3 x 5 km^2 including the city core. Figure 1 shows the two flight lines of the 2010 campaign and the location of the flux towers.

Additionally, surface brightness temperatures were monitored with an infrared camera (Infratec VarioCam® HR) from helicopter on 1st July 2009, 1223 UTC.

2.1 In situ Measurements

The Basel flux tower (MCR) is installed on the roof of the Institute of Meteorology, Climatology and Remote Sensing of the University of Basel (47° 33' 42'' N, 7° 34' 50'' E, 265 m a.s.l.). The tower is 18 meters high and the building has a height of 20 meters, nearby building's heights vary between 15-20 meters. The tower is part of the Urban Flux Network [6], a database run by the International Association for Urban Climate [7]. A second flux tower (Turmhaus) was operated on the top of a 38 m building. Refer to Figure 1 for the location of the flux towers. Measurements at the flux towers consist of standard meteorology (temperature, humidity, wind velocity and direction, shortwave/longwave incoming/outgoing radiation) and an Eddy Covariance (EC) system measuring the turbulent fluxes of momentum, sensible and latent heat, and CO_2.

3 Data, Methods and Data Processing

The data of the two flight paths were pre-processed at RSL Zurich as described in [8]. The data pre-processing includes a radiometric calibration, a geometric and an atmospheric correction [9,10] to provide georectified hemispherical-conical (HCRF) reflectance data in 220 wavelength bands. The Spectral Angle Mapper (SAM) classifier of the ENVI-software package (ITT Visual Information Solutions) was used to separate 30 surface materials based on endmembers extracted from the image itself. Post classification algorithms were applied to minimize false classification and unclassified pixels (sieving and clumping, 3x3). The nearest neighbour algorithm was applied to adapt the APEX data set to the resolution of the building model.

Broadband albedo was calculated from spectral reflectance data considering: i) the ratio of direct to diffuse incoming radiation (modelled), ii) the local horizon (derived from building model) to differ between sunlit and shaded pixels and iii) the respective spectral weighting functions for the time of overflight (white-sky and black-sky irradiance) using the SMARTS radiative transfer code [11].

Net radiation was calculated from: i) measured incoming shortwave and longwave radiation, considering slope, aspect and skyview factor of each pixel, ii) outgoing shortwave radiation using broadband albedo, and iii) outgoing longwave radiation modelled from measured and modelled surface temperatures, using emissivities listed in Table 1and skyview factor.

4 Results

The classification scheme is based on a 3 level approach. The first level simply differs between built-up impervious (roofs), non-built-up impervious (roads), partially impervious (e.g. gravel) and pervious surfaces (soil and vegetation). The following levels then refine these classes. Endmember spectra were chosen according to best represent this scheme. The scheme and the detailed statistics of the surface material classification are presented in Table 1. The main features of the surface classification can be summarized as:

I. Buildings cover 24 % of the area under investigation. 27 % of all roofs are covered with red tiles, these roofs are usually inclined. Another 27.5 % are “green” roofs. 24.4 % were detected as asphalt, bitumen or concrete roofs, 11.8 % as gravel roofs and 6 % are metal roofs.
II. Other impervious materials like asphalt, tar and concrete mainly assigned to roads, pavements and public plazas cover another 19 % of the total are and 27 % of the non-built up area.
III. Green vegetation (trees, lawn and meadow) mark 27 % of the total area, mainly public parks, gardens and avenue trees, corresponding to 38 % of the non-built area.
IV. Soils account for 16 % of the total area (23 % of non-built), mainly agriculture, gardens and pathways in parks.

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Table 1: Urban surface material classification results (tot: % of total area; b: % of built-up area; nb: % of non-built area)

Level I	Level II	Level III	% (b or nb)	albedo	emissivity
buildings/roofs	**tiles**	red	9,8	15-20	0,97
24 (tot); 100 (b)	27.5 (b)	dark red	17,7	12,8	0,97
	metal	I/II/III	1.0/0.3/2.8	16-25	0,8
	6 (b)	silo/high bb	1,9	28	0,28
	gravel	gravel	11,8	12,6	0,85
	11.8 (b)				
	roofing tar	asphalt I/II/III	4.6/5.9/6.2	12-15	0,93
	and asphalt	tar/bitumen	7,6	11	0,93
	24.4 (b)	concrete	0,1	18	0,94
	veg/soil	green	5,6	11-18	0,98
	27.5 (b)	soil	21,9	15	0,91
	others	shadows	0,6	4	0,99
	2.9 (b)	all others	2,3		
non-built impervious	**asphalt**	asphalt I/II/III	6.5/5.6/7.9	12-15	0,93
19 (tot);27 (nb)	20 (b)				
	other solids	tar	2,5	11	0,93
		metals	1,6	16-25	0,8
	6.8 (b)	others	2,7		
partially impervious	partially impervious	gravel	3,4	12,6	0,85
3 (tot)/ 4 (nb)	4 (b)	tennis	0,6	17	0,99
pervious	**soils**	sandy soil	6,3	15	0,93
48 (tot)/68 (nb)	16 (tot)	bare soil I/II	1.3/9.4	15	0,91
	23.1 (nb)	clay	6,1	15	0,95
	vegetation	lawn/meadow	9.8/7.1	16	0,98
	27 (tot)	trees I/II	3.4/14.7	18	0,95
	38.1 (nb)	shadows	3,1	4	0,99
	water	river I/II	6.1/0.7	5-10	0,93
	5 (tot)	pool	0,0	17	0,93
	7.3 (nb)	shadows	0,5	5	0,99
unclassified	5 (tot)				

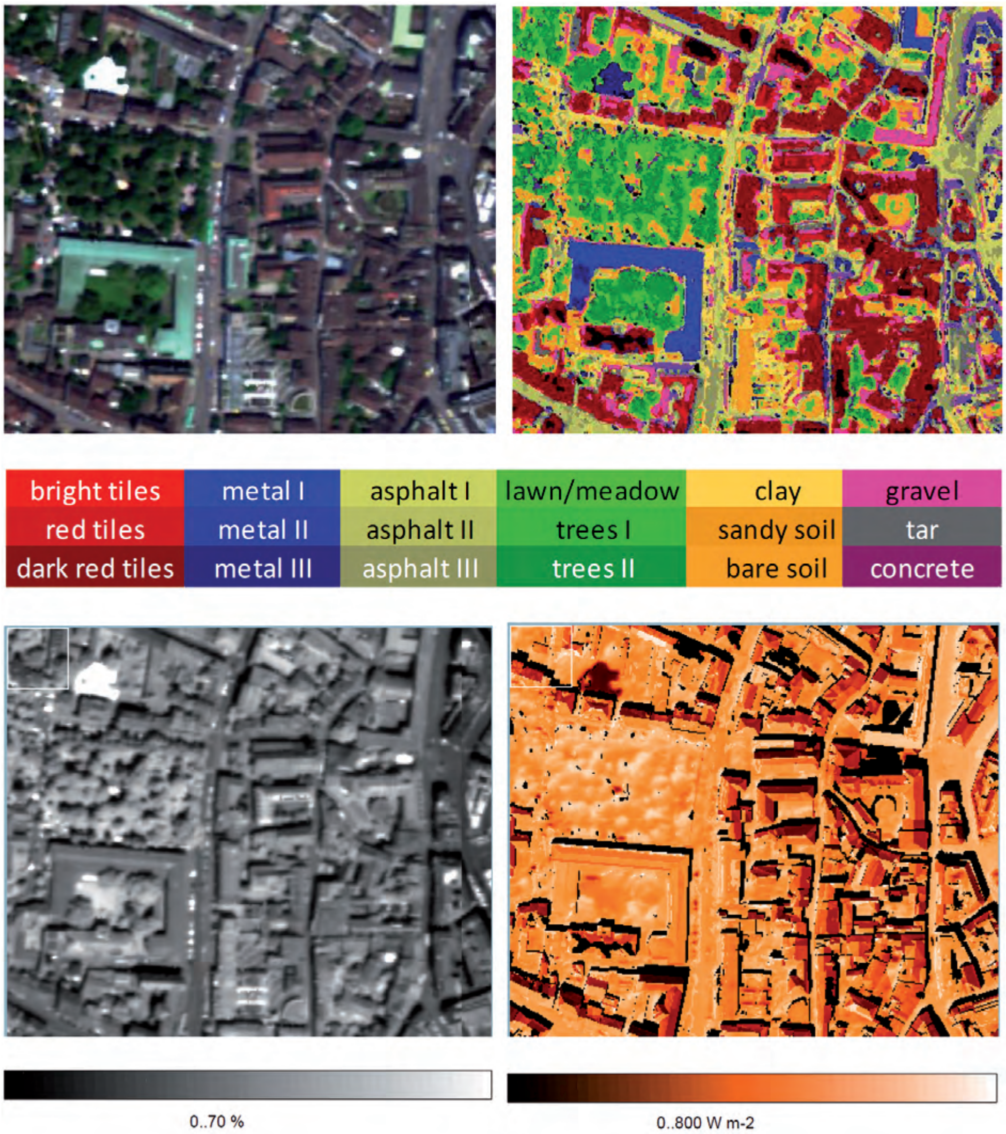

Figure 2: Spatial subset of total area showing the main building of the university of Basel (left side of images) and parts of the old city core (right side of images). UL: RGB of the hyperspectral data set (reflectance data: R=641 nm, G=551 nm, B=461 nm). UR: Result of surface material classification. LL: broadband albedo. LR: net radiation

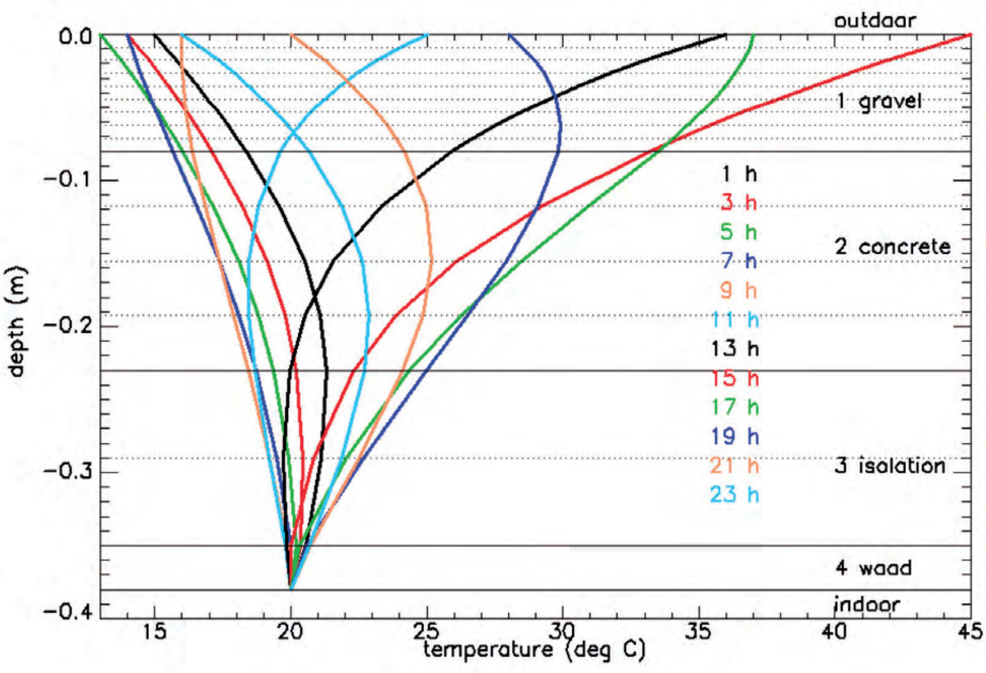

Figure 3: Example for the diurnal course of temperature in a typical gravel roof on a midlatitude summer day. Used values for heat conductance and volumetric heat capacity for layers 1-4 are 2.3, 2.0, 0.03, 0.13 W m-1 K-1 and 1.769, 2.02, 0.29, 0.799 MJ K-1 m-3, respectively.

Note that vegetation on “green” roofs is often sparse and thus, because of the missing “red edge” typical for green vegetation, the dominating surface material of vegetated roofs is mainly soil. This implies that the potential for cooling (by evaporation) of such roofs may be limited. Figure 2 shows a spatial subset of the total area under investigation.

Average albedo values are listed in Table 1. Note that these values may vary up to 5% for certain surface classes. Figure 2 shows spatial subsets of surface brightness temperature and net radiation for the helicopter overflight on 1st July 2009, 1223 UTC.

5 Outlook

The presented results provide an excellent data base for calculating the urban heat storage term in a high spatial resolution and with high accuracy. In a first step we use the discretized form of the continuity equation with daily courses of surface temperatures (derived from infrared camera brightness temperatures and modelled using a sinusoidal diurnal course) and a constant indoor temperature of 20°C as border conditions.

First calculations using typical building material layer schemes for roads and several types of roofs (e.g. Figure 3) show promising results. The calculation processes are currently refined.

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Study on Reduction of Urban Heat Island with Sea Breeze - Visualization of the Inland Penetrating of the Sea Breeze Front

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Abstract

Sea breeze is regarded as the decisive factor to improve summer thermal environment in coastal urban area in Japan. According to the result of previous researches with numerical simulations, a strong ascending air current blocks the inland penetration of the sea breeze. To mitigate urban environment with sea breeze, the information of ascending currents is really important. To visualize updrafts, I used images from satellites, which show distributions of cumulus that give information of ascending current locations. In the same satellite images, boundary line of cumulus clouds along a coast can be acquired. The frontline of cumulus is regarded as sea breeze front. By using data from meteorological observations, I conformed the relation between the cumulus boundary line and the sea breeze front, and patterns of the inland penetrations of the sea breeze in Osaka area. As the result of meteorological observations, the inland penetration of the sea breeze into the central east of Osaka delays in comparison with other area in Osaka. From the result of estimation with satellite data, mean land surface temperatures under the ascending current in the central east of Osaka is estimated to be higher than other area by around 20 degrees centigrade. The higher land surface temperature in the central east of Osaka helps accounts for the result of the delay of the inland penetration of sea breeze into this area. In conclusion, construction methods to keep land surface in lower temperature is very important to mitigate thermal conditions by using sea breezes.

1 Introduction

Currently in Japan, efforts have continued to produce climate maps (klimaatlas) for some cities. The summer heat is one of the most serious topic for Japan. Number of people who are taken to hospitals by ambulance double increased in these years, because of warming up especially in urban area. For that reason, most of all Japanese climate maps (klimaatlas) aim improvement of summer thermal conditions. Because main large cities in Japan locate in coastal region, sea breeze is regarded as the decisive factor to mitigate the urban warming. However, in case of Osaka, although this city faces to the bay, sea breeze does not have enough effects on summer hot situations.

According to numerical simurations such as Yoshikado (1990) [1]?or Kitao (2010) [2], air temperatures in urban area calm down by penetration of sea breeze. Yoshikado (1990) [1] point out that the location of urban area on coastal region disturbs an inland penetration of sea breeze. According to the result of the model-calculation by Yoshikado, ascending air flows over the coastal urban area block sea breeze penetrate in.

Over the pas few years a considerable number of numerical simurations have been done on the relation between urban climate and sea breeze [2]. But no study could estimate locations, numbers and situations of ascending currents.

Air flows such as sea breeze and ascending current are invisible. However we can find traces of sea breeze in frontline of cumulus clouds. Plus, we can find signs of ascending current locations in patterns of cumulus. In this study, I use patterns of cumulus from satellites as the information of air flows and try to clarify behavior of sea breeze.

With this method, this study aim to give some information to construct a cool urban in hot climate zone.

2 Methods

The subject area is Osaka, Japan (Figure 1) In this study two types of data are used. One is an satellite image, and the other is observation meteorological data. Satellite data were used in two points of view; one is to know the location of cumulus clouds and sea breeze front, and the other is to get surface temperatures. In this study, satellite data from ALOS AVNIR-2, MODIS aqua and terra, LANDSAT ETM+ were used. Figure 2 shows an example of satellite data. LANDSAT data was used to calculate land surface temperature.

As the Figure 2 shows, cumulus clouds disappeared along the coast line. The reason why cumulus clouds disappeared is as follows Ascending currents from the surface creates cumulus on their top [4]. When sea breeze penetrate in, sea breeze cut off the thermal supply to the plume of updraft at the bottom [3]. In this study, I call the cumulus front line along the seashore, “cumulus line”.

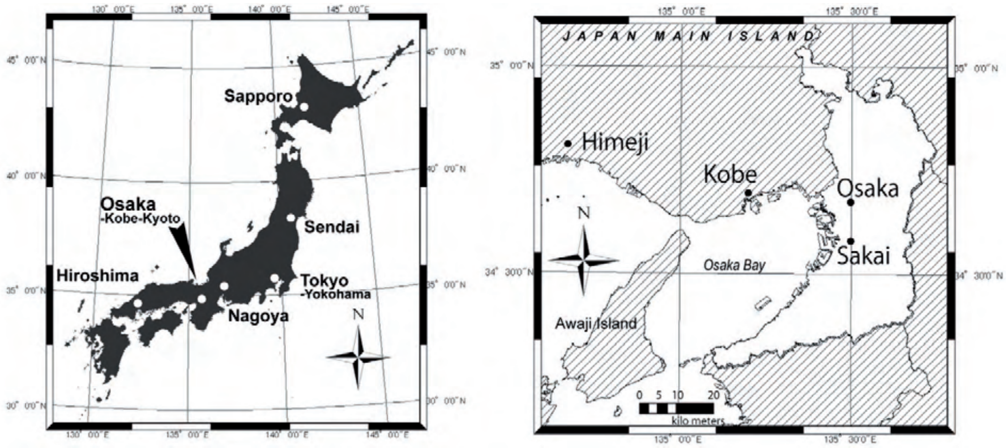


Figure 1: The subject area

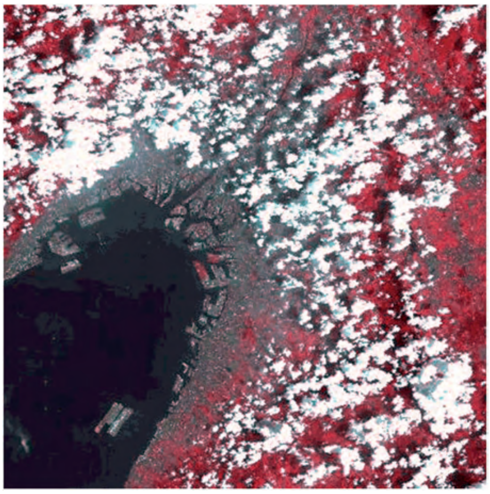


Figure 2: Cumulus pattern Image from ALOS
Acquisition date and time: 11:11(LST), 13 August 2006

3 Result and Discussion

3.1 Frequency of the cumulus pattern observation

The frequency ratio was calculated using ALOS and MODIS images, which acquired in 4 years between 2006 and 2009. The result is shown in Table 1. The ratio shows the proportion on the basis of all acquired images. The cumulus patterns observed mainly in summer at the rate of 24.3%.

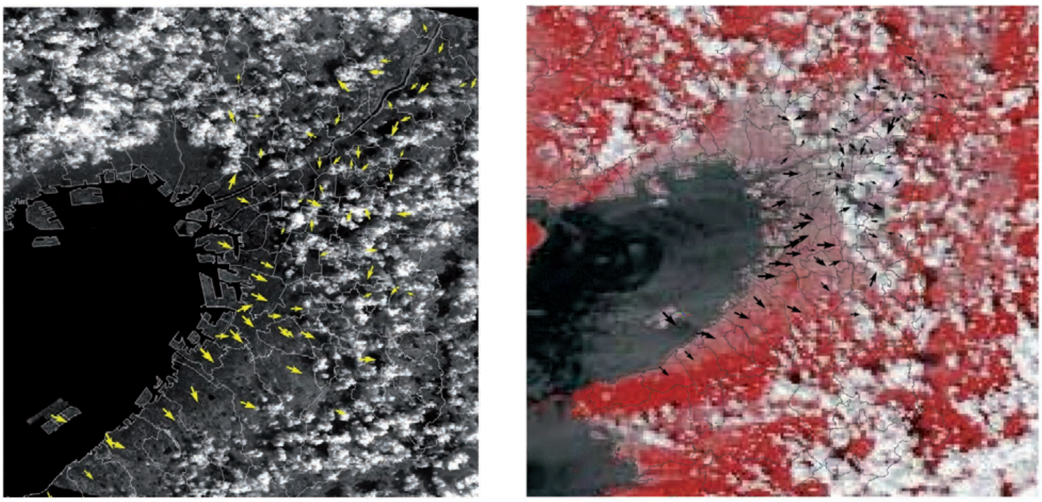
The height of cumulus can be conformed by METAR data. The cumulus clouds, which were used in this research, were on the top of mixture layer. This type of clouds appears frequent relatively in this region.

Table 1: Frequency of the cumulus pattern observation

	Cumulus patterns	
	Observed	Not observed
Winter (Dec.-Feb.)	59 (08.2%)	657 (91.7%)
Spring (Mar.-May)	77 (10.5%)	654 (89.5%)
Summer (Jan.-Aug.)	173 (24.3%)	538 (75.6%)
Autumn (Sep.-Nov.)	90 (12.4%)	636 (87.6%)
Total	318 (11.3%)	2485 (88.7%)

3.2 Cumulus line and sea breeze front

66 meteorological observation stations are located in this subject area. These observatories measures wind speed and direction at every hour. With this data, hourly wind distribution map can be drawn. With this wind distribution map, I investigated the relation between cumulus line and sea breeze front. Figure 3 (a) shows the hourly wind distribution (11:00 (LST)) and the satellite image observed at 11:05 (LST) on 13 August 2006. Figure 3 (b) uses the data observed at 12:54 on the same day. As the figures show, wind arrows, just under the cumulus clouds on the front line, show the winds are from the sea. One can state that cumulus lines are sea breeze fronts.



a b

Figure 3: Wind direction map on satellite image; acquisition time: 11:05, Acquisition date: 13 August 2006 (a)
Wind direction map on satellite image; acquisition time: 12:54, Acquisition date: 13 August 2006 (b)

3.3 Behavior of sea breeze front in Osaka

By using hourly wind distribution maps, I investigate the behavior of sea breeze front in Osaka. Figure 4 shows two examples of a wind distribution map and an estimated sea breeze front. Sea breeze started to penetrate into the Osaka plain around 9 AM (LST). Figure 4 shows two wind direction maps at 11 of two different days. As the figure presents, penetration speeds of the sea breeze front are varied. The penetrating speed toward the central east of Osaka (circles in figure 4(a), (b)) tended to delay. As the geographical figure of the Osaka plain is flat (the highest is 40 meters higher than the sea level approximately), the local topography may make little difference in the frictional resistances to sea breezes.

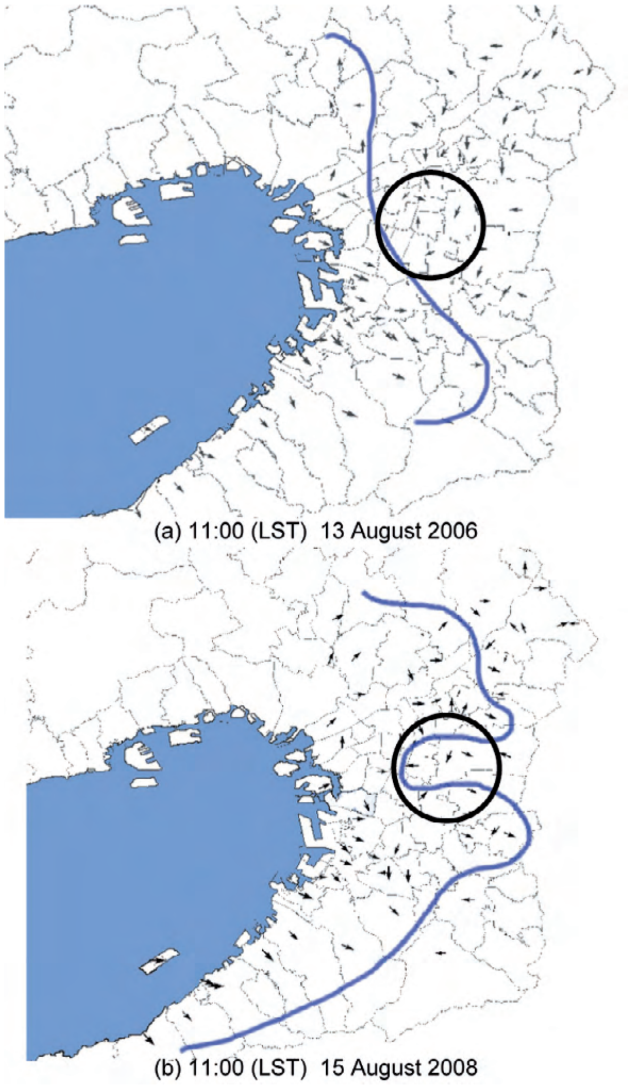


Figure 4: Hourly wind distribution maps and estimated sea breeze front

3.4 Estimation of one cumulus area

In this study, a location of cumulus was used as a location of ascending current. As ascending current may be carried by horizontal winds, a location of cumulus does not match with ascending current. This wind-driving shift may be considered as a parallel translation. So, for the purpose of basic investigation for an outline of ascending current, the information from cumulus locations is quite useful.

Central points of cumulus were extracted visually. In order to clarify an area, which needs to create one cumulus, Figure 5 is the result of application of Voronoi decomposition to the cumulus center points (dots in Figure 5).

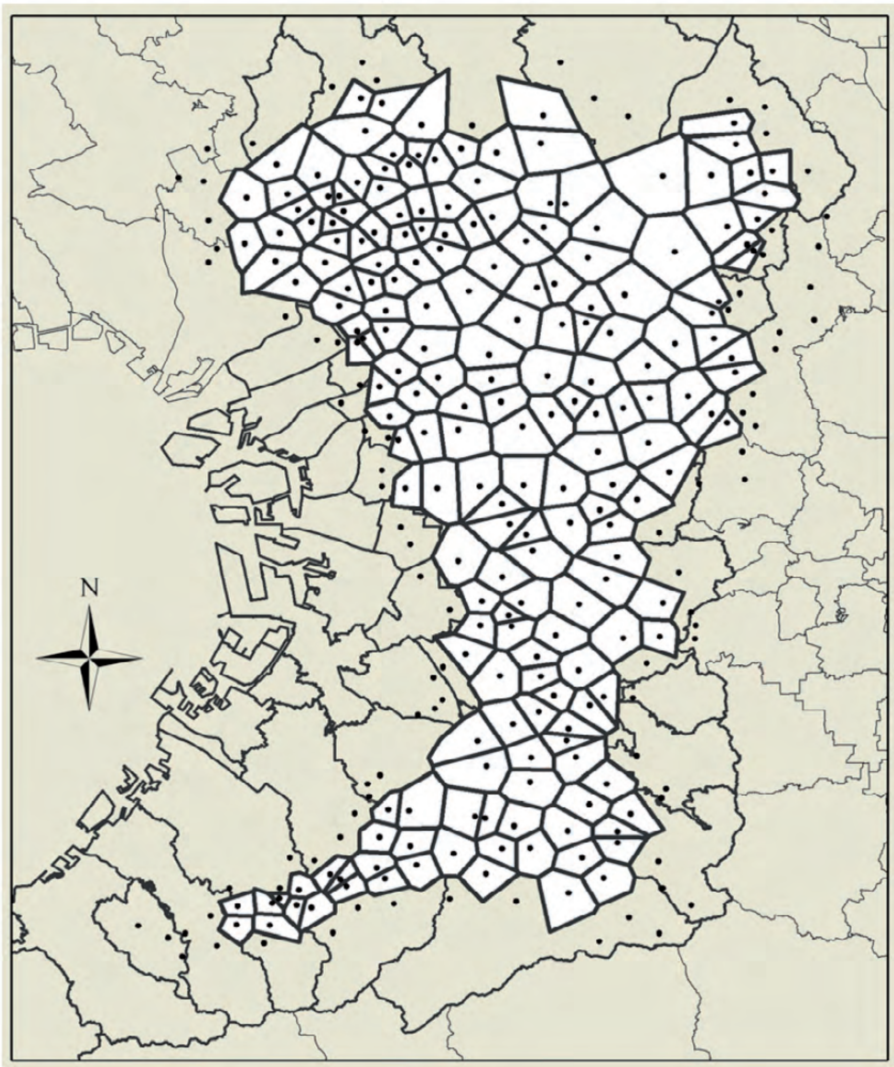


Figure 5: Voronoi diagram created from central points of cumulus

3.5 Land surface temperature of each cumulus area

A driving force of an ascending current is higher potential temperature of land surfaces. In this term, land surface temperatures were estimated with the thermal band data of LANDSAT ETM+, according to NASA's standard transform method [5]. The satellite data was acquired in 15 October 2001. The average land surface temperatures in each Voronoi cell (shown in Figure 5) were calculated. The result of this operation is presented in Figure 6. The average values are varied. Hot cells tend to gather in the central east and north of Osaka.

One group of the hot cells locates in this area, where sea breezes tended to delay penetrating in. The hot Voronoi cells may create stronger ascending current in comparison with other cells. Uneven distribution of hot cells in the central eastern

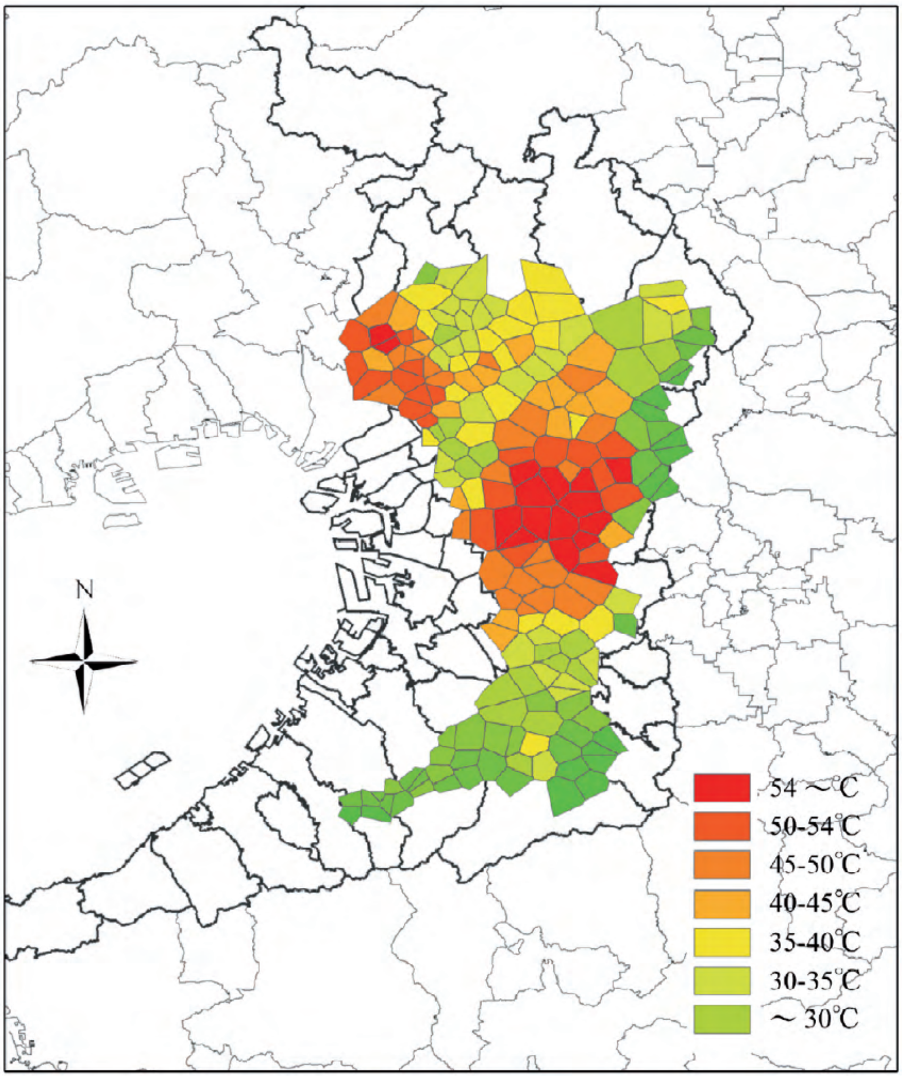


Figure 6: Average surface temperatures in Voronoi cells

Osaka may account for uneven distribution of ascending current. And the reason why the penetrating speed toward the central east of Osaka tended to delay can be explained by this concentration of ascending currents, because a strong updraft blocks the inland penetration of a sea breeze.
The aim of this study was to gain knowledge of an urban construction method, which leads a sea breeze into urban to mitigate thermal conditions. It seems reasonable to conclude that an urban surface should be build with cool materials in order to lead a sea breeze into urban area.

4 Conclusions

Cumulus front lines along the seashore may say sea breeze fronts. From the result of research of hourly wind direction maps, the penetrating speed of a sea breeze toward the central east of Osaka tended to delay. Cumulus clouds, which are formed on the top of mixture layer, are used to visualize ascending current from ground surface in this study. In order to estimate an area, which needs to create one cumulus, Voronoi decomposition was applied to the location of cumulus. Mean land surface temperatures were calculated in these Voronoi cells, and these values were varied. Hot cells tended to concentrate the area, where sea breeze delayed. Hot cells may create strong ascending current, and this causes the delay of sea breeze penetration. In conclusion, construction methods to keep land surface in lower temperature is important to mitigate hot thermal conditions by using sea breezes.

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Subsurface Urban Heat Island in Oberhausen, Germany and its Implications for the Urban Climate in the Context of Climate Change

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Abstract

The urban heat island phenomenon (UHI) is not only well-known for the atmospheric boundary layer of cities but also exists in the near and far underground of sealed areas. Dependent on the time of year near-subsurface urban heat island intensities can reach up to 5 K in comparison to the same depth in the rural environment. In the city of Oberhausen, NRW, Germany, spatially and temporally highly resolved investigations have been conducted to analyse soil temperature, soil moisture and ground heat flux (1.8.2010 - 30.6.2011). It is shown that sealed sites display greater energy content than natural sites most of the year. Calculations of using this underground energy will be given for different urban climate zones.

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Influcence of Urban Geometry on Outdoor Thermal Comfort in Tropical Climate

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Abstract

Urban centers of developing countries, such as Brazil, have been rapidly growing over the past decades without effective planning. This urbanization process has encountered significant impacts on the natural and built environment. In tropical cities, the local climate change has led to thermal stress, affecting comfort and human health. In Brazilian semi-arid region, many cities have just been elaborating their municipal land use law which contains the building regulation code. This paper presents the assessment of different urban geometries generated from the building regulation guidelines of a Brazilian city located in the tropical semi-arid climate. The impact of each urban configuration on outdoor thermal comfort is examined through a microclimatic analysis performed by computational simulation of different urban design scenarios. The impact of the street geometries on microclimatic conditions and on pedestrian comfort levels was then evaluated using PET index and a set of morphological indicators. The impact of individual morphological parameters was then studied through a parametric sensitivity analysis which allowed identifying their relative importance through each considered scenario. Results suggest that the progressive building setbacks imposed by the local regulation which lead mainly to an open-set urban fabric with wider street canyons may be desirable regarding the outdoor thermal comfort in a semi-arid climate. However, changes worked in proportions and building orientation have triggered some important variations.

1 Introduction

Urban centers of developing countries, such as Brazil, have been rapidly growing over the past decades without effective planning. This kind of urbanization process has encountered important impacts on the natural and built environment, especially in local urban-atmosphere. In tropical cities, the local climate change has led to thermal stress, affecting comfort and human health as it damages the environmental quality of livable urban spaces (ASSIS, 2006) [1].

The improvement of the environmental quality of urban spaces and consequently of buildings energy demand should meet a well knowledge of the local urban microclimate as well as its interaction with the surrounding built environment. Therefore, and especially for the new growing urban centers, urban planners decisions shall play a crucial role on setting out rules that will strongly determine the urban environments performance.

1.1 The building regulations and the Brazilian case

The master plan and building regulation which consist of urban development regulatory instruments to set control over land use in cities have been established and stated to “ensure the healthy, safety, welfare and convenience of people in and around buildings” (DCLG website, 2010[b] *apud* IMRIE, 2011) [4].

In Brazil, most of the current municipal building regulations still preserve a part former sanitary code along with their a urban zoning, but some initiatives to encourage environmental adequacy and energy efficiency parameters have been in the past years proposed by the Brazilian Institute of Municipal Management - IBAM/PROCEL (1997) - towards new and existing building regulation. Even though it has been well thoroughly discussed the importance of integrating the energy efficiency and indoors thermal comfort, the outdoor environments still remains vastly underreported in local regulations, even if, in most Brazilian regions, people tends to spend an important amount of their time developing activities in the outside.

The way building regulation and rules affects urban form and consequently the outdoor thermal comfort of pedestrians is the focus of this particular paper which attempts to investigate the performance of the recently proposed building regulation of a tropical semi-arid Brazilian city. The objective of this work is to examine the outdoor thermal comfort responses considering the microclimatic modifications by different urban configurations. The major goal is to quantify the relative contribution of each of the parameters in mitigating the heat stress in urban micro scale.

2 Methods

To reach the above presented goal, some main methodological steps were taken:

a) Understanding of the local climate and its building regulation proposal;
b) Geometrical models definition by putting together the main local building features according to the building regulation parameters through a Design of Experiments method (DOE);

c) Numerical simulation analysis of the scenarios in urban micro scale through ENVI-met model (BRUSE, 2011) [2];
d) PET index assessment (Physiological Equivalent Temperature);
e) Parametric effect size and comparative study cases.

3 Case study - Local climate overview of the tropical semi-arid in Brazil

3.1 Introduction

The climate studied is the tropical semi-arid of the Northeast Brazil. As an example for this case study, we chose the city of Petrolina, situated in the state of Pernambuco, Brazil at 9°22’ South latitude and 40°32´ west at 375m of altitude. Its climate can be mostly characterized by high temperatures throughout the whole year. However, as the relative humidity can fluctuate daily and seasonally, the site presents an important thermal amplitude, during a daily-cycle as well as in between seasons (the summer and winter time). Among other climatic features, the mentioned region presents also a predominantly clear sky with high intense solar radiation all over the year, hence its low latitude. The climate in Petrolina is mostly characterized by a long season extremely hot and dry (through spring and summer) and a winter that is more like a hot and humid climate, with temperatures slightly milder compared to summer time, due to the significant fluctuation of relative humidity. Regarding to the annual average air temperature, it registers a maximum average of 33.5°C and a minimum average of 22°C.

3.2 Urban land use and building regulation of Petrolina - PE - Brazil

The master plan of Petrolina was recently published (in 2006) and provides a restrictive set of instruments for their buildings construction which is mainly defined by the following elements: Plot Ratio (PR); Floor Area Index (FAI); Progressive building setbacks; Soil Permeability Rate (PSR).

Each of these parameters presents specific attributes according to each of the 7 urban zones determined by the local master plan. Each urban zone was classified according to their specific main occupancy characteristics. No climatic adequacy consideration is mentioned in the regulation though. The zones were defined as follows: 4 residential areas (ZR-1, ZR-2, ZR-3, ZR-4); areas of environmental preservation (ZPA); historical patrimony zone (ZPH); multiple activities zone (ZAM); zone of industries and other services (ZIS); port area zone (ZP); urban expansion zone (ZIDU-ZIDU-1, 2) (see Figure 1). For each zone, land use priorities as well as building regulation parameters were established limiting or encouraging urban densification. This work focus on the urban residential zoning regulation (ZR-1) characterized by the predominance of multiple-store housing. By choosing this typological zone, our main interest is to understand the impact of a local strong trend towards densification and verticalization which also presents no building height limit.

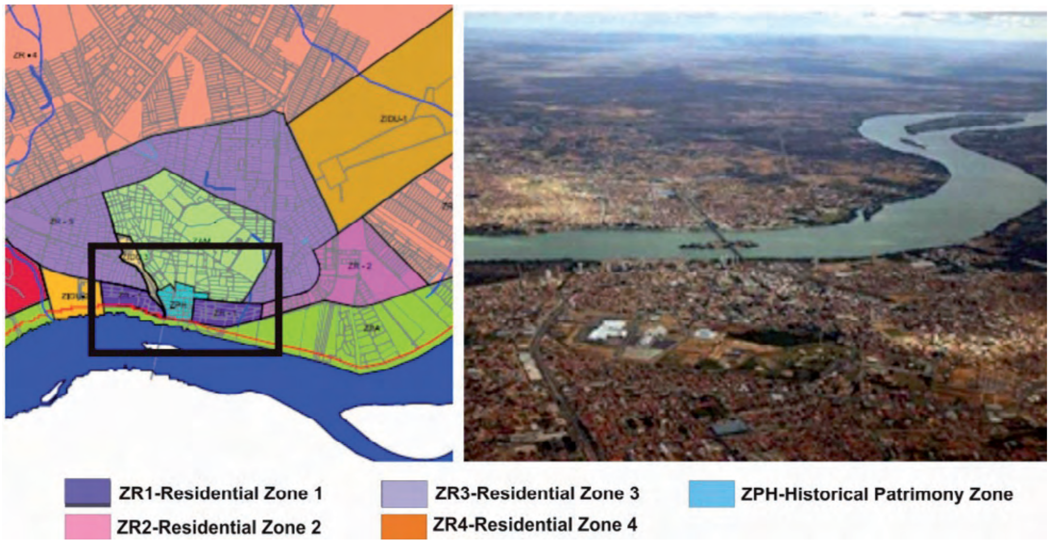


Figure 1: Urban zoning for Petrolina – PE (Source: Government of Petrolina-PE).

Table 1: Building regulation parameters for residential zones in Petrolina (Source: Government of Petrolina-PE).

Urban zone	FAI	PL	Buildings up to 2 floors		Buildings with more than 4 floors		Resulting Building Setbacks	
			IBFS	IBLS	IBFS	IBLS		
R1(*)	4,0	0,7	3,00	0	5,00	2,00	RBS = IBFS + (n-4) x 0,20 RLBS = IBLS + (n-4) x 0,20	
ZR2	3,0	0,7	3,00	0	5,00	2,00		
ZR3	3,0	0,7	3,00	0	5,00	2,00		
ZR4	3,0	0,7	2,00	0	5,00	2,00		
FAI – Floor Area Index; **PR** – Plot Ratio; **IBFS** – Initial Building Frontal Setback; **IBLS** – Initial Building Lateral setback; **n –** Number of floors.								

Even though no height limit has been established as a parameter by the building regulation, the *Floor Area Index* combined with the formula to find the restrictive building setbacks, one gets to find a certain height limit, by tracing up an optimal rapport between the total potential area available and the a interesting floor area.

3.3 The Design of experiments and the local building regulation

At this step, a design of experiments (DOE) method was carried out. Since the experiment of interest consists of the interaction of many morphological variables at a time, we have chosen to work with a multi-factorial, but only in a two levels design sequence, as the microclimatic model selected could be way time-expensive (ENVImet model can take a day or longer to simulate a single experiment). The DOE sequence method allows obtaining the most relevant qualitative informa-

Table 2: Table of experiments to the design urban scenarios.

Exp	Width (m)	Length (m)	Height (m)	Building resulting dimensions	Street width (m)	Orientation street
I	15	20	6	15;14	6	N-S; E-W
II	15	60	6	15;54	6	N-S; E-W
III	15	20	60	4;6	6	N-S; E-W
IV	15	60	60	4;46	6	N-S; E-W
V	30	20	6	30;14	6	N-S; E-W
VI	30	60	6	30;54	6	N-S; E-W
VII	30	20	60	20;6	6	N-S; E-W
VIII	30	60	60	20;46	6	N-S; E-W

tion from a database of experiments with the smallest number of experiment as possible.

This statistical method works as a systematic approach using a smart distribution of points in the design space. This technique allows having a good sample of a configuration space, avoiding subjective bias as well as eliminating redundant observations (MONTGOMERY and HUNTER, 2003). It mostly works as a preliminary exploration of a design space, in order to provide a starting point to check for response sensitivity to study main and high-order interaction between variables.

To prepare a representative sample of experiments, the range for each design variable was established based on the current building plot and local constructions pattern identified in the case-study city residential urban zone of interest. The range intervals and DOE results can be found in the table below.

As a second step, by considering the building regulation parameters, we took each of the generated experiments and calculated the resulting building geometry according to the local design rules.

For all modeled urban scenarios it was considered the same width of street (6m) as well as the same block-type and orthogonal mesh pattern. For each of the eight models, it was also considered two different street orientations, as to verify the impact of each morphological factor in combination with different urban design implantations. The resulting building geometries can be depicted from the images in the table below.

Considering the *Floor Area Index* (FAI)[1] established in the building regulation, scenario IV and VIII would be unfeasible designs, since they exceed the total permitted area for construction, but yet they were taken into account in the study as part of the statistical hypothesis testing sample to enable the evaluation of the effect size of the design variables of interest.

1. FAI - The ratio of the total floor area of buildings on a certain location to the size of the land of that location, or the limit imposed on such a ratio.

Table 3: Resulting urban scenarios.

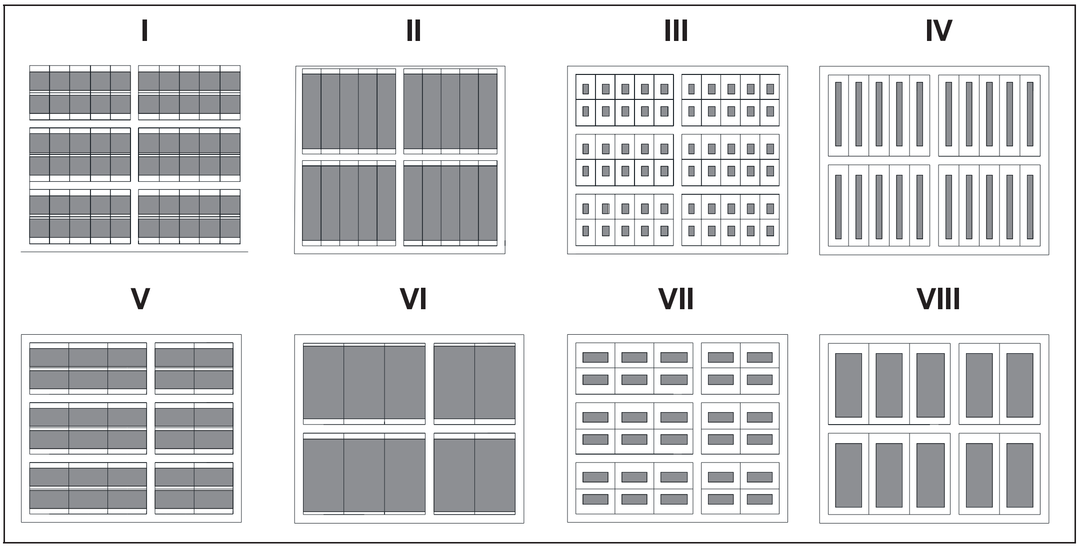
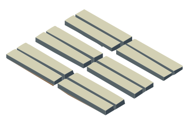
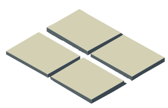
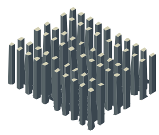
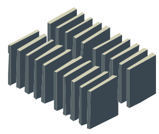
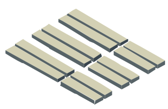
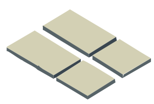
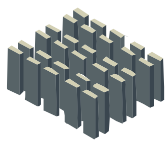
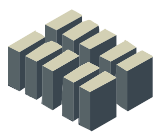


Table 4: Resume of environmental indicators for each morphological model.

	(I) 	(II) 	(III) 	(IV) 
Built density	0,69	0,90	0,08	0,20
compacity	0,31	0,20	0,85	0,56
Contiguity	0,43	0,65	0,58	0,88
Mean SVF	0,66	0,66	0,49	0,43
H/W ratio	0,43	0,43	2,73	2,73
	(V) 	(VI) 	(VII) 	(VIII) 
Built density	0,70	0,90	0,2	0,51
compacity	0,31	0,20	0,45	0,16
Contiguity	0,19	0,27	0,24	0,63
Mean SVF	0,66	0,66	0,38	0,36
H/W ratio	0,43	0,43	2,73	2,73

4 Analysis and results

To carry out the output data analysis (for all the scenarios), it was considered the mean data of a pedestrian walking through the same side-walk of the street and throughout a whole typical day in a summer condition. Calculations were performed for a 1m x 1m x 2m grid net over ENVImet model and the microclimatic data were then extracted for 1,6m above ground level.
In short, the main findings will be presented in the following section.

4.1 Cases comparative analysis

4.1.1 Remarks
Two of the most decisive variables on defining the physiological equivalent temperature (PET) of pedestrians are the mean radiant temperature along with the wind speed rates. Hence, shading percentage was found to be one of the main strategies for keeping the street area cooler, since it not only protects the pedestrians against the direct solar radiation, as it also keeps the surrounding built surfaces cooler. So, the scenarios with high H/W ratio presented, as predicted, the better results concerning the mildest values for air temperature. Moreover, it was also verified that the wind speed rate worked on one hand as an attenuating factor towards PET responses (as it is going to be presented later), but also on other situations, as could be verified in scenarios IV and VIII which both presented the highest rates of wind speed (6,8m/s and 5,5m/s respectively), working as an aggravating one. The important increase of PET in these cases was mainly due to the combination of uncomfortable rate of wind speed with high air temperature.

4.1.2 Mean Radiant Temperature and wind speed
The greater the percentage of shadow projected over the side-walk (produced by a higher H/W ratio and a lower Sky View Factor – SVF- scenario) the minimum radiant temperature were reached in a day-average (e.g. 27,66°C for scenario VII and 29,65°C for scenario III). However, concerning the other two scenarios (IV and VIII, that registered 32°C and 33°C in average, respectively) presenting the same H/W ratio but yet more densely built, they both recorded the highest night-time values. This particular fact could be justified by the long-wave radiation that rests trapped into the street for longer period, because of the high dense built area associated with the highest compacity of the buildings in these scenarios (more surface area exposure).
With exception for the latter mentioned scenarios (which are the unfeasible scenarios, as mentioned before), it is possible to say that the progressive building setbacks might be responsible for two important phenomena: greater long-wave dispersion (especially in the night-time), moderating mean radiant temperature and by providing a more porous urban fabric, leading to greater wind speed rates in the streets at pedestrian level.

For the same morphologies but with N-S oriented street, it was found slightly milder mean radiant temperatures (at daily average), but yet high temperatures for most of the scenarios.

4.1.3 Outdoor thermal comfort

To carry out the assessment of the outdoor thermal comfort responses for each microclimatic scenario, the Physiological Equivalent Temperature (PET) model index were selected.

The PET index, firstly published by Höppe (1984) [3], is defined as the air temperature at which the thermal balance of the human body can be maintained at the same temperatures of the core and the skin surface in a typical reference situation. For this research, the calculation of PET was performed using *RayMan* software developed by Matzarakis (2000) [5] and team.

For the PET results presented, it was shown by the temperature evolution over a daily cycle that the highest PET were verified to all scenarios at 6pm, being the urban scenarios II and VI (the low-rise buildings with no setbacks) the one that presented the highest levels of PET for almost the entire day. This can be explained by the low H/W ratio of the street, offering in this case the highest value of sky view factor among the studied scenarios (SVF = 0,66). In addition to that, these same scenarios presented at the same time the lowest temperature levels during in early morning until 10am, due its canyon street configuration (even if a shallow canyon) which leads to a substantial reduction of direct solar radiation experienced by pedestrians when compared to others scenarios (as there is no sun fenestration through lateral buildings setbacks for these scenarios). Due to the shaded area generated by the towers of 60m (scenarios III and VII), the PET presented the lowest values compared shallow canyons scenarios. However, with the highest solar angle, the proportion of its geometry and its high level of compacity (of about 0.45 - showing more reflective surfaces exposed to the outside) still present high PET in the daytime period (commonly verified phenomenon, especially in low latitudes) and prolonged until early night (PET of 34,9°C and 33,7°C at 6pm). This may be justified by the long wave radiation still retained in the interior of the urban canopy.

4.2 Parametric effect size analysis

To understand the relationship between the studied morphological variables regarding the PET response an effect size statistical analysis was applied. The effect size is a descriptive statistic that takes to estimate the magnitude effect of factor evolved (MONTGOMERY; RUNGER, 2003) [6].

As can be summarized from the above discussion and then depicted from the chart below, it could be identified a larger effect of magnitude for the *number of floors* and *building length* variables. This could however be justified by the major local building regulation rule that establishes a progressive building setback according to the choice of higher-rise buildings. The effect size of the *number of floors* variable concerning the PET was then found in an inverse relation, meaning: the

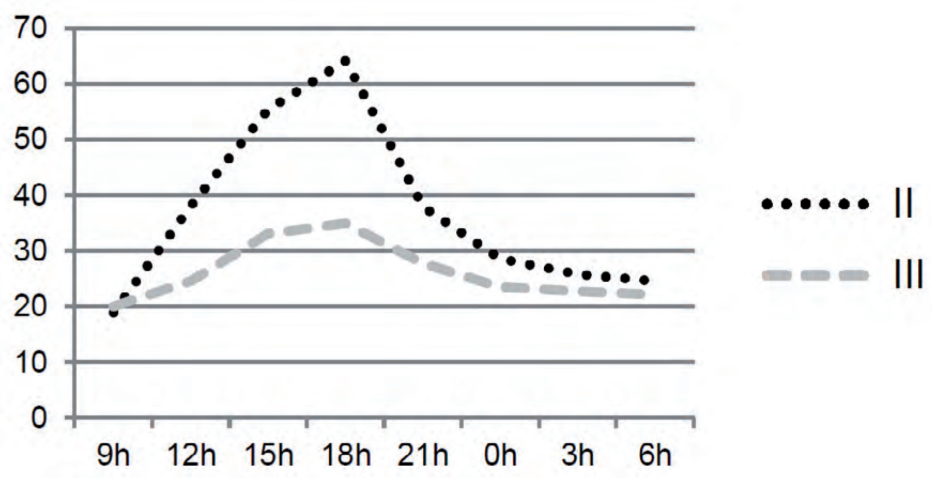


Figure 2: A daily-cycle PET comparison between scenarios II (low-rise canyon street) and scenario III (high-rise with large buildings setbacks).

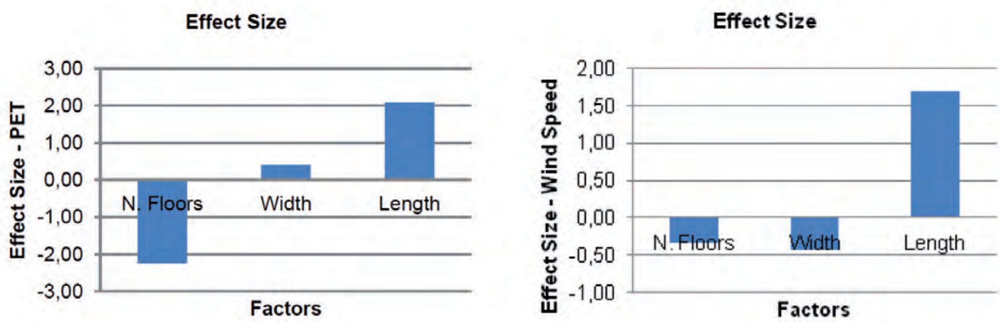


Figure 3: Effect size of the main morphological variables on PET and wind speed rate, respectively.

higher the building (which also means greater distances between buildings), the lower the PET. Considering a t-test for two samples, assuming equal variances, the confidence interval estimation of the variables effect were of 0,006.

Moreover, concerning the effect size on the wind speed rate, it was identified a direct relation to the *building length* which, depending on the street orientation, plays decisive role on attenuating the PET.

5 Conclusions

This paper presented the results of a statistical investigation over the microclimatic and outdoor thermal comfort responses of the recently established building regulation parameters of a city in the tropical semi-arid region of Brazil. A design of experiments sequence were submitted to numerical simulations over ENVImet model and then, analyzed individually and by a parametric effect size calculation in order to identify statistically the magnitude of the relationship between the morphological variables studied and the thermal comfort responses.

Even though the building regulation does not consider a building height limit, the progressive building setbacks (which seem to lead to a larger impact of the number of floors variable) seem to play an important role in mitigating heat stress in urban microclimate in tropical semi-arid climate.

Among the main findings presented, we can also conclude that in urban scenarios with lower H/W ratio, implementing shading strategies, such as applying urban vegetation or architectural devices (e.g. galleries, overhangs etc.) may also compensate the design choice performance regarding the outdoor thermal comfort responses. Bearing this in mind, the problematic investigated here consists of complex phenomena that deserves a more detailed and larger experiment testing, that should be taken into account in future works towards multi-objective optimization of urban configuration towards the same climatic conditions.

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Microclimatic Conditions in Different Geometry of Urban Open Spaces: a Case Study in Semi Arid Climatic Region of Algeria

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Abstract

Sustainable urban development should promote social relationships between individuals by offering them a comfortable environment. That is the reason why such spaces are needed in urban human settlements. The comfort sensation in such areas is the result of combination of many environmental factors such physiological, psychological, …. The microclimate seems to be the most important criterion in the evaluation of such spaces and their use. Moreover, and according to the policy of energy saving and the protection of environment, many researchers have related the achievement of internal thermal comfort to external thermal microclimatic conditions. For that purpose, the present consideration tries to evaluate the microclimatic conditions in urban open spaces with different geometry. The research is based on a site investigation as readings of air temperature and wind speed are taken for a period of several days, and then a simulation using Ray man software program allows the evaluation of external thermal comfort using PET index. The results point out the importance of the sky view factor combined with wind speed and directions, in the resulting microclimatic conditions.

1 Introduction

The city has never been a continuous and dense built entity, but it has always included a variety of forms and urban spaces. These outdoor spaces exercise an essential function; they recreate the life and the enjoyment which gives a full of life interesting environment and of animation. Places of relaxation, places of circulation and communication, places where social relationships can be made by the meetings which they cause. They also allow to fight against various nuisances to offer a good quality of life.

All these multiple functions must be considered in a global way so that the city gives a feeling of unity and thus personality because, alike monuments and buildings, these places are also elements which characterize the city to which they belong.

However in the mind of planners, the success of these spaces is often associated with a positive visual sensation brought by relevant factors of the aesthetics: landscape sights, surrounding buildings, beautiful vegetation, spectacular facades, quality street furniture and so on…; Now the microclimatic factors are of great importance for the activities which take place on this space and to a certain extent determine its occupation or its desertion by the users. “The sensitive quality of a place lies mostly in its climate, in particular in its microclimate. The collection of climatic data contributes to the analysis of the place and to resolve its climatic problems by the means of improvement” [1]

Urban space behavior towards the climate can, in first approach, be subdivided into two elements: the space morphology and the correction brought by elements contained in/by the space itself.

The appropriate morphology of the space orders some phenomena namely:

1. The distribution of shaded and sun exposed zones dependent on sun exposure , orientation and the heights of buildings as well as relationship: height / width or length between the building and the opened space, as demonstrated in many researches [2, 3, 4, 5] that indicate the importance of sky view factor.
2. Air flows under the effects of the wind generated by the degree of porosity or obstruction of the space itself [6, 7, 8]

These two phenomena have a direct action on the comfort of the user of the city; they determine the temperatures of the surrounding surfaces, the speed of air in touch with the human body, and the temperature of air resulting from these exchanges.

So, the present research tries to answer the questions of what are the best forms and dimensions that can set these spaces to be feasible especially in summer long hot and sunny days, for the city of Constantine characterized by a semi-arid climate (Figure 1).

The objective of this research is to highlight the relationship between the morphology of the outside space and the generated microclimate, and to measure its implication on the thermal comfort of the users. It can be a significant step towards the

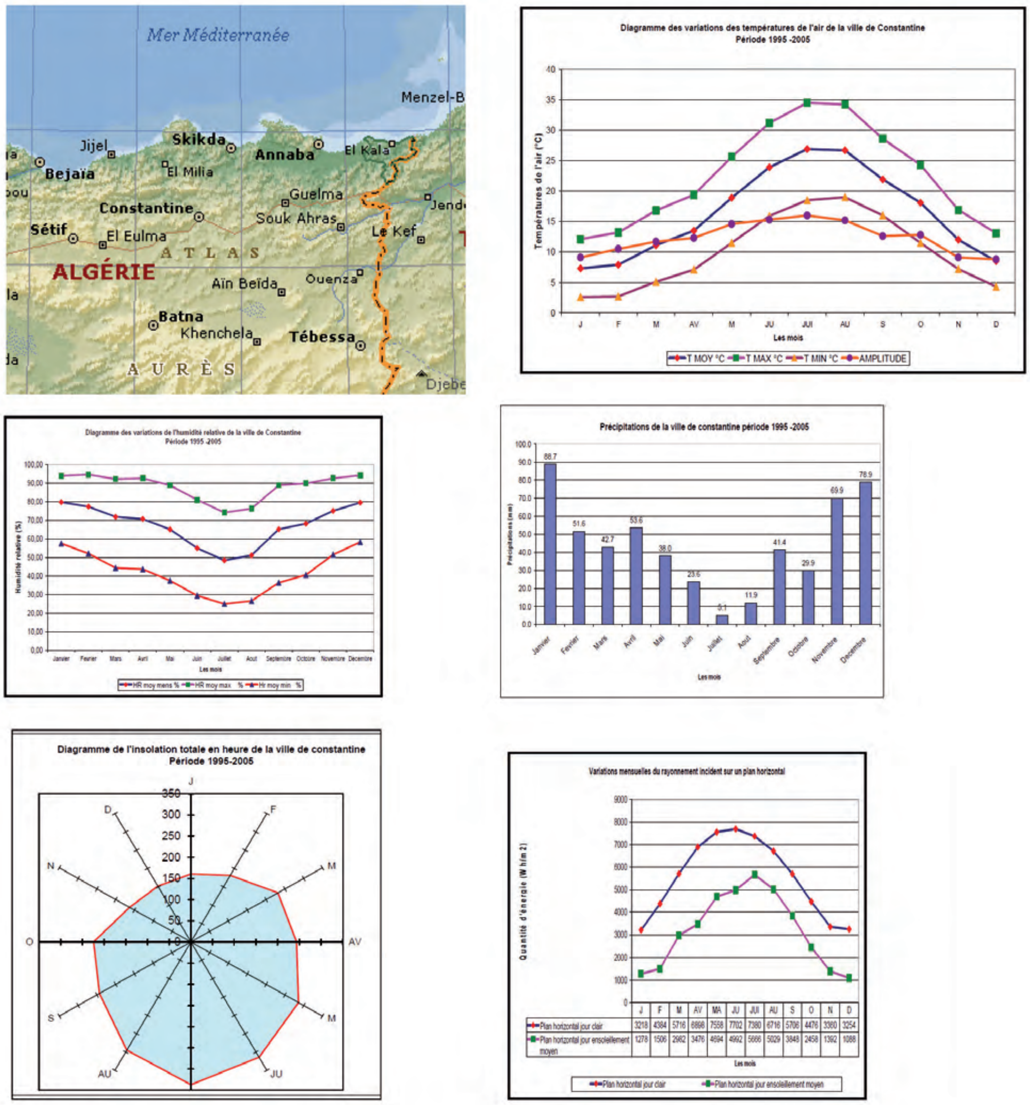


Figure 1: Geographical situation and climatic characteristics of Constantine city, (Source Encarta 2005, ONM Constantine)

identification of the important parameters which must be considered at the stage of the conception of urban public places.

2 Methodology of the investigation

To test the influence of the geometry of the opened public places on the urban microclimate, an investigation was undertaken during the warm season (August) on three different configurations oriented E-SE / O-NO, taking as indicator of geometry the sky view factor (SVF).

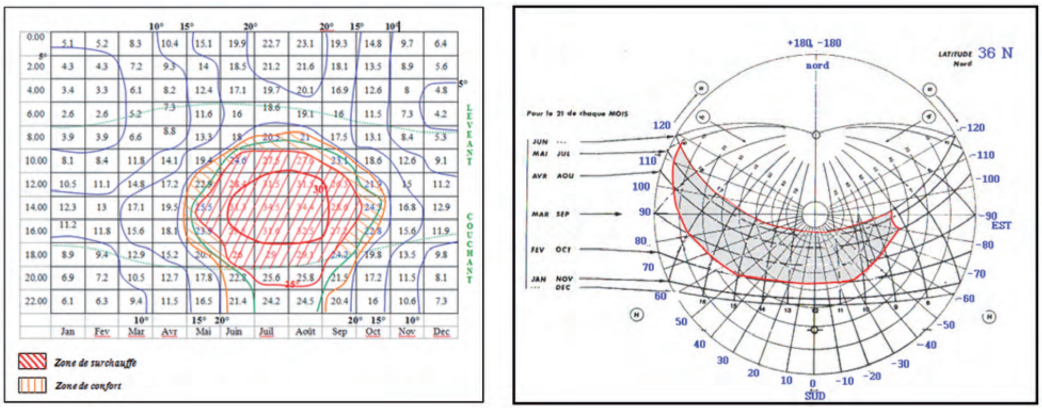
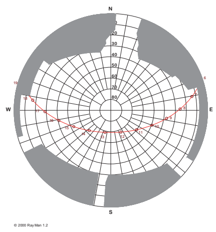
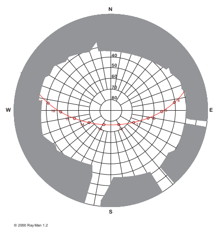
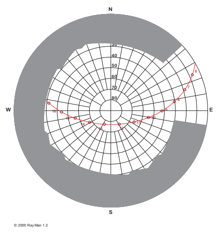


Figure 2: Determination of overheated period and shading area for summer period, Constantine, (source author)

Table 1: Significant characteristics of measured stations, modeled diagrams by Ray man 1.2 program, (source: author)

Station	Stereographic diagram	Altitude (m)	Surface (m^2)	H/W	SVF	Surface Color	Surface Albédo	Soil nature	Soil Albédo	Period of isolation
A		757	7752	0.32	0.688	white	0.90	earth	0.25	11h 53'
B		761	4224	0.32	0.585	white	0.90	Earth and bitumen	0.05	9h 46'
C		790	3025	0.33	0.594	White and beige	0.70	Earth and bitumen	0.25	11h 14'

A Climatic and bioclimatic studies of Constantine city are done at first (fig 1, 2). Then a site investigation that consists on readings of climatic elements such as, air and surface temperatures, relative humidity and wind velocity are undertaken in several open spaces. The main objective is to point out the behavior of the various climatic parameters in the urban opened spaces according to their geometry, and to measure their impact on the thermal comfort of the users.

Then a simulation using Ray man1.2 program intervenes on two phases:

Determination of the SVF of the selected stations (Table 1)

Draw shades for all the period of measurement, in all geometric configurations (Figure 3)

Measure of the thermal comfort index (PET) based on Tmrt (mean radiant temperature) (Table 2)

Finally, Bring improvements of the conditions of thermal comfort in these spaces by making changes on geometry, thermal characteristics of materials, introduction of some plants as solar mask to reduce the sky view factor and this part is not considered in the present work

3 Results interpretation

Results point out several realities on the urban microclimate as Figures 4,5,6,7, reveal the presence of the phenomenon of urban heat island for both day time and night. A strong negative correlation of (R2 = 99 %) between the SVF and the surface temperature which seems contradictory with the important quantity of Solar radiation that allows a big SVF. It finds the explanation in:

The nature of the ground cover of the station B (SVF 0.585): asphalt with small albédo stors more heat than other natural surfaces (Tsmax = 47°C at 14:00h against 44°C for the natural ground at 12:00hin others two stations.

The opening of the station C in the direction of the azimuth (Figure 3) constitutes an additional source of heat which increase surface temperatures Ts in station C (SVF 0.594) of 38°C against 36°C in station A (SVF 0.688) before 12:00h (Figure 8) Wind velocity in station B, and the reduced SVF make air temperature in that station smaller than others, however in the afternoon, when wind speed decreases (0.9m/S), air temperature reaches its maximum value of 33,3°C.

Although the relationship between air temperature and SVF is complex as it depends on many climatic parameters essentially solar radiations, in the present work a positive correlation (R^2 = 76%), between diurnal mean air temperatures and SVF, has been found, and that is very near of H. Andrade results (72%) in open spaces of Telheires in lisbonna [9].

The thermal comfort evaluation reveals an important positive correlation (R^2 = 98 %) between mean radiant temperature (Tmr) governed by the temperatures of the ground and the wind speeds, and the PET index for every station (Figure 9)

From 8:00 hours till noon the conditions of comfort remain in perfect accordance with the small value of the sky view factor (SVF), where the station A shows a maximal value of PET of 42.9°C corresponding to an extreme state of thermal stress (table 2), against 39°C for the station B, and 40.3°C for the station C. .

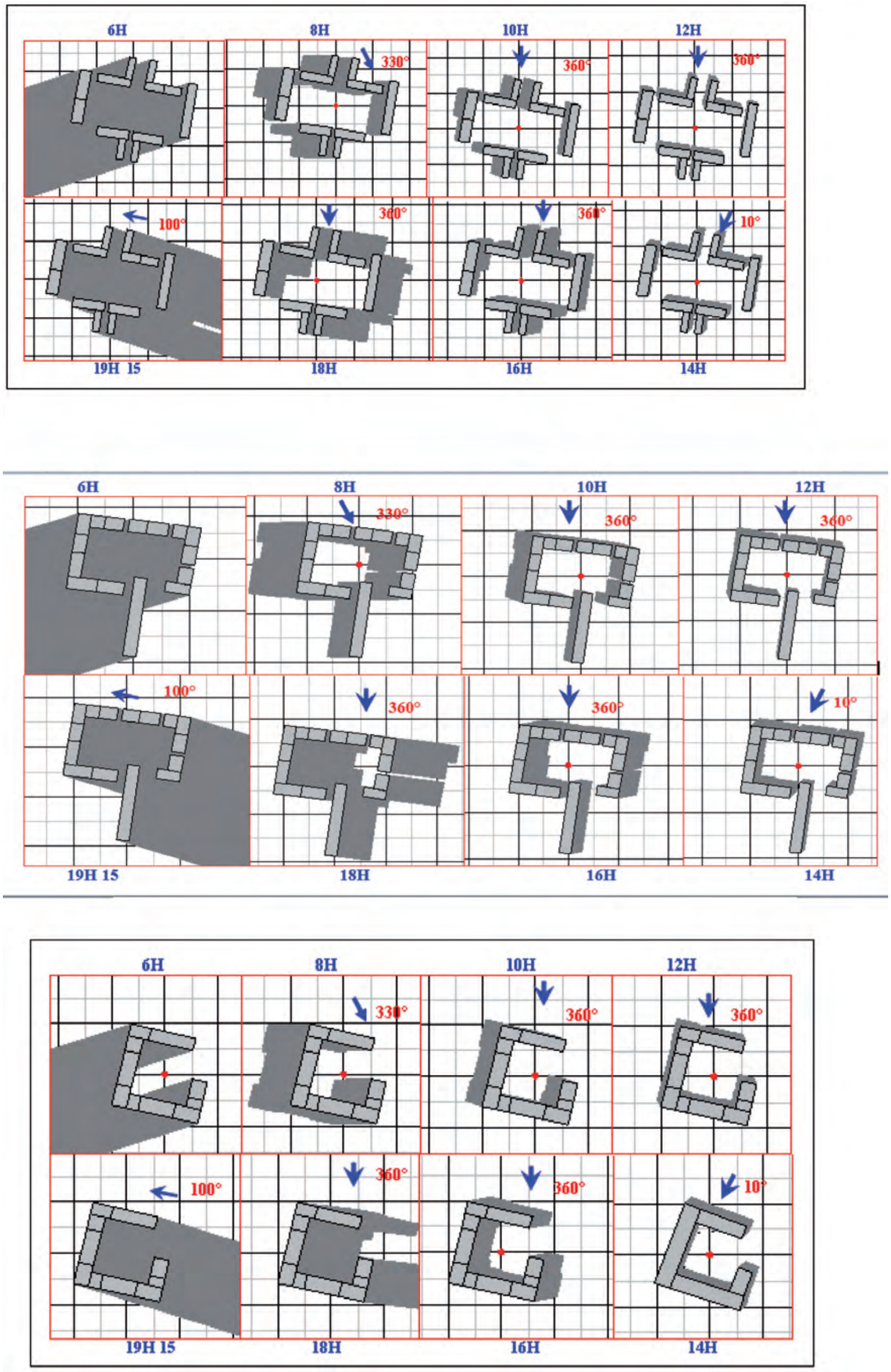


Figure 3: Space configurations and all day shaded areas for station A (0.688), B (0.585) and C (0.594) (Source auteur)

Table 2: Thermal sensation indicated by PET index

PET index	Human sensation
≤4	Very cold
4-8	cold
8-13	cool
13-18	Slightly cool
18-23	comfortable
23-29	Slightly warm
29-35	hot
35-41	Very hot
≥41	extremly hot

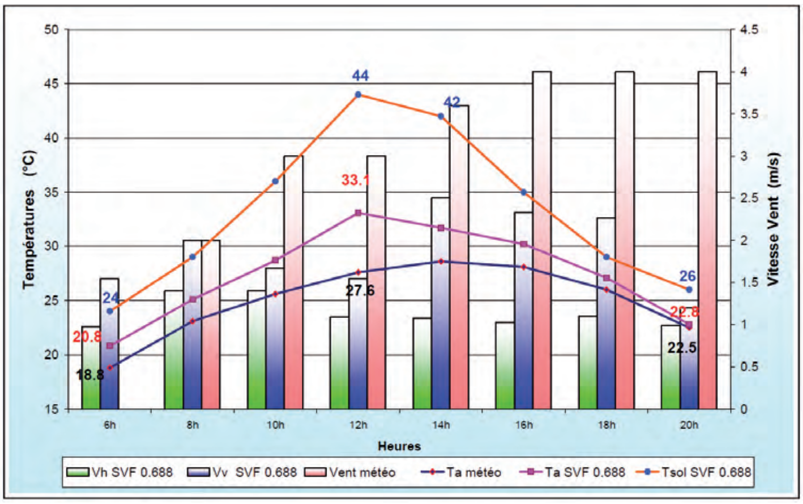


Figure 4: Comparison of climatic parameters between station A and meteorological station for summer time)

At 14:00 hours due to the warm-up of the asphalt, the station B records the maximal PET value of 44.5°C corresponding to an extreme state of thermal stress; however the station C registers a value of 39.6°C i.e. a difference of 4.9°C between B and C. After 14:00 hours, and because in the daytime the difference in PET index depends mainly on conditions of radiation and on wind speed (Andrade, on 2003), the station C with high wind speed continues to record the lowest values of PET (Figure 9)

The calculation reveals a strong positive correlation (R^2 = 96%) between the SVF and PET, this highlights the interest of the geometries to small SVF for the human thermal comfort.

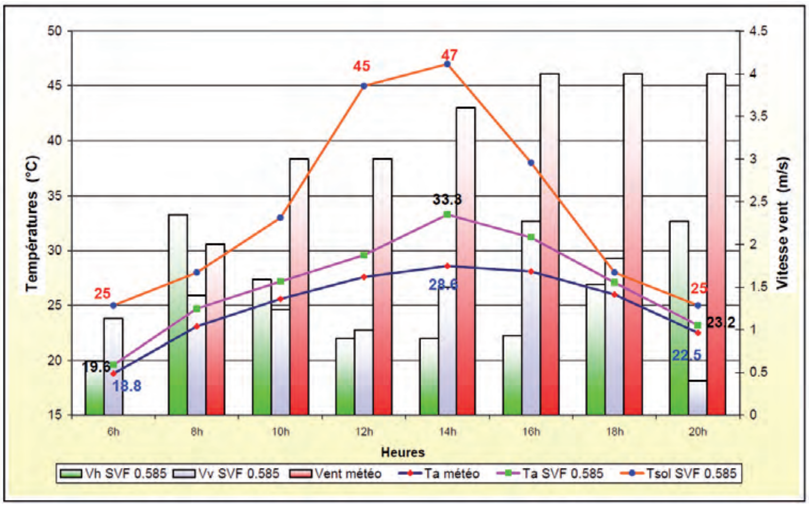


Figure 5: Comparison of climatic parameters between station B and meteorological station for summer time

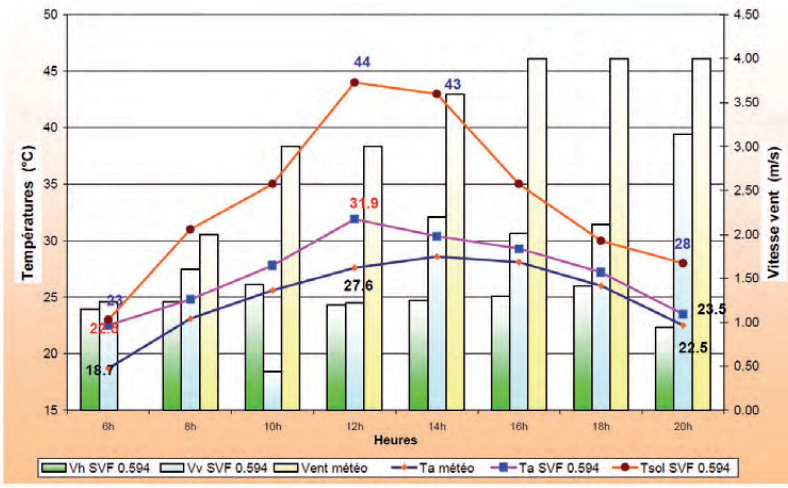


Figure 6: Comparison of climatic parameters between station C and meteorological station for summer time

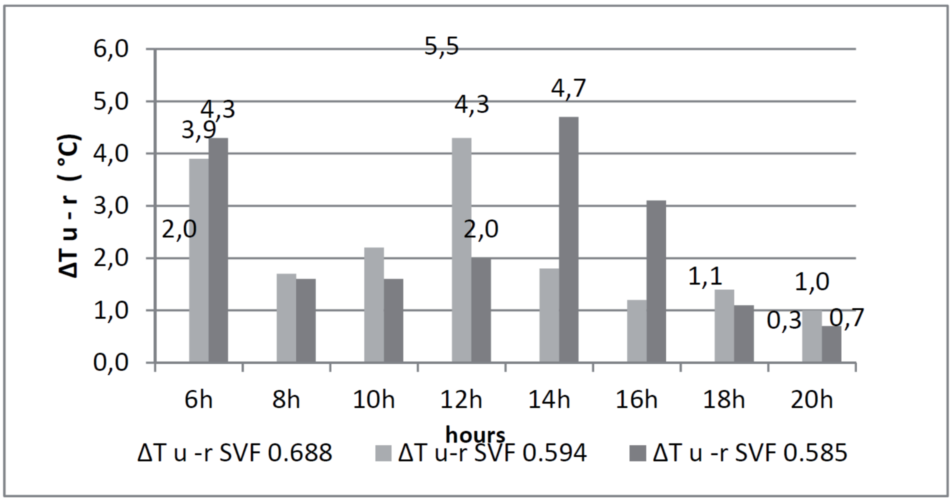


Figure 7: Temperature range between measured stations (A, B, C) and meteorological station. (source author

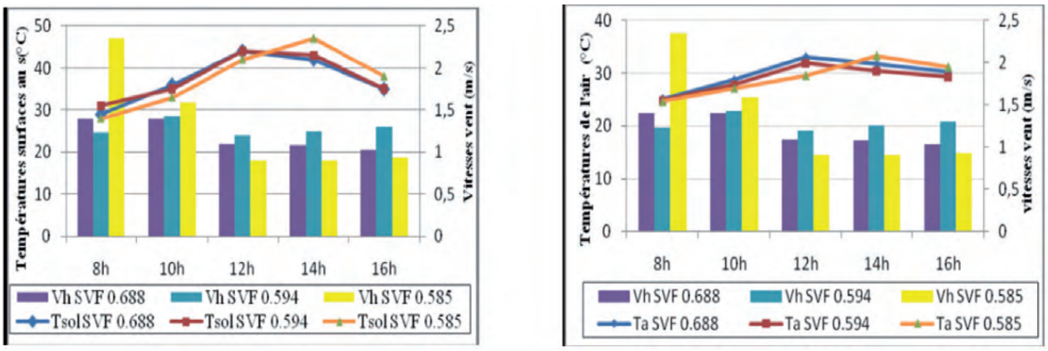


Figure 8: Surface and air temperatures variation according to Wind speed in stations A, B, C.

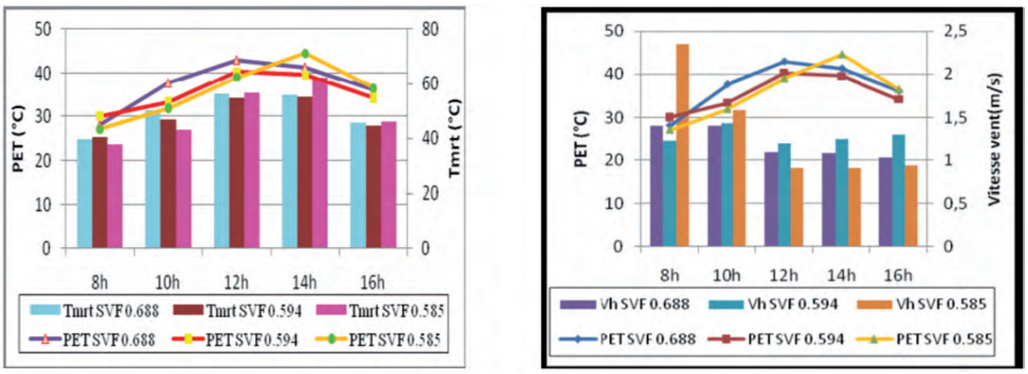


Figure 9: Variations of PET according to Tmr (left) and to wind velocity (right) in stations A, B, C.

4 Conclusion

Whatever the density of an urban tissue, high or medium, the phenomenon of urban heat island is often present. A big correlation exists between its intensity and surface temperatures during day time. However its sense (positive or negative sense) depends on climatic and physical local parameters like wind speed and direction, surface color and nature of surrounding surfaces, water and vegetation plants.

The revealing of the role of the only parameter "geometry" having for indication the SVF seems to be very complicated in pre established spaces where the various already mentioned factors exist.

The improvement of the conditions of thermal comfort for users of such spaces was achieved by the introduction of trees where the ratio 60/40 [10] of planted and unplanted space was respected.

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Adapting Cities to Climate Induced Risks - a Coordinated Approach

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Abstract

In an era of changing climate there is a growing interest to create resilient cities, which can absorb and manage climate induce risks, such as heat waves and natural hazards (flooding, landslides etc). The increased frequencies and magnitudes of these climate hazards are expected to have a major impact on society. In order to maintain risks to society at acceptable levels, measures to reduce the vulnerability need to be taken. Such measures may, however, have significant non-expected and non-wanted impacts elsewhere on society. The need of holistic planning strategies becomes apparent. The overall aim of this new transdisciplinary research project is to develop knowledge and methods that enable an integrated assessment of the impact of climate induced risks on society. The free-port area in Gothenburg, Sweden, will has been selected for a case study that will sharpen both the individual scientific methods and the interdisciplinary and intersectoral cooperation and integration. The project brings together experts in urban climate, atmospheric science, natural risk assessment, stratified vulnerability and multi-criteria analyses with local city planners in an integrated research effort. Strategic plans for climate adaptation will be developed and proposed. The stakeholder involvement will promote transfer of knowledge and applicability of results.

1 Introduction

Sweden is expected to experience greater climate changes than the global average [1]. Winters will be milder and rainier, summers will be warmer and drier and extreme weather events – for example heat waves, flooding, and heavy rains – will become more common. Swedish cities already suffer from the impacts of extreme weather, and the impact is expected to increase with future climate change. For example, the increase in frequency of flooding will have a major impact on basic infrastructure such as water, drainage and communications; extreme temperatures (heat waves) will have a large impact on people's health and well-being. In order to create resilient cities, which can absorb and manage climate risks, knowledge and methods that enable an integrated assessment of the impacts of extreme weather on the society are needed. Once the impacts are understood it will be possible to evaluate and translate this knowledge to provide guidance on how to create resilient cities in a future climate.

The overall aim of this transdisciplinary research project is to develop knowledge and methods that enable an integrated assessment of the impact of climate-induced risks on society. Specific objectives of the proposed research project are to:

1. analyse the role of land use, vegetation and urban morphology for reducing the risks of extreme weather (heat waves, flooding, landslides, changes in pollution situation)
2. evaluate socio-economic impacts of climate change and different adaptation measures
3. develop and propose innovative adaptation strategies to be applied by Swedish city planners to manage climate induced risks

The overall goal will be achieved by cooperation among researchers and intersectoral experts in urban climate, atmospheric science, natural risk assessment, stratified vulnerability and multi-criteria analyses and urban planning.

2 Case study area

The free-port area (Frihamnen), located by the river Göta älv in Gothenburg, Sweden as shown in Figure 1 has been selected to be used as a case study, for sharpening both the individual scientific methods and the interdisciplinary and intersectoral cooperation and integration. The free-port area is about to undergo a transformation from industrial docklands to a modern residential and commercial area. Different climate adaptation strategies will be analyzed in terms of planning and development work. Focus is on how the district's planned buildings can be adapted to rising sea level, heat waves and changed air pollution situation.

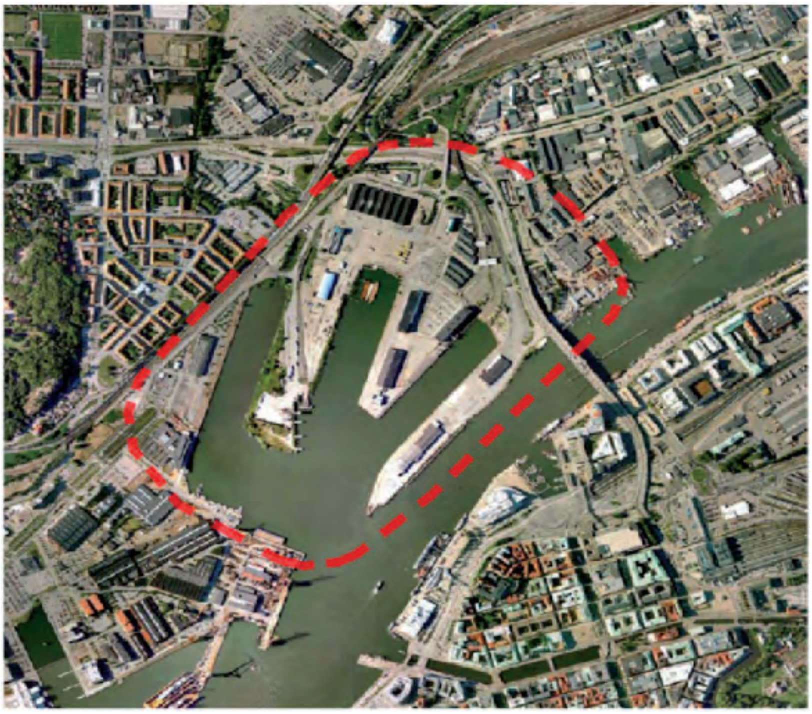

Figure 1: Free-port area located by the river Göta älv in Gothenburg, Sweden

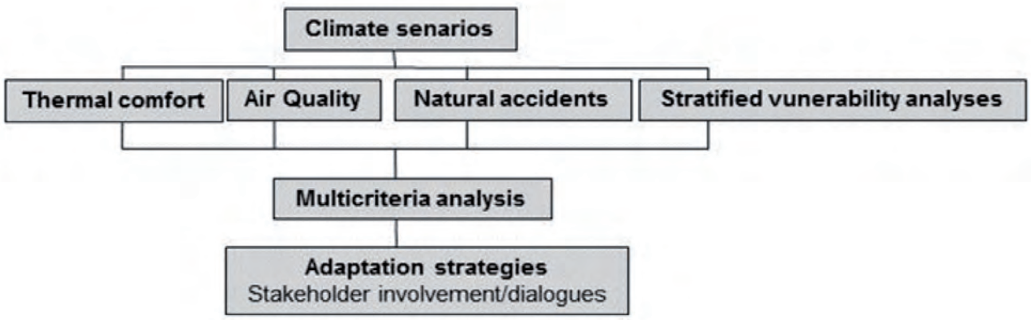

Figure 2: Work plan

3 Methodology

3.1 Remarks

The project is divided into different work packages as schematically described in Figure 2. Methods will include statistical downscaling of meteorological data, thermal comfort and air quality modeling, stratified vulnerability analysis and natural risk and multi criteria analyses.

3.2 Climate scenarios

In order to assess the impacts of climate change on society, reliable predictions of climate change and variability, which are calibrated to match local meteorological conditions, are needed. Regional Climate Models [2] help to overcome GCM's limited resolution, but RCM outputs are still not sufficiently close to observed data that they can be used directly as inputs in further simulations. In this project we will develop methods to generate hourly climate-change scenarios (air temperature, humidity, solar radiation etc.) for the free-port area, by combining observed climate data with climate change projections from the ENSEMBLES project [3]. RCM outputs from different GCMs under different emission scenarios will be used to analyze the change in general trends and extreme weather events and used as inputs into the thermal comfort and air quality analyses, following the methods developed in Thorsson et al. [4].

3.3 Thermal comfort

It is well known that climate-responsive design, utilizing urban geometry, vegetation, different surface and building material, color etc. can be used to provide more comfortable outdoor spaces, reduce the urban heat island, decrease the energy consumption and improve the urban air quality. In this project the influence of urban geometry, land use and vegetation on the outdoor thermal comfort will be analyzed using foremost the SOLWEIG-model [5, 6]. Areas of high risk will be identified and the effectiveness of different adaption measures, such as built density, amount, type and location of vegetation etc. to reduce heat stress at a neighborhood and city block scale will be investigated.

3.4 Air quality

The air pollution spreading within the urban area is affected by the local meteorology, imported air pollution and emissions of air pollutants. In order to understand how different actions could minimize the problems of climate change in the local urban area, dispersion modeling will be used to calculate the concentration of different air pollutants in different scenarios and urban plans. Here common assumptions of future emissions as well as traffic plans for each scenario will be used. The same meteorological scenarios will be used here as in other parts of the project.

3.5 Natural accidents

Climate change is expected to increase the frequency of events with extreme precipitation. In most parts of Scandinavia, increased annual precipitation combined with drier summers are expected. The changes of both increased annual precipitation and variable water levels will increase the risks (combination of probability and consequences) for flooding, erosion and landslides. These risks impact the ability to plan an area, as well as the urban planning impacts the risks. The risk will be assessed based on available information from previous and ongoing assessments of risks for such events including current and future climate projections. The basis will be local mapping and assessments of flooding, erosion and stability when available. When not available for the actual settings, the national general stability risk maps will be used together with results from previous and ongoing assessments.

3.6 Stratified vulnerability analysis

Climate vulnerability of different population segments in an urban context will be investigated. The population will be analyzed according to demographic, socio-economic, geographical, health and life-style factors. A deeper understanding of the exposure, sensitivity and adaptive capacity of 3-to-5 different population segments will be achieved by focus groups and/or interviews with three types of informants: i) municipal employees with responsibility for assisting identified vulnerable groups ii) representatives from groups with varying vulnerability (high/low) and iii) political representatives from the city. Furthermore, the conditions for innovative planning and adaptation strategies that address the vulnerable will be investigated using interviews with planners.

3.7 Multi criteria analysis

The evaluation of potential planning strategies will be done by a multi criteria analysis (MCA). The MCA tool covers global (e.g. greenhouse gas emissions related to adaptation measures or activities), regional and local air quality, water and soil quality, use of energy and raw material and land use capacity, economic and socio-economic aspects including wellbeing and perceived welfare and flexibility [7]. Both the short term and long term perspectives will be regarded. The MCA will be used as a framework for the first step towards a compilation of the outcomes from the studies on thermal comfort, air quality, natural accidents and stratified vulnerability analysis. This holistic compilation of results as mirrored through the perspectives of municipal administrative stakeholders in interviews will be further refined by testing in stakeholder dialogues to ensure its relevance and usability for assessing the potential urban adaptation strategies. The MCA process will contribute to the final project outcome, which will be a framework that enables an integrated assessment of vulnerability of different groups in society, and the formulation of an adaptive strategy explicitly recognizing pros and cons of each adaptive measure on wellbeing in society as affected by thermal conditions, air quality, the risk of natural disasters and stratified climate change vulnerability.

4 Expected outcome

The project is expected to give better knowledge on the integrated assessment of the impact of climate- induced-risks on society, knowledge which will be used to provide guidance on how to create resilient cities in a future climate.

Acknowledgement

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Assessments of the Outdoor Thermal Conditions in Szeged, Hungary: Thermal Sensation Ranges for Local Residents

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Abstract

The aim of this study is to examine the relationship between the current subjective thermal sensation of Hungarians and the Physiologically Equivalent Temperature (PET) (as well as the Universal Thermal Climate Index (UTCI) in the time of the year appropriate for staying outdoors, and to determine more representative thermal comfort ranges for locals. In order to achieve this, questionnaire-based field surveys were performed together with on-site biometeorological measurements (relevant parameters of thermal comfort were measured at the height of 1.1m) in Szeged, Southeast-Hungary. During three study periods (autumn 2009, spring 2010 and summer 2011) ca. 1300 visitors were asked in several city squares about their estimations concerning the thermal environment. According to the results the occupants' subjective thermal sensation vote (TSV) had good relationships with every individual meteorological parameters but the strongest correlation was shown with the UTCI. Although strong correlation was detected in case of PET, where the connection can be described the best with a quadratic function, showing that the reactions of occupants are more sensitive to the thermal situations in cool than in warm conditions. Based on the regression result of PET, lower neutral thermal sensation with wider range was found in Hungary than the recently adopted one, and the warm sensation categories also proved to be modified. The neutral thermal temperatures in terms of PET and UTCI obtained are 16.8ºC and 18.1ºC, respectively.

1 Introduction

Thermal comfort in outdoor settings has received more and more research attention in the last decade [1-5]. To study outdoor thermal comfort detailed information needed about the thermal environment evolved on the area as well as about the way visitors assess these conditions.

Besides the numerous thermal indices derived from heat-balance equation of the human body, which are aimed to asses the thermal environment objectively, subjective approaches (observations, interviews) currently become more and more widespread [e.g. 4-6]. Some of field surveys based on questionnaires have been undertaken to validate the different comfort or stress indices against actual thermal sensation of respondents and to redefining the scale of the various indices in order to create better correspondence between them. Monteiro and Alucci [7] calibrated the scale of several indices in Sao Paolo (Brazil). Lin and Matzarakis [8] adapted Physiologically Equivalent Temperature (PET) index to the actual sensation vote of participants in Taiwan to express more precisely the comfort range at the local circumstances. Tseliou et al. [9] attempted to correct some index values instead of modification of the original thermal sensation ranges according to the subjective thermal sensation and the climatic mean temperature.

The aim of this study to combine two thermal comfort indices (PET and the newest index: Universal Thermal Comfort Index – UTCI) and the actual thermal sensation of the interviewees in Hungary. Based on our results we propose refinement of the thermal sensation or stress categories of both of indices to reach better corresponding to the Hungarian reactions.

2 Materials and methods

To study the subjective estimations of people in accordance with thermal comfort conditions questionnaire-survey was carried out with simultaneous micrometeorological measurements in five recreational areas of an south-eastern (46°N, 20°E, 82 m asl) Hungarian city Szeged. (Szeged belongs to the Köppen's Cfb climatic region, and is characterized by temperate warm climate with uniform annual distribution of precipitation.)

Data were collected on 37 weekdays (between 10 pm. and 6 am.) during September-October of 2009, April-May of 2010 and June-August of 2011.

The questionnaires were based on the international experiences of [1-5] and concerned the subjective assessment of the thermal environment. Inter alia the visitors reported their thermal sensation vote (TSV) using a semantic differential scale with 9 main nominal categories: very cold, cold, cool, slightly cool, neutral, slightly warm, warm, hot and very hot. (The more details of the survey about the connection of the actual thermal conditions and the inhabitants` sensation and perceptions is presented in our poster presentation of this conference).

On-site meteorological data have been obtained near the interviewees by a mobile station equipped with Vaisala and Kipp&Zonen sensors in the height 1.1-1.2 m.

The station includes a rotatable net radiometer to receive the short and long wave radiation fluxes (K and L) from the 6 main directions in order to estimate the mean radiant temperature (Tmrt [°C]) [10]. The measured air temperature (Ta), relative humidity (RH), wind velocity (v) and the obtained Tmrt were used to calculate the thermal comfort index Physiologically Equivalent Temperature (PET [°C]) and the Universal Thermal Climate Index (UTCI [°C]) using RayMan model [11,12,13].

The PET (°C) index is based on a complete two-node heat budget model of the human body [14]. PET provides the equivalent temperature of a reference environment where Ta=Tmrt, water vapour pressure of 12 hPa (50% at 20°C) and practically without air movement (0.1 m s^{-1}). In the model the heat balance of a reference person (metabolic heat production 1.48 MET of light seeting activity; constant thermal resistance of clothing – 0.9 CLO corresponding to light business suit) is maintained with core and skin temperature equal to those under the current outdoor conditions. Thermal sensation and physiological stress categories in term of PET for a standard person are represented in Figure 1 a,b.

UTCI is based on the multi-node UTCI-Fiala model [12,15]. It is defined as the air temperature (Ta) of the reference condition causing the same model response (physiological reactions expressed e.g. as core temperature, skin temperature, sweat rate, skin wettedness) The reference environment is characterised by calm air (wind speed 0.5 m/s, 10 m above the ground, corresponding to approximately 0.3 m/s at the person level), no additional thermal irradiation (Ta=Tmrt) and 50% relative humidity, (above 29°C Ta vapour pressure capped at 20 hPa). The rate of metabolic heat production of the reference person was assumed to be 2.3 MET walking with a speed of 4 km/h (1.1 m/s). Figure 1c shows the scale of the physiological stress level of UTCI index. Because of the possibility of clothing adaptation included in the UTCI-Fiala model, the range of "no thermal stress" category is wider, than in case of PET (Figure 1b,c).

3 Results and discussion

Most of the 1271 interviews were carried out within a Ta range of 24-27°C, although values below 15°C and above 30°C also occurred.

Wind speed fall mainly between 0.5-3.3 m/s with a maximum v of 6.7 m/s. The RH values between 25 and 50% dominated, but some interviews took place at 70-75%. The Tmrt incorporate a range of 10-67°C. The calculated PET values were between 6 and 48°C, UTCI between 3 and 42°C (the different stress categories show nearly normal distribution by both of indices) (Figure 2).

The interviewed persons (1271) were asked to subjectively evaluate their thermal sensation vote (TSV) in a 9-points scale. The most frequent TSV was the slightly warm category, followed by the warm and neutral votes (Figure 3a). Regarding the thermal comfort conditions in terms of the PET index the slightly warm class (23-29°C) occurred most frequently. This was followed by the neutral (18-23°C) and warm (29-35°C) categories. Fewer interviews were carried out during hot (35-41°C) and slightly cool (13-18°C) thermal conditions. The very hot range (above

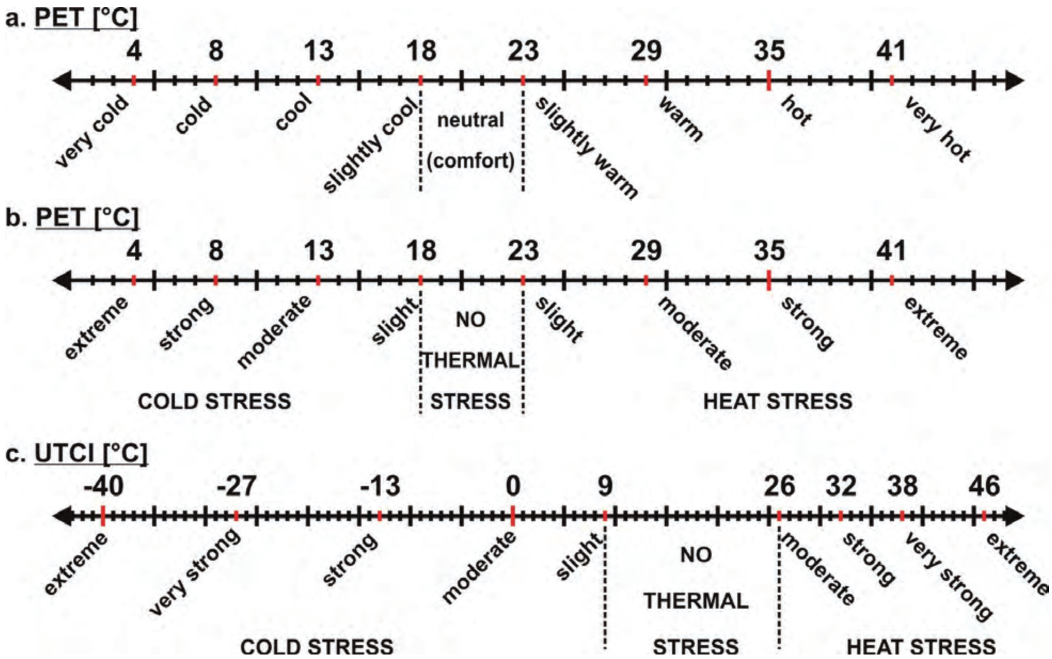

Figure 1: PET categorised in terms of thermal sensation (a) and physiological stress (b) and UTCI equivalent temperatures physiological stress categories (c)

41°C) as well as the cool (8-13°C) and colder (below 8°C) categories occurred very rare. (Figure 3b)

Individuals' thermal sensation significantly differs even when they are in the same environment. To reduce the scatter the thermal sensation vote were averaged and plotted against the objective variables (Figure 4). In case of temperature, TSV was averaged for each 0.5°C Ta bin, resulting N=45 discrete values (Figure 4a). The interval-widths were 0.1m/s v for wind (N=47), 1% RH for humidity (N=46) and 1°C Tmrt for solar radiation (N=54), PET (N= 42) and UTCI (N= 35) too (Figures 4b-d).

According to the results (the slopes of the fitted lines and the determination coefficients) visitors' subjective thermal sensation vote has good relationships with individual meteorological parameters (at a significance level of $\alpha<0.001$). Air temperature (Ta) (R^2= 0.797) and the solar radiation (Tmrt) (R^2=0.832) shows the highest determination coefficients. Lower, negative correlation was found between TSV and relative humidity (R^2=0.682), and the lowest between TSV and wind speed (R^2=0.166). The lowest slope value found in the case of wind with the narrowest range (from -1 to +1.5) could mean, that such calm wind not significantly affects the thermal sensation of people. In some cases the quadratic function describes the relationship a bit better between the subjective thermal sensation and the meteorological parameter: for example the quadratic R^2 by Tmrt 0.856 and by v 0.174 (Figure 4 a-d).

Stronger correlations were detected in cases of complex thermal stress indices, which is especially strong at UTCI (R^2 =0.941). Quadratic line fitted to the PET val-

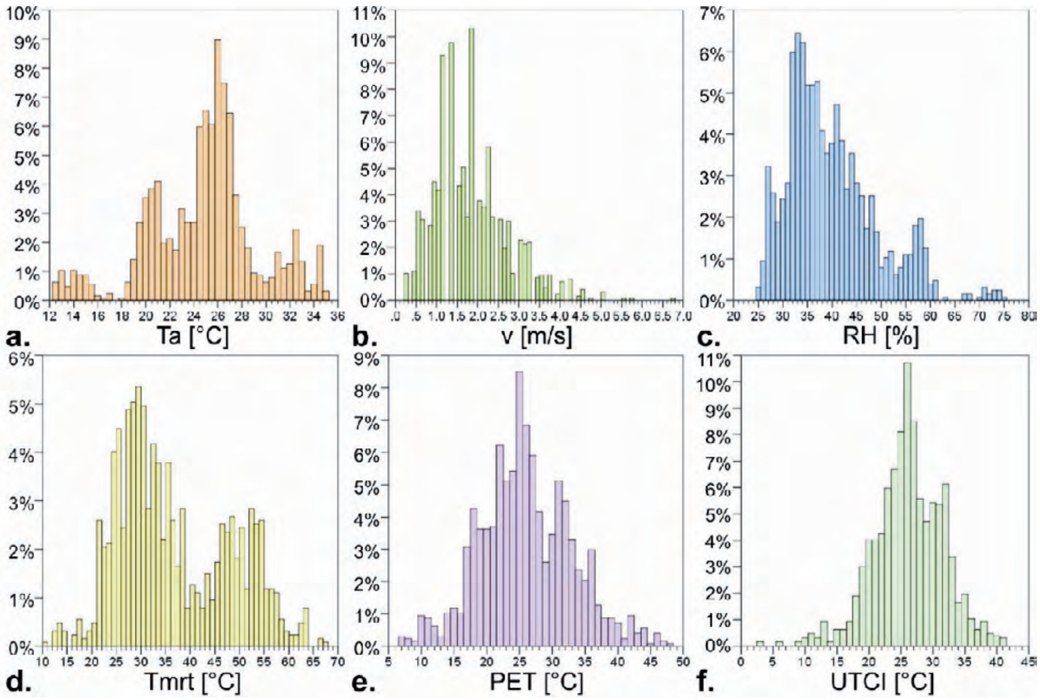

Figure 2: Distributions of the air temperature -Ta (a), wind speed - v (b), relative humidity - RH (c), mean radiant temperature – Tmrt (d), and the different values of PET (e) and UTCI (f) indices

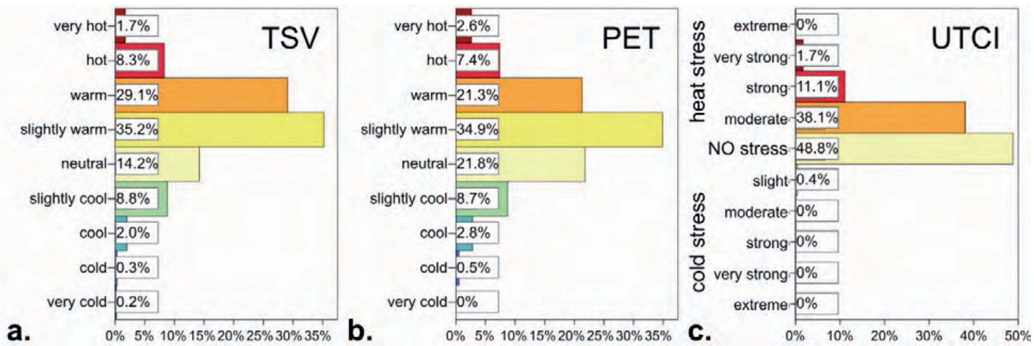

Figure 3: Frequency distribution of the thermal sensation votes (TSV) given by the interviewees (a) and main categories of PET (b) and UTCI (N=1271)

ues brought an improvement in correlation (R^2 Linear=0.878, R^2 Quadratic= 0.916) too (Figure 4 e-f).

Figure 5 shows also these functions together with further comparison between opinion about the current thermal sensation of Hungarians and the original thermal stress ranges of these indices. In the range of neutral PET values (18-23°C)

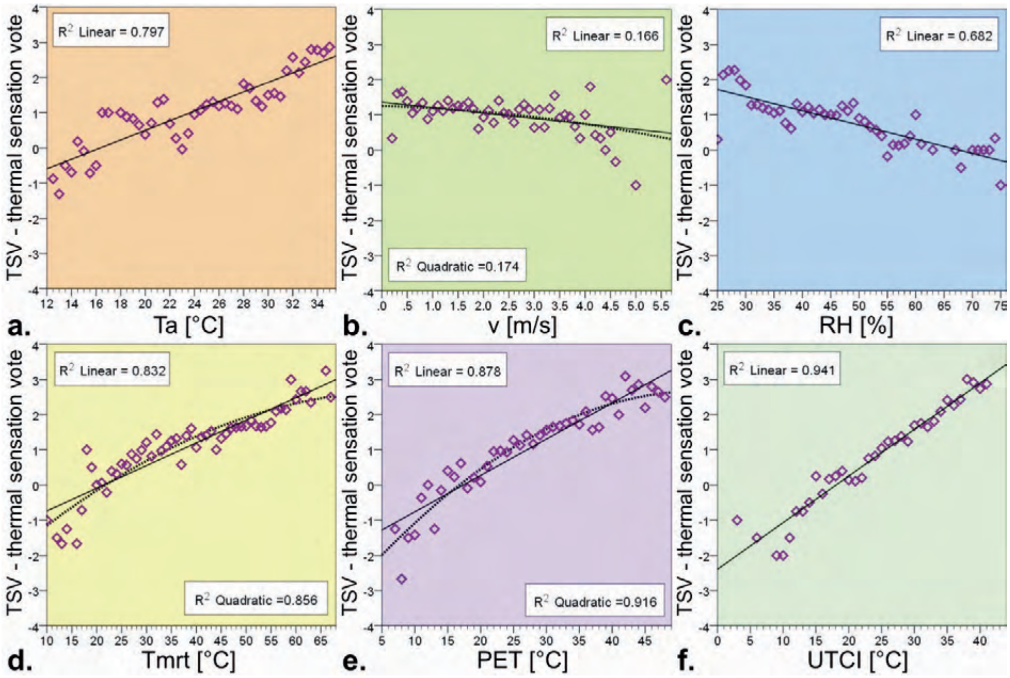

Figure 4: Mean thermal sensations vote vs. corresponding meteorological parameters (a-d) and calculated PET and UTCI values

slightly warm mean thermal sensation votes also occurred by the neutral ones. The best overlap between the objective and subjective evaluations can be found in the slightly and moderate warm PET-categories (23-35°C). The scattering of the values increases across to both of cold and warm stress extremities. It can be caused by the small number of the PET values in these categories (see Figure 2e).

However in the case of slightly cool PET values (13-18°C) and below 13°C the actual thermal sensation is usually better than expected according to the calculated comfort index (the interviewees reported generally neutral thermal sensation) (Figure 5a).

In case of UTCI index the fit of the line is especially good above 12°C UTCI, deviation is higher only in cold range (Figure 5b).

According to the above mentioned we take recommendation to new PET and UTCI boundaries in order to indicate more precesily the thermal sensation domains of Hungarians, may evolve in three relevant seasons of outdoor activity. Figure 6 shows the neutral temperature in both of scales. Neutral temperature indicates the temperature at which people feel thermal neutrality (neither cool, nor warm), i.e. where the mean thermal sensation vote equals 0 [5]. Using the fitted equations the obtained neutral temperatures are PET= 16.8°C and UTCI=18.1°C. The new PET category of neutral thermal sensation shifts lower compared to the recently used,

and the range is wider. The width of the warm range doubles compare to the original, and the hot category shifts to the higher PET value (above 44°C).
In case of UTCI index distribution of categories is more smoothly, the neutral range is located in the middle of the original no stress category. The examination can be refined if more data are at disposal from the extreme categories.

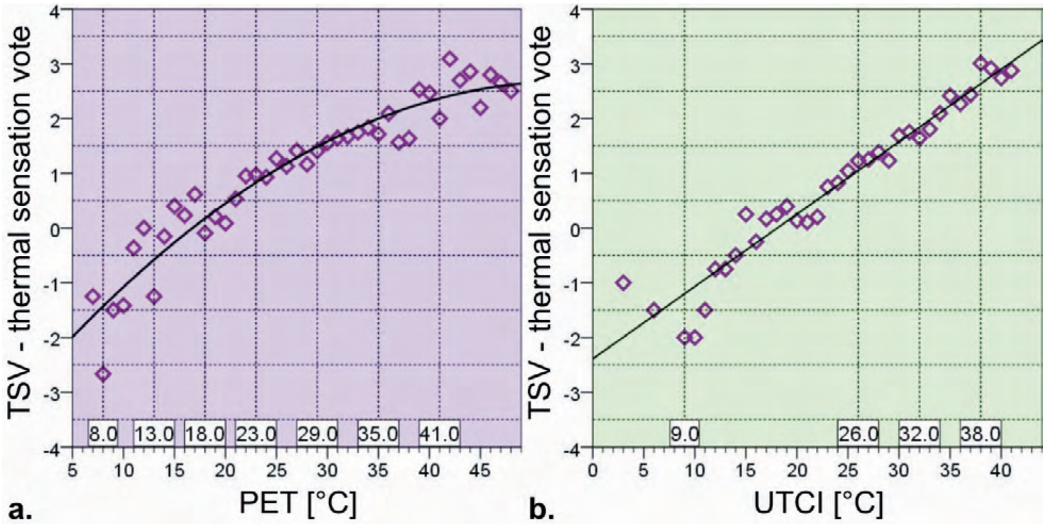

Figure 5: Subjective thermal sensation vs. PET and UTCI values based on 1°C averages (N=), with the original thermal stress ranges of the indices

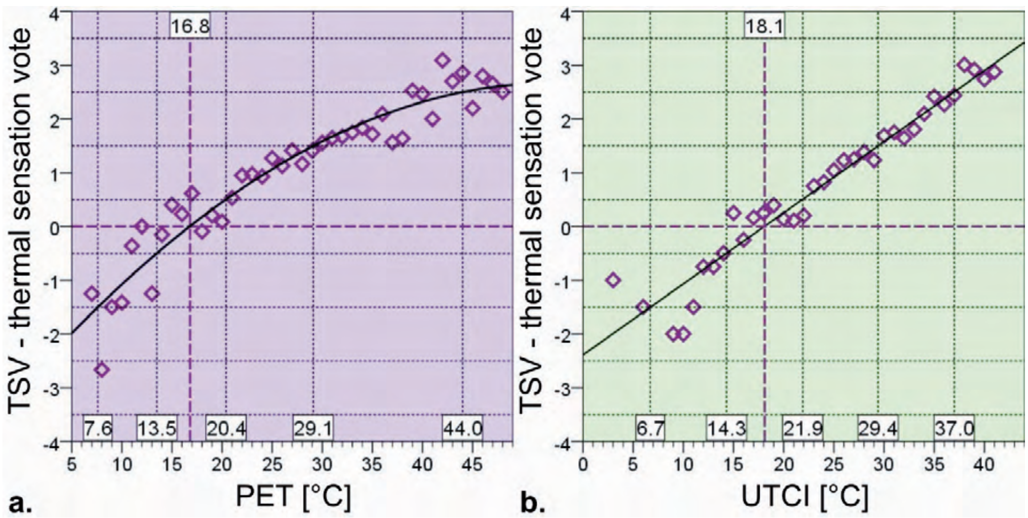

Figure 6: Subjective thermal sensation vs. PET and UTCI values based on 1°C averages with the neutral temperature and the recomended thermal stress ranges of the indices

4 Conclusions

In assessment of thermal comfort not only the physical parameters of thermal environment, but the subjective psychological factors are also important, significantly affect the thermal sensation and behaviour of visitors and their area usage. Due to the additional information of questionnaires we can provide more region specific thermal comfort evaluations.

This paper introduced a Hungarian thermal comfort study carried out in 37 weekdays in three seasons suitable for outdoor staying in the centre of Szeged. Besides the on-site meteorological measurements 1271 visitors were asked to assess the thermal conditions in terms of thermal sensation.

Visitors' thermal sensation shows good relationship with every individual meteorological parameters, especially strong correlation with the air temperature and the solar radiation. The connection between actual sensations votes and wind speed is negative and much lower, partly due to the only few interviews in cases of strong air movement.

Connection between PET and UTCI thermal stress indices and actual thermal sensation of occupants were analyzed too, and very strong correlations were detected. The connection in case of PET can be described the best with a quadratic function, showing that the reactions of occupants are more sensitive to the thermal situations in cool than in warm conditions. In case of UTCI strong linear correlation has been arisen; the scatter of data is small except the low UTCI values (below 12°C). Based on the regression result, lower neutral thermal sensation with wider range was found in Hungary than the recently adopted PET category, and the other sensation categories also proved to be modified.

Acknowledgement

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Climate and Constructions
International Conference, October 24-25, 2011, Karlsruhe, Germany
191–204 (2011)

Influence of Vegetation and Permeable Areas in Pedestrians' Thermal Sensation in Urban Spaces in the City of Belo Horizonte, Brazil: An Analysis Using the Thermal Comfort Index Physiological Equivalent Temperature (PET)

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Abstract

This study presents an analysis of the influence of vegetation and permeable areas in pedestrians' thermal sensation in urban environments, carried out in the city of Belo Horizonte - Brazil, which is located in a tropical of altitude climate region with wet summers and dry winters. Climatic data were measured simultaneously with administration of questionnaires in two representative days of summer and winter, and in two contrasting areas regarding their morphological parameters such as the sky view factor, the height of buildings, the type of pavement, the presence of water sources and the vegetation. The PET index was used to quantify the thermal sensation. In order to quantify vegetation and permeable areas the IDA index (tree density index) and the percentage of permeable areas were respectively used. The PET values were analyzed in the light of previously performed calibration of this index for the city of Belo Horizonte. The results suggest that there were no significant differences between the pedestrians' perceptions of thermal sensation in the environments studied. In both areas, a similar number of people felt comfortable with respect to thermal sensations, both subjective and objectively.

1 Introduction

Research on urban climate shows that urbanization affects the local energy balance causing changes in the climate of cities, influencing their inhabitants' thermal comfort. Local climatic changes of urbanized environments are caused by the shape of built-up spaces and by the thermal properties of the surface materials used (absorption, reflection, heat capacity and emissivity), features that differ from those found in natural environments. Similarly, the difference between the thermal processes that occur in urban areas with a strong presence of vegetation and permeable areas, and in urban areas without these characteristics, is based on the partition between the turbulent fluxes of sensible and latent heat. This occurs because the energy exchange between the vegetation and the surroundings, unlike what happens with inert materials, is due to biochemical processes besides the physical ones, resulting in lower heating of the air when compared to that of the inert materials and the surroundings. In urban environments, the presence of vegetation may also influence the reduction of temperature through the process of shading and evapotranspiration from leaves.

In this context, this study aims to evaluate, both subjectively and objectively, the influence of the presence of vegetation and permeable areas in the pedestrians' perception of thermal sensation in urban environments. The IDA index (tree density index) and the percentage of permeable areas were respectively used in order to quantify vegetation and permeable areas. The IDA index represents the number of trees per 100m², and can be calculated using eq. (1) [1]:

$$IDA = (\text{number of trees/total area in m}^2) \times 100 \qquad (1)$$

For the quantification of thermal sensation, the thermal comfort index Physiological Equivalent Temperature (PET) was used [2], which had been previously calibrated for the city of Belo Horizonte, Brazil, resulting in the definition of the following ranges: 'cold', up to 12°C, 'cool', from 12°C to 15.5°C; 'comfortable', from 15.5°C to 30.5°C, 'slightly hot', from 30.5°C to 31°C; 'hot', from 31°C to 35.5°C, and 'very hot', above 35.5°C [3].

2 The area studied

Belo Horizonte (19°55'S, 43°56'W) is placed in the central portion of the state of Minas Gerais, located in the southeastern region of Brazil. The city, which has about 2.412.937 inhabitants [4] and an area of 331Km², is among the largest cities in Brazil. Considering the Köppen Classification, the climate of Belo Horizonte can be classified as Aw, which corresponds to a wet tropical climate with average temperature of the coldest month above 18°C and distinct dry season in winter. Low velocity winds occur throughout the year (about 1.5 m/s) and the prevailing direction is east. In this study, two case areas were selected in the southeastern region

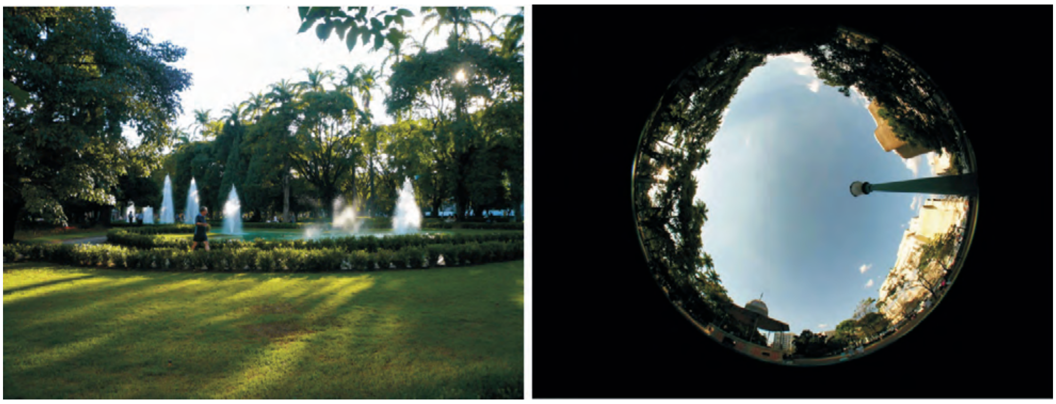

Figure 1: *Liberdade* Square. Source: Hirashima (2010).

of Belo Horizonte – *Liberdade* Square (Figure 1), with a total area of 22,230m² approximately, and *Sete de Setembro* Square (Figure 2), with a total area of 7,356m² approximately. Differences regarding the sky view factor, the height of buildings and the presence of water fountains and vegetation were considered as selection criteria. The contrasting areas should present different microclimatic conditions, which would contribute to the achievement of representative data of the PET index that could be related to the different urban structures.

3 Methodology

The methodology adopted was divided into three main stages: preparatory stage, data collection stage and data processing and analysis stage. In the preparatory stage, the characteristics of the areas chosen were raised and the procedures for carrying out the field investigations were defined. Vegetation of each area was quantified by using the Tree Density Index (IDA) and quantification of the permeable areas was expressed as the percentage of these in relation to the percentage

Figure 2: *Sete de Setembro* Square. Source: Hirashima (2010)

of the total area in each of the squares considered. At the data collection stage, the field investigations took place in two consecutive days, one in *Liberdade* Square and the other at *Sete de Setembro* Square, in the summer, during the afternoon from 2:00 pm to 5:00 pm, which corresponds to the hottest period of the day, and in the winter, during the morning from 7 pm to 12 pm, which corresponds to the coldest period of the day. Physical, individual and subjective variables were collected through field measurement simultaneously with administration of questionnaires. The physical variables were microclimatic data, such as air temperature, relative humidity, globe temperature and wind speed. The individual variables were weight, height, age, gender, acclimation to the environment, eating habits, physical activities and clothing, among others, and the subjective variables were data concerning perception and preferences of thermal sensation. For determining the measurement points, the solar geometry was studied and two specific points were chosen in each area: one in the sun and another in the shade. Therefore, for people located in the sun during the interview, the correspondent data measured with the equipment placed in the sun were used for the calculation of PET, and for people located in the shade, the correspondent data measured with the equipments placed in the shade were used for calculating the PET index. The climatic data was measured at 1.1m, according to ISO 7726 [5]. The following equipment were used: a portable digital anemometer LAMBRECHT, a thermohigrometer HOBO U12-ONSET inside a developed PVC shelter, a 150mm-diameter black globe thermometer INCOTHERM, a 40mm-diameter gray globe thermometer assembled by the researchers of the Federal University of Minas Gerais. In order to calculate the mean radiant temperature, based on the measured values of the 40mm-diameter gray globe thermometer, the equation established by ISO 7726 [5] for forced convection was used, once the measures were taken in open spaces in the presence of higher wind speeds when compared to those present in indoor environments. All the equipment was previously calibrated and/or gauged. Data were measured every 5 minutes and the local assembly of the equipment was performed 30 minutes before field investigation for stabilization of the globes. During the preparation of the questionnaires, at the preparatory stage, the related ISO standards were observed [6-9]. At the last stage – data processing and analysis - for the calculation of the PET index, a software developed by the University of Freiburg/Germany [10], was used and descriptive statistical analysis was performed.

4 Results and discussion

Liberdade Square featured an IDA of 1.15 and 42% of permeable area, approximately, while *Sete de Setembro* Square featured an IDA of 0.8 and 0.2% of permeable areas approximately. In *Liberdade* Square 2.3% of the total area is covered by water fountains, while in *Sete de Setembro* Square there are no water fountains. Approximately 120 people were interviewed in each area and in each season, resulting in a total of 480 interviewees. Data from *Liberdade* Square were collected on 28 January 2010 (summer) and on 07 July 2010 (winter), and data from *Sete de Setembro* Square were collected on 29 January 2010 (summer) and on 08 July 2010 (winter).

Figures 3 to 6 show a temporal series of microclimatic variables measured in both areas studied. The width of the bands representing each field investigation is different because the measurement time is different in each one. Cloud cover values were 5/10 (summer) and 0/10 (winter), for *Liberdade* Square, and 6/10 (summer) and 0/10 (winter), for *Sete de Setembro* Square. Cloudiness data refer to the records of the main weather station of Belo Horizonte operated by the local office of the national meteorological institute (*5º DISME/INMET)* and were recorded at 15h (18UTC), considering local time without corrections for summer time.

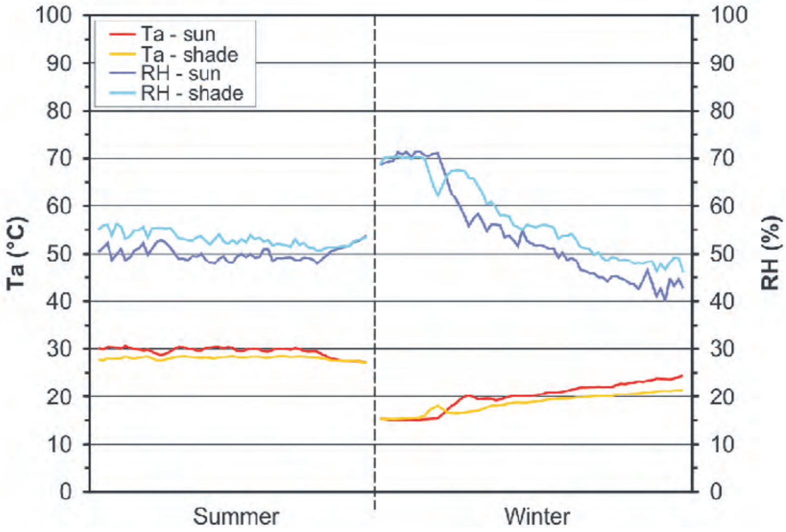

Figure 3: Temporal series of air temperature (Ta) and relative humidity (RH), for summer and winter, measured in the sun and in the shade, at *Liberdade* Square.

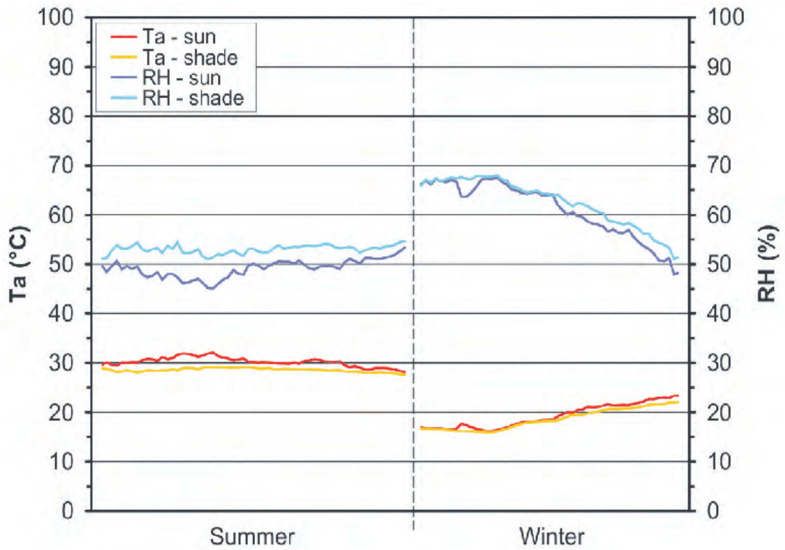

Figure 4: Temporal series of air temperature (Ta) and relative humidity (RH), for summer and winter, measured in the sun and in the shade, at *Sete de Setembro* Square.

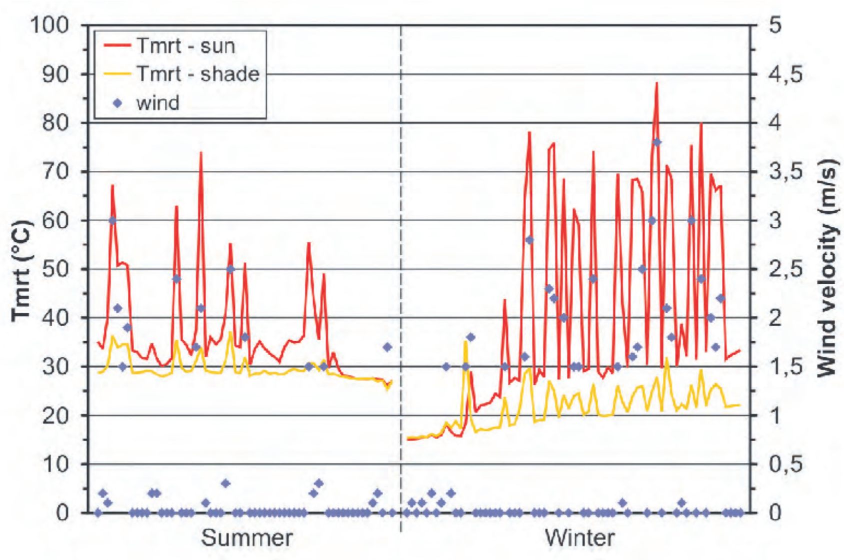

Figure 5: Series of calculated data of mean radiant temperature (Tmrt), for summer and winter, for sun and shade, for *Liberdade* Square.

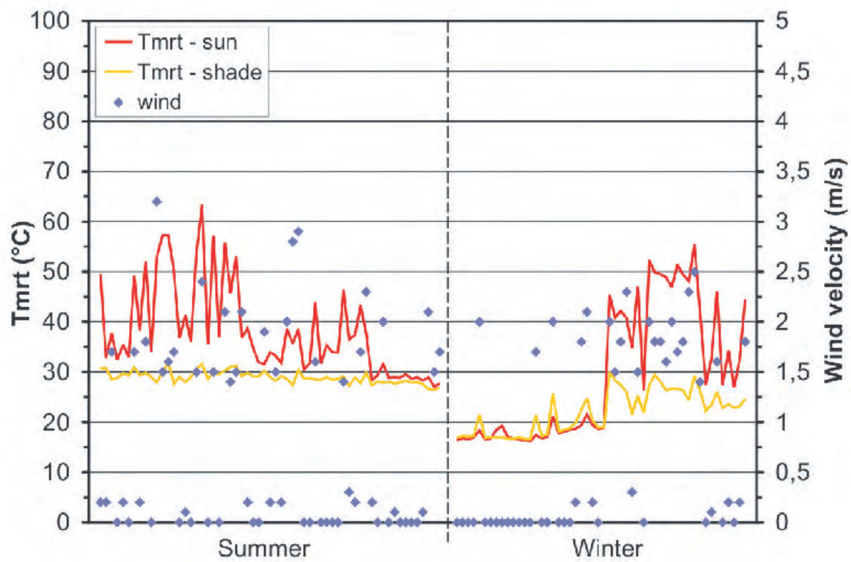

Figure 6: Series of calculated data of mean radiant temperature (Tmrt), for summer and winter, for sun and shade, for *Sete de Setembro* Square.

Figures 7 and 8 show the values calculated for PET index. As it can be observed, the PET values for people who were in the sun presented higher amplitude and greater variability, once the PET values for people who were in the shade were more continuous and with lower amplitude. The discrepant values of PET, close to

35°C or 40°C, were related to subjects who were located in the sun during the interview, which demonstrates the strong influence, on PET, especially, of the high values of mean radiant temperature from the measurements taken in the sun. Field investigation carried out in winter presented the lowest values, while Field investigation carried out in the summer presented the highest ones.

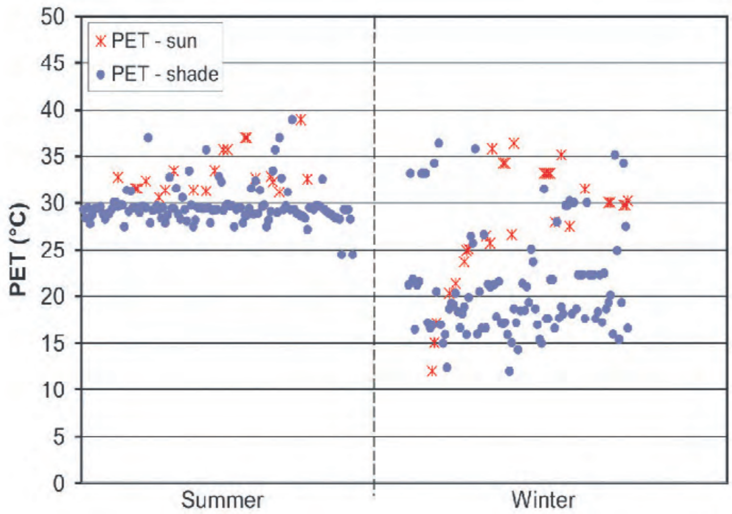

Figure 7: Scatterplot of calculated Physiological Equivalent Temperature – PET (°C) values, for summer and winter, at *Liberdade* Square.

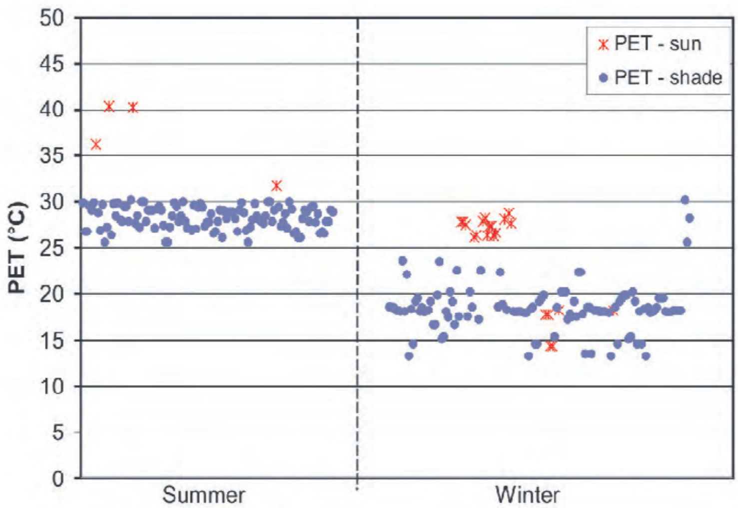

Figure 8: Scatterplot of calculated Physiological Equivalent Temperature – PET (°C) values, for summer and winter, at *Sete de Setembro* Square.

Table 1 and 2 show the descriptive analysis of the microclimatic variables for both studied areas, during the summer and the winter.Microclimatic conditions analyzed in each of the squares are quite similar, but in the summer, *Sete de Setembro* Square presents an average air temperature slightly higher than that achieved in *Liberdade* Square, and also a maximum wind speed slightly higher, with more bursts. The average of the mean radiant temperature measured in the sun was also slightly higher in *Sete de Setembro* Square, which probably contributed to the higher average PET calculated for people who were in the sun, in this square. In the winter, the opposite occurs: both the mean air temperature value and the maximum wind speed value are slightly higher at *Liberdade* Square, which also presents the highest number of bursts.

Table 1: Descriptive analysis of data for summer.

Summer	*Liberdade* Square – 28/01/10			*Sete de Setembro* Square - 29/01/10		
	Max	Med	Min	Max	Med	Min
Ta sun	30,6	29,5	27,2	32,1	30,2	28,1
Ta shade	28,5	28,2	27,2	29,2	28,6	27,6
RH sun	53,8	50,1	47,8	53,5	49,2	45,0
RH shade	56,2	53,2	50,7	54,6	53,0	51,0
Trmt sun	74,2	36,6	26,1	63,4	38,2	27,0
Trmt shade	37,2	29,5	25,4	32,0	28,9	26,4
Wind velocity	3,0	0,8	0,0	3,2	0,9	0,0
PET sun	39,0	33,3	30,6	40,4	37,2	31,8
PET shade	39,0	29,6	24,5	30,2	28,3	25,6

Table 2: Descriptive analysis of data for winter.

Winter	*Liberdade* Square – 07/07/10			*Sete de Setembro* Square – 08/07/10		
	Max	Med	Min	Max	Med	Min
Ta sun	24,4	20,0	15,0	23,3	19,2	16,2
Ta shade	21,4	18,6	15,2	22,0	18,6	15,9
RH sun	71,5	54,4	40,1	67,6	61,0	47,9
RH shade	70,4	57,6	46,0	68,0	62,6	51,1
Trmt sun	88,5	39,5	15,1	55,4	29,3	16,2
Trmt shade	35,4	21,6	15,3	30,1	22,0	16,6
Wind velocity	3,8	0,8	0,0	2,5	0,8	0,0
PET sun	36,4	28,0	12,0	28,8	24,3	14,4
PET shade	36,4	21,2	12,0	23,7	18,2	13,3

The average of the mean radiant temperature measured in the sun was also slightly higher at *Liberdade* Square, which probably contributed to the higher average of PET calculated for people who were in the sun, in this square during the winter.

Figures 9 and 10 show subjects' responses concerning the perception of thermal sensation when they were asked about how they were feeling at the exact moment of the interview. Considering the whole data collected, except for the summer in *Liberdade* Square, the answer "well" predominated. During the summer field investigations there was a high occurrence of the answers "a little hot", "hot" and "very hot", mainly during the field surveys that occurred in *Liberdade* Square. At the field surveys that occurred in the winter, the answers "a little cold", "cold" and very "cold" showed some representation.

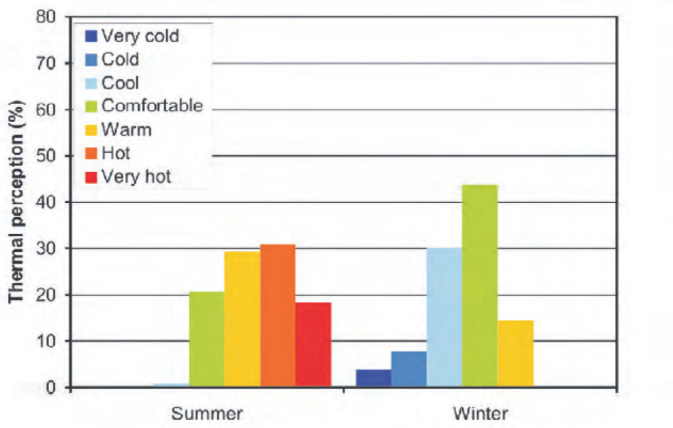

Figure 9: Percentage of interviewees´ answers on the perception of thermal sensation for summer and winter, in *Liberdade* Square. Question: How are you feeling at this exact moment?

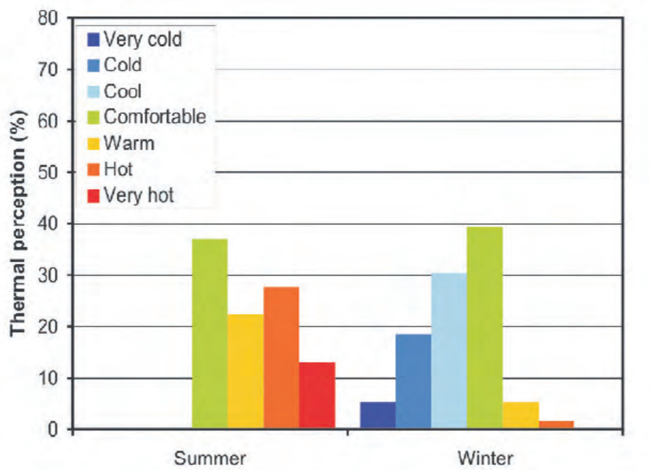

Figure 10: Percentage of interviewees´ answers on the perception of thermal sensation for summer and winter, in *Sete de Setembro* Square. Question: How are you feeling at this exact moment?

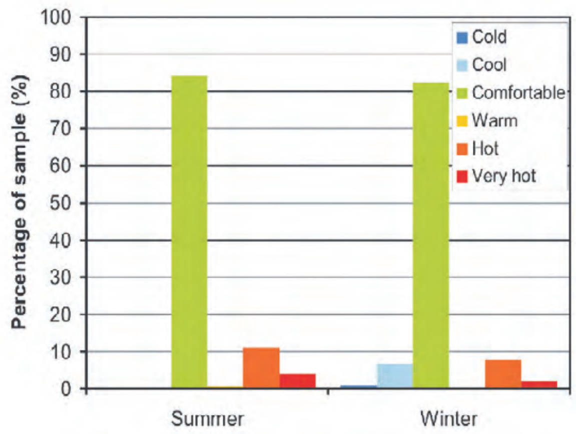

Figure 11: Percentage of PET values calcutated for each person, for summer and winter, in *Liberdade* Square, categorized according to the calibrated ranges of PET defined by Hirashima et al. [3].

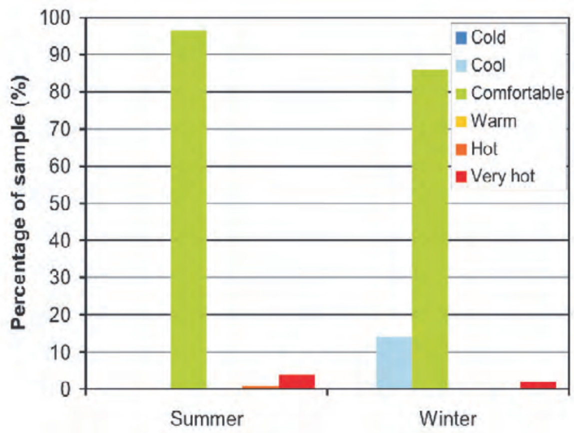

Figure 12: Percentage of PET values calcutated for each person, for summer and winter, in *Sete de Setembro* Square, categorized according to the calibrated ranges of PET defined by Hirashima et al. [3].

The figures shown above express interviewee´s subjective responses concerning their thermal sensations. Objectively, considering the values of PET calculated for each individual, in each area and in each season, and comparing them with the PET calibrated ranges, defined by Hirashima *et al.* [3], the following results, shown in Figures 11 and 12, can be obtained:

It can be noted that, under similar microclimatic conditions, in both contrasting areas studied, regarding the vegetation and permeable areas rates, no significant differences between the pedestrians' perception of thermal comfort of was observed, and even a higher percentage of people within the comfortable range is noticed in *Sete de Setembro* Square, where there is a predominance of areas shaded by buildings, and therefore a smaller number of people exposed to the sun, and in which there was more wind gusts during the period analyzed.

5 Conclusions

This study aimed to analyze the response of pedestrians with respect to their thermal sensations, by comparing their subjective and objective responses raised in an urban environment with low rate of vegetation and low rate of permeable areas, with the responses raised in another urban environment with higher rates of vegetation and higher rates of permeable areas.

Considering that there are no significant differences between the variables air temperature, relative humidity, wind velocity and the mean radiant temperature, the results suggested that there were no significant differences between the perception of thermal sensation in the environments studied, and that in both areas, a similar number of people were comfortable with respect to thermal sensations.

Future studies should aim to quantify the minimum rate of vegetation and permeable areas needed to produce significant effects on pedestrians' thermal perception, as well as the magnitude of these effects and their extent and spatial distribution in urban environments. Future studies should also analyze if other factors such as shading in the area and the presence of wind are more than or as relevant as the presence of vegetation and permeable areas in influencing the perception of pedestrians' thermal sensations and in promoting thermal comfort in urban enclosures.

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Joos de Momper (1564-1635), Winter

Chapter 4: Materials Technology and Construction Techniques

Climate and Constructions
International Conference, October 24-25, 2011, Karlsruhe, Germany
207 – 218 (2011)

Replacement of Cement Clinker by Limestone Powders Improving the Sustainability of Concrete Structures

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Abstract

The cement industry worldwide plays a major role in the emission of the greenhouse gas CO_2. It therefore tries to reduce CO_2 emissions to optimize its ecological balance in the clinker production e. g. by replacing cement clinker by limestone powders. The interaction behaviour of limestone powder during concreting has so far not been investigated systematically but the application of limestone-containing cements exhibits some not explainable and often not repeatable problems. Therefore the presented study tries to identify parameters to optimize the performance of Portland limestone cements by several experimental investigation techniques including chemical, rheological and atomic force microscope investigations. Essentially different types of limestone powders and carrier liquids were analysed in varying combinations. Thereby the scientific findings had to be combined and transferred to a practical application. First results show a high influence potential of the origin of the limestone powder. The type of limestone powder, mainly characterised by its surface parameters, governs the interaction during the first hours of concreting. It could be shown that the differing surface reaction of the limestones play a major role in finding the best performance for the practical application.

1 Introduction

In the Kyoto protocol [1] the international community of states for the first time agreed on common goals and methods of actions to minimize the emission of global warming gases and in doing so protecting the earths climate.

With regard to this goal, the construction industry plays a decisive role. On the one hand, the erection and maintenance of buildings and structures is extremely energy and resource intensive, resulting in a share of approximately 40 % of the natural resources consumption to be attributed to the construction sector [2]. On the other hand, the ongoing climate change results in an increase of weather extremes, thus requiring stronger and more durable building structures, possibly with an increased energy demand and ecological impact during the erection [3]. In contrast to most other industry sectors, the construction industry therefore is faced with two challenges: mitigating its contribution to the climate change while adapting to the changes in climate and weather to be expected in the near future.

The key for combining these two, at first sight contradictory requirements can be found in the materials used for building a structure. Among all construction materials, concrete has an exceptional position with a share of approximately 80 % of the building materials used worldwide [4]. This pre-eminence is mainly due to the formability of the material, its superior durability and mechanical performance and its economic efficiency. However, the production of concrete is afflicted with a pronounced ecological impact [5]. As a consequence, concretes have to be developed, which are characterized by a minimum of energy consumption and emissions in production while providing superior mechanical behaviour and resistance to durability actions. In this context it is central, that the ecological impact of a modification in the concrete is put into relation with the observed changes in the materials performance over the entire lifetime of the structure.

In order to evaluate the ecological impact of a building material, 6 categories can be defined [6]:

- Primary Energy, non renewable (PE.nr), expressed in J/t
- Global Warming Potential (GWP), expressed by the equivalent CO_2 emissions in kg/t,
- Ozone Depletion Potential (ODP), expressed by the equivalent CFC emissions in kg/t,
- Eutrophication Potential (EP), expressed by the equivalent phosphate emissions in kg/t,
- Acidification Potential (AP), expressed by the equivalent SO_2 emissions in kg/t,
- Photochemical Ozone Consumption Potential (POCP), expressed by the equivalent C_2H_4 emissions in kg/t.

As concrete mainly consists of 5 types of raw materials, i.e. aggregates, cement, water, additives and concrete admixtures (listed in the order of magnitude), the overall ecological impact of a certain concrete composition can be calculated as the sum of the share of raw materials used. As can be seen from Table 1, the ecological impact of the cement by far outweighs the impact of all other mix ingredients [5]. In order to improve the ecological balance of concrete, current research activities therefore focus on reducing the ecological impact of the cement itself, on reducing the amount of cement necessary for producing a certain amount of concrete with defined technical properties or on combinations of these approaches.

The high energy demand and ecological impact in the production of cement results from the burning process at temperatures of approx. 1400 °C, at which limestone, silicious and alumoferrous materials are sintered to form cement clinker, i.e. calcium silicates and calcium aluminates. Besides the CO_2 emissions attributed to providing the necessary energy to generate such high temperatures, some 40 % of the total CO_2 emissions in the cement production result from the deacidification of the raw material limestone in this process [5]. Whereas the heating and process energy can be minimized, the CO_2 emissions from the deacidification are process immanent and therefore cannot be reduced, unless the total amount of cement clinker necessary for the production of a certain volume of concrete is reduced.

Before this background, in modern cements up to 20 mass-% of the cement clinker are replaced by finely grinded limestone powder, which due to its low grinding resistance has a very fortunate ecological footprint, see Table 1. At the same time it has to be ensured that the resulting limestone cement provides equal or better performance compared to cements without limestone addition. Hereby the strength reducing effect of the non reactive nature of the limestone is compensated by reducing the water-to-cement-ratio (w/c) and by adding modern concrete additives which ensure an optimal workability at the fresh state. Investigations by Bonavetti et al. [6] further show that the addition of limestone particles to the

Table 1: Ecological footprint of various concrete raw materials [5]

raw material	non-renewable primary energy	GWP	ODP	AP	NP	POCP
	[MJ/t]	[kg/t]	[kg/t]	[kg/t]	[kg/t]	[kg/t]
		CO2-Äq.	R11-Äq.	SO2-Äq.	PO4-Äq.	C2H4-Äq.
CEM I 32.5	5650	951,00	1,64E-05	0,53	3,30E-02	2,20E-03
CEM I 42.5	5750	956,00	1,75E-05	0,56	3,44E-02	2,31E-02
CEM I 52.5	5800	476,00	1,79E-05	0,57	3,50E-02	2,36E-02
limestone powder	350	17,20	5,72E-06	0,12	9,22E-03	8,71E-03
natural sand	22	1,06	2,30E-07	0,01	2,99E-04	2,39E-04
natural gravel	22	1,06	2,30E-07	0,01	2,99E-04	2,39E-04
superplasticizer	28900	106,00	5,70E-05	4,64	4,58E-01	5,23E+01

cement leads to an increased nucleation of hydration products thus accelerating the hydration process.

Within the research project described in this paper, the influence of a cement replacement by limestone powders of high fineness on the fresh and hardened concrete behaviour was investigated. The focus of the investigations was placed on the interaction of different limestone powders with different carrier liquids and the resulting effect both on the macroscopic level (i.e. the rheological behaviour) as well as changes on the surface of the limestone particles. The aim of the project was to derive a relationship between these microscopic and macroscopic effects, thus allowing to improve the concretes performance at very high cement replacement rates.

2 Experimental

Within the experimental investigation programme, a total of 2 cements and 5 limestone powders at different dosages were investigated. The investigational programme consisted of investigations on the influence of the limestone powder type, dosage and type of carrier liquid on the rheological properties of cement suspensions (i.e. suspensions made of cement and limestone powder), on the elution behaviour and chemical reaction of the limestone powder in these suspension, on the zeta-potential of the particles and on changes in the surface properties of the particles. The investigational methods applied in the project will be described elsewhere [8].

In this project a series of different technically used limestone powders as well as a pure calcite as reference material (Iceland spar) were investigated to characterise their behaviour in fresh cement paste. All powders were grinded to a medium grain size d_{50} of approx. 10 µm. As cement being partially replaced by limestone powder a CEM I 42,5 according to Table 2 was used. The results of the experiments with cement limestone mixtures were compared with the rheological investigations of a standard limestone cement CEM II A/LL 32,5. Table 2 shows selected parameters of the investigated materials.

Table 2: Investigated material with fundamental material parameters

Sample	density [g/cm³]	mean particle size (d_{50}) [µm]	grinding fineness [cm²/g]	spec. surface [m²/g]	water demand [Vol.-%]
LSP A	2,725	8,85	5773	6,7	32,200
LSP B	2,717	6,66	6286	6,0	34,962
LSP C	2,714	13,56	3898	0,7	31,901
LSP D	2,722	13,52	2873	0,6	36,014
Iceland spar	2,725	8,92	3163	0,6	28,094
CEM I	3,137	7,14	4949	-	43,250
CEM II/A-LL 32,5	3,054	27,19	4553	-	42,727

As for the carrier liquid three different types of liquids were used:

- de-ionized water at 20 °C
- NaOH/KOH brine (5 g/l) at pH 14
- ion solution extracted from a cement suspension made of CEM I according to Table 2 at w/c = 0.6.

3 Results

Elution tests were carried out in order to investigate the leaching behaviour of pure calcite powder (i.e. Iceland spar) and several technical limestone powders. Herefore, powders with a volume fraction of 5 vol.-%, were continuously stirred in closed PP-bottles at 20° C in 1.6 dm³ of deionised water and NaOH-KOH solution (conc. 5 g/l) with a pH-value of 13, respectively.

All analysed limestone powders (LSP) first showed a very fast dissolution of Ca^{2+} into the liquid phase, followed by a slow but continuing reduction of the Ca^{2+} ions in the solution (see Figure 1). Small recognizable differences in the amount of dissolved Ca^{2+} were observed in all samples. As an extreme sample, LSP A (see Table 2) eluted more than 3 times the amount of Ca^{2+} than the LSP C, the LSP D and the Iceland spar, respectively.

Figure 2 shows the influence of the type of limestone powder in a NaOH-KOH solution on the rheological properties of suspensions made thereof. Comparing all limestone samples, two groups of varying limestone powders were identified. The first group encompasses the powders LSP A and LSP B. The second group is

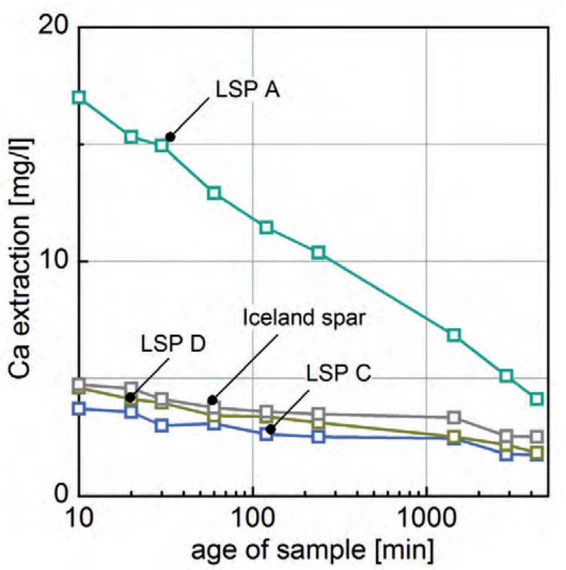

Figure 1: Ca extraction of different limestone powders (LSP A, LSP C, LSP D, Iceland spar) in NaOH-KOH solution at a pH-value of 13 measured over a reaction time of nearly 5 000 min.

marked by LSP C. The groups differ in their flow behaviour, in which the LSP C is more flowable than the powders in group 1 (i.e. LSP A and LSP B). Details regarding the applied measurement techniques can be found in [8]. As can be seen from Figure 3 also the ion content and type of the carrier liquid strongly influence the rheological behaviour of the suspension as they control the surface properties of the particles. The combination of LSP with an ion solution extracted from a cement-suspension leads to a more flowable mixture. In contrast, the combination of LSP with a NaOH-KOH brine reduces the workability of the suspension.

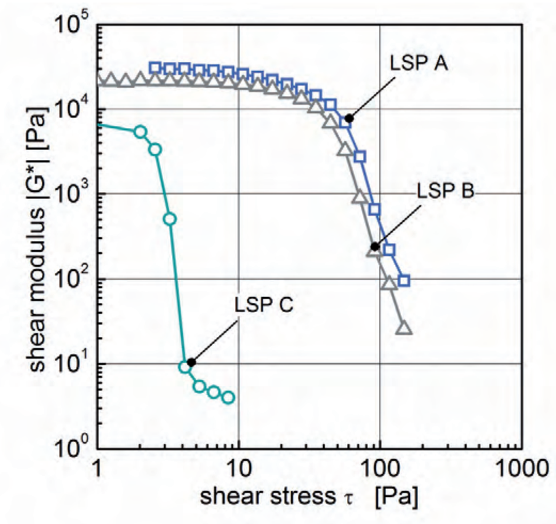

Figure 2: Rheological investigation on three different limestone powders in NaOH-KOH solution a pH-value of 13

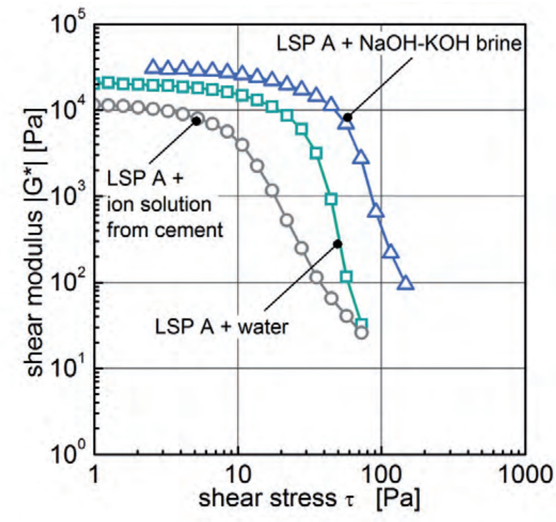

Figure 3: Comparison of the rheological behaviour from LSP A with different carrier liquids

Table 3: Results from the zeta potential measurements by type of limestone and carrier liquid.

Carrier liquid	Zeta potential [10^{-3} V]			
	LSP A	LSP B	LSP D	Iceland spar
de-ionized Water	-40	-40	+15	+17
NaOH-KOH brine	-35	-25	0	./.
ion solution from cement	-8	-9	./.	./.

With the used experimental setup for the rheological investigations it was possible to measure simultaneously the zeta potential of the suspended particles by using electro acoustical methods. The time-averaged results of the measured zeta potentials are given in Table 3.

As can be seen, the same two groups of limestone powders as in the rheological experiments can be distinguished. LSP A und LSP B show in all experimental mixtures a considerable negative zeta potential whereas LSP D and the Iceland spar show contrary positive zeta potential results. It is obvious that the carrier liquid plays an important role in the formation of zeta potential at the particles surface. The ion solution from cement, containing a high concentration of Ca^{2+}-ions leads to a zeta potential near zero. The highest absolute value of the zeta potential can be observed for the samples in de-ionized water, indicating the lack of zeta-potential determining ions to be adsorbed to the particles surface.

The physical changes of the particles surface was studied using AFM-tests. The first series of atomic force microscopic measurements was performed in a dry experimental setup. The samples were previously treated with water or brine as described above. Iceland spar treated with water exposed dissolution process. The comparison of a reference surface and a surface after one day reaction time in water illustrates that the dissolution process mainly occurs on the edges and cleavage faces but also on the whole crystal face (Figure 4).

During further measurements, the calcite surface was observed in-situ during reaction processes in an AFM fluid cell setup. Dissolution processes on the calcite surface could be observed during the whole experiment by a flattening or a levelling of the surface (Figure 5). The leaching reaction starts in general on edges sometimes as edge pit on a crystal face probably on crystallographic disbands, in a scalenoedric form.

4 Conclusions and summary

The increasing replacement of cement clinker by limestone powders strongly enhances the sustainability of concrete structures. However, this beneficial effect is contrasted by problems regarding the workability of the limestone cements at the fresh state.

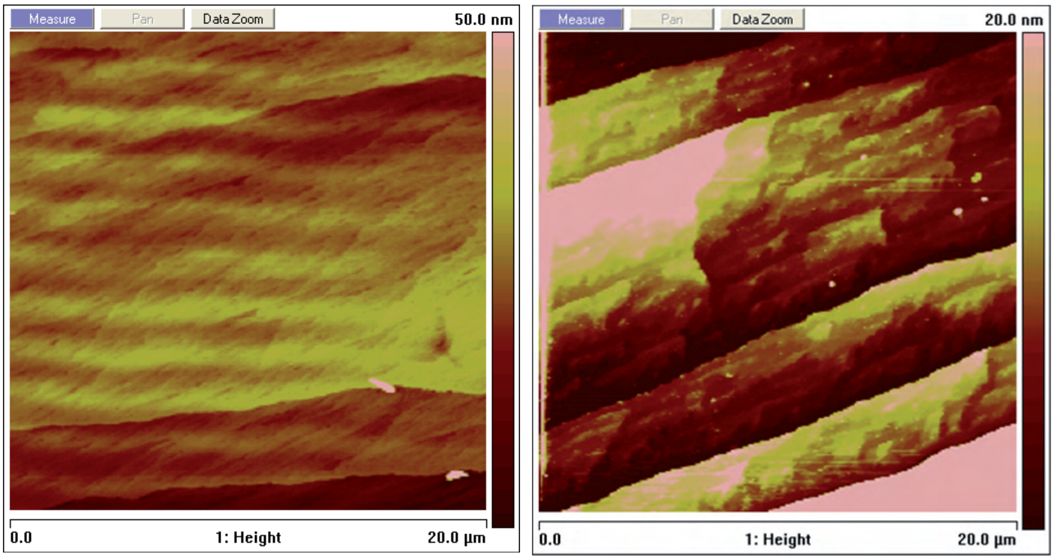

Figure 4: AFM height information: Comparison of Iceland spar surface with non reacted reference (left) and surface after one day reaction time in water (right), 20x20 µm².

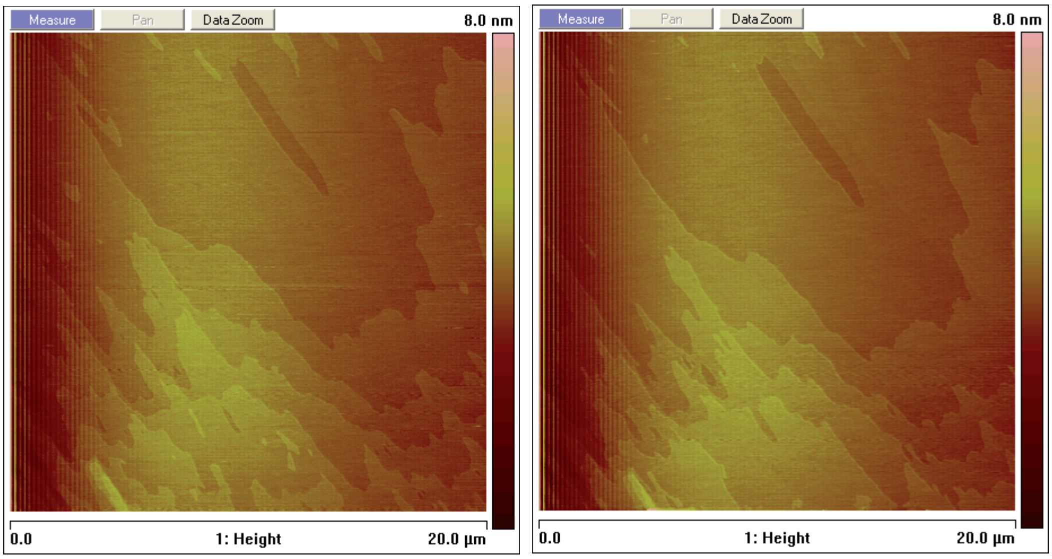

Figure 5: AFM height information: Iceland spar surface reacting in a fluid cell with NaOH-KOH solution and showing growing edge pits in a scalenoedric form (top middle) (reaction time between left and right picture = 3 min).

The presented results indicate that the physical interaction of the limestone particles in a streaming fluid and therefore the rheology of the suspension are strongly affected by dissolution and precipitation processes at the particles surface. According to the results of AFM measurements both processes mainly occur on edges sometimes as edge pit on a crystal face probably on crystallographic disbands in a scalenoedric form. With increasing number of dissolution spots, the velocity of the dissolution into the carrier liquid increases as can be seen in elution tests with different carrier liquids. The results of the zeta-potential measurements indicate that the reactive surface spots (i.e. edges or pits) also strongly influence the formation of the electrical double layer. With decreasing number of edges, the absolute value of the zeta potential is decreased, indicating that the zeta-potential is not only determined by the ion strength of the carrier liquid but also by the available sorption spots on the particle surface (wether vacant or not; see Table 3 from left to right). As predicted by the DLVO Theory [9] also the type of ion solution strongly affects the formation of the zeta potential (see Table 3, from top to bottom). In pure de-ionized water very large absolute values of the zeta potential are observed, indicating that the open surface spots cannot be saturated with ions with opposite charge from the solution. The replacement of de-ionized water with NaOH/KOH-brine leads to a pronounced reduction in the value of the zeta potential. This demonstrates that both Na^+ and K^+ are adsorped to the particle or bound in the electrical double layer and reduce the value of the zeta potential. As a result of the reduced value of zeta potential the shear modulus of the suspension made with NaOH/KOH is significantly higher than for the suspension in de-ionized water.

When replacing NaOH/KOH brine by cement ion solution with a very high content in calcium again a pronounced drop in the value of the zeta potential can be observed (see Table 3, bottom line). Interestingly this does not correlate with an ongoing increase in the shear modulus of suspensions made thereof. From this it can be concluded, that the changes in measured zeta potential are not only a product of the original charge of the particle and the ions adsorbed to the surface, but that the type of ion adsorbed also influences the distance of the zeta shear plane with respect to the particles surface and thus the zeta potential. Further investigations are planed to study this effect more closely.

The results of the shown study indicate that higher replacement rates of cement clinker by limestone powders to improve the sustainability of concrete structures can be applied and that the associated problems in the rheological properties can be controlled. Further research with a focus on the surface reactions of limestone in alkaline solutions and in presence of admixtures should be carried out.

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Impact of Cool Materials on Ambient Temperatures in an Urban Area

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Abstract

The urban heat island is a problem that affects our cities and results in a warmer climate in urban and residential areas compared to surrounding rural areas. One solution involves the use of materials with high solar reflectance and thermal emissivity, the so-called “cool materials”. Usually cool materials are used to *decrease* heat flow entering in a building. Their surface temperatures are much lower than those of typical building materials and if used on an urban scale, they lead to a lower heat exchange between air and surfaces, helping to decrease the air temperature of the urban environment. The paper reports the results of a study carried out on a densely populated area of Rome of about 500.000 m^2. The study was divided into three parts. The first part concerns the numerical analysis of indoor air temperatures of a typical urban flat located both in a rural and in an urban heat island contest. The second one includes measurements of thermal properties of some “cool” asphalts. The third part is focused on a numerical analysis of the urban heat phenomenon through the creation of a model included in a SVAT software that allows to compare the outdoor air temperature of an area before and after a hypothetical use of Cool Materials on external surfaces of buildings and street pavements. The results of this study demonstrated the significant influence of cool materials on the reduction of heat island effect, increasing consequently the thermal comfort of the area.

1 Introduction

The urban heat island is an effect that results in a warmer climate within the urban and residential areas compared to surrounding rural areas. It depends on: anthropic actions (end uses of energy in buildings, transport, industry and associated greenhouse gas emissions); reduction of green and permeable areas (lower evapotranspiration); high solar absorption of materials normally used in urban areas for buildings and paving and phenomena associated to the accumulation and release of thermal energy absorbed [1 - 5]. The rise of the ambient air temperature is the main cause of a number of problems on the urban scale and building scale energy management. These include:

- The increase of energy consumption for cooling demand of buildings;
- The increase of the peak demand for cooling, leading to greater sizes of refrigeration equipment;
- The rising of energy costs;
- The risks for energy supply at peak loads during the summer;
- The reduction of the effectiveness of passive cooling strategies, which could achieve indoor comfort without mechanical air conditioning.

There are several passive cooling techniques to mitigate urban heat island mitigation. In this regard, cool materials are a solution that enjoys an increasing interest. They are characterized by high values both of solar reflectance (ρ_e) and emissivity in the far-infrared range (ε). The first reduces the absorption of solar radiation of building materials, so as to limit the rise in temperature in presence of high solar loads during daylight hours; the second allows to emit the accumulated heat into the sky during the night. Typical construction materials, except metals, generally have a high emissivity but high solar absorption, which causes a significant rise in temperature of the material, above the values of air temperature. A parameter used to express the ability of materials to remain cool under solar radiation is the SRI index (Solar Reflectance Index), calculated in standard conditions as a function of emissivity and solar reflectivity [6]. The concept, therefore, is certainly not new, but new technologies are now available. In particular, by analyzing the reflectance spectrum of cool materials between 300 and 2500 nanometers, its values are much higher with respect to typical building materials in the near infrared band, maintaining the typical value due to color in the visible range [7, 8].

2 Numerical Analysis of the indoor temperature

The simulation software TRNSYS (Transient System Simulation Program) was used to calculate the free-floating indoor air temperature profile in a typical flat, from July 29th to July 31th 2010. The apartment is positioned on the top floor of a building, in order to take into account also the roof slab as a radiant surface. The floor area is 76.4 m^2. The building has windows on three sides: north, south, and west. The entire structure is poorly insulated. The simulation takes as input the

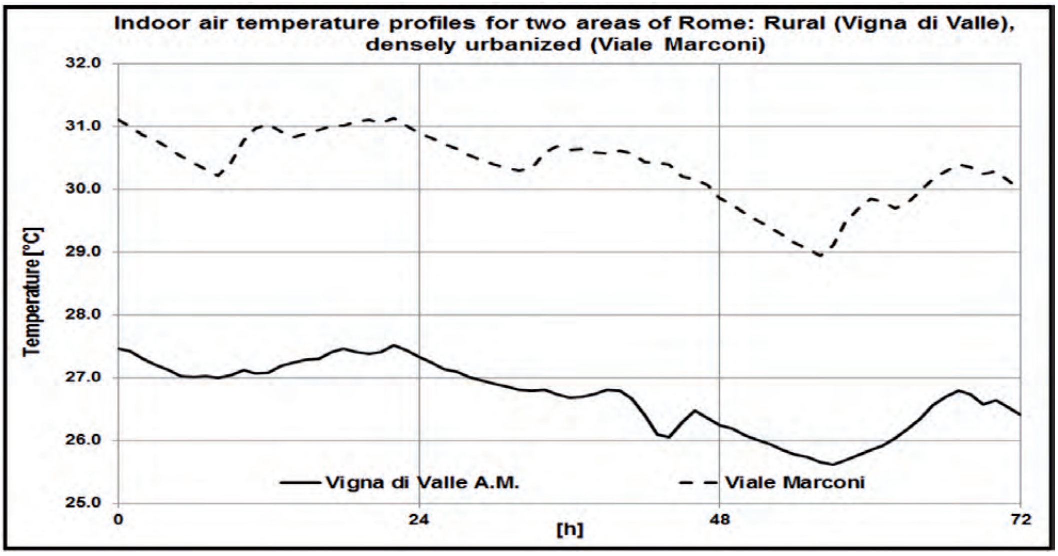

Figure 1: Indoor air temperature profiles for the two specified areas of Rome

temperature and humidity detected in two different areas: a rural area 30 km far from the center of Rome (Vigna di Valle) and a densely urbanized borough of Rome (Viale Marconi).

The results obtained from simulations (Figure 1) show that the internal temperature in the massively urbanized area is constantly 3 °C higher or more, as compared to the one obtained in the same dwelling located in the rural area. This results show that comfort conditions are significantly worse in the first case, with temperatures almost always above 30 °C during the period. A more specific comparative study, which also includes other sites is postponed to further work.

3 Cool Asphalts

The second part of this work concerns the preliminary analysis of the surface properties of some building materials with high solar reflectance. In particular, thermal images were used to evaluate the temperature reached by some asphalt paints under solar radiation. Samples consist of five different color pigments: white, gray, green, red and blue.

The following table shows the maximum and minimum temperature measured on the samples using a thermal image processing software. In it, mean values and the temperature differences compared to the average temperature of the asphalt were also calculated.

All “cool asphalt” samples have a temperature lower than the typical asphalt. Obviously, white sample has the highest temperature difference, but it is important to highlight also the values achieved by green and gray samples, with about 7 °C difference with the asphalt (Table 1). A better evaluation of the performances of

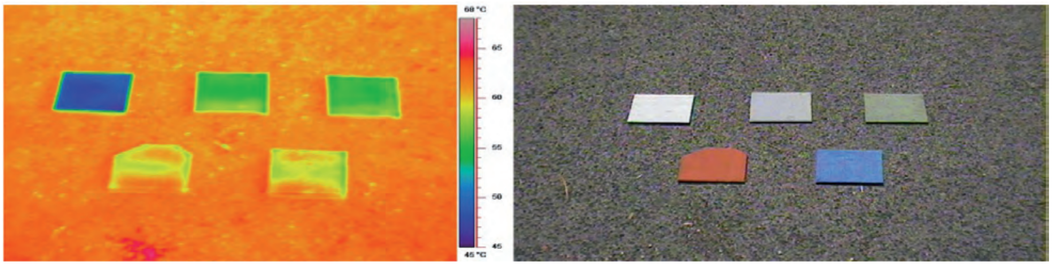

Figure 2: Images of the cool asphalt samples, thermal and visible

Table 1: Measured surface temperatures of the cool asphalt samples

	White	Green	Gray	Red	Blue	Asphalt
T_{min} [°C]	46.6	54.7	54.9	58.6	58.9	-
T_{max} [°C]	48.8	57.8	58.1	62.3	62.0	-
T_{media} [°C]	47.7	56.3	56.5	60.5	60.5	63.5
ΔT [°C]	15.8	7.3	7.0	3.1	3.1	-

these materials would be obtained with measurements of spectral and integrated reflectance by means of a spectrophotometer to estimate the real potential and then make a comparative analysis with measurements of surface temperature. A typical asphalt has a reflectance value of about 10%. From experiments carried out in other works a cool asphalt is over 30% [9]. One aspect still not well investigated is the possible depletion of the surface properties of these products when subjected to seasonal changes and atmospheric agents.

4 Numerical analysis of an urban area

The increase in temperatures in the urban area leads to investigate the ability of cool materials to reduce the temperature profiles in the cities, improving conditions of external thermal comfort and reducing air cooling needs in buildings. Some studies have demonstrated the potentialities of this strategy [10]. The third part of the study presents the results of numerical analysis in which it was evaluated the impact of materials with high sunlight reflection properties on the horizontal distribution of temperatures at neighborhood scale. A densely urbanized central area of ??Rome of approximately 500,000 m^2 was the subject of the study using ENVI-met, a software that uses a deterministic calculating method called S.V.A.T. (Soil, Vegetation, and Atmosphere Transfer). It operates at a level of urban micro-scale and, through thermo-fluid dynamic equations, can simulate the behavior of a three-dimensional climate model. A grid map is analyzed in input. On this grid can be recreated a 3D portion of an urban area, including both distribution and type of vegetation. The purpose of the simulations was the measure of the influence of cool materials on the ambient temperature of the settlement. In this regard,

Table 2: Reflectance values used for the three configurations

Material	Buildings Reflectance [%]		Asphalt Reflectance [%]
	Roof	Vertical Wall	
Not Cool	25	45	13
Cool Low Impact	50	45	25
Cool High Impact	70	60	35

three simulations were performed covering two days of summer to limit the transitory effect, 20th and 21st July 2010, with three different configurations of reflectance for buildings, sidewalks and streets (Table 2).

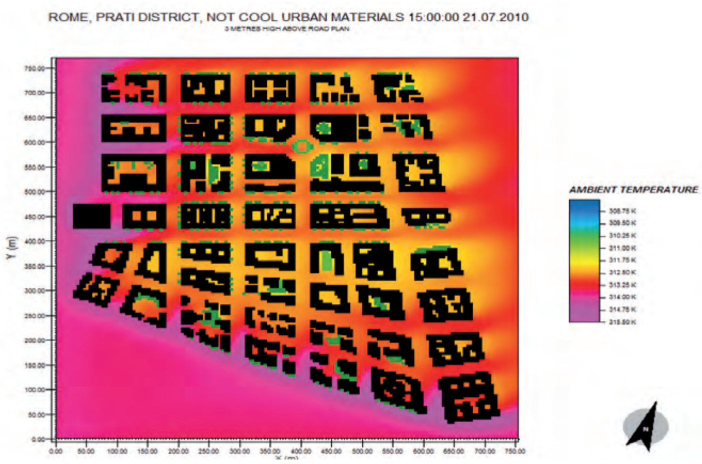

Figure 3: Ambient temperature [K], not cool urban materials 21/07/2010, 3 m high above street

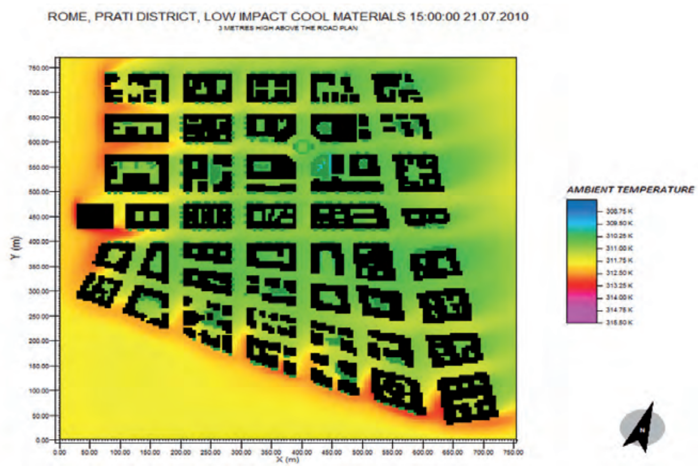

Figure 4: Ambient temperature [K], cool materials low impact 21/07/2010, 3 m high above street levelt

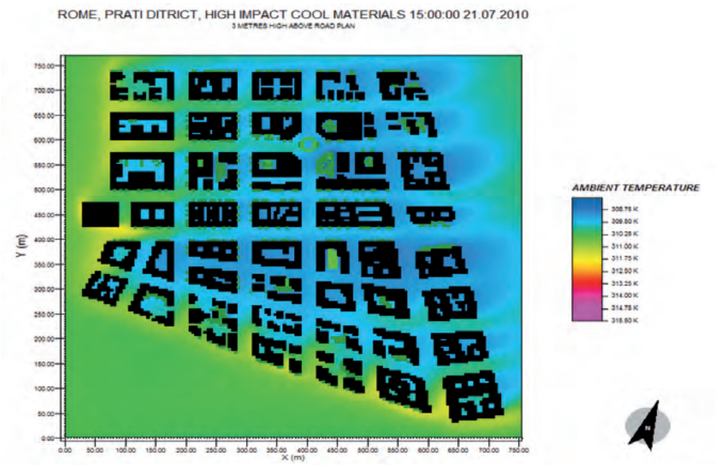

Figure 5: Ambient temperature [K], cool materials high impact 21/07/2010, 3 m high above street levelt

Figure 6: Snapshot of the area of study and receptors positions

The figures above (Figures 3, 4, 5) show, through a color scale of ambient air temperature, as this decreases by an average of about 2°C passing from a situation without cool urban materials to one in which the area was simulated with a low impact application of cool materials. Considering the high impact application of cool materials, the temperature decreases further, with an average difference of

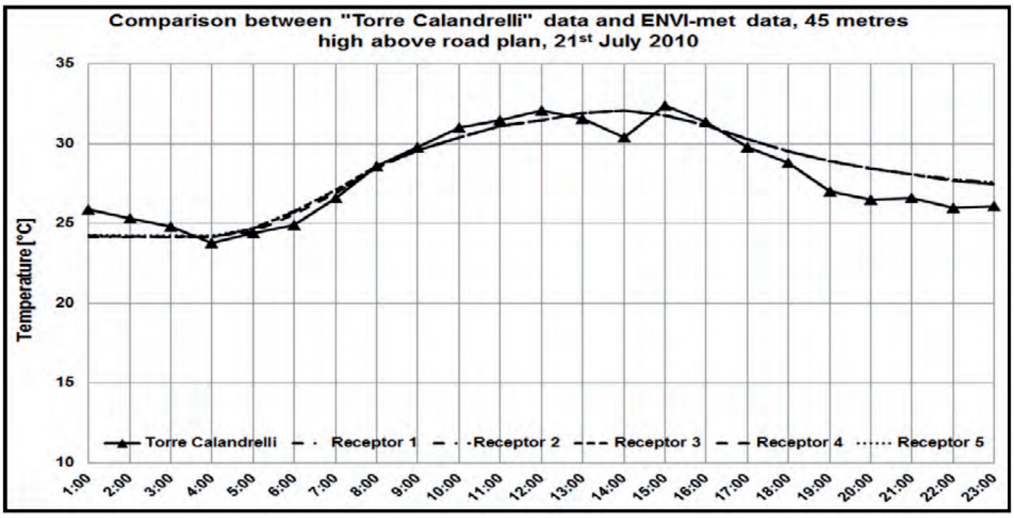

Figure 7: Comparison between ”Torre Calandrelli” data and ENVI-me

3.5 °C. The figures represent a "snapshot" of the area at 15:00 on 21st July 3 meters above ground. Inside the area, five receptors were placed for more accurate monitoring of the outside air temperature for the three configurations (Figure 6).

The positioning of the sensors was chosen in order to evaluate the temperature in an area near zones with vegetation (receptor 1) and areas where vegetation is absent, progressively more distant from that green area (receptors 2, 3, 4, 5).

In order to verify the reliability of the results provided by the simulations, the temperature profile generated by ENVI-met throughout the day (21st July, 2010) at 45 meters in height was compared with the measured values provided by “Meteorological Observatory Torre Calandrelli” [11], also at 45 meters above street level (Figure 7). Although they refer to two different areas of Rome, it makes sense to make a comparison between these values because they are representative of a situation “over the canopy”, above the average height of buildings.

The temperatures detected by the five receptors are almost perfectly superimposed and it depends on the height at which the data were taken (45 meters). In fact, at 45 meters above the ground the effects of mitigation of temperature related to areas with vegetation become completely negligible. Interestingly, the shape of the trend generated by real data (in black continuous line) is very similar to that obtained through simulation, both in terms of form, and in terms of the peaks. This represents a first assessment of the reliability of the results of simulations also considering the fact that they were obtained through the software with values of solar radiation calculated with statistical methods that do not reflect the real sunshine duration in the area under study. At 4.5 meters above the ground, the maximum temperature, calculated in the simulation, occurs at 15:00. The values for receptors 2, 3 and 4 are very similar at any time of day. Receptor 5 shows the high-

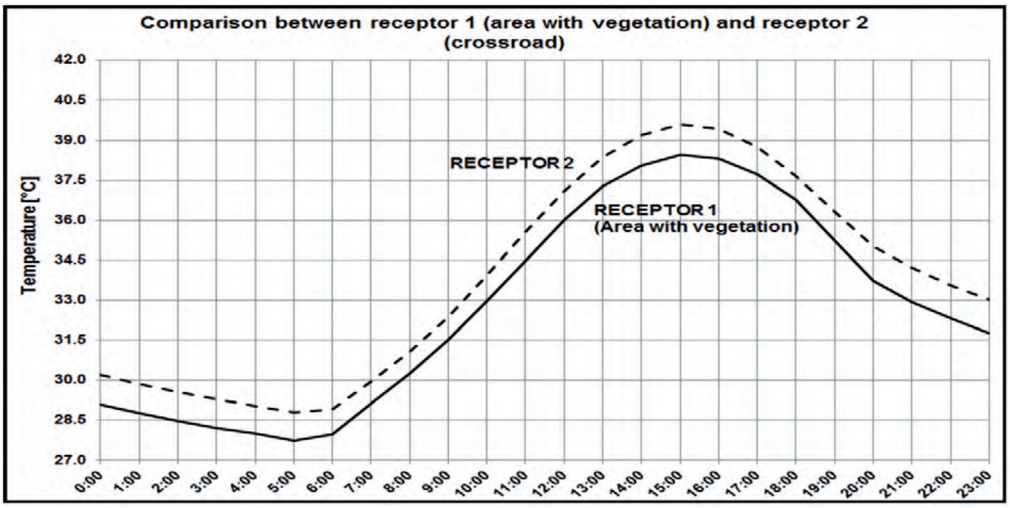

Figure 8: Comparison between receptors 1 (area with vegetations) and 2 (crossroad)

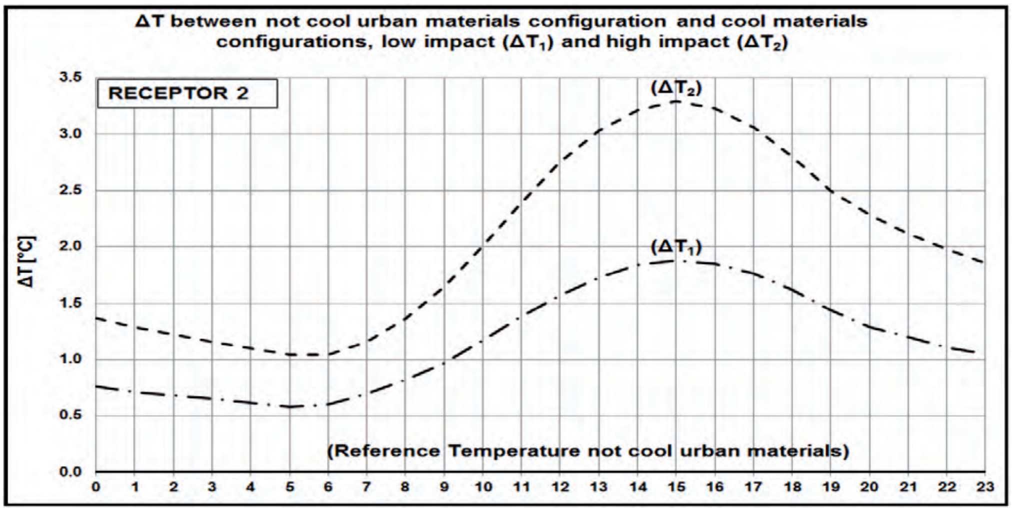

Figure 9: ΔT between not cool urban materials configuration and cool materials configurations, low impact (ΔT_1) and high impact (ΔT_2)

est values of the five. The latter, however, is closer to the edge of the grid and is affected by problems concerning the boundary conditions. The lower temperature of receptor 1 puts in evidence the importance of vegetation as an additional technique for mitigating the temperatures in densely urbanized area. A comparison of the temperature trend of the latter with another receptor, relative to a urban crossroad, is shown in the figure below.

The maximum temperature difference between the not cool material configuration and the one with low impact cool materials is 1.8 °C for the receptor 1 and 1.9 °C for the other receptors. If the not cool configuration is compared to the situation involving the application of high impact cool materials, the difference increases to 3.1 °C for receptor 1, 3.3 °C for receptors 2, 3, 4 and 3.4 °C for receptor 5.

The figure in the next page represents the trends of the temperature differences between the not cool materials configuration with the two applications of cool materials for the receptor 2. By comparing the trends with the reference (in black continuous line) there is a significant increase of ΔT near the middle of the day, with a peak at 15:00. The cool material generate a lower profile of surface temperature reflecting the most of solar radiation and the difference of behavior compared to a normal surface is accentuated during high solar loads. This property is also highlighted by comparing the two trends together. In the lower peak, which occurs at 5:00 am the temperature difference is about 0.5 °C, while during the peak corresponding to the higher solar loads the difference increases to 1.5 °C.

5 Conclusions

The urban heat island effect is a phenomenon that interest significantly urban areas. The results of a simulation, that take in input outdoor temperature data detected in rural and urban areas, demonstrated the presence of this phenomenon in Rome and how this affects indoor temperatures. The studies highlight the potentialities of materials with high solar reflectance and high emissivity in the infrared, the cool materials, in order to mitigate some dangerous aspects relative to global warming. The application in an urban scale of these materials was analyzed by a software simulation S.V.A.T., the ENVI-met. It has allowed to quantify the influence they have on the outside air temperature in a portion of a borough of Rome. The area was equipped with cool materials with two levels of reflectance (low impact and high impact). Altering with the software the surface properties of horizontal and vertical walls of buildings and pavement, it was obtained a decrease in temperature of air of about 2 °C with low impact cool materials and about 3.5 °C with high impact cool materials, improving comfort conditions. The overall cooling of the urban area determines a reduction of demand for air conditioning inside the buildings resulting in lower internal loads. The quantification of energy savings will be dealt with in other studies. Please use references to deepen the individual themes introduced in this work.

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A Study on the Thermal Performance and Construction Method of the Traditional Wooden House with Roof Tiles – Learning from the Nakamura House as Cool Roof Technique in Okinawa, Japan

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Abstract

This study aims to clarify the relationship between the thermal performance and construction method through the analysis of the Nakamura House, which is the traditional wooden house with Ryukyu roof tiles. This house was built about 260 years ago and located at the Ogusuku village, middle and east coast of the main island of Okinawa. This has been preserved as a major cultural asset and the oldest farmer house of Okinawa. In August of 2010, we measured the temperature and humidity of this tiled roof and made detail drawings of it. This roof is composed of only two types of roof tile, which are the semicircle & flat tile. And the form of combination of these roof tiles is so characteristic that the width of the flat tile (equal to length between semicircle tiles) is narrow and height of the semicircle tile is deep to give the roof shade and lower the surface temperature of this roof. This tiled roof is fixed by the plaster including the coral above the clay layer and thin bamboos as a substitute for a sheathing roof board because of the high humidity. Also, this house has many vents near the main ridge and several devices of detail construction at the eaves and ceiling to flow the air between the attic and rooms as much as possible. Thus, this roof is made of the local materials and more porous than today's roof. As a result, the temperature and humidity of this house are equal to the outside air. This data indicates this house has high performance of ventilation.

1 Purpose and background of this study

Nakamura house, a major cultural asset designated by the national government, is the oldest traditional wooden house in Okinawa built in the middle of the 18th century. It is located inside the world heritage buffer zone of Nakagusuku castle, and Ogusuku village [1]. After World War 2, Okinawa was influenced by United State of America, recently when people own their house, they mostly build them by not wood, but reinforce concrete structure. And then, Nakamura house is very important example house in accordance with regional climate, hot and high humidity without air-conditioner. There are two purposes of this study. Firstly, we are looking for the device of improving the thermal performance and protect the high temperature and humidity in case of the tiled roof, and measured them and draw the detail design of the house, especially its roof. We believe the roof has the devices for the thermal performance because usually Japanese traditional wooden houses as well as Nakamura house has few wall so as to get the comfortable breeze. In other words, these are mainly composed of column and roof without wall. We think we should research the traditional and regional house in Asia from the viewpoint of not only history and culture, but also the high technology of thermal performance. Secondary, we measured the temperature of the roof, underneath the roof and the attic. Through this survey, we will understand how to decrease the temperature from the surface of the roof tile to the attic, the relationship between the roof tile and construction method, and detail design from the viewpoint of the thermal performance. So, the method of this study is unique, and combined with the analysis of the historical design and material, and the environmental technology.

2 The characteristics of the Nakamura house

2.1 Site plan and space constitution

Originally this site is gentle hillside and opens to the south. The site of Nakamura house is surrounded by limestone wall and Fukugi trees. This is composed of four buildings, which are main house, guesthouse, storage and barn. They are hip tiled roofs. Main house connected the guesthouse by the veranda and both are faced to the court made of limestone through the entrance. These houses are located below the original ground level because of the protection of the storm from the sea with the limestone wall and Fukugi trees.

2.2 The characteristics of tiled roof

Roof tile in Okinawa (we call Ryukyu roof tile in this paper) has only two types as its shape. One is semicircle type people call man-roof tile, and the other is flat type people call woman-roof tile. Compared with the typical tiled roof of Japan mainland, there are two differences. One is that Ryukyu tiled roof has no ornament tile, and the other is that Ryukyu roof tile is not smoked, but biscuit one like terra cotta. In Ryukyu tiled roof, main ridge, corner ridge, eaves and trough are all composed

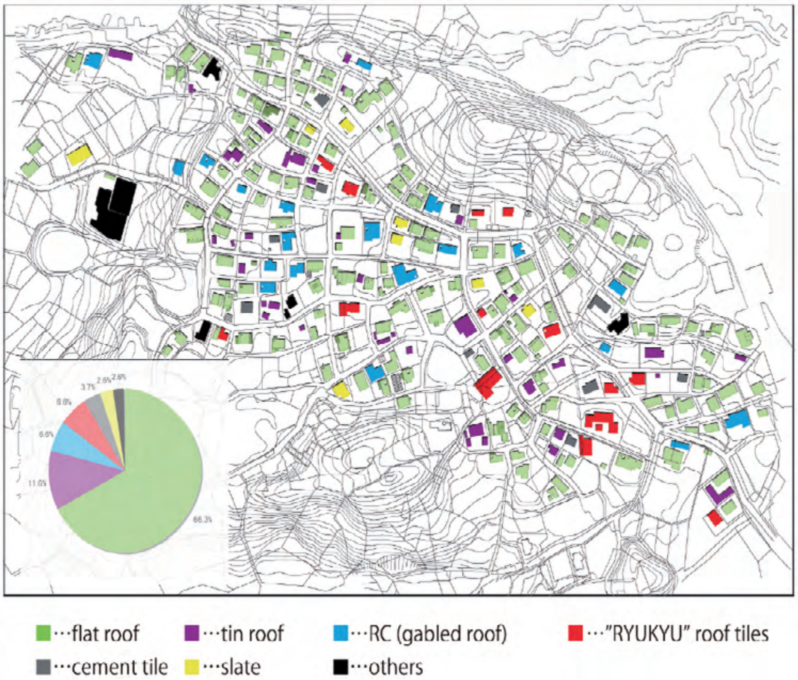

Figure 1: The classification of the roof in Ogusuku by material

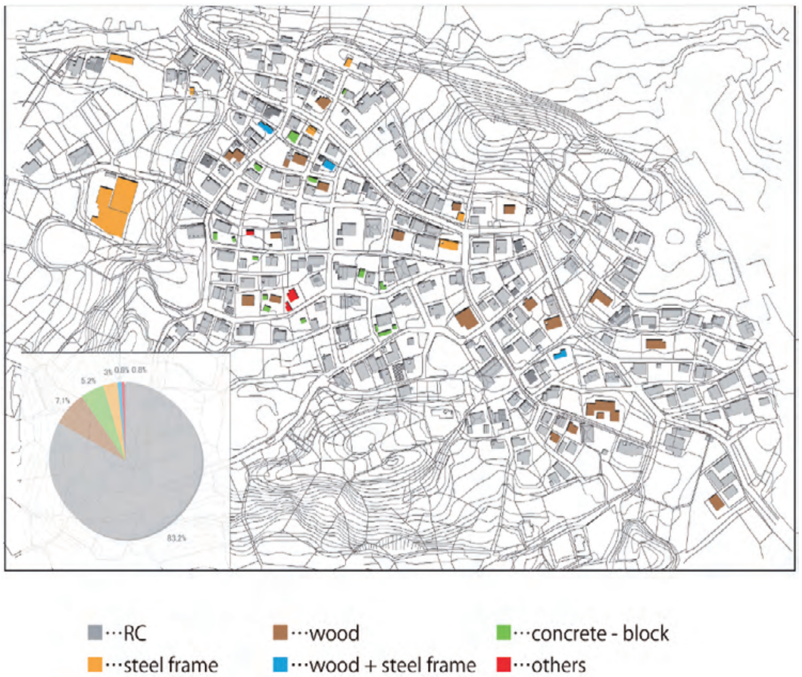

Figure 2: The classification of the roof in Ogusuku by the structure

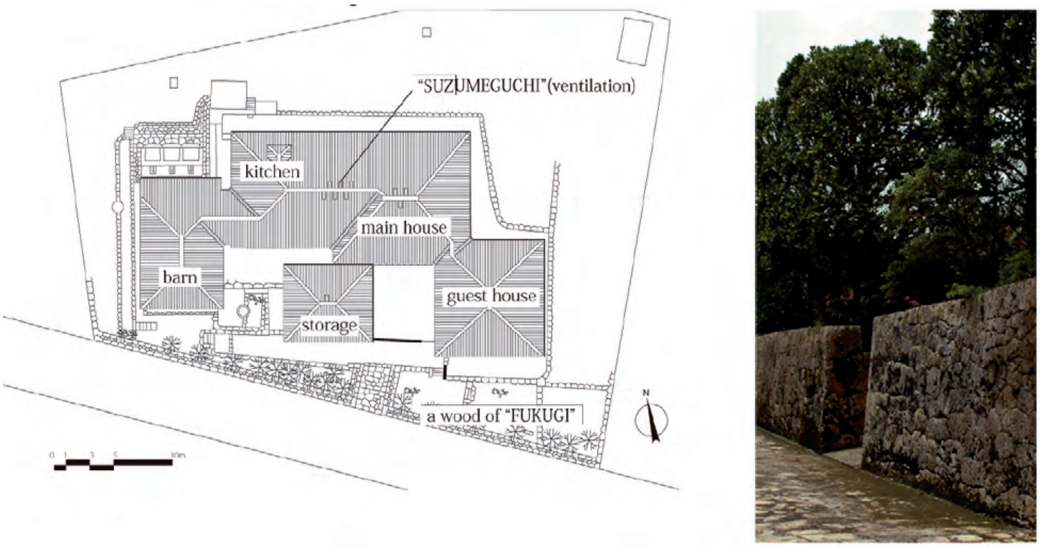

Figure 3: The roof plan of Nakamura house (right: *picture 1 the limestone wall and Fukugi tree*)

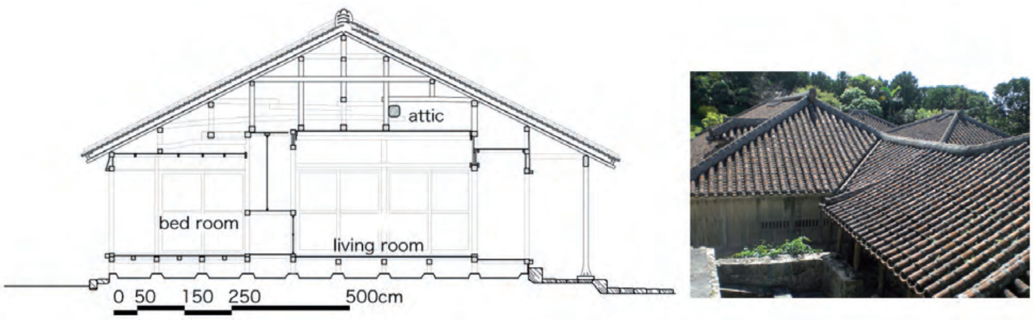

Figure 4: The section of the main house (right: *picture 2 Nakamura house Fukugi tree*)

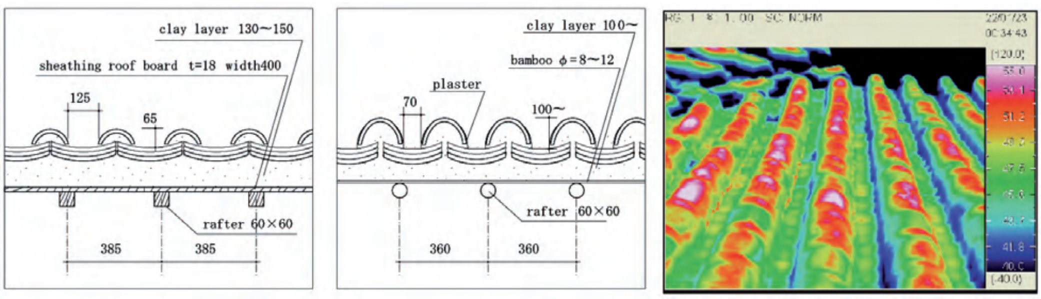

Figure 5: Comparison between Osaka (left) and Okinawa (right) (right: *picture 3 temperature of the roof*)

of only two types of tiles. And then, Japan mainland has same shape of Ryukyu tiled roof, but shape of tile and width between every semicircle tile are different. Ryukyu semicircle tile is higher and width is narrower than mainland's one in order to make a shade and improve the thermal performance rather than the tiled roof of Japan mainland.

2.3 Construction method

Ryukyu tiled roof is fixed by the plaster made of coral. The plaster is usually repainted every eight years. Originally material of the plaster had been made by the dead coral in Okinawa. People reuse the dead coral and we call this process as the sustainability. But nowadays this reuse has been prohibited by the government to carry out the conservation of nature. The clay layer including the coral is 10~20 centimeters in thickness and used as an insulation and a waterproof material under the tiled roof. And Ryukyu bamboo which is about 10 ? in thickness and

Table 1: Comparison of the pattern of the semicircle and flat roof tile between several houses in Japan

area	house name	type of roof tile	working length (flat tile)	thickness of clay layer under the flat tile	clay layer element under the semicircle tile	working width (flat tile)	working hight (semicircle tile)
OKINAWA	NAKAMURA HOUSE	RYUKYU	120	200	CLAY(mixed with sand)	70	100
	TAKARA HOUSE	RYUKYU	—	—	CLAY	>100	100
CYUGOKU	OHASHI HOUSE	—	120	—	—	120<	65
	OTAKE HOUSE	—	120	—	—	120<	65
SHIKOKU	TANAKAKE HOUSE	—	120	100	CLAY	120<	65
	KOHIGA HOUSE	—	110	—	CLAY	120<	65
KINKI	KONISHI HOUSE	SENSYU	120	150	CLAY	125	65
	OKU HOUSE	—	120	?	PLASTER	120<	65
	TAKAGI HOUSE	—	110	40	CLAY(without stickiness)	120<	65
TOUKAI	NAKAMURA HOUSE	—	120	—	—	120<	65

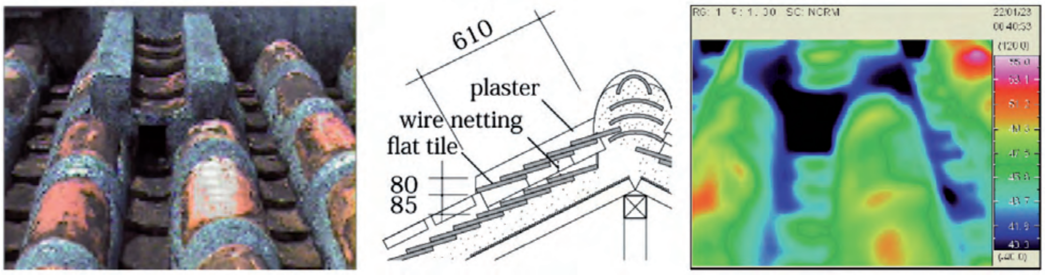

Figure 6: The detail of the vent (left: *picture 4 the vent (Suzumeguchi)* and right: *picture 5 temperature of the vent*)

harvested in Okinawa is lay out under the clay layer instead of the sheathing roof board. Because it is difficult to get the timber in Okinawa and plywood cannot be used as the sheathing roof board influenced by high humidity.

3 The detail design and devices for porous roof and architecture

3.1 Vents(Suzumeguchi) near the main ridge

Main house has totally 9 vents near the main ridge face to the north and south. The south side of the main ridge has 4 vents and the north side has 5 ones alternately. The roof tile craftsman usually calls it as “Suzumeguchi “(Picture 4). Originally semicircle tile put on the flat tile, but the way of making the vent is reverse of this composition of two types of tiles, in other words, flat tile put on the two semicircle tiles in order to flow the air between the roof and the attic. We measured the temperature of this vent by the thermography camera, Picture 5 indicates that the temperature of the vent and around it is extremely lower than the surface of the roof (Figure 7, Picture 6).

3.2 The detail of eaves

Rafters of eaves are not block, but log 60 ? in thickness. And Ryukyu bamboo is used at the front of the house in a row instead of the sheathing roof board except for the guest house. Therefore this house has an opening in the every eaves and the air can flow between the inside and outside, or the alcove and the attic easily. (Figure 7, Picture 7)

3.3 The kitchen and the attics

There is a void over the kitchen. This void connected the attic. Therefore the ceiling is not completely separated between the attic and rooms contrastive to the typical house of today in Japan. The smoke from the kitchen contributed to maintain the attic and the bamboo.

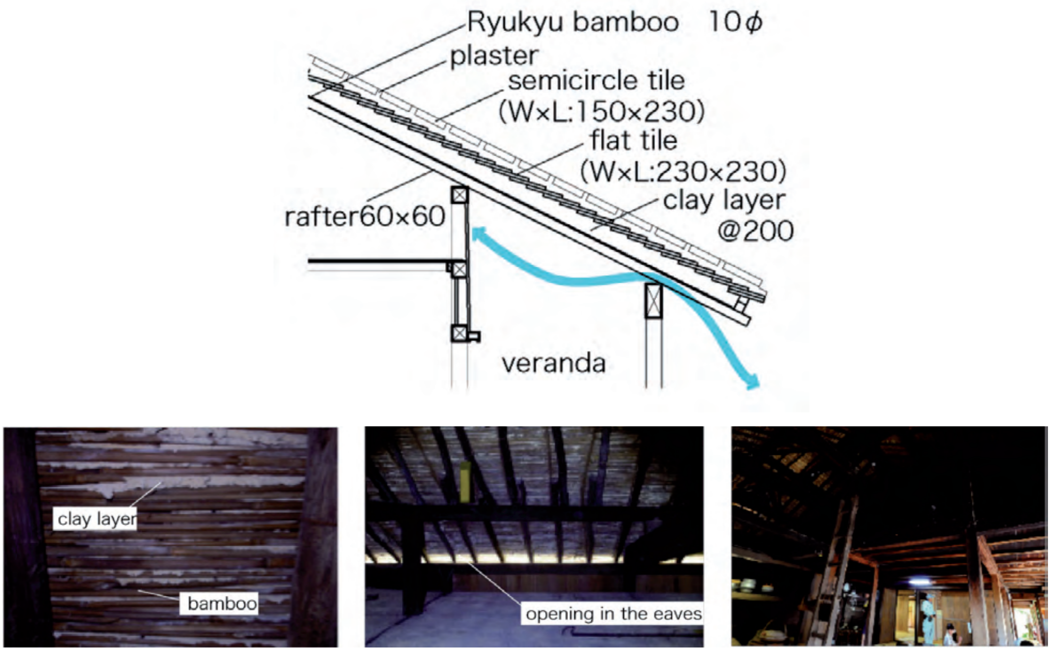

Figure 7: top: the detail of eaves
left: *Picture 6 clay layer and bamboo*, middle: *Picture 7 the eaves* and right: *Picture 8 the void over the kitchen*

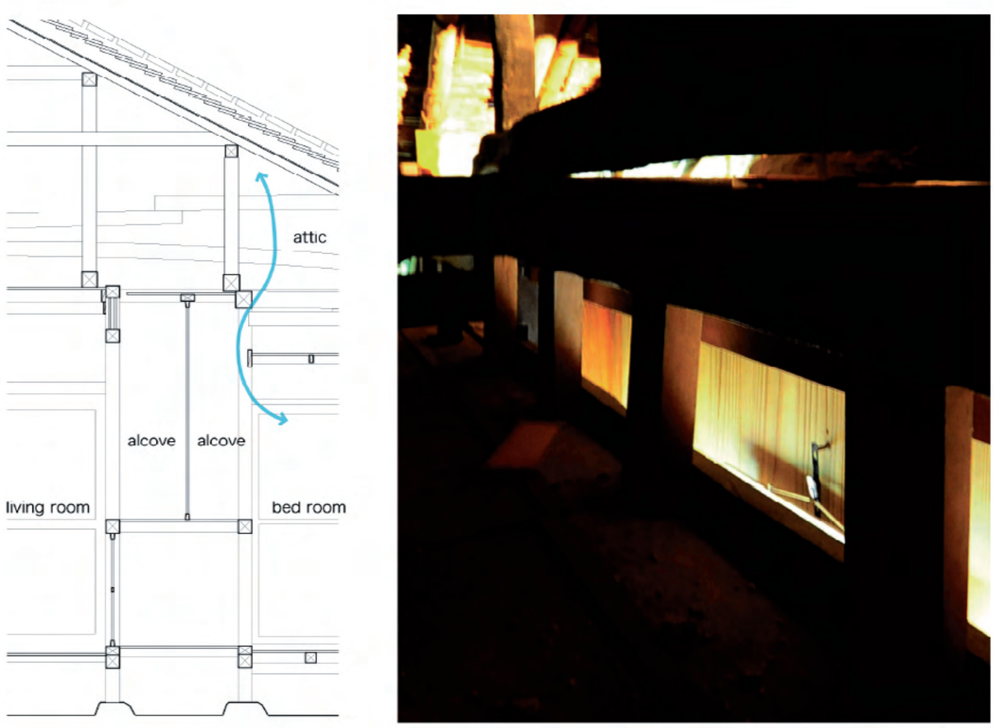

Figure 8: The detail of the bed room, right: *picture 9 the ceiling of the bed room*

3.4 The ceiling of the bedroom

The plan of the main house divides living room into the private room by the wall including the family altar and alcove. This is the typical and traditional plan in Okinawa. The private room mainly is used as the bedroom, so the ceiling height is lower than the salon as the living room. The air can be flowed through the alcove of the private room according to making use of this difference of the ceiling height (Figure 8).

4 The thermal performance of Nakamura house

4.1 The method of measurement

We used “ONDOTORI” as a measure (T & D corporation RTR-52, RTR-53 and temperature sensor: Thermistor and humidity sensor: The platinum resistor) and took measurements every 5 minutes. The globe thermometer is 150mm in diameter. And we measured the climate around Nakamura house, that is temperature, humidity, rainfall, solar irradiation, wind direction, average wind speed, the maximum instantaneous wind speed and air pressure every 10 minutes by the weather bucket.

4.2 Analysis result of temperature

We measured at Nakamura house from August 11th to September 4th (25 days), and at Kiyu house from September 1st to 4th (4 days). We analyzed the thermal performance of Nakamura house compared with Kiyu house of the cement-tiled roof. We indicated the analysis result on September 2nd when it was fine and dry day. Figure 10 shows the comparison of temperature between Nakamura and Kiyu house. The temperature of Nakamura house was almost same degrees and graph of outside air temperature, but the maximum temperature of Kiyu house was beyond 40 degrees. We speculate the difference of temperature reflects the difference of ventilation. There was the reason why Nakamura house has vents on the main ridge & surroundings of eaves and void of the ceiling, but Kiyu house has no vent at the attic. [2 - 4]

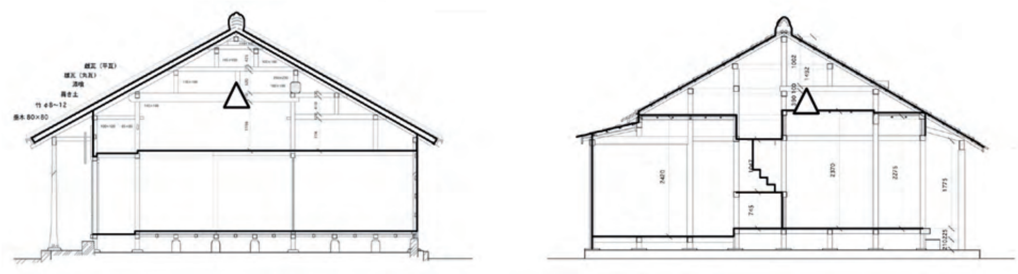

Figure 9: The location of “ONDOTORI” in Nakamura house (left) and Kiyu house (right)

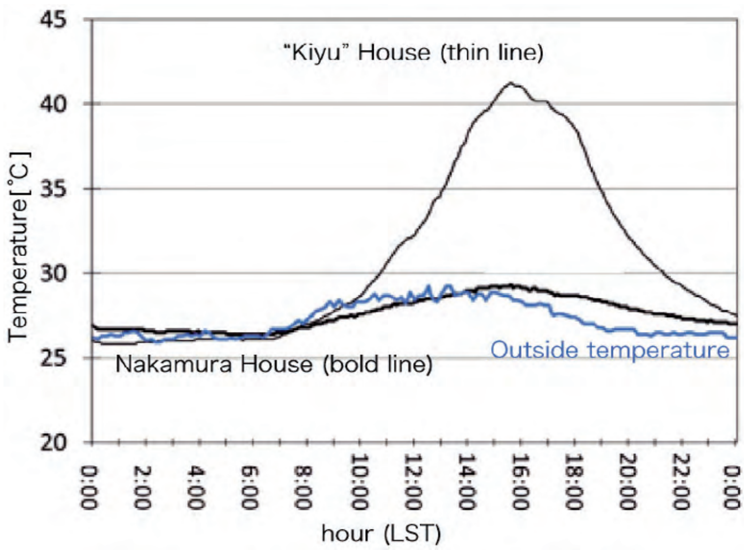

Figure 10: Comparison of the temperature between the attic of Nakamura house and Kiyu

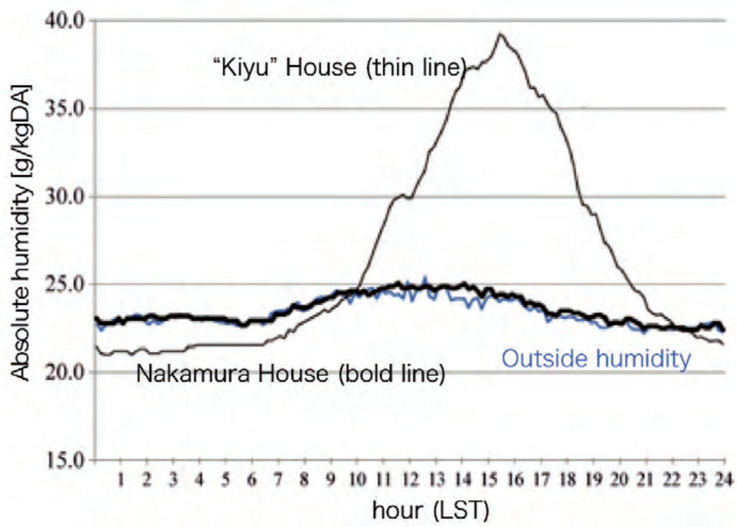

Figure 11: Comparison of the temperature between the attic of Nakamura house and Kiyu house

4.3 Analysis result of humidity

Figure 11 shows the comparison of humidity between Nakamura house and Kiyu house. (we calculated absolute humidity based on the outside air temperature and relative humidity) the absolute humidity of Kiyu house rose greatly at 10 to 22 hours. On the other hand, the absolute humidity of the attic in Nakamura house was almost equal to its outside air humidity. There is a big difference with Nakamura house because water vapor content increased in proportion to rise in temperature at Kiyu house. We think the reason why it is enough to ventilate the attic of Nakamura house whole day and the clay has the performance of moisture absorption, but Kiyu house has no clay layer and vent, the attic of Kiyu house stored the humidity as liquid phase.

5 Conclusions and Suggestions

5.1 Conclusions

1. We often feel comfortable when we sit under a tree. Through this study, it makes clear that the traditional Ryukyu tiled roof had been built to be porous as a metaphor of the shade of a big tree.
2. The traditional Ryukyu roof tile only can make the vent of Nakamura house easily and Japan mainland never has this type of the vent(Suzumeguchi) on the tiled roof. We can speculate that this vent has an ability to not only improve the thermal performance of the tiled roof, but also control the high humidity of the house, especially the attic influenced by the regional climate in Okinawa.
3. It is characteristic that the beautiful Ryukyu tiled roof is composed of the semicircle and flat tile only and the plaster, which fixes the roof, tile overlays painting about every eight years. As a result, the width between two semicircle tiles of Ryukyu tiled roof becomes narrower and deeper like the pleats. Therefore, it makes a larger shade of the porous roof with the bamboo and the clay including the coral of regional materials.
4. The temperature and absolute humidity of the attic in Nakamura house was almost equal to the outside air because we speculate it has a lot of vents and its clay layer and the bamboo has the high performance of moisture absorption.
5. We should measure how the clay layer including the coral has the performance of the moisture absorption with the insulation. And the humidity in Okinawa was too high that we failed in the measurement of its humidity. So we must reconsider the way of accurate measurement of the humidity.

5.2 Suggestions

When we interviewed the owner of Nakamura house, we were impressed how his grandfather lived in it. He always moved to the comfortable space in the house time by time. We should not only develop the architectural technique, but also have second thought about our life style because we often never move with the remote control. And through the analysis of the traditional and vernacular house, we think it will be important how we mix the digital with bricorage as the handmade work.

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Sustainable Construction in the Middle East Case Study: United Arab Emirates

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Abstract

With the wealth derived from the discovery of oil comparatively huge artificial cities in the Middle East arose within only a few decades, braking with Islamic traditions of urban planning and ignoring the desert environment. As a consequence of this development several countries of the Middle East, like the UAE, Qatar, Bahrain and Kuwait are within the top ten list of countries with the largest ecological footprint per capita in the world. In the UAE, since the global economic crisis hit the region the term sustainability is seen as the remedy for problems derived from short-termed economical decisions during the boom time. The necessity to think and act ecologically and the discussion about the rising loss of identity led the governments of the UAE increasingly support environmental organizations and awareness campaigns, and started to work intensively on new sustainable building codes. Abu Dhabi launched their Pearl Ratings System for Estidama in 2010, Dubai introduced their Green Building regulations in January 2011. While Dubai focuses on Construction regulations to protect the environment, Abu Dhabi's Estidama is linked to the new concept of integrated design process, encouraging design coordination of professionals at the early stages of the project. The design guidelines are responsive to culture and to the unique harsh climate, focusing in the first place on passive design techniques, rather than on fancy technologies.A number of "green building construction" examples have been recently planned and built in the UAE, which have the potential to serve as models for the region. It shows that the UAE are on the right track, but in the first place awareness, education, responsible design techniques and quality control during and after construction have to pave the way for sustainable construction as a standard.

1 Climate and retrospection of urban development until today

1.1 United Arab Emirates Climate

The climate in the United Arab Emirates is sub-tropical and arid. The line of the Tropic of Cancer crosses through the UAE. During summer months (May to October) the weather is extremely hot and humid. The temperature average is above 40 degrees up to 50 degrees Celsius, humidity is about 90% near the cost. Even the sea temperature reaches 37 °C. In winter (November to April) the average daytime temperature is around 25 degrees Celsius in coastal areas. Humidity is less during winter months with an average of 50-60% in coastal areas and less humid inland. Rainfall usually occurs infrequently between November and March. On average, it rains only 120mm a year. The UAE records 8 sunshine hours per day in January and 11.5 in June. The Shamal brings sandstorms occasionally. [1]

1.2 Middle Eastern traditional Islamic Urban System

The Islamic traditional oasis town was generally dominated by a strong segregation of public and private life, in which the area of private housing occupied the most land. The mosque and the Sheikhs palace usually dominated the center of the settlement. The souqs (markets), which were the only other public spaces despite the mosque in the town consisted of small shops lined on narrow main roads. The width of these main roads had to be at least the width of two packed camels. The roads did not follow any plan or grid, moreover the direction of the lines developed over time in accordance with how buildings were erected and the spaces left over. [2] The knowledge about Building technologies had been passed on from one generation to another. Building rules and regulations have been based on Islamic traditions and were dictated by the desert climate. Buildings had been constructed from regional building materials available like stone, coral and shell stone, bricks, adobe, palm trunks and fronds. The settlements were usually built on infertile land surrounded by a protective wall.

Smaller winding alleys, with a minimum width of at least one packed camel led from the main roads to the private homes. The vernacular courtyard house was the common building type for private houses. It had an inner open-air court to which most of the windows and doors were oriented. The exterior walls of the building block remained mainly closed especially in the ground floor. Small windows served mainly ventilation purposes. The courtyard and roof-tops provided important living space for the families and ensured privacy especially for female family members. [3]

This building type allowed a close narrowness of buildings by respecting the privacy of the users at the same time. The narrowness created shading, protecting the alleys and neighboring buildings from direct sunlight, reduced heat gains through high thermal mass, and used prevailing winds for ventilation. The mainly closed exterior walls protected the inhabitants from sandstorms as well.

The use of wind-towers, a prominent feature of traditional architecture in the UAE provided ventilation and passive cooling by capturing winds above the roof and directing it through narrow shafts into the interior spaces of the building.

Consequently the vernacular oasis-towns had been built in close dependency to the desert climate and the Islamic culture and is therefore serving as a good example for a sustainable urban development.

1.3 Urban development after the discovery of oil

With the wealth derived from the discovery of oil comparatively huge artificial cities in the Middle East arose within only a few decades, braking with Islamic traditions of urban planning and ignoring the desert environment. Antithetical to traditional towns, the cities arose after the discovery of oil had become among the most unecological cities in the world due to their enormous energy consumption per capita. The new buildings had been build state of the art, but using highly unsustainable building materials like none or not sufficient insulated concrete skeleton structures with large glass openings and with no reference to the desert climate. These buildings have an extremely high dependency on air-conditioning.

During the real estate boom especially in Dubai, projects have been resold several times before they even were built. Most buildings were planned and built by developers focusing solely on reducing initial building costs rather than ensuring quality or considering maintenance and operating costs of these projects, which usually the final user (owner or tenant) has to bear. In the absence of any green building regulations purely commercial decisions paved the way to unsustainable design practices.

The water in UAE is scarce and the country is highly depending on desalinating seawater, which is a high energy consuming technique on the one hand. On the other hand water is wasted for watering lawns, cleaning pavements and cars. Water and energy is subsidized by the government, which is not really an incentive in using these resources cautiously. It is estimated that the emirate of Abu Dhabi uses more than half of its domestic energy use in desalination. [4] As a consequence of this development several countries of the Middle East, like the UAE, Qatar, Bahrain and Kuwait are within the top ten list of countries with the largest ecological footprint per capita in the world. UAE's carbon footprint counts at about 32 tons per person per year. Qatar is around 50 tons per person per year, the US is around 20 tons, and the UK is down to around 8 tons per person per year [5]. In the Middle East a correlation of major oil exporting countries and their very high carbon emissions per capita such as mentioned above Qatar, Kuwait, UAE and Bahrain as well as Saudi Arabia, Oman and Libya can be clearly distinguished to countries with less oil-resources and their comparatively low carbon emissions per capita such as Algeria, Jordan, Syria, Iraq, Lebanon, Tunisia, Egypt, Morocco, Yemen and Palestine. [6]

The energy waste also interrelates to the common urban sprawl of the post-oil-cities. The waste of area and the functional division of housing, working, and supply areas, results in a high dependency on the car. A constant decrease of quality of life caused by traffic jams, pollution, accidents and occupation of urban land by streets and parking lots is the result.

Another challenge is the dependency of the society on guest workers with the risk of increasing unemployment rates of locals as well as the loss of the traditional identity within the built environment. The local population, with a constant decreasing share of the entire UAE population (only 11.5% in 2011), was catapultedwithin a few decades into a modern environment unrelated to its cultural heritage. Cities are facing a growing conflict between the opposing cultural forces, the Islamic Traditions and the Western Consumption Industry. Until today the question of identity is a rising conflict as well as ecological, social and economical concerns, which arose from this development.

2 Recent Development: Case Study UAE

2.1 Rising awareness

The enormous success of the city marketing which established Dubai and Abu Dhabi as tourism hubs on the one hand and the deficiencies caused by the rapid development of the cities on the other hand forced the govern-ments to promote and support environmental organizations and awareness campaigns. Since the global economic crisis hit the region in 2008 the term sustainability is seen as the remedy for problems derived from short-termed economical decisions during the boom time and as a promising marketing tool as well, due to the international critic on the unsustainable development in the past. The necessity to think and act ecologically and the discussion about the rising loss of identity led the governments of the UAE started to work intensively on new sustainable building codes and a local green scene took root.

As examples for the emerging local green scene serve the “Emirates Environmental Group” or the “Emirates Green Building Council”. The first one is a non-governmental Organization, founded in 1991, which received ISO 14001 (environmental management) certification in 2001 [7] and the latter (Emirates GBC) is an organization of building industry professionals established in 2006, with the goal of advancing green building principles for protecting the environment and the mission to facilitate collaborative solutions to promote sustainable practices in the UAE [8].

In the absence of Green building codes or rating systems the US Rating System LEED (Leadership in Energy and Environmental Design) was promoted in the UAE. In addition several Resolutions and Circulars have been published to address the new trend towards Green awareness in Dubai such as the Administrative Resolution, which proves regulations on the Technical Specifications? for Thermal Insulation Systems, the Circular on Implementing Green Building Regulations in the Emirate of Dubai and the Circular on implementing Building Green Roofs and facades. These regulations will be revoked after the implementation of the Green Building Regulations. [9]

The lack of central planning became an obvious issue, which needed to be addressed by a more comprehensive and integrative planning.

2.2 Abu Dhabi and Dubai are implementing sustainable Building Codes

2.2.1 Abu Dhabi and Estidama

Within its 2030 plan to become the sustainable capital of the Middle East Estidama (Arabic for sustainability) and its Pearl Rating System have been developed by the Abu Dhabi Urban Planning Council (UPC). Abu Dhabi's Estidama is linked to the new concept of integrated design process, encouraging design coordination of professionals at the early stages of the project. [10] The design guidelines are responsive to culture and to the unique harsh climate, focusing in the first place on passive design techniques, rather than on fancy technologies.

Abu Dhabi developed in the beginning of the millennium slower and obviously more thoughtful and sustainable in comparison to Dubai. During the last few years Abu Dhabi is developing much faster than Dubai despite or due to the global financial crises, which hit Dubai massively. Abu Dhabi has released an extensive Urban Structure Framework Plan for its own development called 'Plan 2030'. Within that plan, Abu Dhabi will triple its population to 3.1 million. [11] The Pearl Rating system of Estidama is the first green building rating system in the Arab World. It is, like the Dubai green building regulations, based on LEED and BREAM (British Research Establishment Environmental Assessment Method), but it is following a much more comprehensive and integrative strategy based on four equal pillars of sustainability: environmental, economic, social, and cultural. [12]

The first Version of the Estidama Pearl Rating System was launched in April 2010. Following a year of implementation and market adaptation to the requirements of the new policy directive, the Urban Planning Council has updated the System. A draft version of Pearl Rating System Version 2.0 was launched in April 2011 and is currently following a consultation process with all stakeholders. Under the Estidama initiative, all new facilities in Abu Dhabi must attain a minimum rating of one pearl, and government facilities must have at least a two-pearl rating.

The Pearl rating System is encompassing a Pearl Building Rating System (PBRS), a Pearl Community Rating System (PCRS) and a Pearl Villa Rating System (PVRS), introducing rating practices across the design and construction phases of development projects. The system provides a set of measurable guidelines for rating sustainability performance. It addresses seven categories; Integrated Development Process, Natural Systems, Livable Communities and buildings, Water, Energy Materials and Innovating Practice. For each category, there are mandatory and optional credits as well as weights with maximum credit points delivered to each. Three stages of the Rating process are distinguished: The Pearl Design Rating is engaged at the design phase of the project and is relevant until construction is complete. Following that, Pearl construction Rating is introduced for two years post a project's completion. Pearl Operational rating then assesses the operational performance of an existing development and takes effect for a minimum of two years after completion and when a development has reached a minimum occupancy of 80%. The PearlBuildingRatingSystem and the PearlCommunityRatingSystem are applied at the design and construction stages to ensure the sustainability targets are being addressed through all stages of the project. [13] A big challenge during the implementation of the pearl rating system is to raise sustainability awareness and to educate all stakeholders such as municipality employees, developers, architects, engineers, contractors etc.

Estidama is unique in carving out the specific cultural, social and local climatic concerns of the region and eliminates typical Western cultural, climatic and environmental concerns of its predecessors LEED and BREAM. To name some of the achievements is that the Pearl Rating System provides credits to design approaches that are based on traditional Emirati urban systems including the pedestrian routes, informal communal spaces and plazas. “Through the application of the PRS, communities in Abu Dhabi will be equipped with walkable, shaded, well-connected streets and public realm that improve livability and reduce reliance on motorized vehicles. “[14] Estidama aims to address all of these regional differences and to close the loopholes that LEED and other established rating systems are criticized for. As for instance daylighting requirements are adapted to the harsh climate, less glazing, more shading devices and the importance of building orientation are considered. LEED credits, which make no sense for the region are eliminated like for avoiding wetlands and credits for bicycle racks, where riding a bicycle to work is culturally and climatically inappropriate. It gives credits to the proximity to services and transportation rather than for brownfield development, which is less of an option in the region. [15] One of the important social concerns addressed in Estidama’s Pearl Rating System is the facilitation of fair labor practices for guest-workers in building construction by defining requirements for the accommodations of foreign laborers (so called labor-camps).

In calculations of water it even considers cultural issues like the water consumption at Muslim’s pre-prayer ablution activity or water consumption by handheld bidet sprays in addition to the standard water consumption for the flushing of the WC. [16] But beside cultural and social aspects Estidama emphasizes mostly on water and energy conservation, due to water scarcity and dependency on water desalination, and the energy required for that and the active cooling.

In particular Estidama is seeking for advancememt regarding future building performance. The first years of implementation will show if the expectations are met. Admitting improvement by continuous revision and by publishing updated versions is a best practice method in reaching goals.

2.2.2 Dubai Green Building Regulations and Specifications

In 2007 the government of Dubai decided finally to implement Green Building Regulations. In January 2011 the Dubai Municipality in Collaboration with the Dubai Electricity and Water Authority launched the Green Building Regulations and Specifications. The aim of these regulations is mainly to ensure environmental design for buildings by using energy-efficient construction materials and methods to reduce consumption of energy and water. Another goal is to improve public health, safety and general welfare as well as to enhance planning, design, construction and operation of buildings. The Green Building Codes are based on LEED and BREAM as well, adopted according to Dubai's local (cultural and climatic) requirements, but not designed as a rating system. The regulations are currently in the testing phase. The adoption of the regulations will be voluntary for the next three years and will apply to all new buildings; additions, extensions and refurbishments requiring a building permit; Chapters encluded in the regulations are Ecology and planning, Building vitality and Resource effectiveness encompassing energy, water, and materials and waste, broken out by building type.

Contrary to Estidama, Dubai focuses on the performance of buildings itself (before construction only) rather than on the city, which is a lot less comprehensive approach. An indication that Dubai is suffering from the recession more than Abu Dhabi is that they decided in April this year to postpone the enforcement of the new Green Building regulations to 2014 because they want to avoid any additional costs to building owners and investors in times of recession. [17] On July 1st, 2010 Brent Ridgard, director of WSP Environment and Energy consultancy stated in an interview with the Gulfnews magazine Property: "One can fully understand why the Dubai government might be a little nervous about putting a new set of regulations into the market in a downturn, especially where they add more cost (in the short-term) in an already stressed property market." [18]

On March 9, 2010 Mr. Al Tayer, Managing Director and CEO of Dubai Electricity and Water Authority (DEWA), stated in a Press Release "Dubai will be the first city in the Middle East that officially applies the green buildings standards on its residential and commercial buildings." [19] Dubai hoped to be first, but obviously 'lost the race'.

2.3 In view of the Middle East Region

Another green assessment method of the region has been launched recently as well: The Qatar Sustainability Assessment System (QSAS). It integrates best practices from 6 established rating systems for commercial, residential and school projects and very soon environmentally sustainable sporting venues as well, due to the hosting of the FIFA World Championship in 2022.

Dubai and Abu Dhabi as well as Qatar are in a permanent competition to each other. Headlines of local newspapers announce achievements of the respective cities with superlatives such as the first… the highest…, the fastest…, the biggest….. In terms of sustainability they are going their own way as well and disregard efforts of the "competitors" instead of pooling their strengths and working together on a common goal. The whole region has similar climatic as well as cultural conditions suitable for a co-production. A common strategic plan of the oil-producing countries in the gulf, which make also Bahrain and Saudi discharge their duties seems to be an idle wish. Central planning is still missing and not in sight.

Currently it seems that Abu Dhabi scored a coup with Estidama and hopefully it "will subsequently be introduced in all seven emirates in the country and will serve as a prototype for other countries in the region" according to CMPi Group Director, Chris Fountain during an interview in 2008.

3 Sustainable projects in the UAE

3.1 LEED certified projects

During the last 5 years more than 40 buildings in the UAE have been Leed certified. Some even received Platinum certification such as the Tecom Management Office renovation (2009) or the Pacific Controls HQ Building (2008). These building are fulfilling certainly Leed requirements, but rarely show much of an innovative design though.

3.2 Marketable green designs put on hold

Due to the financial crises the realization of many of the planned building projects had been postponed or put on hold. A number of high-rise projects have used wind turbines and photovoltaic panels as green features and visible statements of a green intention with a high-tech aesthetic design, but have not been built to proof their actual performance like the Dubai Light House Tower by Atkins or the Burj Al Taqa by the German architect Eckhard Gerber. [20]

3.3 Sustainable models for the region

Neverthess some projects, planned or are under construction, show the potential to serve as green models for the region. Masdar City by Foster + Partners is definitely the sustainable flagship of the UAE and the entire region, but a project like Xeritown in Dubai Land by X-Architects and SMAQ is very remarkable as well.

Masdar City was promoted as the world's first zero-carbon and zero-waste city, which would rely entirely on renewable energy, mostly solar. It hosts the Masdar Institute of Science and Technology, a research-oriented university focused on alternative energy and sustainability for the region, and wants to attract the best companies in clean tech. No ordinary cars are allowed inside the city. Transportation works via Personal Rapid Transit electro- vehicles. The urban layout by Norman Foster combines classic Arab design with 21st century technology. [21] The Masdar City masterplan combines passive design features such as shading and thermal mass with efficient cooling systems and small renewable energy systems to reduce energy loads.

Masdar City was originally scheduled to be completed by 2015, but the financial crises pushed back the date indefinitely. Though the first phase of the project, the Masdar Institute of Science and Technology was completed in fall 2010 and opened its doors to students. The aim of the city is now to be a low-carbon city instead of a zero-carbon city, which apparently was a too ambitious goal. [22] But as Brian Walsh closing his article in the time magazine about Masdar City: "No one knows the answer to the energy and climate challenges the planet faces, which is why experiments count - even the ones in the desert." [23]

4 Summary and Conclusion

The conflict between the built environment and the growing need for ecological, economical and social balance in the entire gulf region need to be addressed and in this regard Abu Dhabi seems to be on the right track. Since the UAE is still caught up in the service society, it is necessary to move towards a health-and nature oriented society through education and awareness, which already happened in other parts of the world.

Landmarks like the Palm Jumeirah, the Burj Khalifa and the Emirates Palace Hotel or Yas-Island, gave a new face to the UAE with a major emphasis on luxury and tourism. Mega projects like Masdar city and Sadiyat Island started to reflect the aim to be visionary in terms of ecological and cultural aspects as well.

Urban Design and architecture became a city marketing factor in order to gain international recognition and to attract investors.

Maybe in no other cities of the world the marketing strategy is so obvious like in Dubai and recently in Abu Dhabi. The world’s star architects such as Hadid, Foster, Ando, Gehry, Koolhaas, Nouvel etc. are not commissioned because of their architectural concepts. The reason is their name as a branding-strategy in the first place. Image gorges content. [24] Even an amazing project like Masdar City, the world’s first planned zero-carbon, zero-waste, car-free city in Abu Dhabi gets a taste of branding and the apprehension this could be just a “sustainable bubble” could cross one’s mind.

The Middle East has to move towards a more holistic approach for a sustainable strategic development. The lack of central planning has to be replaced by a comprehensive and integrative planning.

To address the issue of reducing CO_2 emissions commonly used energy subsidies need to be cancelled for the benefit of subsidies in employing renewable energies in order to make the use of the region’s abundant solar and wind resources economical.

To address the issue of identity and livability, the future cities of the UAE will be characterized by the protection of natural resources, by the enforcement of new building standards and the application of modern technology instead of typical investor-friendly fast and cheap mass production. This will upgrade the quality of the built environment in terms of structure, design and energy consumption.

It shows that the UAE are on the right track, but in the first place awareness, education, responsible design techniques and quality control have to pave the way for sustainable construction as a standard. Conducting quality control during as well as after construction as stipulated in Estidama’s Pearl Rating System, will be a new but very important challenge for the respective authorities in order to assess results rather than intentions. The common building practice in the UAE needs to develop towards a state of the art building practice adopting sustainable construction techniques. In order to achieve this, not only contractors and supervisors at the construction site need to be educated, but foremen and construction workers as well.

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Alternative Base and Binder Courses for Urban Roads with Application of Recyclable Materials

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Abstract

Alternatives to traditional cement or bitumen stabilized base courses, where usually high amounts of aggregates are used, can be found in structural pavement courses if local materials, i.e. soils or recyclable materials are applied. In the paper described techniques for such courses usually need increased content of cement reaching 10-12 %-wt. what is about 7 %-wt. more than in traditional cement stabilizations. To avoid in the laid pavement course hydration cracking and allow some flexible behavior as well chemical additives (RoadCem) are used to modify the material behavior. Solutions where utilization of recyclable materials and by-products are used have added environmental value and combination with special additives might reduce the contents of energy demanding binders. On the other hand the target is to reach better durability by improved performance and to reduce more frequent rehabilitation. So far gained results of mechanic and performance characteristics for mixes with RoadCem, cement and soil or reclaimed asphalt material (RAP) have shown interesting results. By application of this technique savings in non-renewable materials can be reached, there is decrease of loading the road network by construction transports, consumption of fuels and produced emissions. These savings can in terms of economy support this technology and increased content of cement, if compared to traditional stabilized mixes.

1 Introduction

The traditional material used for base courses in the Czech Republic are bitumen-bonded layers of the asphalt concrete type or, using the older terminology, coated aggregates, unbonded mixtures like crushed stone mixture, vibrated gravel or mechanically consolidated aggregates or hydraulically bonded layers. The most commonly used aggregates are stabilized by cement, but other hydraulic binders may also be used as regulated in European standards of the EN 14227 series. The positive benefit of European standards for the Czech environment is the fact that individual technologies based on hydraulic binders are mutually replaceable guaranteeing that the finally produced mix reaches always the same qualitative parameters. Of three classification systems, the Czech Republic has chosen the simplest one according to which bonded (stabilized) mixtures are solely characterized by their compressive strength.

From the perspective of routine operation of laboratories, the performance of control production testing may seem to be a good choice, even though the chosen single characteristic does not describe the properties of mixes well enough. Frost and water resistance are characterized by the maximum allowable drop in compressive strength after the prescribed number of freeze-thaw cycles. This system does not make it possible to distinguish properly the quality of individual technologies as it only works with a single performance parameter, while the other parameters, both empirical and performance-based, are not considered in any way. Table 1 shows compressive strengths of hydraulically bonded layers and their potential use in pavement structures.

Table 1: Exploitation of bonded layers in road pavement constructions, [1].

Strength class (MPa)	Recommended traffic load class			Old name for the technology
	Wearing course	Base course	Protective layer	
< $C_{1.5/2.0}$	-	-	-	-
$C_{1.5/2.0}$	-	without limitation	without limitation	S II (stabilization)
$C_{3/4}$	-	without limitation	-	S I (stabilization)
$C_{5/6}$, $C_{6/8}$	V, VI	without limitation	-	KSC II (cement-consolidated aggregates)
$C_{8/10}$, $C_{9/12}$	V, VI	without limitation	-	KSC I (cement-consolidated aggregates)
$C_{12/15}$, $C_{12/16}$	V, VI	without limitation	-	VB I rolled concrete

2 RoadCem technology

The RoadCem admixture is fine-grained material which, in combination with cement, water and local soil, may be used as a structural layer of road pavements and other consolidated surfaces. Its production technology is very similar to lime or cement stabilization techniques. The RoadCem material is dosed in amounts of roughly 1.6 – 2.4 $kg.m^{-3}$ and cement in amounts of 160 – 240 $kg.m^{-3}$ of the final mixture. Depending on the traffic load, soil is used in thicknesses from 0.20 to 0.45 m. The mixture is processed with soil milling machines. The resulting material possesses a good deformation ability without the appearance of cracks, it usually well co-acts with asphalt wearing courses and allows reducing their thicknesses. The surface of less trafficked road sections of e.g. service roads may be finished by emulsion surface dressings and crushing or microsurfacing.

3 Environmental compatibility approach

Techniques promoting utilization of locally available materials and optimal use of binders combined with suitable admixture or additives follow the idea of environmentally compatible structures (ECS). Theoretical definition of EC is based on three basic assumptions concerning the animate and inanimate parts of the environment while, at the same time, defining the relationship of human beings to both those areas:

- permanent sustainability principle,
- the global balance principle,
- the limited resources axiom,

The theoretical concept of ECS as described in [5] in its simplified form solves direct relationship between the amount of loosen GHG emission and energy consumed by odd structures and/or structural material production. From this assumption the similar proportional dependence between material volume and energy embodied in the structure can be induced. For different material systems of course considerable difference in the embodied energy can be found and is directly subject to used binders, use of natural resources or recyclable materials, in-situ or in-plant technique etc. Environmental compatibility is then immoderate to the total volume of used materials. If the structure with respect to energy and structural material is more low-demanding (thinner structures, structures applying local materials etc.) the impacts on environment are decreased. This can be according to [5] calculated by using the engineering multiparameter optimization.

By using environmental compatible concepts the key requirements should be specified:

- limit existing sources of air, water and soil pollution, including impacts negatively affecting human health and climatic conditions,
- define unambiguous objectives in the field of alternative energy sources and systems, including an intensification of research in the field of thermal nuclear fusion,

- define and specify compliance between environmental protection and free market conditions that can best be summarised under the so-called EC factor,
- limit air pollution caused by vehicle traffic, identify suitable improvements or alternatives in the field of fuel and propulsion for vehicles, set-up sustainable traffic growth with respect to sufficient population mobility.

4 Using soil in road pavement structural layers

The regulations in force in the Czech Republic require for the hydraulically bonded structural layer to reach the minimum compressive strength on cylindrical specimens with a slenderness ratio of 1:1 or 2:1 at least 2 MPa or 1.5 MPa respectively. In this case, it does not matter whether the structural layer was made with the use of aggregates or soil bonded with hydraulic binders. Reaching the required strength values is not a problem when aggregates are used, but reaching them with soil may only be possible when using increased contents of hydraulic binder, which, however, is accompanied by the increased occurrence of hydration cracks which reduce the mechanical resistance of the whole structural layer and are the cause of reflection cracks (bottom-up cracks) arising in asphalt wearing courses. The advantages of such technologies using local soil, on the contrary, are:

- savings of granular, non-renewable materials,
- reduced costs for material transport,
- fuel savings related to construction site transports,
- reduced traffic loading of the road network,
- reduced negative impacts of heavy vehicle construction traffic on local inhabitants.

The first verifying tests were performed in the laboratory of FCE, CTU in Prague testing whether the combination of RoadCem with cement allows reaching such compressive strengths making the mixture usable in base layers of pavement constructions and making it an alternative to traditional stabilized technologies. Table 2 lists all results of laboratory measurements performed.

The results clearly show that by combining mix design compositions strength values complying with the requirements for hydraulically bonded road pavement structural layers may be reached. The applicability of the technological procedure was also verified during real site operation and is testified by the strength ratio measured on laboratory-prepared specimens and sampled cores from the laid structural layer. The layer performance (paving) technology is strongly affected by the large amounts of binder used, by the requirement for increased amounts of mixing water and thorough mixing of the mixture. An interesting result reached was the determination of the stiffness modulus in non-destructive testing on cylindrical specimens (IT-CY) according to [2]. Presuming that no hydration cracks arise in the layer, the assessment of the pavement construction observing the boundary

Table 2: Results of tests of improved (RoadCem-stabilized) soils

Locality	Jílové	Kladno
Mix composition	Soil: 100 %	Soil: 100 %
	Cement: 12 % 1)	Cement: 10.7 % 1)
	RoadCem: 0.12 % 1)	RoadCem: 0.11 % 1)
	Water: 15 % 1)	Water: 19.8 % 1)
Compressive strength after 3 days (MPa); laboratory-prepared specimens	---	2.7
Compressive strength after 7 days (MPa); laboratory-prepared specimens	2.07	4.6
Compressive strength after 14 days (MPa); laboratory-prepared specimens	---	6,2.
Compressive strength after 28 days (MPa); laboratory-prepared specimens	3.02	7.1
Compressive strength after 7 days (MPa); in-situ results	1.57	---
Compressive strength after 28 days (MPa); in-situ results	2.91	---
Freeze-thaw and water resistance of cement-bonded soils (-20°C, 10 cycles), compressive strength (MPa) and strength decrease (%)	2.39 (79 %)	---
Stiffness modulus from indirect tensile test at 15°C (MPa)	8 340	---
Flexural tensile strength after 28 days, laboratory-prepared specimens	---	1.6 MPa
Note 1) dry soil weight		

conditions according to the design methodology [3] allows saving up to 60 mm of asphalt-bonded layers and ca 200 mm of unbonded layers as compared to the traditional construction.

Table 3: Results of cold recycling tests

		Mix A	Mix B	Mix C	Mix D
Mix composition in %	R-material	100	100	100	100
	Cement	4	4	4	12
	RoadCem	---	---	0.04	0.12
	Emulsion	2.5	---	---	---
	Water	6	6	6	6
R_i (MPa) after 7 days in the air		0.643	0.694	0.631	1.073
R_i (MPa) after 7 days in the air and 7 days in water		0.723	0.279	0.531	1.076
Water susceptibility (%)		113	40	84	111

5 Cold recycling technology and RoadCem application

The next step towards using nano-chemical admixtures in base courses of road pavement structures was their introduction in in-place cold recycling technologies regulated in the Czech Republic by the regulations of Czech Ministry of Transport. The basic idea was whether the cement plus admixture combination could replace the traditional cement plus emulsion formula. It is only in such a case that the application of the nano-chemical admixture requiring large amounts of hydraulic binder may be economically justified. The alternative layer (mixture) should further possess a higher user, qualitative potential. This comparison was performed on four mixes whose composition is evident from Table 3. Prior to drawing conclusions it must be stressed that this is the first series of results which are affected by the non-homogeneity of the unbonded granular material with the maximum grain size of 63 mm. The number of tested specimens of each mixture as well should be increased against the prescribed three test bodies to at least five of them.

Despite these reservations, let us interpret the obtained results:

- indirect tensile strength values (ITS) of the reference mix with emulsion reached standard values; our experience with similar mixes is that their strengths after 7 days range in the interval of 0.55-0.75 MPa and after 7 days in the air and after 7 days in water within 0.65-0.95 MPa,
- ITS of the mix with only cement are comparable to expected strengths,
- presence of emulsion positively affects the mix sensitivity to the negative effects of water,
- strength of the mix with the RoadCem admixture is comparable to the strength of the mix without admixtures,
- water susceptibility is nearly twice higher using the RoadCem admixture, the same as in the mix without the nano-chemical additive,

- using the RoadCem admixture complied with the requirement for water susceptibility,
- the mixture with only cement without RoadCem failed to comply with the requirement for water susceptibility,
- increasing the amount of cement and RoadCem by three times resulted in increased ITS,
- increasing the amount of cement and RoadCem the water susceptibility of the mix decreases,
- designed high amounts of hydraulic binder increased the strengths above the strength level of mixtures with combinations of binder, cement and asphalt emulsion.

6 Conclusion

As manifested by the presented test results of strength characteristics for both stabilized soils and the in-situ cold recycling technology can be shown that the fulfilment of the prescribed requirements is not too difficult. Using such high amounts of hydraulic binder, in our case cement, a different development is beyond any speculation. The next step in research, apart from the economic comparison of the applicability of the new technology, is the extension of the investigation of the behaviour of these alternative base courses adding functional tests. Strength characteristics on their own are not able to assess the overall benefits of these technologies in comparison to their cost-efficiency. These goals are the objectives of follow-up research projects and studies.

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Selected Performance Characteristics of Warm Asphalt Mixes and Used Binders

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Abstract

Warm mix asphalts represent a general trend in many countries of Europe and in United States. The motivation can be found in reduction of energy consumption and in lower CO_2 release. Several technical approaches are known based on waxes, fatty acids, zeolites or chemical organic additives. Besides the partial reduction in processing temperature the behavior of the mixes might be changed and several experimental works and researches already documented improvements or potential risks in performance behavior of asphalt mixes and the pavement structure. The ability to improve performance is then related to further decrease in environmental impacts because of longer maintenance cycles. In the Czech Republic WMAs are used since beginning of the century. Testing and comparison has been so far always done only for standardized volumetric and mechanic properties. During the last three years research the focus has been fixed on performance characteristics and search for relations between low-viscosity bitumen and warm mix asphalts to explain better the potenials for longer lasting pavements. Several tests has been done by various methods to analyze stiffness, fatigue behavior and low temperature behavior. Some of the results gained are presented in the paper.

1 Introduction

Warm mix asphalts represent a general trend in many countries of Europe and in the United States. The fundamental idea originates in great extend in Germany and first applications have been realised more than 25 years ago in the field of mastic asphalt. The basic effort was improvement of workability at slightly reduced temperatures. Later, beginning of this century was again in Germany when the Sasobit-technology has been introduced and applied in the field of traditional asphalt mixes. During the last 10 years several techniques and approaches have been developed based on various technologies with application of different additives or even modifications on the mixing plants. The motivation can be found in reduction of energy consumption and in lower CO_2 release. Not less important is the issue of bitumen fumes or aerosols and total organic compounds emission. This problem is related to health aspects and critical observations have been made during the last years. Several technical approaches are known based on waxes, fatty acids, zeolites or chemical organic additives. Besides the partial reduction in processing temperature the behaviour of the mixes might be changed and several experimental works and researches already documented improvements or potential risks in performance behaviour of asphalt mixes and the pavement structure. The ability to improve performance is then related to further decrease in environmental impacts because of longer maintenance cycles. In the Czech Republic WMAs are used since beginning of this century. Testing and comparison has been so far always done only for standardized volumetric and mechanic properties. During the last three years research the focus has been fixed on performance characteristics and search for relations between low-viscosity bitumen and warm mix asphalts to explain better the potentials for longer lasting pavements. Several tests has been done by various methods to analyze stiffness, fatigue behaviour and low temperature behaviour. Some of the results gained are presented further.

2 Asphalt roads and energy consumption

The majority of today's roads are made with hot-mix asphalt. Bitumen makes up a relatively small fraction (5-8 %) of the total mixture and acts as a viscoelastic binder between the aggregate particles. Hot-mix production typically takes place at 150 to 180°C. Paving and compaction on the road typically take place at 120 to 160°C. Aggregates and bitumen are heated to high temperatures to enable the bitumen to coat the aggregate particles properly and to make the total mixture viscous enough to allow good workability during mixing, laying and compaction. Reduction of the processing temperature somewhere in the manufacturing chain inevitably impacts on other parts and it more often than not reduces quality of the final asphalt mixture limiting the applicability of the final product.

From previous it can be clearly stated that the production of hot-mix asphalt is characterized by an extensive use of energy because of high processing temperatures. The energy plays therefore together with the volume of used structural materials key parameters in the environmentally compatible approach which can be directly related to the mutual relationship between pavements and the climate. Necessary amounts of materials and their production consume considerable quantity of energy. The energy producing emissions affects then the environment and climate. Further, materials have to be hauled to the construction site. On the site additional impacts are created by loosening fine or ultra-fine dust particles.

If focusing only on asphalt mixes and energy consumption, the key issue is in consequence to reduce the asphalt production temperatures without compromising mix performance. Balance between the low viscosity of the binder and necessary workability during paving and compaction has to be found out.

Since more than 20 years ambitious energy saving projects can be identified in several countries. E.g. the Dutch Asphalt Pavement Association ratified an agreement with a target to achieve a reduction of 20 % of energy consumption per tone hot-mix asphalt within 10 years. This implies the reduction of CO_2 emissions and the reduction of the use of fossil fuels. The target was not been reached completely, nevertheless the monitoring showed that a reduction of 11 % was reached [3]. Such success is possible if we will encourage following strategic steps:

- energy consumption has to be one of the items that are subject of the environmental permits and licenses,
- companies taking part on energy savings should profit from the financial support of the government,
- there should be better organization and logistic of the production.

Another example might be the current trends followed and promoted by European Asphalt Pavement Association with support to warm mix asphalt techniques, [2, 4]. This is closely related to emissions and requirement of registered products within the REACH directive.

3 Development in the field of warm mix asphalts

In the Czech Republic and in Slovakia techniques of warm mix asphalts (WMA), i.e. mixes where the processing temperature is reduced by 10-30°C, have been gradually developed for more than ten years. The basis were experience and successful applications in Germany, which started as first country to apply more the bitumen doping by so called intelligent fillers and flow improvers. In the case of mastic asphalt is the history even longer especially with respect to the use of montanous waxes used for improved workability on site. In general it can be stated, that processing temperature reducing asphalt techniques introduced and partly standardised actually in both countries should be included in the first generation of WMA, especially if various types of waxes or fatty acids additives are applied.

Generally the energy demand of asphalt mix production and the decrease of necessary process temperatures can be divided in following fields:

- measures done at the mixing plant (improved insulation, covered aggregate storage to avoid excessive wetting especially by rain water);
- improved bitumen viscosity at reduced process temperatures;

- modification of the asphalt mix by improving viscosity and therefore also the workability at reduced temperatures. In this case the use of moist aggregate or less heated aggregates is possible if suitable technique used (hydrophobic additives, foam techniques, zeolites).

In the first case the success is related to the approach of the mix producer and plant owner. Possible solutions are not changing the mix composition and a WMA is not produced. The energy demand and CO_2 emissions are reduced by optimizing the production process and the plant operation. Covered aggregate storages in this connection should be today a required standard, because extended aggregate drying before mix production due to increased moisture is in fact an inefficient step.

The second group of solutions can be seen as the most widespread and allows modify the viscous behaviour of binders at elevated temperatures. Within these solutions the first generation additives can be found, like FT paraffin (FTP), fatty acid amides (FAA) or Montana waxes applied usually in amount of 3-4 %-bitumen mass. Named additives have nevertheless been complemented during last few years by substances with different chemical principles. In this connection especially Rediset WMX, Iterflow (tensides), Evotherm 3G or Densicryl should be named. The doping of these additives is lower and they can be added to the bitumen or directly to the asphalt mix. If added to the binder up to 1 %-bitumen mass is used. Specific dope agent, which is originally foreseen as a viscosity improver, nevertheless is positively influencing viscous behaviour of the bitumen, is polyphosphoric acid (PPA).

Using low-viscosity bitumen it is according to our experimental findings in general possible to reduce the mix production temperature by about 10-20°C. From the practical applications it is known, that the paving temperature can be reduced in comparison with traditional mix by up to 30°C and the compaction process can be done until 90-80°C. Usually more important than the reduced paving temperature is a longer period for mix treatment on site and the possibility to pave and compact mixes also at lower outside temperatures.

Last group of flow improving techniques is represented by additives or suitable processing steps realised directly during asphalt mix production. Technologies like synthetic zeolites application based on micro foam generation after mixing them with bitumen and hot aggregates in the mixing plant can be named as the traditional representative. Another solution is the original Evotherm ET technique, where special bituminous emulsion was mixed with aggregates at 115°C. Later Evotherm DAT followed, where additives are added to the bitumen just before mixing with aggregates. Besides these technologies foamed asphalt can be used or Low Energy Asphalt (LEA®) is known. Nevertheless these techniques might be defined more as semi-warm asphalts similarly to new types of binders, like ECO^2 developed and tested in recent years in France, where temperature decrease can reach up to 50°C.

4 Low-viscous bituminous binders

Within the framework of the experimental solution as such, a number of low-viscosity bituminous binders have been designed so far. This field constitutes one of the three possibilities of achieving decreased process temperatures during asphalt mix production. A relatively broad spectrum of additives currently marketed and further developed has been used; so far, synthetic waxes or FAAs as well as some organic chemical additives, like tensides (IF) or nanochemical additives have been tested so far. Overall results are presented in following Tables 1 and 2.

From the point of view of force ductility a comparison to bitumen 50/70 shows that the application of viscosity-improving additives increases the deformation energy under the same test temperature (15°C) which supports the expected higher stiffness of the binder. It has been repeatedly proven that lower test temperatures cannot be used because in such cases the bitumen fibre failed to extend to at least 40 mm as required. The findings obtained by this test to compare asphalts correspond relatively well with the results obtained for asphalt mixes. If we restrict ourselves to a comparison of individual additives, following conclusions can be formulated:

- by far the highest values were achieved for bitumen with 3 % FTP;
- FAA, PPA and both chemical additives are almost comparable under extension to 200 mm from the point of view of deformation energy. In the case of the qualitative indicator of deformation energy difference between 200 mm and 400 mm, the greatest potential was reported for tensides based additive. The nanochemical additive only reached a half value;
- if comparing 70/100+3% FAA and 70/100+3% FAA+0.5% PPA it is obvious that the combined additive does not yield any improvement from the point of view of ductile deformation energy. In contrast to that, the comparison with 50/70+3% FAA is interesting – this binder has worse results in both deformation energy and qualitative indicator E20-40.

5 Experimental mixes and basic characterisation

To assess the performance behaviour of various viscosity improving additives applied to bitumen with subsequent utilization in WMA, mixes described in more detail in [2, 8] were selected and tested. Different types of mixes for binder and base pavement courses (ACL16 and ACP22+) were selected. These mixes comply with the conditions of standard ČSN EN 13108-1. The grading curve of individual mixes is given in [8]. With respect to the findings on increased stiffness values particularly when FTP, FAA or PPA is applied, the application of warm mix asphalts in these layers is much more purposeful than e.g. in the wearing course. The reason is the fact that individual mixes usually reach increased resistance against permanent deformation and this property can be taken advantage of in the binder course in particular.

Table 1: Fundamental characteristics of bitumen 50/70 and 70/100 with different viscosity improving additives.

Basic bitumen	Additive		Softening point (°C)	Penetration @25°C (0.1 mm)	PEN index (-)
	type	content (%-wt.)			
70/100	no additive	-	46	82	-1.07
	FTP	3	91	53	5.85
	FAA	3	95	60	6.64
	FAA and PPA	3 + 0.5	99	50	6.55
50/70	no additive	-	51	53	-0.82
	FTP	3	76	40	3.18
	FAA	3	94	41	5.51
	PPA	0.5	53	53	-0.34
	PPA	1.0	56	49	0.14
	nano-chemical additive	0.1	50	55	-0.99
	tensides	0.5	51	40	-1.44

Table 2: Results of force ductility for selected 50/70 a 70/100 binders with different additives.

Bitumen	T	E_s	E_{20}	E_{40}	E_R	E_{20-40}
	(°C)	(J/cm^2)	(J/cm^2)	(J/cm^2)	(J/cm^2)	(J/cm^2)
50/70 A +3% FAA	20	0.042	0.440	0.478	0	0.039
	15	0.085	1.096	1.273	0	0.177
50/70 DE +0,5% PPA	20	0.025	0.306	0.332	0	0.025
	15	0.163	1.133	1.318	0	0.185
50/70 DE +3% FAA	20	0.074	0.682	0.746	0	0.064
	15	0.103	1.801	2.047	0	0.246
50/70 DE +0,1% ZYC	15	0.078	0.926	1.024	0	0.098
	10	0.207	3.580	1.313	2.407	0.074
50/70 DE +0,5% IF	15	0.076	1.308	1.512	0	0.204
	10	0.209	3.819	2.147	1.968	0.242
70/100 DE +3% FTP	15	0.036	0.279	0.353	0	0.074
70/100 DE +3% FAA	20	0.064	0.538	0.583	0	0.045
	15	0.095	1.509	1.737	0	0.228
70/100 DE +3% amid +0,5% PPA	20	0.030	0.272	0.285	0	0.013
	15	0.081	1.301	1.488	0	0.188

Table 3: Basic specification of mix type ACL16.

Asphalt mix	REF2009	2009_2	2009_3	2009_4	2009_5	2009_6	2010_2
Used binder	50/70	70/100	50/70				
Used additive	-	FTP (3 %)	PPA (1%)	PPA (0.5%)	FAA (3%)	FTP (3 %)	ZY (0.1 %)
Processing temperature	150°C						
Voids content (%-vol.)	4,1	4,6	4,3	3,2	4,0	3,5	4,3

Table 4: Basic specification of mix type ACP22+.

Asphalt mix	**ACL22_1a**	**ACL22_1b**	**ACL22_2a**	**ACL22_2b**
Used binder	50/70		industrially produced bitumen CP-M	
Used additive	FTP (3 %)			
Processing temperature	145°C	130°C	160°C	145°C
Voids content (%-vol.)	2,3	8,9	1,9	5,3
Asphalt mix	**ACL22_3a**	**ACL22_3b**	**ACL22_4a**	**ACL22_4b**
Used binder	50/70		50/70	
Used additive	AMK (3%)		PPA (0.5 %)	
Processing temperature	145°C	130°C	145°C	130°C
Voids content (%-vol.)	4,5	7,1	2,6	1,9

The mixes were produced with no PmBs and the production temperature was uniformly set to the 150°C level; the Marshall specimens were compacted by 2x50 hits under the aforementioned asphalt mix temperature. Later the potential of reducing this temperature was assessed as well, producing the WMA at five different temperature levels and comparing the bulk density results with the reference mix, according to the Czech technical conditions and German regulations [9, 10].

In the case of mix ACP22+ a comparison of the effect of temperature was conducted already in the beginning stage; the mixes were first produced under standard temperature; then, the temperature was reduced by 15°C and second set of test specimens was prepared. For ACL16 mixes originally the binder content was decided with 4.2 %-mass which has proven to be the threshold proportion of bitumen; this follows the general trend of the Czech practice applying as low quantity of bitumen in the mixes as possible. However, this circumstance very frequently only results in quality deterioration and premature occurrence of some defects. Based on this fact the mix design has been modified and bitumen content was slightly increased to the level of 4.4 %-mass.

From the perspective of basic tests, only slight influence of certain additives on void content is obvious. According to the experience received, it should be pointed out that the mix with bitumen improved by PPA organic additive is sensitive on

Table 5: Stiffness of experimentally assessed mix ACL16 (test method IT-CY).

Temperature/Mix	REF2009	2009_2	2009_3	2009_4	2009_5	2009_6	2010_2
T=5°C	21,400	17,900	17,100	20,600	26,900	27,300	21,600
T=15°C	8,800	8,500	9,800	11,200	11,900	13,800	13,600
T=27°C	2,000	2,200	3,300	2,800	3,900	5,200	4,000
T=40°C	400	600	700	900	1,200	1,600	900
Thermal susceptibility (-)	10.70	8.14	5.18	7.36	6.90	5.25	5.40

Table 6: Stiffness modules of experimentally assessed ACL22+ test method IT-CY).

Mix	Binder	Process temp. (°C)	Stiffness modulus (MPa) at temperature T (°C)				Thermal suscept.
			0°C	15°C	27°C	40°C	
ACL22_1a	50/70+3% FTP	145	25,400	10,600	4,300	1,600	15.88
ACL22_1b	50/70+3% FTP	130	14,500	6,900	2,500	500	29.00
ACL22_2a	CP-M	160	23,700	13,200	4,600	1,800	13.17
ACL22_2b	CP-M	145	23,200	12,900	6,000	2,200	10.55
ACL22_3a	50/70+3% FAA	145	26,800	15,100	5,100	1,200	22.33
ACL22_3b	50/70+3% FAA	130	21,700	11,600	3,200	900	24.11
ACL22_4a	50/70 + 0,5% PPA	145	24,100	10,800	3,400	900	26.78
ACL22_4b	50/70 + 0,5% PPA	130	19,900	8,000	2,200	600	33.17

doping percentage. It has been confirmed that dosage >1.0 %-mass of PPA resulted in instable results. In contrast to the findings for ACL16 mixes, the probable effects of low-viscosity additives can be declared quite simply in the case of mix ACP22+ by comparing the void contents at two temperature levels. In this context, the significant increases of the void content value in the mixes with a binder and synthetic wax and fatty FAA should be pointed out. Based on the results given, it can be concluded that under process temperatures decreased by 15°C the mixes would not comply with the requirements of the technical conditions for subsequently determined void content.

6 Deformation characteristics

From the perspective of the tests performed on asphalt mixes, attention focused primarily on performance characteristics. In this regard, the key properties are the stiffness modulus, complex modulus and resistance to permanent deformation. This paper does not address the relative water susceptibility indicator (ITSR) although, in relation to some additives, this area receives considerable critical attention abroad. In contrast to that, characteristics under low temperatures are observed with respect to the potential deteriorations of mixes with higher stiffness, especially possible susceptibility to frost crack formation.

The results of stiffness modules, using the IT-CY method according to ČSN EN 12697-26, are given in the following Tables 5-6. The stiffness is usually assessed for at least three different temperature levels. An auxiliary characteristic of thermal susceptibility was determined at the same time, representing the proportion of the stiffness at minimum and maximum testing temperature. The lower the thermal susceptibility value the better quality the mix can be considered to have.

From the gained findings following conclusions can be made:

- the designed mixes meet the requirements for minimum stiffness modulus requirements for asphalt concrete at 15°C according to the Czech Pavement Design Manual (7,500 MPa for asphalt concrete and 9,000 MPa for mixes with high stiffness modulus) – with the exception of the reference mix ACL16S with binder 50/70 as well as the mix with binder 70/100 and FTP additive;
- the stiffness value of the majority of mixes listed in Tables 5 and 6 exceeds 11,000 MPa; these could be labeled “second generation of high stiffness modulus mix” although any further stiffness increase should be approached with caution and the fatigue parameters of the mix should be assessed in detail;
- asphalt mixes with FTP additive show the biggest improvement of stiffness (approx. 25 %);
- very good comparability of the mixes with 50/70 and 70/100 with FT paraffin was demonstrated; binders could be practically substitutable;
- the dependence of temperature and stiffness can be statistically well expressed by an exponential regress function with correlation coefficient of 0.97-0.99;
- the flow-improving additives have an effect which is obvious not only in stiffness modulus values but also in the case of the qualitative indicator of thermal susceptibility. The most suitable seems to be additives PPA or FTP. In the case ACL16 asphalt mixes, a 25-50 % improvement of thermal susceptibility was observed in comparison to the reference mix;
- the results obtained also suggest a rather promising development of a second generation of viscosity-reducing chemical additives which are dosed in smaller quantities and allow likely improvement of some other functional characteristics.

In the case of ACP22+ experimental mixes it is obvious that the mix with bituminous binder which contains FAA achieves the highest values. This finding is close to the results of mix ACL16 as well. In contrast to that, the worst results were recorded by binders with FTP although the term “worst” is rather relative in the case of the values achieved. Again, the asphalt mix with PPA dope is noteworthy;

Table 7: Results of rutting test on asphalt mix samples.

Mix	REF2009	2009_2	2009_3	2009_4	2009_5	2009_6
Max. relative rut depth PRD_{AIR} (%)	5.7	3.8	3.9	5.0	5.6	4.1
Max. increment rut depth WT_{SAIR} (mm/10^3 cycles)	0.154	0.080	0.069	0.058	0.107	0.044

it should be emphasized again that the additive is not primarily intended to reduce the working temperature.

Stiffness testing can be compared to assessment of resistance against permanent deformation. In this connection standardized rutting test according to CSN EN 12697-22 at 50°C air bath with at least 10,000 cycles has been performed. Against the usual conditions for ACL16 mixes the specimen thickness was 50 mm and not 60 mm to allow the utilization of specimens for further testing as well. Results are summarized in the Table 7. Because for ACL16 mixes the minimum requirements are not set it has been decided to use requirements according to CSN EN 13108-1 for ACL16S mixes (PRD_{AIR} = 3 %; WTS_{AIR} = 0,05 mm/10^3 cyklů).

7 Summary

Solutions for environmentally compatible structures, which would in case of asphalt pavement technologies allow reduction of traditional process temperatures, make sense only if there are added values not only with respect to decreased emissions but the required performance can be guaranteed. From the practical applications it is so far known, that asphalt mixes with FTP, FAA or tenside additives can be used at temperatures decreased in average by 15°C. If the bitumen potential is combined on the plant with necessary measures to avoid unwanted aggregate moister, the CO_2 emission can be lowered at least by 20 %. Further effects can be found in minimum bitumen fume emergence and in economic savings of less fuel consumption during the mix production.

From the technical point of view and experimental testing done so far it could be documented that the flow-improving additives have usually also a positive effect on performance characteristics, especially if deformation characteristics are assessed. As has been reported [2] properties in range of low temperatures, which are usually related to frost cracking and similar pavements defects, have not been affected by these additives. The only area where problems can arise is water susceptibility. This phenomenon is partly solvable by application of suitable adhesion promoters.

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Fatigue Behaviour of a Glass Fiber Reinforced Asphalt Mix in 4-Points Bending Test and Damage Evolution Modelling

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Abstract

Fatigue cracking is one of the major causes of asphalt pavement deterioration. One of the methods employed in practice to retard this phenomenon is the inclusion of fiber glass grids coated with special resins in the pavement's structure. The complex asphalt – fiber glass grid is a composite material that proved its role in practice, but nowadays there is still a lack of information concerning the material behavior and its role in the asphalt structure. This paper describes a first study that shows the reinforcement role of fiber glass geogrid on the fatigue behavior of the asphalt layer. The fatigue behavior is studied in two cases: non-reinforced asphalt structure and reinforced asphalt structure. This is achieved with finite element modeling firstly and after that with four points bending tests performed in the laboratory. In the first phase a finite elements model of the fatigue damage evolution is realized with the software Cast3M. The damage evolution is achieved by the Bodin (2002) [7] 'three regimes' law. Two different models are constructed: a simple asphalt specimen and a reinforced asphalt specimen with the fiber glass grid. The comparison of results shows a positive effect of the coated glass fiber grid. In the second phase, a first series of laboratory four point bending tests were carried out with a special device to characterize the elastic behavior of the material under cyclic loading. The fatigue life is estimated on both non-reinforced and reinforced structures and the gain in fatigue life is deduced.

1 Introduction

The service life of an asphalt pavement depends on its performance under the action of traffic loads and thermal stresses. Cracking is one of the major causes of pavement deterioration. The phenomenon known as "fatigue cracking" happens with time and under repeated loadings induced by traffic. Numerous methods are suggested to delay this phenomenon and among them, the use of coated glass fiber grid called "geogrid". This grid started to show its interest in this field in the 90's, when it was used in different applications, such as treatment of cracking produced by thermal changes in rigid and semi-rigid pavements, cracking of flexible pavements and treatment of longitudinal cracks in the case of road extensions. It was observed in practice that the complex made of asphalt and fiber glass grid, called in this work "composite material", has a very good behavior in time under repeated loading. Nowadays the grid is employed as reinforcement of asphalt layers to delay the fatigue crack initiation and propagation.

This work studies the fatigue behavior of this composite material, in order to give more information on the subject. The paper is organized as follow: in section 2 we present the choice of the fatigue test, the device and procedures, in section 3 we describe the materials, in section 4 we show the sample preparation, in section 5 we explain the finite elements model of the Four Point Bending Fatigue Test and the simulation results, in section 6 we present the fatigue test performed in the laboratory and the tests results. The paper ends with the conclusions and perspectives in section 7.

2 Fatigue four points bending test and device

2.1 Choice of the test configuration

The standards [EN 12697-24, 2007] [1] admit four different test configurations to study the fatigue behavior: Two Point Bending Tests on trapezoidal specimens, Three Point Bending Tests or Four Point Bending Tests on prismatic beam specimens and Indirect Tensile Test on cylindrical specimen.

In this work, the study of the composite material behavior under cyclic loading is performed in laboratory using the standard Four Point Bending Test on asphalt beams. The test's importance is recognized [Huurman and Pronk, 2009] [5] and it is favored because failure is believed to happen in an area of uniform stress corresponding to the central part of the beam between the two loading lines. Equations of the beam theory can be applied if some hypotheses are taken into account. These hypotheses consider the materials to be homogeneous and isotropic. In the reinforced specimen it is considered that the grid is perfectly incorporated within the asphalt with a layer of residual bitumen emulsion. Neither the shear phenomenon nor the possible slip of the grid inside the specimen's structure is taken into consideration. Considering the dimensions of the grid, it is also the only fatigue test able to characterize this composite material.

2.2 Four point bending device and procedures

The standard Four Point Bending Equipment is adapted for the dimensions imposed by the tested materials according to the European Standard [EN 12697-24, 2007] [1]. The test configuration is represented in Figure 1 and the bending device used in this work is presented in Figure 2. In Four Point Bending Tests the central part is bent in the vertical direction with a sinusoidal waveform, creating a symmetrical bending around the original position (from a positive to a negative deflexion). The test can be performed with a haversine waveform, where the central part is bent from the initial position to the double amplitude of deflexion. Translation and rotation are free as regards the reactions and the loading lines. The vertical deflexion in the center of the beam is measured at the bottom side with a linear variable differential transducer (LVDT). The material response and the phase angle are measured all along the test.

In the European Standard [EN 12697-24, 2007] [1], the suggested specimen dimensions for the asphalt beam are 450 x 50 x 50 mm. In the case of the geogrid, three coated fiber glass yarns in the width of the beam have been imposed. It results a minimum width of 100 mm and the dimensions of the beam are 620 x 100 x 90 mm.

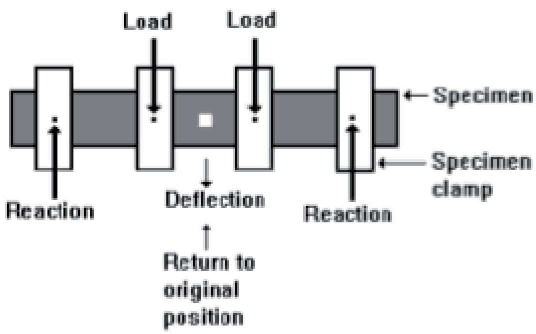


Figure 1: Four point bending configuration

Figure 2: Zwick four point bending device

3 Materials

The tested asphalt mixture presented in Table 1 is a standard BBSG class III after the European Classification [EN 13 108-1, 2006] [3], with an Elastic Modulus of 9 GPaThe geogrid used as reinforcement is the coated fiber glass grid CIDEX 100 SB of 6D Solutions, presented in Table 2. The product is an elastic composite made of warp yarns, filling yarns and a nonwoven part of polyester fiber, forming a mesh of 40 x 40 mm. The warp and filling yarns are made of continuous fiber glass roving and resin. The grid is employed in the pavements rehabilitation as a reinforcement material for the surface course to delay cracking phenomenon. The grid is placed at the interface between surface course and base course with an emulsion made of residual bitumen. The Young Modulus of the warp yarns is 43.0 GPa.

4 Sample preparation

Two types of samples are made and subjected to Four Point Bending Test in the laboratory EPSILON Engineering. There are three steps in the fabrication process (Figure 3) of the asphalt slabs, respectively: the compaction of the first asphalt layer, the insertion of the geogrid with emulsion applied at ambient temperature (22-23°C) and the compaction of the second asphalt layer. The last phase is sawing the 620 x 400 x 90 mm slabs to obtain four 620 x 100 x 90 mm beams. The final structure of the beams' vertical section from the bottom to the top is: 29 mm asphalt layer, 1mm geogrid with bitumen emulsion and 60 mm asphalt layer. In the case of non-reinforced specimens the fabrication remains the same, adding only an emulsion layer between the two asphalt layers. Four specimens are tested: two asphalt beams A1 and A2 and two reinforced asphalt beams RA1 and RA2. The difference between the beams RA1 and RA2 is the number of warp yarns in the width of the beam: two in the case of RA1 and three for RA2.

Table 1: Formula of the asphalt mixture

FORMULA
45% 0/3
15% 3/8
40% 8/15
5,97% BITUMEN 35/50
Compactness 93 – 95%

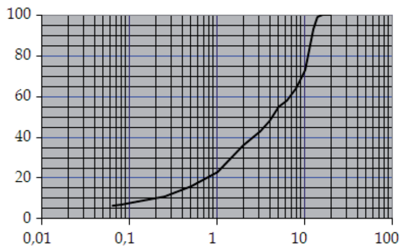
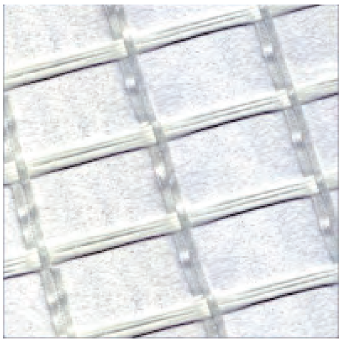


Table 2: Properties of the coated glass fiber grid

GRILLE CIDEX 100 SB – Chomarat Composites
Grid: Fiber glass + resin (type SB): 383 g/m^2
Fiber of polyester : 17 g/m^2
Mechanical resistance at failure : 100 KN/m
Mechanical resistance 1% deformation 35 KN/m
Residual bitumen for embedding: 600 g/m^2
Modulus of Young: 43.0 GPa



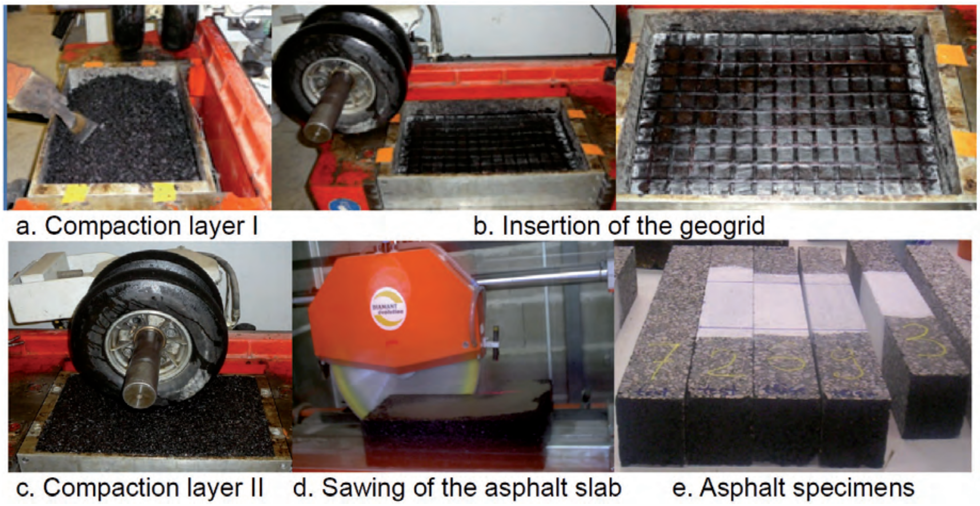


Figure 3: Fabrication process in laboratory (a, b, c, d and e)

5 Finite element model and results

5.1 Finite Element Model

The fatigue of reinforced and non-reinforced asphalt concrete beams under 4-points bending fatigue tests is modeled by finite elements using CAST3M software. The fatigue evolution of the asphalt is derived by the Bodin (2002) [7] model. In this model, the damage variable is introduced as a scalar as presented in the eq. (1):

$$\sigma_{ij} = (1-D)\cdot C^{O}_{ijkl}\cdot\varepsilon_{kl} \tag{1}$$

In which: σ_{ij}, ε_{kl}, C^{O}_{ijkl} are the components of the stress tensor, respectively strain tensor, and elasticity tensor.

$0 \leq D \leq 1$ – damage scalar variable

During the test the damage evolves. This evolution is given by eq. 2:

$$\dot{D} = f(D) \cdot \bar{\varepsilon}^{\beta} \cdot \langle \dot{\bar{\varepsilon}} \rangle \tag{2}$$

In which:

$$f(D) = \frac{\alpha_2}{\alpha_1 \cdot \alpha_3} \cdot \left(\frac{D}{\alpha_2} \right)^{1-\alpha_3} \cdot \exp\left(\frac{D}{\alpha_2} \right)^{\alpha_3} \tag{3}$$

α_1, α_2, α_3 are parameters.
$\bar{\varepsilon}$ and $\dot{\bar{\varepsilon}}$ are the average of the equivalent strain and its strain rate. The Macauley brackets are used to account only the positives values.
β is the slope of the fatigue curve in log – log coordinates

The hypothesis of plane stresses is used to model the asphalt beam. Considering the symmetry of the problem only half of the beam is modeled. In Figure 4 is presented the geometry and the limit conditions. The reinforcement is modeled by linear elements. Two different types of fatigue solicitations are applied; constant strain and constant force alternating loading.

- Geometry
  L = 600 mm, l = 200 mm, e = 10 mm, H = 100 mm, the reinforcement position h = 0 or h = 15 mm.
- Properties of materials
  E_{BC} = 12 GPa and ν = 0.35. The fatigue evolution parameters, of the Bodin 'three regimes' law, are β=4.0, α_1= 5.58*10^{-15}, α_2=0.42, α_3=3.0.

The reinforcement grid is modeled as a non-damageable material with a Young's modulus E = 43 GPa and a Poisson's coefficient ν = 0.35.

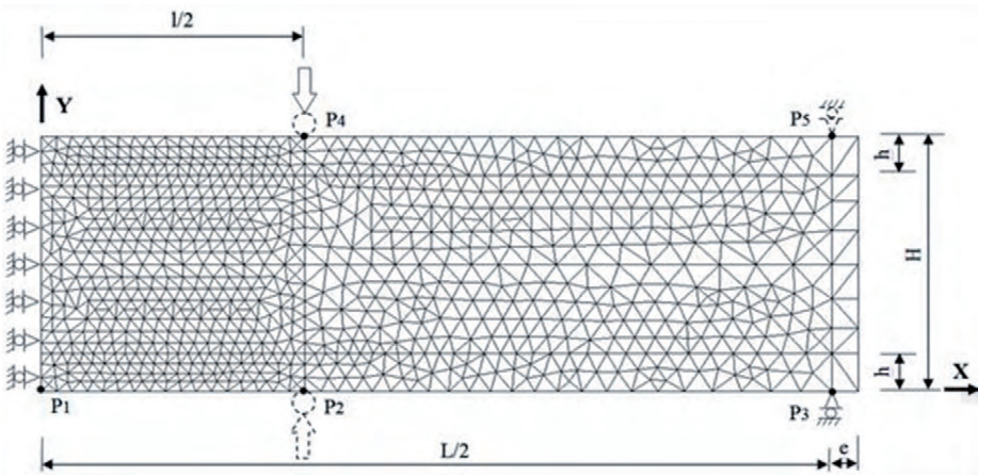


Figure 4: Geometry of the problem

5.2 Results of finite element simulations

Figure 5 presents the damage evolution of the 4-points bending fatigue test under constant deformation loading. In this figure is observed that the third phase of the damage evolution is influenced by the presence of the reinforcement.

Figure 6 presents the damage evolution of the 4-points bending fatigue test under constant force loading. In this figure is observed that the second phase of the damage evolution is influenced by the presence of the reinforcement.

Models are realized under different loading levels. Based on the modeling results we conclude that the reinforcement prolongs the beams' life time by around 25% Fatigue tests and results

5.3 Fatigue tests

The fatigue tests consist of repeated bending and are performed in controlled strain which is kept constant during the test, and in consequence the stresses decrease. During the controlled strain fatigue test, the deflexion is constant and the response of the material is the necessary force to keep the deflexion constant. The tests are performed at 10°C with a 25Hz frequency, values considered in the French Pavement Design Method [Technical Guide, 1998].

The "fatigue resistance" of an asphalt mixture considered in the design of a road pavement represents its ability to withstand repeated bending without fracture [Pais et al., 2009] [6]. The strain value of 200 µm/m was chosen in order to obtain a "fatigue life" of the non-reinforced asphalt mixture close to 100 000 cycles. The fatigue life defined by the European Standard [EN 12697-24, 2007] [1], and accepted by the American Standard AASHTO T321-03, is the number of fatigue cycles corresponding to a decrease to half of the material initial stiffness, or the moment when the force decreases at half of its initial value (criterion I). The initial value is considered after the first 100 cycles. Because there are no existing fatigue criteria concerning the composite asphalt mixtures, another criterion was considered by the authors. The criterion II considers the fatigue life as the number of cycles corresponding to an 80% reduction of the initial material stiffness. Both criteria were considered in the results interpretation. The material stiffness decreases with the number of cycles and, as a consequence, the response force decreases.

5.4 Results of the fatigue tests

The graphic in Figure 7 illustrates the ratio between the measured force and the initial force (in the cycle 100) as function of the number of loading cycles. Three cases are compared, respectively: the non reinforced samples A1 and A2, the reinforced sample RA1 and the reinforced sample RA2. The notion of fatigue life is used to compare results obtained on A1, A2, RA1 and RA2, for each mentioned criterion in Tables 3 and 4.

In the criterion I (Table 3), the reinforcement used in RA1, respectively in RA2, improves averagely, the fatigue life of the non reinforced samples of 1.37 times, respectively of 1.46 times. In the criterion II (Table 4), the reinforcement used in

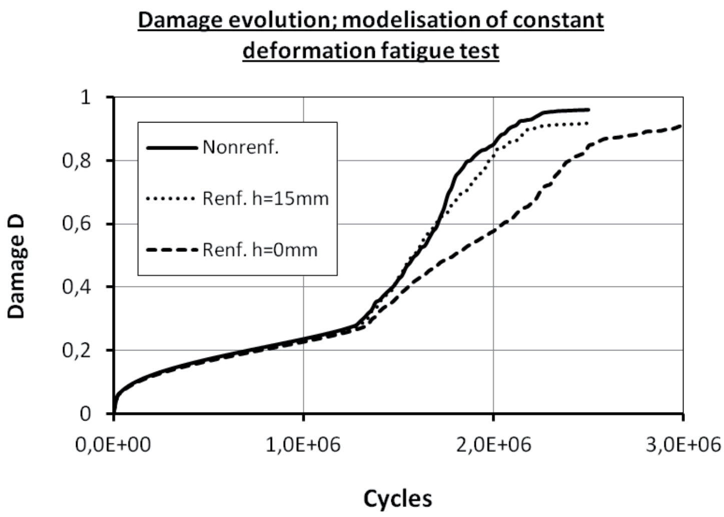


Figure 5: Damage evolution under constant strain fatigue test ε = 130 x10-6

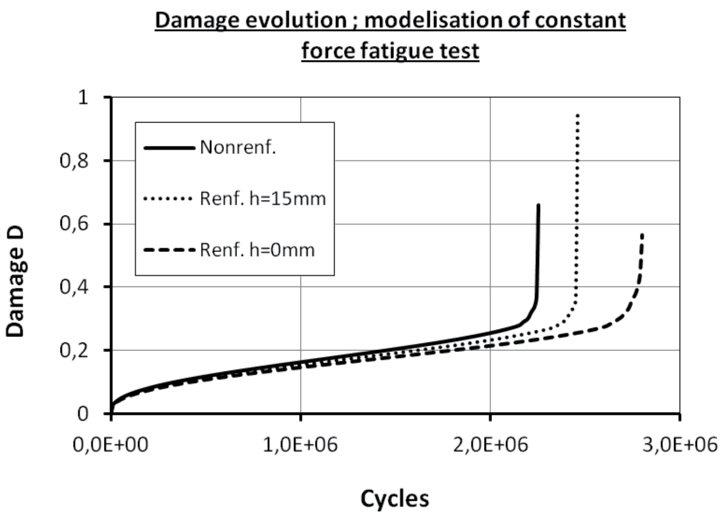


Figure 6: Damage evolution under constant force fatigue test F = 900 N

RA1, respectively in RA2, improves averagely, the fatigue life of the non-reinforced samples of 1.37 times, respectively of 1.68 times. As expected, the results show that the fatigue life of the sample increases with the number of fiber glass yarns. For criterion I, the fatigue life increases with 10% between RA1 and RA2 and for criterion II with 31%. These two criteria considered for the analyses allow the observation of the grid reinforcement role in two intervals of the samples' life cycle. The fatigue life is the same for criterion I and II for the sample RA1, but not for the sample RA2, where the increase in fatigue life is significant. More fatigue tests in Four Point Bending are ongoing to confirm these observations.

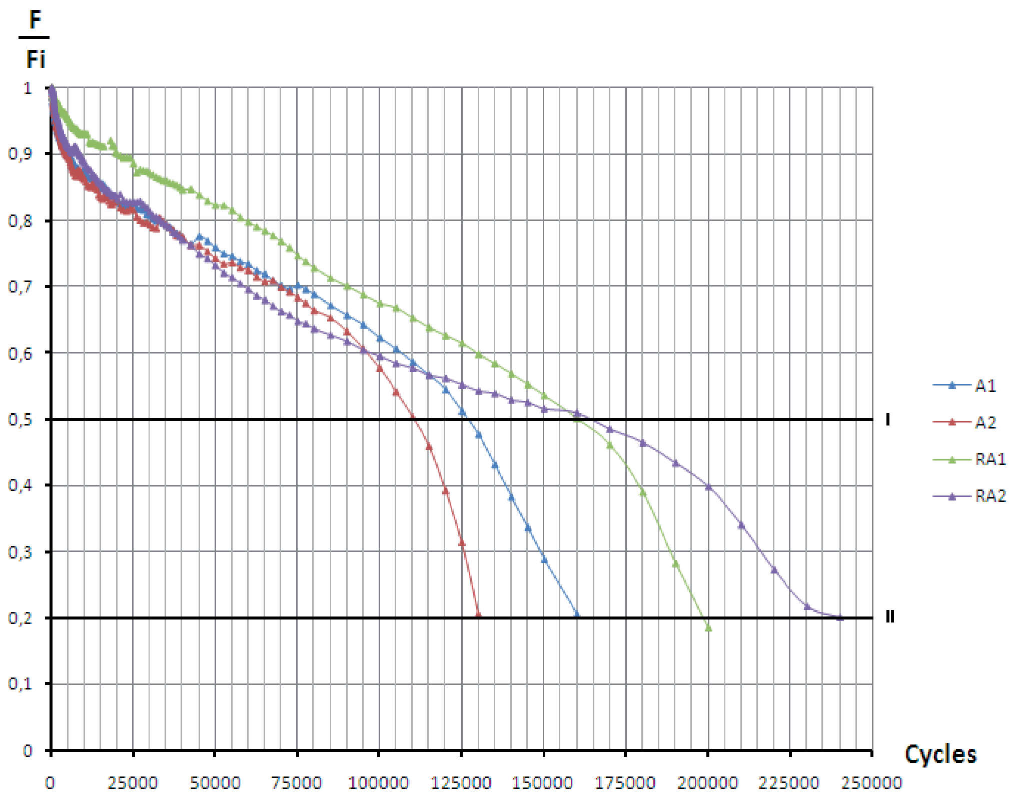


Figure 7: Evolution of the response force during fatigue tests

Table 3: Fatigue life for criterion I

Specimen	N_f	$N_{f1} = N_{fRA1}/N_{fA}$ Average = 1,37	$N_{f2} = N_{fRA2}/N_{fA}$ Average = 1,46	$N_{f1} - N_{f2}$ Average = 0,09
A1	125 000	1,28	1,36	0,08
A2	109 000	1,47	1,56	0,09
RA1	160 000	-	-	-
RA2	170 000	-	-	-

Table 4: Fatigue life for criterion II

Specimen	N_f	$N_{f1} = N_{fRA1}/N_{fA}$ Average = 1.37	$N_{f2} = N_{fRA2}/N_{fA}$ Average = 1.68	$N_{f1} - N_{f2}$ Average = 0.31
A1	160 000	1,23	1,50	0,28
A2	130 000	1,51	1,85	0,34
RA1	196 000	-	-	-
RA2	240 000	-	-	-

6 Conclusions and perspectives

Based on the finite element simulations presented above, we observe that the glass fibers reinforcement offers a prolongation of life time around 25%.

The objective of the Four Point Bending Tests performed in the laboratory was to show the improvement in the asphalt mixtures fatigue life due to the coated glass fiber grid. The number of tested specimens is not sufficient to give a general value of this improvement. However, the fatigue behavior of the composite material confirmed that the reinforcement role should be tested on RA2 type specimens and studied with the criterion II. In this case, we obtain an efficacy of the geogrid of 68%.

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Joos de Momper (1564-1635), Landscape of Winter

Chapter 5: Poster

Climate and Constructions
International Conference, October 24-25, 2011, Karlsruhe, Germany
289–290 (2011)

Sustainable Design for Building Envelope in Hot Climates: A Case Study for the Role of the Dome as a Component of Building Envelope in Heat Exchange

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Abstract

Architectural design is influenced by the actual thermal behaviour of building components, and this depends not only on their steady and periodic thermal characteristics but also on exposure effects, orientation, surface colour, and climatic fluctuations at the location. All these parameters enter into heat transfer computations in a complex manner with the form and shape of the building. The present paper will be carried out with an objective of thermal behaviour assessment and characteristics of the opaque and transparent parts of one of very unique component used as a symbolic distinguished element of the building envelope, and the impact of sol-air temperatures and heat gain. Data will be presented in the light of criteria of indoor thermal comfort in terms of design parameters and thermal assessment for a model dome also. Design alternatives and considerations for energy conservation, will be discussed as well using comparative computer simulations. Findings will be incorporated to outline the conclusions that clarify the important role of the dome in heat exchange for approaching indoor thermal comfort level and further research in the future.

Climate and Constructions
International Conference, October 24-25, 2011, Karlsruhe, Germany
291–298 (2011)

Risk Assessment of Salt Laden Building Materials of Archaeological Sites

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Abstract

Salt weathering is a universal phenomenon affecting rocks and man made materials all around the world. There is an overwhelming literature available on the simulation of salt damage effects. However, most researches deal with single salts. Situations get more complicated if one passes from single salts, of which the deliquescence points are well known, to real practice situations in which building materials contain a complex mixture of ions. The assessment of the critical environmental conditions of salt laden building materials, and hence potential risks of salt damage, requires the knowledge of the thermodynamics of the phase transitions. The conditions of climate to minimise damage can be modelled using a computer program ECOS capable of predicting the crystallization behaviour of salt mixtures. The model requires data of quantitative salt analyses as input. The output enables the user to determine 'safe' ranges of relative humidity and temperature in which phase transitions, and hence salt damage, are kept to a minimum. In this contribution, the approach of the risk assessment of salt laden building materials is explained for two archaeological built constructions, the ice houses of Oudergem (B) and the Cologne Mikveh (G). The results show that ideal climatic conditions for an optimum conservation of building materials of archeological sites, and hence "best practices", can not be defined and depend on the type and content of salt contamination. This as such has consequences for the type of rehabilitation project.

1 Introduction

Crystallization of salts is recognized as a major factor in the degradation of porous materials in built heritage. In the absence of a liquid moisture source crystal growth in a porous material is always the result of a phase transition reaction induced by changes in temperature or relative humidity (RH) [1-4]. Hence, unfavourable environmental conditions may cause repeated cycles of deliquescence-crystallization or hydration-dehydration, which can lead to the decay of building materials.
The assessment of the critical environmental conditions of salt laden porous building materials, and hence potential risks of salt damage, requires the knowledge of the thermodynamics of the relevant phase transition reactions [5]. In the framework of a research project funded by the European Commission, a computer program ECOS (Environmental Control of Salts) was developed capable of predicting the crystallization behaviour of salt mixtures as a tool to predict environmental conditions to minimise salt damage [6-8].
In this contribution, the results of two archeological built constructions are discussed, the ice houses of Oudergem (B) and the Cologne Mikveh (G). The experimental determination of the salt content of building materials is dealt with, in the framework of a proper rehabilitation of the site and a prediction of the behaviour of the salt mixture related to the climate.

2 Methodology - case studies

The methodology of the laboratory research is based on determining the ambient and hygroscopic moisture content as well as the quantitative salt content. The latter is based on quantitative analyses of the soluble salts by means of Ion-Chromatography (Cl^-, NO_3^-, SO_4^{2-},Na^+, K^+, Ca^{2+} and Mg^{2+}). The quantitative data are entered into the RUNSALT [9] software - ECOS thermodynamic model [6].

2.1 Ice houses at Oudergem (B)

The two ice houses at Oudergem were constructed in respectively 1874 and 1894 to stock ice for industrial purposes. Their function disappeared together with the development of modern cooling systems like refrigerators. Completely constructed in brickwork, the ice cellars comprise a unique industrial heritage and witness of historical industrial activities typical for that region. Monitoring of the climate during several months of this non ventilated underground built construction revealed a temperature between 15 and 18°C and a RH not lower than 90 %. In such humid conditions, almost all salts are dissolved in hygroscopic moisture and hence invisible. Today, the question rises concerning the state of conservation in conditions of drying, which might occur in case comfortable climate conditions (RH between 30 and 70% and a temperature between 20 and 26°C [10]) are requested and a ventilation and/or a heating system is installed. Therefore, an environmental assessment was requested as to define the possible environmental modifications as a function of the actual salt load of the porous building materials.

Samples were lifted at different locations, as a function of the architectural concept at different heights and depths. Apart from gypsum it is clear that in case of decreasing relative humidity and hence drying, little or no salts will crystallize if the ambient RH remains above 54%. An example of an ECOS-output is presented in Figure 2. From this research it was shown that the recommended climate of the ice cellars to minimize salt damage is as such that the relative humidity should be at least 54 %.

Figure 1: Ice houses, Oudergem (Brussels, 1874)

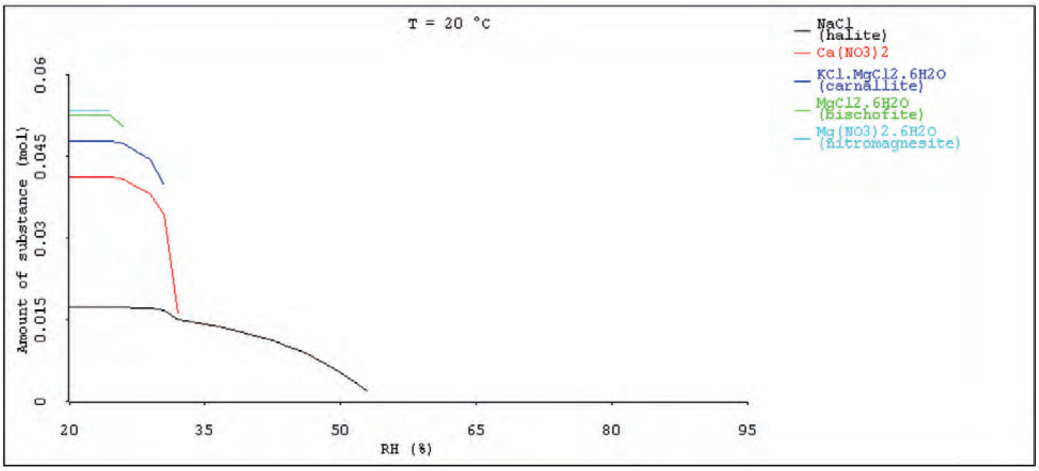

Figure 2: Crystallization sequence of soluble salts using ECOS (mortar,15 cm height, 0-1 cm depth).

2.2 The Mikveh at Cologne (G)

The Mikveh (Figure 3), an underground built construction of 17m depth, is located in the Jewish quarter of the city of Cologne within the Roman town wall. Although its construction date is not exactly known, from archives it is known that the Mikveh already existed when an earthquake caused damage between 780 and 790, after which it got repaired.

The research results showed high ambient moisture contents (up to 100%). These conditions can not be considered as comfortable for visitors and hence the question arises as to what would happen in case the RH is lowered induced by a ventilation system. The investigation has shown that the “sacrificial” plaster applied in the 1970s showed besides a lower moisture content compared to the underlying stone, a different salt load which was explained by inefficient moisture transport between the two. Moreover, a different salt load was noticed depending on the orientation of the walls (north-south). The ion mixture of the underlying stone is locally characterized by an excess of sodium ions, indicative for the presence of sodium carbonate which is known for its destructive properties.

In case the RH is lowered in the Mikveh, it is expected that the plaster starts drying out followed by the masonry. Depending on the conditions of the climate, salt damage in the plaster during its drying is locally expected. During the drying out of the masonry, salt crystallization at the interface plaster-stone as well as in the pore structure of the stone might occur, resulting in destructive crystallization pressures, and this to an extend depending on the climate conditions.

Figure 3: The Mikveh at Cologne during sampling

To define proper climate conditions in the Mikveh in which no phase transitions occur, and hence an equilibrium is reached, the RH should be kept constant at a value of at least 90%. This value is based on the crystallization sequence within the plaster of the north wall characterized by an ionmixture out of which, in case of drying, mirabilite will crystallize first. Hence at conditions of 90% RH the salts in the plaster will remain in solution. For the masonry the value should be adapted to minimize the destructive effects of sodium carbonate. Sodium carbonate can be present in different hydrated forms with transitions occurring up to 97% RH. For an optimal conservation of the masonry the minimum RH in the pore structure should be 97%. Keeping in mind that building materials of this archaeological site are in principle constantly in contact with water present in the surrounding ground as well at the bottom of the Mikveh, one needs to know the real RH at a depth of at least the interface plaster-stone. Hence, the modeling of the moisture transport properties between the plaster and the underlying masonry was considered necessary, which is at present running and will be published later.

3 Conclusions

In this article, the results of two case studies dealing with the experimental determination of the salt content of building materials of archaeological sites in the framework of a proper rehabilitation and the prediction of the behaviour of the salt mixture using ECOS-model are discussed.
The results show that ideal climatic conditions for an optimum conservation of the building materials of archaeological sites, and hence “best practices”, can not be defined and depend on the type and content of salt contamination. This as such has consequences for the type of rehabilitation project.

Acknowledgement

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299 – 306 (2011)

Innovative Building Concepts to Reduce Exergy Consumption and Improve Comfort of Building Occupants

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Abstract

On the path towards sustainability of our future buildings, a new approach to solving the problem of high energy use has to be conceived. The paper deals with the problem of high energy use hierarchically, from the analysis of building envelope characteristics at different locations, to the evaluation of warm radiant exergy in relation to thermal comfort. The new approch of reciprocial consideration of location characteristics, building characteristics and thermal comfort conditions is important for the design of new builing concepts. Test room (163.4 m^3) is located at the Faculty for Civil and Geodetic Engineering, University of Ljubljana. Three cases of building envelope of the test room are located in 3 climatic zones in winter conditions. The problem of high energy use for heating in Slovenia is analyzed with exergy and energy analysis. Results of energy analyses show that the highest energy use appears in the case with less thermal insulation, especially in colder climate. Results of exergy analysis are the same as those of energy analysis. The main difference appears, if the whole chain of supply and demand is taken into consideration. The most effective solution is to improve building envelope together with boiler efficiency. Better thermal insulation also causes higher surface temperatures resulting in a larger warm radiant exergy emission rate and consequently better thermal comfort.

1 Introduction

To attain targets of EPBD Directive 2010/31/EU [1], a new approach of solving problems related to high energy use has to be conceived. The problem of high energy use for heating is tretated hierarchically, from the exergy and energy analysis of building characteristics at different locations, to the evaluation of warm radiant exergy in relation to thermal comfort. The new approcah is important for the design of new builing concepts and their application in near zero energy buildings.

2 Methodology

Test room (163.4m^3) is located at the Faculty of Civil and Geodetic Engineering, University of Ljubljana. It has one exterior wall with 15 m^2 glazed window, other walls are interior. Building heating energy demand was calculated as a result of steady state energy analyses with a computer program called TOST. The exergy consumption was analyzed from the supply side to the demand side (from boiler to building envelope) by following the calculation procedure described by Shukuya [2, 3]. Calculation of thermal radiant exergy flow rate from a unit area of building wall surfaces is based on equations given by Shukuya [2, 3]. Three cases of exterior building walls were assumed: Case 1, in situ test room with poor thermal insulation of the building envelope (U_{cu}=1.29 W/m^{2}K, U window=2.90 W/m^{2}K, n=1.0); Case 2 (U_{reg}=0.28 W/m^{2}K, U window=1.14 W/m^{2}K, n=0.7) and Case 3 (U_{add}=0.15 W/m^{2}K, U window=1.14 W/m^{2}K, n=0.7) with improved insulation and unchanged boiler efficiency. In Case 2/1 ($U_{reg+eff}$) and Case 3/1 ($U_{add+eff}$) additionally boiler's efficiency is improved from 0.80 to 0.95. Three cases are located in 3 climatic zones in winter conditions (climatic zone I: Koper, Mediterranean part, T_{avg} 8.4°C; climatic zone II: Ljubljana, Continental part, T_{avg} 5.5 °C; climatic zone III, Rateče, Alps, T_{avg} 4.9 °C). Room air temperature was assumed to be constant at 20 °C.

3 Results

3.1 Average heating energy demand

Maximal average heating energy demand appears in Case 1 in Zone III, Alps (1968 W), mainly due to high transmission losses through poorly insulated building envelope (1299 W). The average heating energy demand in Case 1 in Zone II, Continental is 1898 W. Minimal average heating energy demand appears in Case 3 in Zone I, Mediterranean (663 W), mainly due to low transmission losses through well insulated building envelope (302 W). Maximal decrease of average heating energy demand appears in the Alps, because of additional thermal insulation, improved windows and air tightness (Case 1 - Case 3: 56% or 1108 W decrease of average heating energy demand and 70% or 907 W decrease of transmission losses).

3.2 Exergy consumption patterns

Table 1 shows a comparison of accumulated exergy consumption rate for four stages of space heating, for Case 1, Case 2 and Case 2/1 in Ljubljana. Exergy consumption is represented by the difference in exergy between input and output. For example, in Case 1 (U_{cu}) 2003 W of exergy are supplied to the boiler and 299 W of “warm” exergy are produced and delivered to the heat exchanger by hot water circulation. Their difference, i.e. 1704 W, is consumed inside the boiler due to combustion. The exergy input of 2003 W (Case 1, U_{cu}) also presents the total exergy consumption rate in the whole process of space heating. The value of the average heating energy demand calculated by TOST (1898 W) could be compared with the space heating exergy demand (1705 W) that causes all other portions of the exergy consumption in the whole process of space heating. The results of exergy analysis are the same as those of energy analysis, if the comparison is made only for the energy supply and exergy supply. The small difference appears because of calculation approaches.

Exergy consumption within the boiler is the largest among the sub-systems. For this reason it may be considered that the improvement of boiler efficiency is essential. Case 2/1 ($U_{reg+eff}$) presents the situation after boiler improvement (from 0.8 to 0.95). The decrease of exergy consumption rate is marginal (161 W). The next intervention is improvement of buidling envelope. Improvement of building envelope in Case 2 (U_{reg}) causes dramatic decrease of exergy supplied to the boiler (from 2003 in Case 1 to 1016 W of exergy consumption rate in Case 2). Exergy output in Case 1 (U_{cu}) is also the highest among these cases (299 W). Exergy consumption rate inside the boiler to combustion is decreased with improved thermal insulation (from 1704 W to 864 W). The extremely high boiler efficiency alone cannot make any significant contribution to the reduction of exergy consumption rate in the whole process of space heating. It can be established that the heating exergy load, which is the exergy output from the room air and the exergy input to the building envelope, is 84 W in Case 1 (U_{cu}), 43 W in Case 2 (U_{reg}) and Case 2/1 ($U_{reg+eff}$), 41 W in Case 3 (U_{add}) and Case 3/1($U_{add+eff}$). It is only 6 to 7% of the chemical exergy input to the boiler, so that introduction of a measure to reduce the heating exergy load may be considered as marginal. However, as can be seen from the difference in the whole exergy consumption profile between Case 1 (U_{cu}) and Case 2 (U_{reg}), it is more beneficial to reduce the heating exergy load by installing thermally well-insulated glazing and exterior walls (difference between Case 1 - Case 2: 987 W reduction) than to develop a boiler with extremely-high thermal efficiency (difference between Case 2 - Case 2/1: 161 W reduction) in order to decrease the rate of total exergy consumption. The reduction in exergy consumption rate of the boiler sub-system due to the improvement in boiler efficiency turns essentially meaningful together with the improvement of building-envelope’s thermal insulation (difference between Case 1 - Case 2/1: 1148 W reduction). The improvement of boiler efficiency becomes meaningful once the thermal insulation of the envelope is improved.

Table 1: Comparison of exergy consumption rate (W) for 4 stages of space heating, Continental part (Zone II), Slovenia.

Zone II	Boiler [W]	Heat exchanger [W]	Room air [W]	Building envelope [W]
Case 1 U_{cu}	2003	299	111	84
Case 2 U_{reg}	1016	152	56	43
Case 3 U_{add}	983	147	54	41
Case 2/1 $U_{reg+eff}$	855	152	56	43
Case 3/2 $U_{add+eff}$	827	147	54	41

Table 2: Comparison of exergy consumption rate (W) for 4 stages of space heating, Alps (Zone III), Mediterranean part (Zone I).

Alps, Rateče	Boiler [W]		Heat exchanger [W]		Room air [W]		Building envelope [W]	
Zone	III	I	III	I	III	I	III	I
Case 1 U_{cu}	2086	1603	315	228	119	76	92	54
Case 2 U_{reg}	1058	813	160	116	60	38	46	27
Case 3 U_{add}	1023	786	154	112	58	37	45	27
Case 2/1 $U_{reg+eff}$	891	684	160	116	60	38	46	27
Case 3/2 $U_{add+eff}$	862	662	154	112	58	37	45	27

In the Alpine area 2086 W of exergy are supplied to the boiler and in the Mediterranean part 1603 W (Table 2). In the Alpine area 315 W of “warm” exergy are produced and delivered to the hot water heat exchanger and in the Mediterranean part 228 W. 1771 W of exergy are consumed inside the boiler due to combustion in the Alpine area and 1375 W in the Mediterranean part. These values are significantly different from those in the Continental part regarding different environmental temperatures.

3.3 Radiant exergy flow rate from interior surfaces

Beside thermal energy and exergy flows through building envelope, another aspect from the viewpoint of comfort should also be considered. This is “warm” radiant exergy available from the wall surfaces. The increase of radiant exergy coming from the interior surfaces of the exterior building walls is related to higher surface temperatures on thermally well insulated building walls. Thermally well insulated walls have higher surface temperatures and thereby contribute more to comfort conditions inside the heated indoor environment space.

The amount of warm radiant exergy flow rates available from interior surfaces of our test room in Ljubljana is low (1458 mW/m^2) due to poor insulation (U_{cu}=1.29 W/m^{2}K) (Fig.1). Better insulation makes possible a larger amount of warm radiant exergy flow rate, especially in the Alps (2189 mW/m^2 in Case 3) and also in the Continental part (2016 mW/m^2 in Case 3). Higher surface temperatures are provided by thermally well insulated wall in the manner of linearity. The surface temperatures in the Continental part are 17.6 °C in Case 1 (U_{cu}), 19.5 °C in Case 2 (U_{reg}) and 19.9 °C in Case 3 (U_{add}). The surface temperatures in the Alps are 17.5 °C in Case 1 (U_{cu}), 19.5 °C in Case 2 (U_{reg}) and 19.7 °C in Case 3 (U_{add}). The surface temperatures in the Mediterranean part are 18.1 °C in Case 1 (U_{cu}), 19.6 °C in Case 2 (U_{reg}) and 19.8 °C in Case 3 (U_{add}). If the three cases at one particular location are taken into consideration, the differences between surface temperatures or warm radiant exergy flow rates are quite significant (0.4 °C - 2.3 °C or 68 - 558 mW/m^{2}K among the cases in the Continental part). If changes in the surface temperatures together with warm radiant exergy flow rates for three cases at different locations are taken into the consideration, the differences also become considerable. The difference between Case 1 in the Alps and Case 3 in the Mediterranean is almost 2.3 °C for surface temperatures and 300 mW/m^2 for warm exergies.

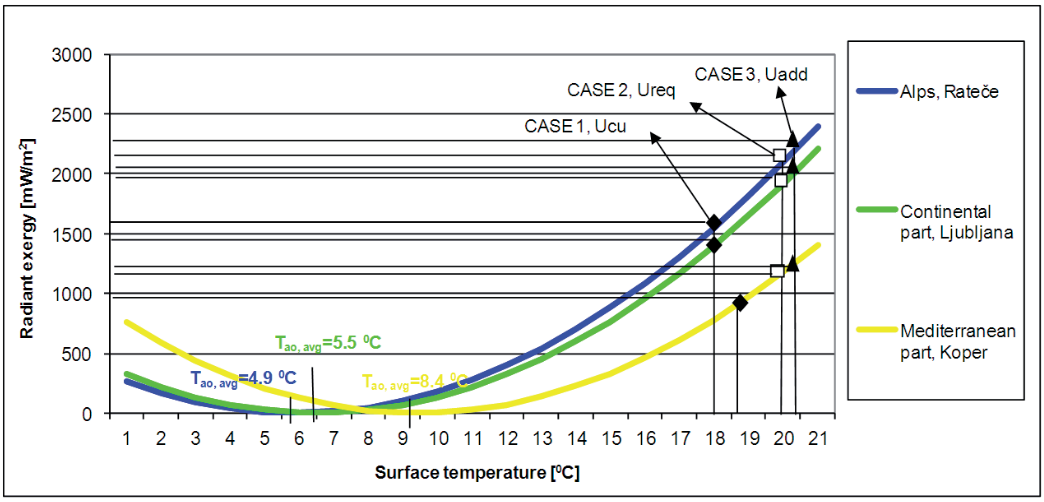

Figure 1: Radiant exergy flow rates for three cases of exterior walls in three climatic zones

4 Conclusions

Exergy analysis enables a more precise insight into how exergy is consumed, more or less at every step in the process of space heating. Exergy analyses bring better understanding of the problem, show possible solutions and enable the search for an effective and practical solution to minimize the building exergy consumption. The most effective solution is holistic approach, i.e. improvement of boiler efficiency together with thermally well insulated building envelope. Better thermal insulation also causes higher surface temperatures resulting in a larger warm radiant exergy emission rate and consequently better thermal comfort. Reciprocial consideration of climatic characteristics, building characteristics and thermal comfort conditions is important for the design of new builing concepts and their application in near zero energy buildings.

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Assessments of the Outdoor Thermal Conditions in Szeged, Hungary: Perceptions and Preferences of Local Individuals

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Abstract

This study presents the connections found between the subjective thermal comfort assessments of Hungarians and the prevailing thermal conditions during seasons suitable for staying outdoors. The former was measured using questionnaires (ca. 1300) in the city of Szeged (Southeast-Hungary), which contained queries about thermal sensation and perception of the individual meteorological parameters (air temperature, humidity, wind and solar radiation) and also the desire of changing them, i.e. the thermal preferences. The relevant parameters of thermal comfort (air temperature, relative humidity, wind velocity, mean radiant temperature, physiologically equivalent temperature-PET) were measured or determined at the height of 1.1 m, near the interviewees. Taking into account the large number of data relatively strong inter-relationships have been arisen in the case of the subjective assessments. If a parameter was perceived weak (low) then it was usually desired to be stronger (higher). Thermal sensation relates stronger to the individuals' air temperature and solar radiation perceptions (positive correlation), than to their perceptions about wind velocity and air humidity (negative correlation). Examination of subjective reactions against the objective parameters set light on Hungarians pronounced sensitivity against the variations of the radiant environment, while they react less to the changes of humidity. Replacing the basic parameters to PET we obtained weaker correlations with the perceptions and stronger relationships with preferences of all the individual parameters, except the humidity preference. Above PET=27-28°C Hungarians wished for lower air temperature, more air movement and less solar radiation.

1 Introduction

Thermal comfort in outdoor settings has received more and more research attention in the last decade [1-3]. To study outdoor thermal comfort detailed information needed about the area itself and the thermal conditions evolved there as well as about the visitors and their subjective assessments. This paper presents the influences of the momentary thermal conditions on the thermal comfort-related subjective reactions of Hungarians.

2 Materials and methods

Interviews were carried out with simultaneous micrometeorological measurements in five recreational areas of Szeged, Hungary (46°N, 20°E, 82 m asl). Data were collected on 37 weekdays during autumn of 2009, spring of 2010 and summer of 2011. The questionnaires concerned the subjective assessment of the thermal environment [1-3]. The visitors reported their thermal sensation vote (TSV) using a semantic differential scale with 9 main nominal categories from very cold to very hot. Perceptions about the momentary air temperature, wind velocity, air humidity and solar radiation were measured by 7-point scales (ranging from weak-low to strong-high) and the preferences for better conditions in the case of these parameters by 3-point scales (decrease/no change/increase).

On-site meteorological data have been obtained near the interviewees by a mobile station equipped with Vaisala and Kipp&Zonen sensors in the height 1.1-1.2 m. The station includes a rotatable net radiometer to receive the short and long wave radiation fluxes (K and L) from the 6 main directions in order to estimate the mean radiant temperature (Tmrt [°C]) [4]. The measured air temperature (Ta), relative humidity (RH), wind velocity (v) and the obtained Tmrt were used to calculate the thermal comfort index Physiologically Equivalent Temperature (PET [°C]) [5].

3 Results and discussion

Most of the 1271 interviews were carried out within a Ta range of 24-27°C, although values below 15°C and above 30°C also occurred. Wind speed fall mainly between 0.5-3.3 m/s with a maximum v of 6.7 m/s. RH values between 25 and 50% dominated, but some interviews took place at 70-75%. Tmrt incorporate a range of 10-67°C. PET index cover the range from 6 to 48°C and the slightly warm class (23-29°C) occurred most frequently.

The predominant TSV was the slightly warm (1), followed by the warm (2) and neutral (0) votes. Regarding the estimated climate factors perception and preference values of 0 were the most frequent and extreme perception votes (-3 or +3) hardly occurred. The proportion of 0 perception vote is conspicuously high in the case of relative humidity and air temperature, and overall the people felt the former lower (-2, -1) while the latter higher (1, 2). The distribution of the perception votes in the cases of wind and solar radiation is more balanced, and the overall perceptions reflect that the air was calm-moderate (-2 to 1) and the sunshine was strong (0 to 2). The high proportion of 0 preference votes (50-75%) reflects that people were mainly satisfied with the prevailing meteorological parameters.

In favour of the more clear evaluation the percentage distribution of the preference votes by perception categories were also investigated for every climate parameters (Figure 1). As the higher or stronger was felt a parameter the more people desired it to be lower or weaker. All of the presented relationships are significant (?<0.001); the Spearman rank-correlation coefficients between perception and preference votes in the cases of all parameters are relatively large: =-0.584, -0.457, -0.397 and -0.511 for air temperature, wind, humidity and solar radiation, respectively.

The next two figure-series (Figure 2 and 3) show the relationships between the thermal sensation and the evaluations regarding the particular climate parameters. TSV has the strongest correlation with the perception of air temperature and solar radiation (=0.613 and 0.451). As the perception votes increased (temperature felt higher and solar radiation stronger) the ratio of the higher TSV-s also increased gradually (Figure 2). In the case of wind and humidity perceptions the relationships are not so unequivocal: the coefficients are smaller, moreover their signs are negative (=-0.226 and -0.188).

As expected the connections between the TSV and preference votes have opposite directions compared to the TSV-perception relationships (Figure 3). Accordingly, coefficients for preferences of air temperature and solar radiation are negative (=-0.488 and -0.405), while for preferences of wind and humidity the connections are positive (=0.330 or 0.081).

We explored also how sensible the visitors are at the perception of the particular objective parameters. Even in the case of the same environmental conditions subjective perceptions may differ remarkably, thus perception values were averaged and plotted against the objective variables (Figure 4). Temperature perceptions were averaged for each 0.5°C Ta bin, resulting N=45 discrete values (Figure 4a). The interval-widths were 0.1m/s v for wind (N=47), 1% RH for humidity (N=46) and 1°C Tmrt for solar radiation (N=54) perceptions (Figs. 4b-d). The slopes of the fitted lines indicate the sensitivity of respondents against the objective variables. The lowest slope value was found in the case of humidity and the largest at solar radiation, as the obtained mean perception values are in the narrowest range in the former case (from -1 to +1) and in the wider range in the latter case (from -2.5 to +3). The fitted regression lines give the best determination coefficients in the cases of Tmrt - solar radiation and Ta - air temperature perceptions: R^2= 0.874 and 0.85, respectively.

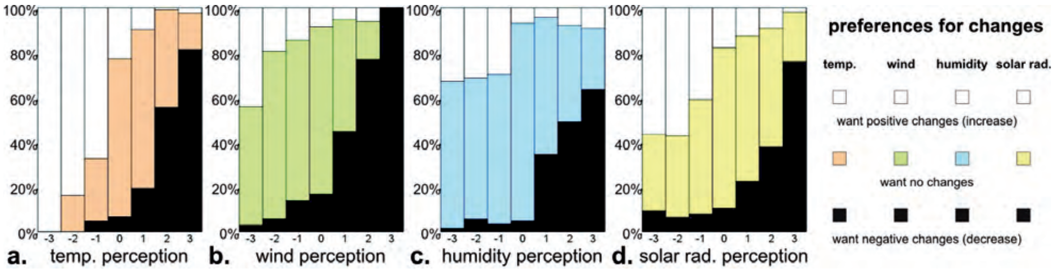

Figure 1: Relationships between perception and preference votes

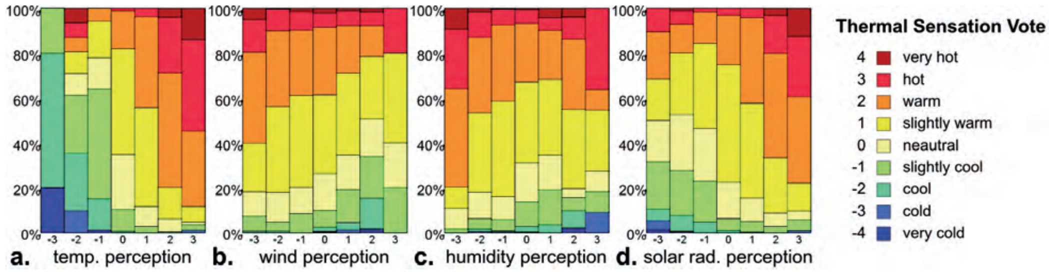

Figure 2: Relationships between the thermal sensation and perception votes

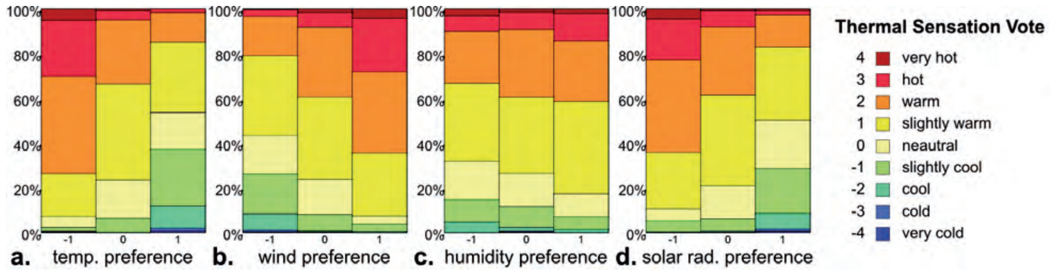

Figure 3: Relationships between the thermal sensation and preference votes

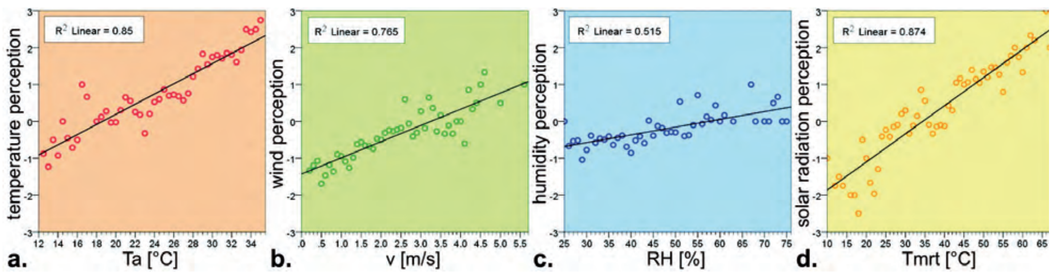

Figure 4: Mean perception votes vs. corresponding meteorological parameters

As expected, we found are negative relationships between the mean preference votes and the corresponding objective parameters (Figure 5). The Ta - temperature preference connection is the strongest (R^2=0.883) followed by the Tmrt - solar radiation preference (R^2=0.798), v - wind preference (R^2=0.621) and finally, the RH - humidity preference (R^2= 0.379). According to the determination coefficients the correlation of Ta with the corresponding preference vote occurs stronger than with the perception (R^2=0.883 and R^2=0.85, respectively), while the Tmrt, v and RH are in a stronger connection with the visitors' perception votes than with their preferences.

A row of diagrams (Figure 6) with PET values on the x axis (1°C bin, N=42) instead of Ta, v, RH and Tmrt help us to reveal whether the connections of the subjective evaluations with the corresponding meteorological parameters are stronger or with the combined effect of the climatic factors.

The relationships with PET are weaker in the case of perception votes (Figure 6a-d) and stronger in the case of preference votes (Figure 6e-h) than with the corresponding objective parameters. Exception is only the humidity preference. In the cases of wind and humidity the relations have different signs: at the increase of the PET values the people's perception-votes become lower, while the preference-votes higher. According to the fitted regression lines, people prefer for lower air temperature, stronger wind and less sun from PET = 27-28°C (Figure 6e, f, h), which values are in the category of slight heat stress or slightly warm thermal sensation (based on the PET-scale referring to Central-Europeans). Visitors wanted the decrease of humidity below PET = 24.7°C (Figure 6g).

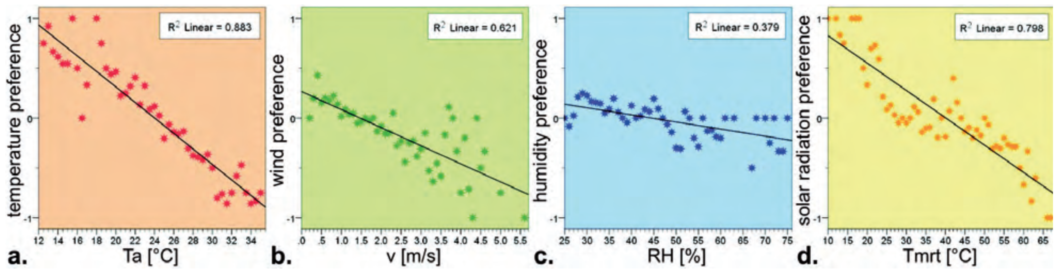

Figure 5: Mean preference votes vs. corresponding meteorological parameters

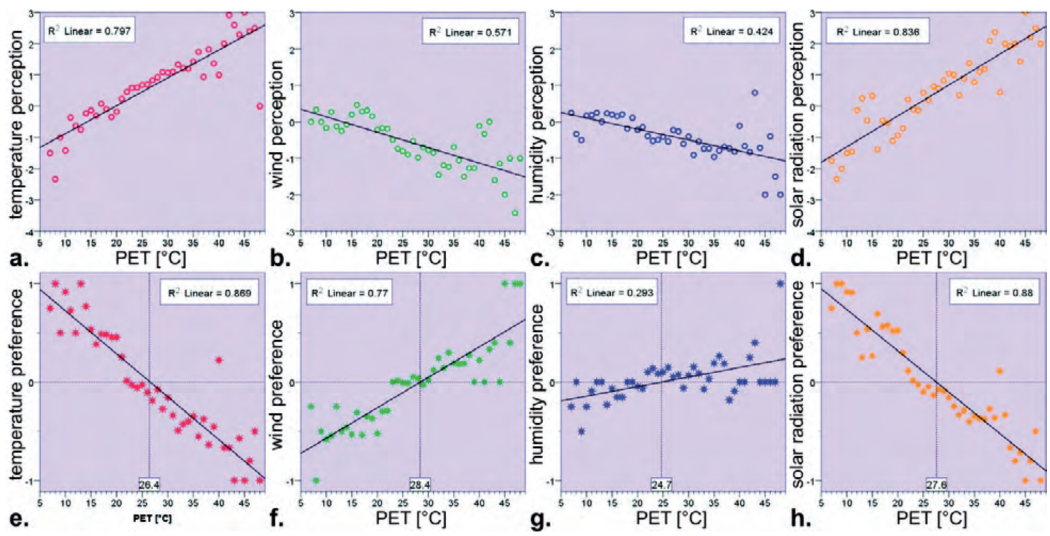

Figure 6: Mean perception votes (a-d) and preference votes (e-h) vs. PET index (N=42)

4 Conclusions

This paper introduced a Hungarian thermal comfort study carried out in seasons suitable for outdoor staying. Besides the on-site meteorological measurements 1271 visitors were asked to assess the thermal conditions. The correlation coefficients between the perceptions and preferences indicate strong negative relationships in the cases of all meteorological variables, from which that refers on humidity is the weakest. Subjective thermal sensation relates stronger to the individuals' air temperature and solar radiation perceptions (positive correlation), than to their perceptions about wind velocity and air humidity (negative correlation).

Examination of subjective perceptions against the objective parameters of thermal environment (Ta, v, RH, Tmrt) set light on Hungarians pronounced sensitivity against the variations of the radiant environment (Tmrt) while people react less to the changes of humidity (RH). Replacing the basic parameters to PET we obtained weaker correlations with the perceptions and stronger relationships with preferences of all the individual parameters, except for the preferences for humidity. A "set-point value" has been arisen around PET=27-28°C, i.e. above this value Hungarians wished for lower air temperature, more air movement and less solar radiation.

Acknowledgement

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Climate Control of Underground Built Structures

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Abstract

Underground archaeological remains are often made accessible for the general public after excavation. In some cases, a climate system is installed as the visitor centre is opened, which is as such only rarely controlled afterwards to verify whether and to what extent the original objectives for the climate are met. However, the climate conditions with respect to the requirements for the public health and comfort may well conflict with an optimal protection strategy. The control of the climate in these underground structures and their surroundings is therefore essential to protect them from future degradation. Such a control of the climate as part of a preventive conservation strategy can be defined as an indirect action aiming at increasing the life expectance of archeological remains, and at keeping them in a preferred state where minimum damage and/or deterioration occurs. Two case studies will be presented to illustrate some of the problems met when underground structures become part of the public space: the icehouses and the Coudenberg archaeological site and museum with the remains of the former palace of Charles V, both in Brussels.

1 Introduction

Conservation of underground archaeological remains accessible to the public requires an assessment of the delicate balance between the requirements for public health and safety and for the protection of the archaeological remains from future degradation. Such a control of the climate as part of a preventive conservation strategy can be defined as an indirect action aiming at increasing the life expectancy of the archaeological remains, and at keeping them in a preferred state of conservation where minimal damage and/or deterioration occurs.

2 The icehouses of Oudergem

The icehouses of Oudergem (Figure 1) were constructed in two phases (1875 and 1894) to store during winter periods collected ice necessary for the production of beer in the neighboring brewery 'Brasserie de la Chasse Royale' [1]. Having a storing capacity of 5000 m³, they are today, as far as we know, the last remaining relicts of their size in the Brussels region and a unique witness of the industrial activities at the end of the 19th century.

Figure 1: general view on the first icehouse from 1875 (left) and the second icehouse from 1894 (right) (© KIKIRPA)

The study of the climate within the icehouses serves two objectives: i) to assess the appropriate climatic conditions for material conservation and ii) to ascertain the installment of such climatic conditions within the context of the planned development of the site. A major problem for the conservation of underground structures within an urban context is a lack of visibility, which makes them in a certain sense unknown and undefended by the general public. The icehouses are a typical example: they are listed as a monument and the property of the Brussel's university VUB, while the site itself was sold to a real estate-agent, who plans to construct a huge complex of offices.

The climate within the icehouses has been studied under conditions of a natural ventilation between April 2008 and February 2011 (Figure 2). The natural ventilation is driven by an inlet at the north-east side of the first icehouse and an outlet, topped by a chimney, at the south-west wall-end of the most recent icehouse. A door opening and one opening close to the ceiling in the wall between both icehouses ensures a ventilation between them.

A study of the natural ventilation of the icehouses evidences that the internal climate is almost entirely buoyancy driven. Measurements taken in September 2009 reveal a temperature gradient in function of the height of ca. 0.15°/m, while a comparison between the climatic records of the oldest icehouse and the inlet demonstrate that drying only occurs during the winter period when the outside air temperature is at average lower than the temperature within the icehouses. In such conditions, the dry outside air flows into the icehouses, replacing the warmer, more humid air inside. In the summer, the air within the icehouses moistens again to regain a relative humidity of 100%, probably due the effect of moisture transport through the walls.

Based on the experimental analysis of the presence of a number of different anions and cations and a thermodynamic modeling, a maximum of 54% of relative humidity has been identified to prevent damage accumulation due to salt crystallization cycles [2-3]. Currently, the relative humidity drops to a minimum of approximately 80%, which is still far sufficient to prevent material damage. However, whenever lower temperatures would be attained over a longer period, humidity levels could drop to even lower levels. A condition which necessarily depends on the external climate. However, another issue lies within the construction plans of the surrounding office and parking lots, which could hinder or even prevent the rehumidification of the underground structure during the summer. If so, a continuous drying year to year could be the effect, with an increasing risk in material damage as consequence. For now, the construction works are not yet scheduled, but the monitoring of the climate is planned in the coming years in order to take the necessary action whenever needed.

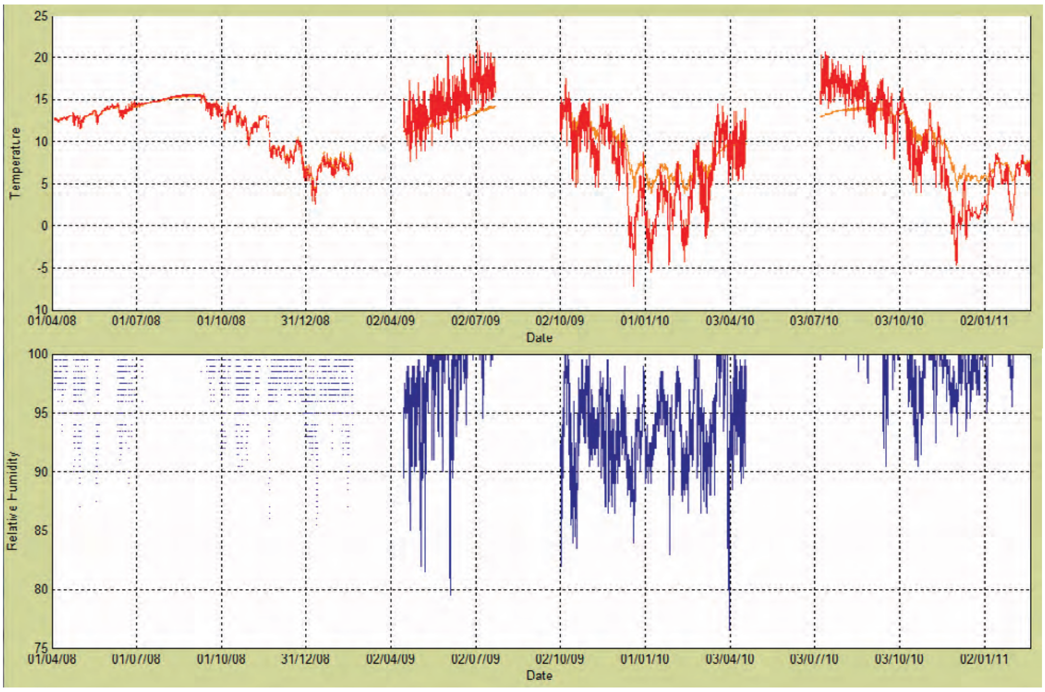

Figure 2: Comparison of the temperature evolution between the inlet, showing a strong influence of the outside climate (red), and in the middle of the oldest icehouse (orange). Below the evolution of the relative humidity over the same period is given within the oldest icehouse (blue). During the first year both dataloggers were situated within the oldest icehouse, showing a neglectable difference in temperature.

3 The archaeological remains of the former palace of Charles V on the Coudenberg hill

During the middle ages, the palace of the Dukes of Brabant towered the city of Brussels. However in the night of February 3th 1731 tragedy struck and a huge fire destroyed the entire palace. After years of abandon, the remains were partly buried and partly integrated into the neighboring houses in a rehabilitation project of the area. In 2000 the excavation of the remains, now laying under the Royal Square, next to the Royal Palace, was started and the underground site was opened for the public in 2004 [4-5].

As part of a conservation strategy of the whole site consisting of a complex of different connected volumes, illustrated in Figure 3, the climate was monitored to understand the complexity of the actual climate control and to assess risks to the material degradation. A total of 26 dataloggers were installed on the site.

Figure 3: Map of the archaeological remains of the former palace of Charles V on the Coudenberg hill. The main building remains are the chapel (orange) and the basement (kitchen area) of the Aula Magna (green), which was the main reception hall of the palace. All along the palace a street, the Isabella street (grey), went up to the main entrance South of the Aula Magna. The basement of the living quarters (blue) of the former palace are connected with the chapel.

A large area of the site is influenced by a rudimentary ventilation system, currently installed near to the choir area of the chapel, which simply blows air from the exterior, heated to the desired temperature, all along the chapel. The air flow influences the entire chapel area, as well as the neighboring living quarters and the down area of the Isabella street. Daily fluctuations can be observed, especially on the relative humidity, as well as in the weekends when the ventilation system didn't function. These important daily variations remained unnoticed during the previous monitoring phase, since temperature and relative humidity readings were noted every day at a fixed hour, and hence, systematically pinpointing the climate conditions at almost exactly the same spot. In addition, from our monitoring campaign,a non systematic functioning of the ventilation system, which sometimes chanced the desired temperature level without any particular reason, was concluded. At a certain moment the air was even heated up to 26°C.

In winter seasons, a simply heating of external cold air blown inwards results in a significant lowering of the relative humidity (values down to 15% relative humidity have been measured), with the drying out the masonry and salt crystallization as consequences. Indeed, a systematic research carried out on the salt contamination confirmed that the actual climate conditions favor salt crystallization and the resulting material loss. Further, such low values of relative humidity are inappropriate for the human health and comfort. In awaiting of an alternative solution, which should preferably control the humidity of the air rather than its temperature, the ventilation system is currently shut down.

Different from the chapel area, the remains of the Aula Magna are entirely influenced by the external climate. A number of ventilation shafts in the ceiling open up the subterranean area to the public square above. The temperature and the relative humidity of the underground area follow the daily variations of the external climate, however to a lesser extent. In general, a rather high relative humidity is observed most of the time, which increases even further near to the bottom as capillary moisture is absorbed by the floor and brickwork walls. Such conditions favor the growth of mould as noticed on site and rendering strengthening interventions more complex.

4 Conclusions

Monitoring the climate of underground structure is essential to define an appropriate conservation strategy, including the assessment of the climate conditions, to i) define the potential risks of material damage, ii) to define the appropriate materials and conservation techniques and iii) to assess the proper functioning of climate installations and achievement of the desired climatic conditions.

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The Effect of Land Use Change on Urban Climate in Case of Addis Ababa, Ethiopia

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Abstract

This paper identifies the effect of land use change on climate of Addis Ababa. A satellite image was utilized for the assessment of land use change. The city climate change studied using temperature and rainfall observation data. Surface temperatures pattern was also studied to investigate the urban heat island (UHI) effect associated with increasing impervious surfaces both spatially and temporally. The spatial analysis of total population and density of each sub-city obtained from the State statistics institute. Finding from this study shows that urban land use coverage significantly increased from 35% in 1973 to 74% in 2005. The 2006, tota population density of the city as compared with year 2000 increased by 1624 persons/km^2. There is an evidence for urban climate change in Addis Ababa city. The annual surface warming of maximum temperature induced by urbanization is increase in every ten year in Addis Ababa (OBS) than Addis Ababa Bole. Increase in maximum temperature, in urban Addis (OBS) Station larger than the Bole rural station being 0.55°C and 0.27°C respectively. The result of this change can have significant effects on city local weather and its climate. The study also recommends an adaptation measures to reduce the negative effects of urban climate change.

1 Introduction

Urban areas are the most dynamic region on earth. Their size has been constantly increasing during the past and this process will go on in the future. Especially in developing countries a strong trend towards the concentration of people in urban areas can be observed. Human population in the world has more than doubled during the past 50 years, passing the 6 billion mark in 2000 and now approaching the 6.5 billion mark. This overall growth is mainly driven by the growth of population in less developed countries; however the number of people living in developed countries remains more or less the same and is predicted to decrease in the second half of this century (Moeller, 2005). Cities and urbanized areas are the social centers of our modern life and they provide most of our daily needs. They promise security, welfare and a place where people may find better living conditions compared to rural areas. As a consequence urbanized areas have become the densest populated regions on earth over the past (United Nations, 2002).

Landscapes will always change, as they are the expression of the constant interaction between natural and cultural forces in the environment. Applied to an urban/peri-urban case, changes are seen as a menace.Urban growth, both in population and in constructions of areal extent, transforms the landscape from natural cover types to increasingly impervious urban land. The result of this change can have significant effects on local weather and climate (Xian, 2005). Changes in land cover modify the reflectance of the land surface, determining the fraction of the Sun's energy absorbed by the earth surface and thus affecting heat and moisture fluxes. These processes also alter vegetation transpiration and surface hydrology and determine the partitioning of surface heat into latent and sensible heat fluxes.

2 Urban Climate change

2.1 Remarks

The global average temperature (surface temperature) accounted for an increase between 0.6 and 0.7°C degrees (WMO, 2003). Land temperatures in 2003 were 0.83°C above average, ranking third in the period of record while ocean temperatures ranked as second warmest with 0.44°C above the 1880-2003 mean (NCDC-NOAA, 2003). Land-use and land-cover change is linked in complex and interactive ways to global and local climate change, and the feedback between the two exists at multiple spatial and temporal scales.

The urban heat island effect (UHI) of in a city develop when a large fraction of the natural land cover in an area is replaced by built surfaces that trap incoming solar radiation during the day and then re-radiate it at night (Quattrochi et al. 2000; Oke 1982). This slows the cooling process thereby keeping night-time air temperatures high relative to temperatures in less urbanized areas (Oke 1982).

2.2 Study Area

Addis Ababa, the capital of Ethiopia, was established in 1889, situated (9°N, 38.5°E) in the high plateaus of central Ethiopia in the North-South oriented mountain systems neighboring the Rift- Valley and covers an areal extent of approximately 530.14 square kilometres. About 54% of the area of Addis Ababa is upon. Of this, 64% is devoted to residential use while 18%, 10% and 8% are used for public, commercial and industrial uses respectively. The residents of the city are primarily located in the built-up area (99%) at a density of about 7000 per km^2) (UN, 2000).

The city has a population of 2.9 million, and the major urban migration into the city began in the mid-1970s, driven mainly by unemployment, poverty, and declining agricultural productivity in rural areas. This population figure of Addis Ababa has doubled in the last 20, and is projected to grow to 5.1 million by 2015. The average mean maximum temperature is 24.5°C, and the average minimum temperature is 12.0°C. The average of the three seasons extreme Temperature of Maximum is 31°C and the extreme minimum temperature is 7°C. Addis Ababa receives an average of 1255.2 mm rainfall per year. The highest monthly rainfall ever recorded (424.7 mm) occurs in August 1970 and the lowest rainfall (62.3 mm) was recorded in November 1976.

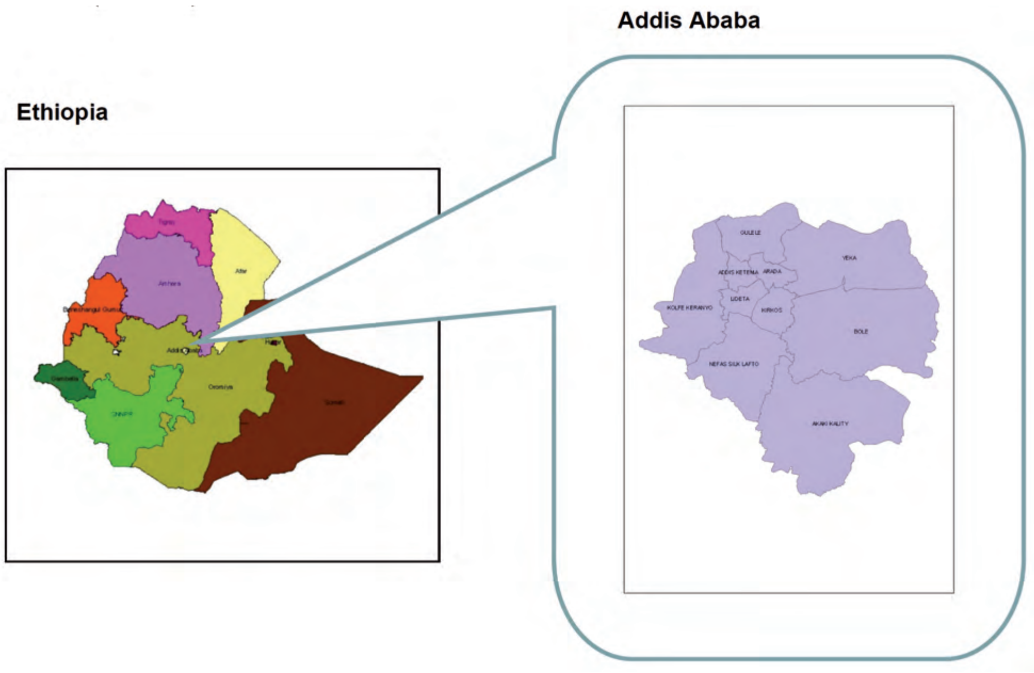

Figure 1: Study area

3 Objectives of the Study

3.1 Remarks

The over all objective of this study is to identify the development pattern of land use change in relation with climate of Addis Ababa.

3.2 Specific Objective

The specific objectives of the research study are:

1. To analyze the land use change in the city of Addis Ababa
2. To analyse the current micro- climate and its change
3. To identify the Urban Heat Island (UHI) intensity
4. To recommend possible adaptation strategy for the climate Change impact in the city.

4 Limitations

Some difficulties were faced by this study to attempts and to come up with sound conclusions for the study. Unavailability of sufficient meteorological information's for the city. There are only two meteorological stations in the city. And also unavailability of required documents in the archives of the city's change in land use information.

5 Methods

This study uses Landsat Thematic Mapper (TM) and Arc GIS to analyze the influence of urbanization on land use and surface temperature in three areas of the city to analyze the UHI of the city of Addis Ababa. Urban extent and development intensity are determined from measurements of percent impervious surface area (ISA) obtained from Landsat remote sensing data. Both the spatial and temporal distributions of associated with ISA are evaluated. Historical climate information collected by the National meteorology Agency of Ethiopia are utilized to study temperature trends in the city and to assess the effect of urbanization on the local climate.

An investigation into the changes in urban heat island intensity (from 1952 – 2003) at Addis Ababa Observatory and Bole International Airport Meteorological Stations was conducted. The Observatory station is located in the built area of the city. The Bole international Airport is in a suburban area, surrounded by farm lands. Temperature anomalies, including for annual mean minimum and annual mean maximum temperature, were obtained as the difference between yearly values and the climatic average for period of 1971-2000. The Urban Heat Island Intensity (UHII) for Addis Ababa (OBS) Station was obtained by calculating the difference between mean maximum and minimum temperature of Addis Ababa Observatory station and the rural Bole station, and the trend of UHII series is estimated by using the least square method.

6 Finding

6.1 Land Cover

The data revealed that the land-cover in two different times showed significant changes. Urban land use coverage significantly increased from 35% in 1973 to 74% in 2005. It expanded to all directions particularly to the south, west and North West side. Urban land cover over Yeka, Kolfe and Gulele grew by more than 50% in 32 years (Table 1.). It was suggested that the expansion of the urban area to the surrounding environment had an impact on the decrement of agricultural, forest, and grassland fields. Thus, agricultural and forest land, which constituted 65 % of the total area in 1973, diminished to 26% in 2005. As depicted on Table, the built up land cover class has experienced a remarkable growth (21,088.55ha) between 1973 and 2005.

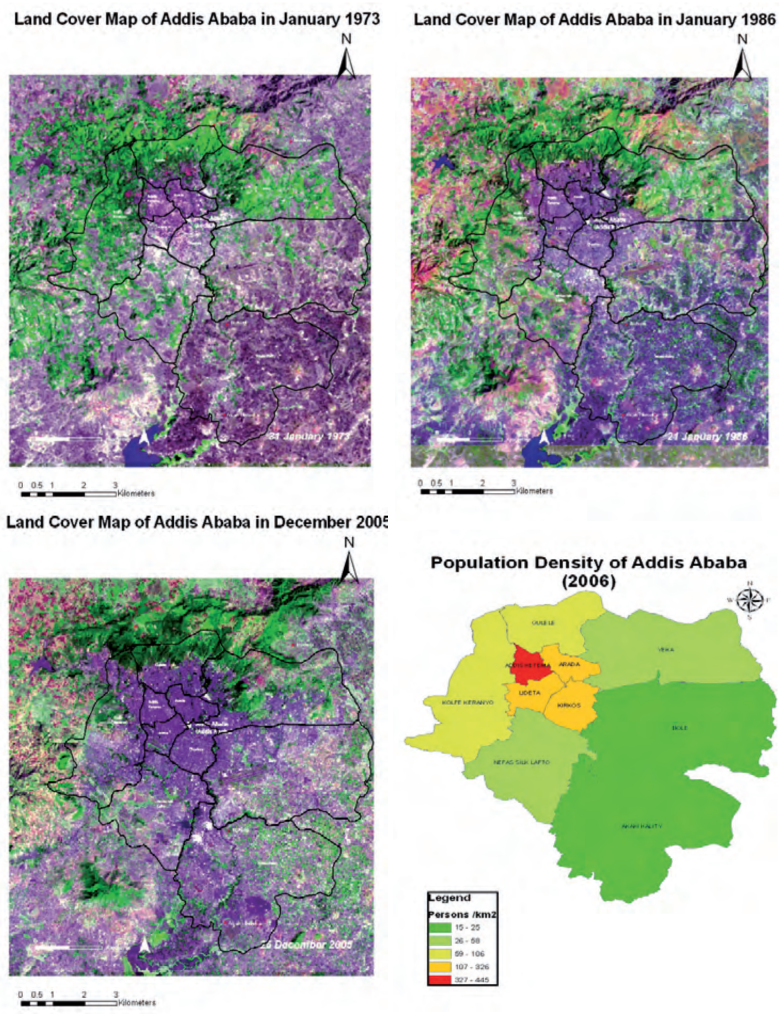

Figure 2: Land use and land cover map for the year 1973, 1986 and 2005

Table 1: Land use Change in Addis Ababa

LUC	1973		2005		1973-2005	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Change (ha)	Change in Percent (%)
Urban and associated development	19,100.2	35	40,188.75	74	21,088.55	39
Agricultural, forest Water, Wetlands and Vegetated areas	34,899.79	65	13,811.24	26	-21,088	-39
Total	53,999.99	100	53,999.99	100	-	-

Thus, by the expense of agricultural land and vegetated areas including natural and man made forest, sparse forest, shrub wood land, natural grassland and mixed forest, the built up areas including urban, industrial, commercial and residential units with other associated urban facilities dynamically increased in the period of 32 years. This will be due to high acceleration of population increment with high demand for land and urban provisions, coupled with a weak land allocation policy of the government and unplanned (slum) urban sprawl at the periphery of the conurbation.

6.2 Population growth

During the past century, the population of Addis Ababa increased significantly. The population size in year 2000 was 2,112,737 and in 2006 population census, the size became 2,973,004, with a density of 5608 persons per kilometer square. This shows the total density of the city as compared with year 2000, increased by 1624 person/km2. The spatial data analysis of population density was done using Arc GIS. The analisis shows that the central parts of the city including Addis-Ketema, Arada, Kirkos and Lideta sub-cities has significantly very high density (100-455 persons per kilometer square) as compared with Bole, Yeka, Nifas-silklafto and Akaki Sub-Cities.

6.3 Urban Climate change

The anomalies of annual mean minimum temperature and annual mean maximum temperature for urban Addis Ababa (OBS) Station and rural Bole Airport stations from 1965 to 2009. Table 2 gives the trends of annual and seasonal mean UHII for 1965- 2009. Significant warming of minimum and maximum temperature at Addis Ababa (OBS) Station and the rural Bole station can be found from 1965 to 1983, but the warming at Addis Ababa (OBS) Station is significantly larger than that at the rural station of Bole for both minimum and maximum temperature. In every ten year, increase in maximum is larger than increase in minimum temperature, with the rates of maximum temperature for Addis (OBS) Station and the Bole rural station being 0.55°C and 0.27°C respectively, and the rates of minimum temperature for them being 0.47°C and 0.19°C respectively.

The temporal change of UHII at Addis Ababa (OBS) Station over the periods of 1952-2003 and 1981-2003 was studied. Table shows that the change in UHII at this site of the city is also very significant, especially for nighttime and for the later period. The trends of minimum and maximum are 0.45 and 0.15°C respectively for period of 1952-2003, but Average and maximum temperature increase to 0.71 and 0.52°C respectively for period of 1981-2003, indicating an enhanced urban warming in the later 22 years. Seasonally, urban warming is generally more apparent in dry season (Bega) & short rainy season (Belg) and it is weaker in rainy season (Kiremt).

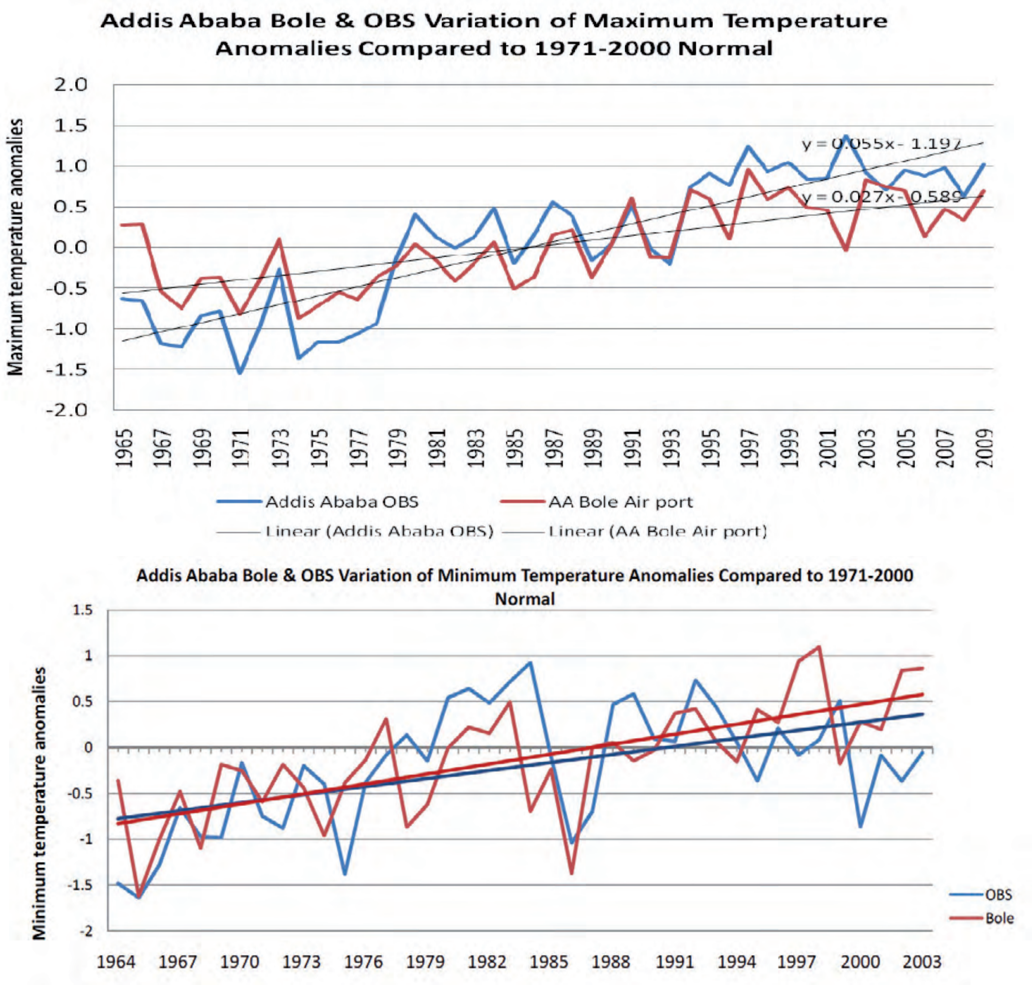

Figure 3: Urban climate change

7 Conclusion

Urban coverage has significantly changed from 35% in 1973 to 74% in 2005. The agricultural and forest land, which constituted 65% of the total area in 1973, diminished to 26% in 2005. In 2006 the total density of the city as compared with year 2000, increased by 1624 person/km2. This landscapes change, as they are the expression of the constant interaction between the above change of natural land and population increment forces in the environment. Applied to an urban/peri-urban case, changes are seen as a menace.Urban growth, both in population and in areal extent, transforms the landscape from natural cover types to increasingly impervious urban land. The result of this change can have significant effects on city local weather and its climate.

Temporal trends of annual and seasonal mean air temperature for period of 1952-2003 and 1981-2003 at Addis Ababa (OBS) and Bole suburb meteorological stations are positive, and the trends of annual and seasonal mean UHII for the two periods for Addis Ababa (OBS) station is also positive. Urban heat island effect at Addis Ababa station has significantly intensified for the periods analyzed. The annual surface warming induced by urbanization at Addis Ababa (OBS) Station for every ten year reaches 0.71°C for the period 1981-2003 analyzed. Warming, in terms of annual mean minimum air temperature, induced by intensified urban heat island effect for the city station is even larger for 1952- 2003, for every ten year reaching 0.45°C. Although negative trend in UHII as measured by annual mean average air temperature is found for 1952-2003, it does significantly increases for 1981-2003. As expected, the increase of UHII during 1981-2003 as compared to the earlier years dominantly occurs in nighttime of rainy season (Kiremt) and daytime of dry season (Belg and Bega). Local authorities in the sub-cities of Addis Ababa need to design the Climate Change Initiative to adapt and mitigate the climate change impact in the city. A basic conclusion is that the costs of strong and urgent action on climate change will be less than the costs thereby avoided of the impacts of climate change under business as usual.

8 Recommendation for Adaptation on the City Climate Change

8.1 Remarks

This study will recommend on developing a strategy for Climate Change Initiative (CCI) will need to design in the city of Addis Ababa to support the GTP strategies of the wider national development strategies.

8.2 Adaptation measures in key vulnerable sectors

The sub-cities Open Spaces will give pleasant pockets of green space, which not only offer the space to relax and enjoy for all sub-cities, but are also of vital importance to wildlife. Additionally, their effect on microclimates is gaining more importance as the climate becomes warmer. Trees and planting can result in the reduction of peak hot season temperatures by up to 5° Celsius. Thus trees are included in the City's street scene designs wherever possible, to provide shade and cooling (City of London, 2008). Funding is vital in order for developing countries cities to plan for and implement adaptation plans and projects.

Vulnerable sectors	Reactive adaptation	Anticipatory adaptation
1) Sub-cities Water Resources	•Protection of groundwater resources •Improved management and maintenance of existing •Water supply systems •Protection of water catchment areas •Improved water supply •Groundwater and rainwater harvesting	• Aply on new constraction & investment sectors better use of urban recycled water (development of waste water treatment and recycling) at sub-city level •Conservation of water catchment areas •Improved system of water management at kebel level •Development of flood controls at kebele level
2) Sub-cites Human health	• Public health management reform •Improved housing and living conditions •Improved emergency response	•Development of early warning system at sub-city level •Better and/or improved disease/ vector surveillance and monitoring at kebele level •Improvement of environmental quality at kebele level in (solid waste, green space and drainage system)
3) Sub-cities Terrestrial ecosystems and Urban Heat Iceland (UHI)	•Improvement of management systems including control of urban deforestation, reforestation and afforestation •Improvement of management systems constraction sectors of sub-cities including satisfactory provision of green areas for managment of open spaces, recreation areas, sport fields, vehicular access, drainage and sewerage lines. Also constraction stakeholder participation and public involvement in green space management is highly needed.	•Using GIS, planning and creation of sub-cities parks/reserves, protected areas and biodiversity corridors in each sub-city •Identification/development of species resistant to climate change •Better assessment of the constraction sectors vulnerability of urban ecosystems •Monitoring of species of each kebele

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Climate and Constructions
International Conference, October 24-25, 2011, Karlsruhe, Germany
335–336 (2011)

Energy Efficiency and Natural Climate Control in Buildings: Lessons from the Traditional Houses in Kerala

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Abstract

Rising demands in energy associated with changing climate and lifestyle necessitates urgent measures in energy efficiency in the domestic sector. Encouraging the use of natural light and natural cooling system has become important, as the world is heading towards an energy crisis. The traditional typical houses known as nalukettu in the humid tropical state of Kerala, India that utilises use maximum sunlight and natural temperature control systems are among the best examples. The traditional architecture is typically a rectangular structure where four halls are joined together with a central court yard open to the sky. The open space at the centre brings a lot of sunlight and wind. Heat inside the building also escapes through this space. Rainwater that falls at the centre cools the building, in addition to recharging the groundwater, making water available in the open well attached to the house throughout the year. Walls are made of locally available strong wood. In certain houses, there are two walls and the space in between the walls is filled with gravel, to resist the conduction of heat. In the top, there is enough ventilation. The wooden ceiling below tiled roof prevents heat from the top. In addition, there are certain trees planted around, mixed with beliefs. Leafs of certain plants and oil from native tress efficiently prevented the termite attack, keeping the houses through decades and centuries

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337–338 (2011)

Study of the Atmospheric Processes Effect on the Chemical Composition of Atmospheric Precipitation on the Example of Tashkent Province

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Abstract

Regarding the natural water of Republic of Uzbekistan the atmospheric precipitation are less studied item in relation to their chemical composition. This is caused by their spatial and temporal variability. Nevertheless, the precipitation composition is in general typical for this location and presents the type of geographical landscape. The methodology of studies has included the statistic data processing by the types of synoptic processes and comparison of the resulted data with the chemical composition of the one-time taken precipitation samples which characterize specific meteorological situations. At the same time, the percentage correlation between the maximum sulfate concentrations in the one-time taken atmospheric precipitation samples and their relationships with synoptic processes were investigated. The calculation of correlation factors has shown the homogeneity of the processes over the whole studied territory. High frequency of the maximum values of sulfate concentrations in these processes is observed during spring when the maximum precipitation amount falls out on the studied territory. This proves the possibility of the pollutants washing out from the atmosphere as in winter the accumulation of products of the sulphur dioxide transformation to sulfates in atmosphere at the expense of the pollutants emissions from the local emissions sources to atmosphere takes place.

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Influence of Selected Chemical Additives on Cold Recycling Mixes Characteristics

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Abstract

Present trend in road construction is focusing on reduction of natural materials exploitation and effective increase of by-products and recyclable materials utilization. These strategies supports directly the decrease in environmental impacts as well. Substantive stress is laid on decrease of energy demand for building materials and construction realization, as well as on reduction of GHGs. In the Czech Republic during last 10 years increased attention has been paid to progressive cold recycling techniques. For improvement of cold recycling mix characteristics suitable additives and substituting materials for energy demanding hydraulic binders are searched. Such alternatives, of course, should reduce the production costs as well. Within the experimental activities of the Faculty of Civil Engineering at CTU in Prague application of chemical additive Iterstab and of fluid fly-ashes has been tested and analyzed. Especially fly-ashes can be seen as another environmental issue where significant challenges can be found. Resulting mixes were assessed by standardized volumetric and mechanic tests, deformation characteristics and performance behavior has been tested in parallel with evaluation of alternative parameters. Cold recycling mixes combined especially with fly-ashes should result in higher quality structures with longer life-time. This can be directly related to less impact on environment and climate in particular.

1 Introduction

Present trends in road construction focus on reduction of natural materials exploitation and effective increase of by-products and recyclable materials utilization. These strategies support directly the decrease in environmental impacts as well. Substantive stress is laid on decrease of energy demand for building materials and construction realization, as well as on reduction of GHGs. In the Czech Republic during the last 10 years increased attention has been paid to progressive cold recycling techniques. For improvement of cold recycling mix characteristics suitable additives and substituting materials instead of energy demanding hydraulic binders have been searched. Such alternatives, of course, should reduce the production costs and support the strategy of low-emission mixes as well. Within the experimental activities of the Faculty of Civil Engineering at CTU in Prague application of chemical additive Iterstab, of nanochemical additive RoadCem, of mineral active binder Dastit and of fluid fly-ashes has been tested and analyzed. Especially fly-ashes can be seen as another important environmental issue where significant challenges can be found. Resulting mixes were assessed by standardized volumetric and mechanic tests, deformation characteristics and performance behaviour has been tested in parallel with evaluation of alternative parameters.

2 Recycling in road construction

The road network requiring continuous renovation increases the demand for prospective, economical and environmentally friendly technology, in particular for pavement reconstructions. Emphasis is put on recycling the original pavement material with minimum disruption to the traffic operation and maximum suppression of any negative effects associated with excessive construction transport. The cold recycling technology allows this method of exiting pavement renovation; it has been applied in many countries for a number of years. In the Czech Republic, this group of recycling technologies has been developed increasingly during the last 15 years based on the necessary preference of repairs and reconstruction to the construction of new transport network segments. Another incentive for recycling technology development has been the passing of legislative measures supporting the sustainable development concept in particular as well as the general no-waste society direction of EU. The in-situ cold recycling technology allows reducing the consumption of non-renewable resources while maximising the use of materials from the original pavement structure or other, locally available waste materials which are frequently deposited on landfills or within the alternative utilization (incinerating, fill-ins etc.). In road construction, cold recycling is understood to mean modifying the properties of materials milled from the existing pavements, i.e. regrinding and sorting of reclaimed material, addition of granular materials and binders. The technology can declare 40-50 % lower production costs than the application of conventional pavement reconstruction methods the completion is faster and involves a lower environmental load in total (less demand for construction machinery, minimum material transport, and shorter road work times). This results in reduced energy demands of the production process as such and, last but not least, reduced greenhouse gas production (by at least 30-40 %). Other negative effects like noise and vibrations are also restricted.

In the EU states, construction and demolition waste amounts to approx. 25-35 % of all waste produced; this is a significant proportion considering the fact that the materials come from non-renewable resources. Natural aggregate built in pavements are not subject to degrading; therefore, it can be effectively re-used as adequate construction material. In this regard, the European-wide target is achieving construction waste recyclability of 70 % by 2020, [5]. In the Czech Republic, the relative proportion of recyclable material to the total quantity of natural aggregate quarried since 2003 has been decreasing steadily (from 8.2 to 6.4 %), [2]. The cold recycling mixes most frequently use recyclable asphalt material (RAP). The quantity of RAP produced in the Czech Republic is illustrated in figure 1.

Bituminous emulsion (in the quantity of 2-6%-wt. of the mix), cement or lime (in the quantity of 1-4%-wt. of the mix) or combinations thereof are used most frequently to form a bonded layer out of the recycled material. The technical parameters and requirements for such mixes are defined in CZ by technical requirements, TP 208, [1].

3 Fly ashes from fluid combustion process

Energy consumption increases with the society's economic development. To obtain such energy, large amounts of non-renewable natural resources are used. The transformation of such resources into energy is great burden for the environment in a number of cases. In the Czech Republic, the primary energy sources are solid fuels, soft coal in particular, where 69 % of coal (soft and hard) is used for electricity generation.

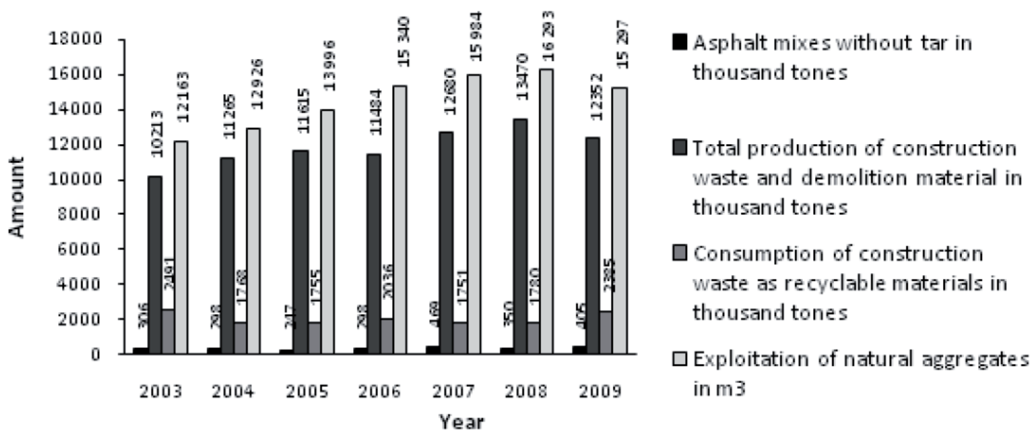

Figure 1: Construction and demolition waste material in CZ - approx. values (source: Czech Statistic Bureau)

Approx. 1 tonne of coal is used to produce 1 MWh of electricity on average. CO_2 emission production by burning coal in CZ is approx. 0.565 kg of CO_2 per kWh of electricity produced. Besides this, in 2000 thermal power plants produced 9.1 mil. tonnes of solid by-products (flue dust, fly ash, dry ash and agglomerates or power-generated spar, sag or slag - about 7,230 thousand tonnes; fluid ash - about 600 thousand tonnes; energo-gypsum - about 1,810 thousand tonnes) and the quantity had gradually increased to the 10 million tonnes level of 2007.

Some of the solid burning residues can be considered good quality secondary products. Such products vary in granularity, chemical and mineralogical composition but also in properties and utilisation methods. About 60 % are used nowadays as reclaimed material in this manner.

There are several thermal power and heat plants in CZ; for several years have these been using fluid furnaces (roughly since 1996) where 85-88 % efficiency can be achieved. In fluid furnaces, the ground fuel with an additive is burned in a circulating layer under 850°C. During the dissociation process, the SO2 released from the fuel bonds to $CaSO_4$, which is of considerable environmental significance; if that is not the case SO_2 is released into the air. In modernised operations, solid fuels occur in the form of bottom ash and flue ashes from the electrical filters (separators). The resulting product is a mix of ashes, unreacted desulphuring agent (CaO with possible $CaCO_3$ residues), calcium sulphate ($CaSO_4$), products of the reaction between ash materials with CaO and un-burnt fuel. With respect to the fact that the burning temperatures are lower in fluid processes than in granulation burning, the unreacted CaO is present in the form of "soft-burnt" lime (up to 30 %) which is the main driver behind the effort to use it in the cold recycling technology. Fluid ashes contain relatively higher proportions of SO_3 (7-18 %) which might cause the formation of ettringite in the binder. In this regard, some new methods resulting in products like DASTIT® are being developed. Fluid ashes are also characterised by the practically absent melting. Due to the transport of smoke gases from the fireplace individual fractions of the mix separate, fine components are taken away with the exhaust in the form of outlet while the coarser ones remain in the burning area. The solid substances outlet is removed from the smoke gases by means of common methods (cyclones, filters). Therefore, each fluid combustion unit usually produces two types of fluid ashes - the ash from the fireplace ("bottom ash") and the fly ash (also cyclone, filter ash etc.) The properties of the two types differ greatly both as to the physical characteristics (grading, specific surface, density, and bulk density) and as to the chemical and mineralogical composition although they come from the same technological process of fluid burning and desulphuring. Analogously to the traditional ash both types of fluid ash demonstrate the disadvantage of fluctuating characteristics, particularly the chemical composition, specific weight and other parameters caused by a lack of stability of the burning process and variability of the input components. Another disadvantage of fluid ashes is the volume changing driven by moisture content variability.

Fluid ashes as a by-product of energy generation has pozzolan characteristics and might become a material appropriate for construction purposes. In the case of cold recycling technology, fluid ashes could substitute the high-energy hydraulic binder.

The use of the power generation by-product for construction purposes is currently in the development stage both in the Czech Republic and abroad.

4 Designs of experimental mixes

Within the framework of the experiments as such, a set of various laboratory cold recycling mixes with variable representation of fluid ashes and DASTIT®, was designed. Some chemical additives, like Iterstab and RoadCem, have been assessed in selected mixes as well. A set of laboratory tests was determined to verify the effect of such materials on the properties of the mixes. Specifically for fluid ashes, the possibility of substitution thereof for the hydraulic binder was observed; at the same time, there was an effort to maximise the partial substitution of RAP. A similar intention was pursued in the case of DASTIT® application. The cold recycling mixes were prepared according to the principles stated in the Czech technical requirement TP 208. Sorted RAP, fraction 0/11 from a mixing plant was used; a grading analysis and extraction was performed with a determination of the grading curve for the aggregate extracted, see figure 2. The content of bitumen in the RAP amounted to 7.3 %-wt. A C60B7 bituminous emulsion as commonly used was applied to the designed cold recycling mixes. Analogously, the standard Portland slag cement CEM II/B-S 32,5R was used in the majority of mixes. From the perspective of fluid ashes, two representatives were chosen - filter ash from the CEZ Ledvice power plant and bottom ash from the CEZ Pocerady power plant. From the point of view of chemical composition, the most interesting circumstance was the high quantity of SiO_2 (approx. 40 %) and a lower quantity of free CaO (approx. 5 %). Within the framework of the mixes produced with the ash, leaching and presence of toxic substances have not been verified for the time being. Some mixes also used DASTIT® which can be characterised as inorganic loose binder the sole component of which comes from fossil fuel burning together with an additive in a fluid furnace. The fluid ash containing at least 50 % SiO_2 + $Al2O_3$ is subsequently ground in a high-speed mill. The maximum grain size after grinding must be below 200 μm. The material adjusted in this manner is reactive and requires no other additives. The third material added to the mixes which should partly substitute RAP was waste filler from various stone quarries with maximum grain size of 0.09 mm. A chemical additive Iterstab 2000 is a mixture of inorganic salts in an aqueous solution. The additive allows stabilising layers of clay soils and soils containing organic particles. It was examined whether the interesting properties would have any positive impact on the cold recycling mixes, too [3]. Last but not least, the nanochemical additive RoadCem, which reacts with cement and is used primarily for soil improvement, was tested as well. Within the framework of assessing the effect of RoadCem on cold recycling mixes, the dependencies of functional characteristics on the quantity of hydraulic binder and bituminous emulsion in the mix were examined.

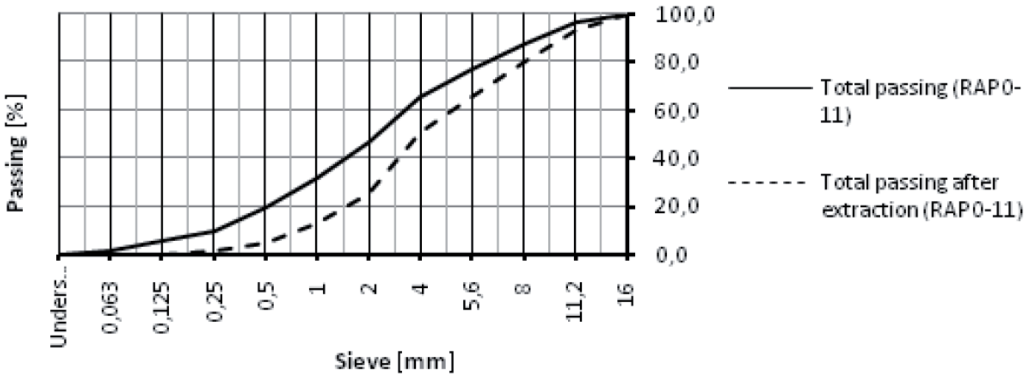

Figure 2: Grading analysis of reclaimed asphalt material

The composition of individual mixes is given in Table 1. At least 16 to 20 cylindrical specimens were prepared for each mix according to TP 208; Densities, moisture contents in fresh mixes and, for selected mixes, void contents were determined for the specimens. Primarily strength and deformation characteristics were tested for:

- indirect tensile strength (ITS) after different curing periods (7,14 and 28 days) at 15°C according to the TP 208 technical specifications;
- stiffness by repetitive non-destructive indirect tensile stress test on cylindrical specimens according to CSN EN 12697-26 (IT-CY method);
- water and frost susceptibility test for selected mixes.

5 Assessment of volumetric, strength and deformation characteristics

To determine the properties of cold recycling mixes, standard tests under TP 208 were carried out first. The results are summarised in Table 2. Bulk density was determined by the SSD method and according to the dimensions. All results obtained by the SSD method were roughly 3 % higher on average than the measurement by dimensions. From the perspective of void content, an interesting trend occurred where increasing quantities of fly ashes in the mix resulted in relatively linear increase of void content, even in the cases of varying quantities of cement and bituminous emulsion used, see Figure 3.

The technical requirements for cold recycling mixes with bituminous emulsion and cement requires an indirect tensile strength (ITS) test after 7 days' curing; subsequently, after 14 days' curing on specimens which were stored in water for 7 days. These values are then used to determine water susceptibility which is a qualitative criterion applied in practice. Beyond the requirements of the technical regulations, the experimental measurements involve ITS measurements after 14 and 28 days' curing in dry conditions.

Table 1: Composition of experimental mixes

Mix design	REF	P01	P02	P03	P04	P05	P06	P07
Water content	4.5%	4.5%	5.3%	5.5%	5.2%	5.2%	5.2%	5.2%
Cement content	3.0%	0.0%	0.0%	1.0%	1.0%	0.0%	0.0%	0.0%
Bituminous emulsion	3.5%	3.5%	3.5%	2.5%	2.5%	2.5%	2.5%	4.0%
Fly-ash (Ledvice)	0.0%	3.0%	5.0%	10.0%	15.0%	15.0%	5.0%	5.0%
Fly-ash (Počerady)	-	-	-	-	-	-	-	-
Waste filler	-	-	-	-	-	-	10.0%	10.0%
Mix design	P08	P09	P010	P011	P012	P013	P014	P015
Water content	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.5%	4.5%
Cement content	1.0%	1.0%	0.0%	0.0%	0.0%	3.8%	0.0%	2.0%
Bituminous emulsion	2.5%	2.5%	3.5%	3.5%	3.5%	3.5%	3.5%	2.5%
Fly-ash (Ledvice)	0.0%	0.0%	3.5%	7.5%	12.5%	3.8%	-	10.0%
Fly-ash (Počerady)	10.0%	15.0%	-	-	-	-	-	-
Iterstab 2000	-	-	-	-	-	-	-	0.9%
Dastit	-	-	-	-	-	-	3.0 %	-
Mix design	P016	P017	P018	P019	P020	P021		
Water content	5.0%	5.0%	5.0%	3.3%	3.8%	4.3%		
Cement content	7.0%	5.0%	3.0%	7.0%	7.0%	7.0%		
Bituminous emulsion	0.0%	0.0%	0.0%	3.5%	2.5%	1.5%		
Clay	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%		
RoadCem	0.07%	0.07%	0.07%	0.07%	0.07%	0.07%		

Table 2: Fundamental characteristic of assessed cold recycling mixes

Characteristic	REF	P01	P02	P03	P04	P05	P06
Bulk density (g/cm^3); dimension	2.121	2.124	2.111	2.064	2.000	1.977	2.068
Bulk density (g/cm^3); SSD	2.189	2.159	2.164	2.097	2.029	2.019	2.115
Voids content (%-wt.)	10.0	10.2	11.2	12.3	13.4	14.3	-
Moisture of produced mix (%vol)	6.6	6.5	7.4	6.2	6.8	6.1	6.9
Characteristic	P07	P08	P09	P010	P011	P012	P013
Bulk density (g/cm3); dimension	2.089	1.987	1.936	2.093	2.065	2.012	2.090
Bulk density (g/cm3); SSD	2.131	2.032	1.981	2.135	2.098	2.037	2.129
Voids content (%-wt.)	-	-	-	11.3	12.6	13.2	11.9
Moisture of produced mix (%vol)	7.6	6.1	5.6	6.3	6.1	5.5	6.0
Characteristic	P014	P015	P016	P017	P018	P019	P020
Bulk density (g/cm3); dimension	2.111	2.033	2.159	2.150	2.152	2.159	2.163
Bulk density (g/cm3); SSD	2.174	2.088	-	-	-	-	-
Moisture of produced mix (%vol)	6.7	5.8	5.3	5.5	5.9	4.2	4.4

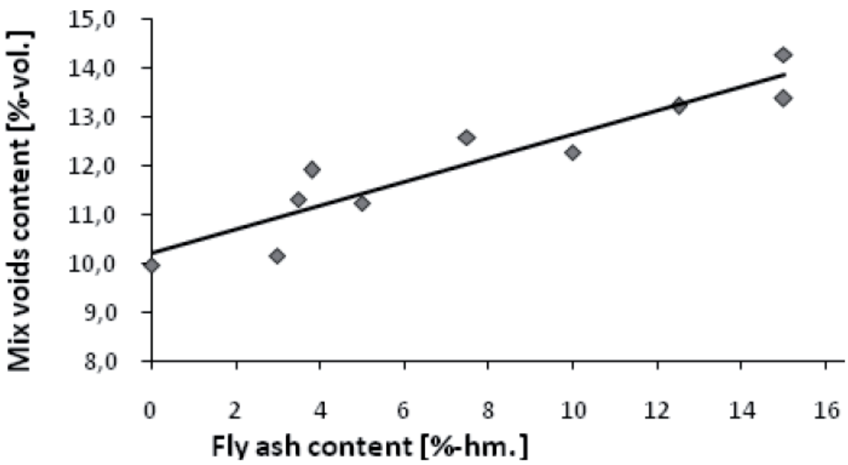

Figure 3: Relation of voids content and fluid ash content in the cold recycling mix

The results of strength characteristics in specimens with combined curing in dry and wet conditions were subsequently compared to determine the water susceptibility according to TP 208 [1] and to determine modified ITSR ratio commonly applied to asphalt mixes.

The following findings can be inferred from the results indicated in Table 3 for the mixes assessed:

- the increasing proportion of fly ashes usually results in decreasing ITS;
- all mixes demonstrate an obvious impact of cement on the strength characteristics and water susceptibility;
- the combination of fluid ashes in the mix demonstrates reduced strength characteristics;
- in the case of DASTIT®, hydration occurred during the first 7 days when the maximum indirect tensile strength was achieved;
- Iterstab has a positively effect on cold recycling mixes;
- the chemical additive, RoadCem, co-acts positively with the cement which increases indirect tensile strength; the decrease of the proportion of bituminous emulsion in the mix results in a slight decrease of indirect tensile strength;
- in the case of modified ITSR indicator and ITS decrease indicator, it is obvious that the ITSR rate results in deteriorated values and, therefore, the ITS decrease indicator should be amended with a specific minimum indirect tensile strength value in the technical conditions;
- increased proportions of filter ash are usually associated with reduced water and frost resistance (see Figure 4)

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Table 3: Indirect tensile strength results

Mix	Indirect tensile strength (MPa) @ 15°C, curing (days)				ITSR	Decrease of ITS
	7 air	14 air	7 air + 7 water	28 air		
REF	0.45	0.84	0.56	0.91	0.68	1.24
P01	0.71	1.05	0.78	0.82	0.74	1.10
P02	0.62	0.76	0.52	0.98	0.69	0.84
P03	0.4	0.55	0.41	0.63	0.74	1.02
P04	0.19	0.22	0.15	0.38	0.69	0.79
P05	0.21	0.3	0.13	0.38	0.43	0.61
P06	0.30	0.36	0.16	0.40	0.44	0.53
P07	0.41	0.54	0.33	0.60	0.61	0.80
P08	0.49	0.51	0.42	0.66	0.82	0.86
P09	0.41	0.49	0.40	0.55	0.82	0.98
P010	0.48	0.65	0.45	0.87	0.69	0.95
P011	0.51	0.58	0.43	0.82	0.74	0.84
P012	0.44	0.41	0.27	0.57	0.67	0.62
P013	0.74	0.84	0.78	1.01	0.93	1.05
P014	0.66	0.63	0.54	0.65	0.86	0.82
P015	0.74	0.71	0.73	1.18	1.03	0.99
P016	1.34	0.72	0.91	-	1.26	0.68
P017	0.78	0.79	0.87	-	1.10	1.12
P018	0.63	0.57	0.57	-	1.00	0.90
P019	1.23	1.54	1.29	-	0.84	1.05
P020	1.26	1.36	1.15	-	0.85	0.91
P021	1.11	1.47	1.06	-	0.72	0.95

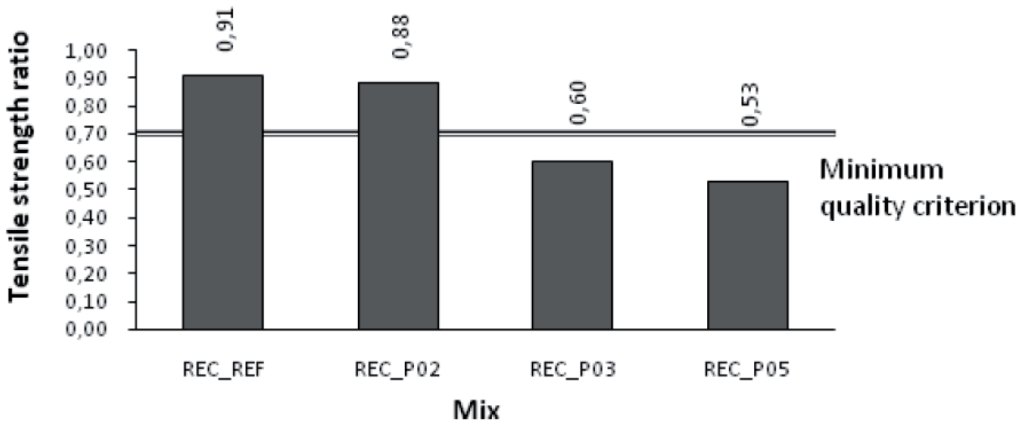

Figure 4: Frost susceptibility of selected cold recycling mixes

The stiffness modulus of a cold recycling mix is an important deformation characteristic which is used along with the Poisson ratio to design pavement structures. The stiffness modulus was measured on cylindrical specimens by the Nottingham Asphalt Tester.

Received results indicate the following facts:

- the mixes with a proportion of cement demonstrate higher stiffness modulus and reduced water susceptibility ITMR values; at the same time, they are less temperature-sensitive;
- increasing proportions of filter ash result in distinctive decrease of the stiffness modulus and ITMR; the opposite trend is demonstrated in the case of bottom fly ash;
- Iterstab has a distinctly positive impact on stiffness modulus values;
- the thermal susceptibility of the mix decreases with higher quantities of bottom fly ash.

Table 4: Stiffness modulus of assessed cold recycling mixes

Mix	Stiffness modulus @ 15°C (MPa), curing (days)			Ratio of stiffness modulus decrease (ITMR)	Thermal susceptibility (τs)
	14 air	7air + 7 water	28 air		
REF	4,200	3,100	4,700	0.74	2.30
P01	4,000	3,500	5,000	0.88	2.81
P02	2,200	1,700	3,400	0.77	4.00
P03	3,600	3,100	4,300	0.86	2.43
P04	1,100	400	2,400	0.36	2.57
P05	1,300	400	1,600	0.31	5.00
P06	1,600	700	1,800	0.44	4.50
P07	2,000	1,100	2,300	0.55	6.00
P08	4,000	3,500	5,600	0.88	2.00
P09	5,400	4,200	5,900	0.78	1.59
P010	1,800	1,100	2,300	0.61	6.57
P011	1,500	1,200	2,200	0.80	5.86
P012	1,100	700	1,600	0.64	5.50
P013	4,900	4,400	6,200	0.90	2.19
P014	3,200	4,000	3,600	1.25	3.36
P015	6,700	6,300	8,000	0.94	-

6 Summary

The application of cold recycling in road construction has an unambiguously positive impact on the environment as well as on reconstruction effectiveness which increases together with the time savings achieved when processing the mix in situ. From the environmental point of view, a frequently discussed topic is the issue of greenhouse gas emissions, CO_2 in particular. The production of 1 tonne of Portland cement results in a total of 1 tonne of CO_2 of which 0.55 t is released during lime calcinations and the remaining 0.40 t is caused by fuel combustion; substitution by alternative binders like fluid ash or DASTIT® could be used to reduce indirectly the production of CO_2. The substitution would also result in a considerable saving of production costs primarily for investors.

The results achieved so far have proven that there is a potential for the utilisation of power generation by-products; it can be assumed that a more distinctive effect should be obvious with coarse RAP. Based on the results above, the following conclusions can be arrived at. From a certain level, the quantity of fly ash added causes certain properties to deteriorate; however, it depends on the origin of the fly ash in question. In the case of water and thermal susceptibility, it has been confirmed that a combination of a small quantity of cement with fly ash has a significant impact on the resulting mix. In the case of frost susceptibility, it has been observed that mixes with up to 7.5 %-wt. of fly ash will meet the requirements for indirect tensile strength decrease by max. 30 %. In other cases, the mixes demonstrated poorer quality than that. Due to be above, we can recommend the maximum quantity of fluid ash from the filter in a cold recycling mix to be 8-10 %-wt. and, in the case of bottom ash, 10-15 %-wt. Chemical additives Iterstab and RoadCem demonstrate a positive effect on cold recycling mixes.

Acknowledgement

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Method for Representative Siting of Urban Climate Station Network - Novi Sad (Serbia) as an Example

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Abstract

Mean annual urban heat island (UHI) pattern was modelled by an earlier developed empirical method in the medium-sized city Novi Sad (Serbia), located on the low and flat Great Hungarian Plain. This method was based on datasets of temperature, 2D urban surface cover data and the distance from the city boundary from urban areas of Szeged and Debrecen (Hungary). In order to determine the built-up ratio by cells a Landsat satellite image (from June 2006) was used. The pattern of the obtained UHI intensity values show concentric-like shapes, mostly increase from the suburbs towards the inner urban areas with some local maximums. The spatial structure of this thermal pattern and determination a map on areas of Local Climate Zones were used for recommending 10 locations for representative stations of an urban climate network in Novi Sad.

1 Introduction

In the atmosphere of settlements a local climate (urban climate) develops which means a modification to the pre-urban situation. This climate is a result of the construction of buildings, as well as by the emission of heat, moisture and pollution related to human activities. In the course of urban climate development the near-surface (canopy layer) air temperature shows the most obvious modification compared to the rural area [1]. This urban warming is commonly referred to as the urban heat island (UHI).

In order to acquire long-term data as a basis for studies on the spatial and temporal variability in UHI patterns, measurements in a network established in the city are needed. Selecting the exact sites of the individual stations to ensure the representativeness of the thermal conditions across a wider area in the complex urban environment is a difficult problem [2].

In order to classify these sites several classification systems exists [2, 3]. For example Local Climate Zones (LCZ) are defined by [3] as regions of relatively uniform surface-air temperature distribution across horizontal scales of 10^2 to 10^4 meters.

Given the above mentioned requirements for siting an urban climate network, two initial steps can be regarded as highly useful: (1) Conducting some preliminary mobile surveys traversed through areas of interest to see where are the areas of thermal anomaly of interest or modeling the general thermal patterns. (2) Mapping of some type of climate zone classifications within the urban area of the city. The importance of this kind of classification lays not in the absolute accuracy of a given type to describe the site but its ability to classify areas of a settlement with similar capacities of modifying the local climate [2]. Such classification is crucial when setting up an urban station to ensure that spatial homogeneity criteria are met for a station.

The main objectives of this study are: (a) determination of the mean pattern of nocturnal urban canopy layer UHI intensity (ΔT) in the city of Novi Sad, Serbia using a model developed by [4], (b) mapping of the climate zones using the LCZ system of [3] in the studied urban area, and (c) designation the possible sites of the stations of a planned urban climate network in Novi Sad based on the obtained ΔT pattern in (a) and on the map of the climate zones in (b).

2 Study area and method for modelling the mean UHI pattern

Novi Sad (45°N, 20°E) is located in the northern part of Serbia, i.e. on the southern part of the Great Hungarian Plain and it is the second largest city in the country with a population of about 285 000 in a built-up area of approximately 60 km^2. River Danube crosses the city at its south-eastern part. The investigated area is plain (mostly from 80 to 86 m a.s.l.) on Holocene sediments with a gentle relief, so its climate is free from orographic effects. According to Köppen-Geiger climate classification, this region is categorised as Cfa climate (temperate warm climate with a rather uniform annual distribution of precipitation) [5]. In Novi Sad the annual mean air temperature is 11.1°C with an annual range of 22.1°C and the precipitation amount is 615 mm.

The applied method for the determination of the hypothetical spatial structure of the mean annual UHI intensity in Novi Sad is based on [4]. The main advantage of this regression method is to predict the ΔT pattern using just a few input parameters which can be determined by remote sensing technique without having detailed local information about the city.

The model in [4] dealt with UHI patterns of cities located in a rather homogeneous region, therefore it is more region- than site-specific. Datasets from Szeged (population 165 000) and Debrecen (population 204 000) situated on the Great Hungarian Plain in Hungary were used to construct this empirical model. The values of the datasets belong to the elements of the 500 m x 500 m meshes in these cities. The ΔT as dependent variable was measured by mobile transects. As independent variables for estimating the UHI field, 2D urban surface cover data and the distance from the city boundary were determined.

In study of [4] the obtained model was extended to other, different-sized settlements where the environment, like topography and climate, is similar to that of Szeged and Debrecen without taking country borders into account. Only certain Landsat satellite images of the settlements were necessary, from which the independent variables can be determined. The standard Kriging method and linear variogram model of Surfer 8 software were used to interpolate the temperature values by cells and for the spatial tracing of the isotherms [6, 7].

3 Results and discussion

According to the method described in Section 2, first a grid network (500 x 500 m) was established which contains the study area. A Landsat satellite image taken at June 26, 2006 [8] was used for the evaluation of NDVI and then of built-up ratio by cells. Large density can be found in the central part of the study area with the highest values in its eastern areas near the Danube. More local built-up maxima are located in the western, northern, north-eastern and eastern parts of the study area (Figure 1a).

The main feature of the obtained ΔT pattern by model equation of [4] is that the isotherms show concentric-like shapes with values increasing from the suburbs towards the inner urban areas with a highest ΔT (>4ºC) in the densely built-up centre (Figure 1a). Deviations from this concentric-like shape occur in the western, northern and north-eastern parts where the isotherm of 2ºC stretches towards the outskirts. In addition, three island-like local maxima appear in the northern, north-eastern and eastern parts of the study area with values over 3ºC, 2.5ºC and 2ºC, respectively. The largest area with very low ΔT values, owing to the influence of the Danube, is in the south-eastern part of the study area.

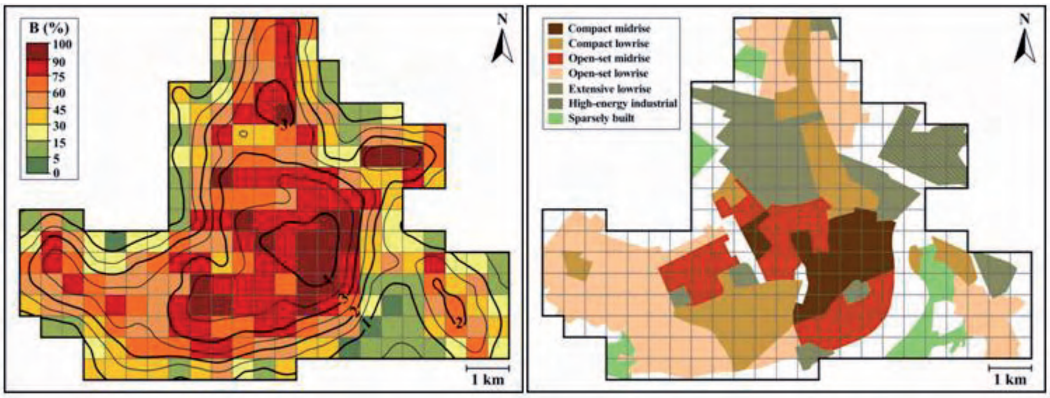

Figure 1: (a) Spatial distributions of the built-up ratio (%) and the modelled annual mean UHI intensity (°C), as well as (b) urban Local Climate Zones (based on [3]) in the study area of Novi Sad

The demarcation of LCZs was based on information extracted from [9], on guidances given in [2, 3], and on the personal experiences of the second author (Figure 1b).

The planning of the possible sites of the stations of an urban climate network in Novi Sad is based on the structural features of the obtained ΔT pattern (Figure 1a) and on the LCZ map (Figure 1b). While searching for the appropriate (representative) locations, two criteria were considered: (i) the stations should be located at around the high and low ΔT areas, as well as at around the areas of the local maxima and stretches assumed by the modelled UHI intensity pattern, and (ii) homogeneous LCZ areas a few hundred metres wide should be around the sites.

According to previous criteria, ten representative station locations in the urban area of Novi Sad have been detected (Figure 2). The locations represent the different neighbourhoods of the city, from the densely built-up area with medium narrow streets to the almost natural outskirts. The location numbered 1 is placed into the city's downtown with *compact midrise* landscape. The next three locations (2-4) are situated in *open-set midrise* zones, with open natural surroundings among >3 stories tall buildings. Locations 5 and 6 characterise *compact lowrise* areas with tall buildings <3 stories and separated by narrow streets, whereas locations 7 and 8 are in *open-set lowrise* zones, mostly with detached buildings separated by natural surfaces. The last two stations (9-10) are situated in industrial and warehouses zones (*high-energy industrial* and *extensive lowrise*).

4 Conclusions

The applied empirical model can be regarded as a useful tool for estimating the mean UHI patterns for Central European cities (typically of little vertical development) situated on a plain in the humid-continental climate type.

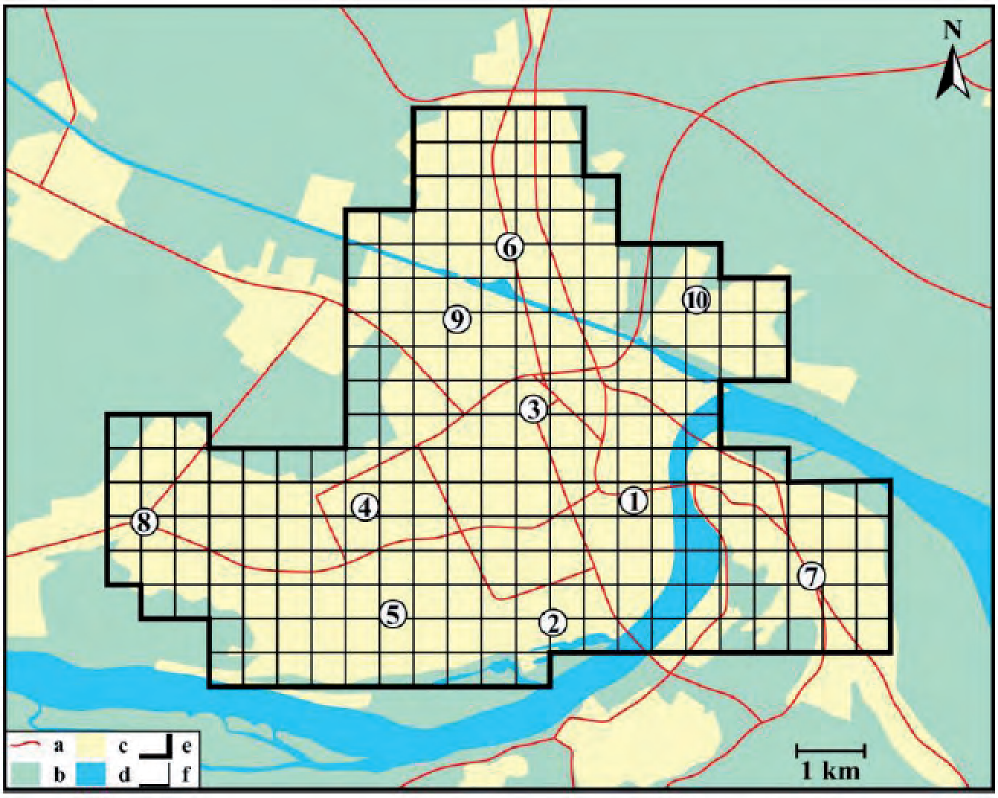

Figure 2: The recommended sites of a 10-station urban climate network in the urban area of Novi Sad

The presented method (analysis of UHI intensity distribution and some type of climate zone classifications) had the intention to detect sites which can be suggested for the stations of an urban climate network in Novi Sad.

According to the defined criteria, a representative 10-station network in the urban area has been determined in order to prepare further UHI research, i.e. (i) to monitor and provide measurement data of the urban heat island in the urban canopy layer of Novi Sad city and (ii) to determine areas inside the city being less stressful for the citizens during heat waves using thermal comfort indices.

The locations represent the complete range of the city's neighbourhoods from the densely built-up area with medium narrow streets to the almost natural outskirts.

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Microfiber Reinforcement Iterfibra C, C/V and C/S in Hot Mix Asphalts

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Abstract

The ability of hot mix asphalt to withstand tensile stresses is limited. Cracks and joints are common disturbances. This leads of course to delimit durability and life-time which can bee directly related to different environmental impacts. Less durable pavement means more frequent repairs and maintenance measures. These are related to utilization of non-renewable materials and extra transports producing additional emissions and consuming energy. This paper presents influence of different microfiber reinforcement types ITERFIBRA to hot mix asphalt behavior in this chosen properties: Bulk density of hot mix asphalt, Dynamic modulus, Resistance to the permanent deformation and Resistance to the crack propagation. It is proven and additionally expected that reinforcement can prolong the life-time of a structure by avoiding some of the early defects and structural failures. The comparison with traditional asphalt mix should confirm this presumption.

1 Introduction

The process of developing a construction material starts right at the moment of production or use in construction structures. The process aims to improve the material's useful characteristics which affect the behaviour of the structure it is incorporated in. Improvements are achieved through reduction or removal of the material's negative effect on the future structures without affecting the positive characteristics based on which the material is used. Such strategy is closely related to the general target of sustainable development which could be defined as a progress securing the demands of present generations by not endangering any future evolution. This principle is known as the Brundtland's statement expressing the social and moral aspect of environmental compatibility formulated already in 1983. In the civil engineering the target of sustainability can be fulfilled by reduced consumption of non-renewable natural sources used for structural materials production. In this connection especially bitumen and aggregates play an important role. The limited exploitation of these resources can be reached by progressive recycling techniques, smart and thinner structures able to avoid some defects by self-healing effects or by application of suitable admixtures or additives which can secure same characteristics of the final material with less non-renewable sources. The location of alternative resources is another theoretical possibility, which is nevertheless significantly limited in case of aggregates used in pavements.

The improvement of material characteristics, which is achieved by an admixture, an additive or an ingredient, is conducted e.g. for lowering of construction and maintenance expenses. Such expenses are usually closely connected to environmental impacts as well. If a structure gains better characteristics resulting in more durable pavement with less maintenance and repair actions or preventive checks, the user is less limited in using the infrastructure, the traffic flow is more fluent consuming decreased amount of fuels and therefore also producing reduced concentration of emissions. At the same time less repair actions usually means that reduced transport of construction machinery and materials including removal of old pavement structure. This can be seen as another important source of reduced impacts of infrastructures to the climate.

In road construction we want the materials used for the individual structural layers to have improved resistance to occurring loading, weather and climate conditions. The reason for this can be seen especially in the necessity to safe additional investments and generate economic and environmental added value of such type of infrastructures. With asphalt mixtures, modified binders, surface reinforcement at the bond of two layers or 3D reinforcement evenly distributed in the mixture can be applied. At the same time the mix can be improved by adding intelligent fibres into the mix and strengthen the cohesion of such material. Speaking about fibre reinforced asphalt pavement some specifics should be named:

- method of reinforcement application;
- change in the manner of pavement construction;
- higher demand on work quality;

- difference in pavement structure homogeneity;
- necessity to identify places of cracks occurrence and their behavior;
- more experience with application;
- no negative effect on compaction, no additional compaction needed

2 Experimental assessment with selected fibres

The main objective of researched project was to provide an influence of different types of microfiber reinforcement ITERFIBRA to hot mix asphalt behaviour in this chosen properties:

- Bulk density of hot mix asphalt
- Stiffness (dynamic) modulus
- Resistance to the permanent deformation
- Resistance to the crack propagation

The testing was conducted with typical mixtures used in CZ in wearing and binder courses. In this paper results of a comparative study on the Stone Mastic Asphalt SMA 11 S with respect to chosen properties are presented. The experimental assessment has been done recently at the Faculty of Civil Engineering, Czech Technical University in Prague. The microfiber reinforcement ITERFIBRA type C, C/V and C/S was used in hot mix asphalts under consideration. These microfibers effect as a stabilizer of bituminous binder and can be specified as traditional cellulose fibres and fibres using glass or specific plastics. The dosing of microfibers and common used stabilizer (in non-reinforced mixture), which is made by Czech based CIUR company as trade name S-CEL, was 0.33% of hot mix asphalt. The grain size curve of hot mix asphalt SMA 11 S is in figure 1, with the inclusion of upper and lower passing restrictions according to CSN EN 13108-5. All mix types were made with 50/70 pen grade bitumen. The percent of bitumen content was 6.2 % by mass of hot mix asphalt.

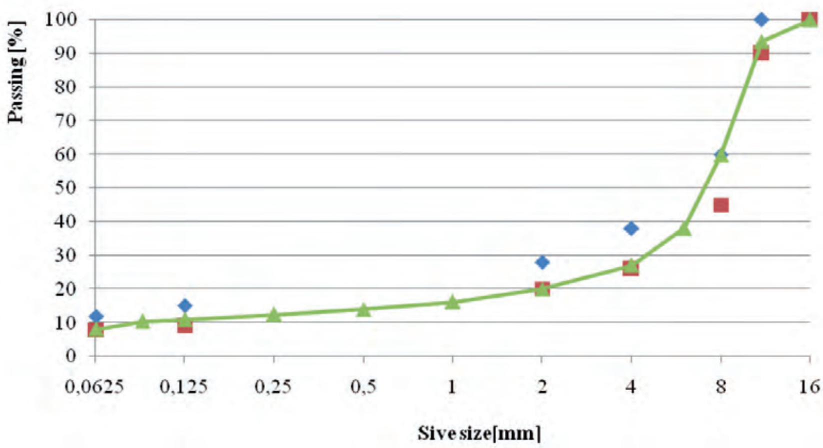


Figure 1: Grain size curve of SMA 11 S s

3 Results

Summary of variants of hot mix asphalts type SMA 11 S ("S" stays for use in pavements with most loaded structure):

- SMA 11 S
- FRSMA 11 S ITERFIBRA C
- FRSMA 11 S ITERFIBRA C/V
- FRSMA 11 S ITERFIBRA C/S

The average bulk density was determined from cylindrical (Marshall) specimens, which have been done by Marshall Hammer Compactor. The specimens were compacted by 50 strokes on both sides (according to CSN EN 13108-5). The specimen bulk density has been determined according to procedure b) as indicated in CSN EN 12697-6+A1. From the figure 2 it is visible, that the mixtures with microfibers ITERFIBRA C/S and C/V have lower bulk density than base mixture (SMA 11 S). The type C has similar bulk density [1, 2].

The test method 4PB-PR, based on the applied sinusoidal stress, according to CSN EN 12697-26 standard, was used to acquire dynamic (stiffness) modules data. The comparison of dynamic modules was done for frequency 8Hz. The stiffness has been assessed for 0, 15 and 27°C. From the figure 3 and the table 1 we can clearly see that the type C fiber has similar value of dynamic modulus as a reference essential mixture. Types C/V and C/S have lower values of dynamic modules [1, 3, 4]. Generally all tested mixes reached quite high stiffness values fulfilling the requirements given by the Czech Road Design Manual TP170.

The resistance of assessed asphalt mixtures to permanent deformation was measured with Hamburg-Wheel Tracking Test method according to CSN EN 12697-22+A1. The test procedure was done at small test device-procedure B in accordance with aforementioned standard. The specimen was tempered with air to temperature 50°C. The values as a rut depth at 10,000 cycles (PRD_{AIR}) and rut depth increment between 5,000 and 10,000 cycles (WTS_{AIR}) characterize the permanent deformation resistance. The influence of microfibers ITERFIBRA C and C/V to permanent deformation resistance was not proven. The type of microfibers C/S has negative effect on permanent deformation resistance (figure 4 and 5), [1, 5].

The resistance to crack propagation was measured in accordance with CSN EN 12697-44, which will be soon in force. The resistance is measured on semi-cylindrical specimen with notch in the middle. The load is applied in three areas on the tested specimen so that the middle of tested specimen is subject of tension. The bend is caused by applied constant increment of strain deformation (5 mm/s). During the test the force and deformation are automatically recorded. The resistance to crack propagation is based on the maximum load (F_{max}) which the material containing a notch can resist before failure (K_{Ic}).

This summary report is aimed to residual strength moreover, that is expressed as work (R_W), which the test device performs to achieve 50% of F_{max}. The tests were conducted by two temperatures 0°C and 40°C. The reinforced hot mix asphalts

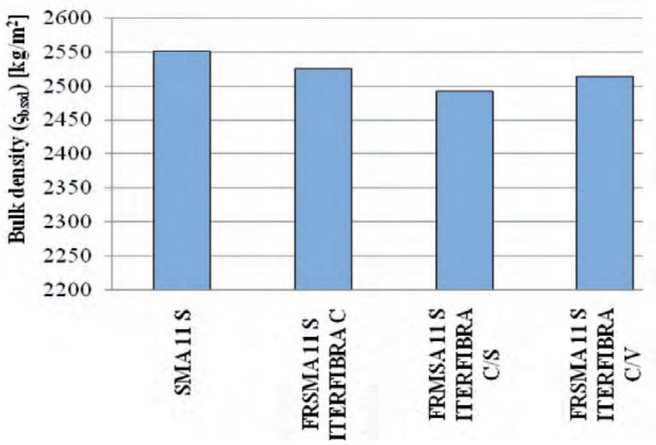


Figure 2: Bulk density of hot mix asphalts, type SMA 11 S

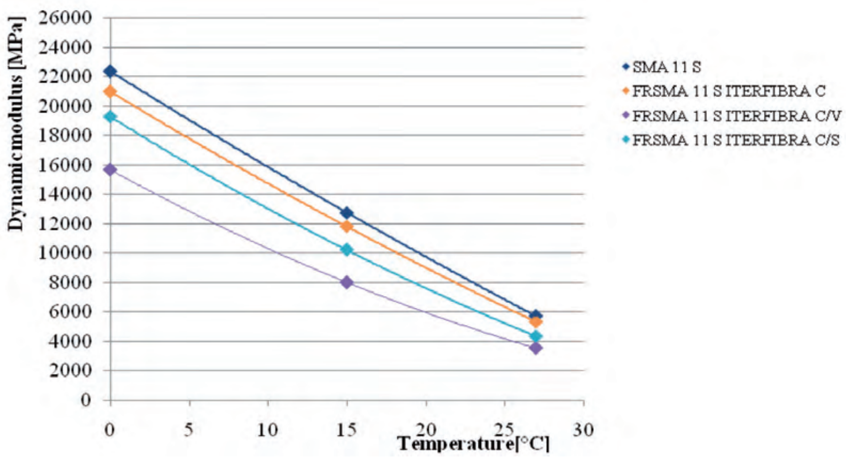
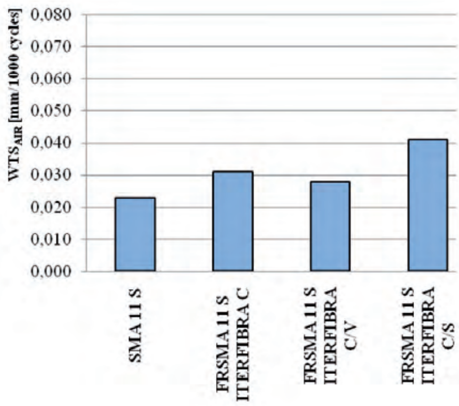


Figure 3: Dynamic modules of SMA 11 S mixes by frequency 8Hz

Table 1: Dynamic modules data of SMA 11 S mixes by frequency 8Hz

Test temperature	Hot mix asphalt type						
	SMA 11 S	FRSMA 11 S ITERFIBRA C		FRSMA 11 S ITERFIBRA C/V		FRSMA 11 S ITERFIBRA C/S	
	E*	E*	Change of E*	E*	Change of E*	E*	Change of E*
[°C]	[MPa]	[MPa]	[%]	[MPa]	[%]	[MPa]	[%]
0	22,300	20,950	-6.1	15,600	-29.9	19,300	-13.5
15	12,700	11,800	-7.2	8,000	-37.1	10,200	-19.7
27	5,700	5,300	-6.1	3,500	-37.8	4,300	-23.7



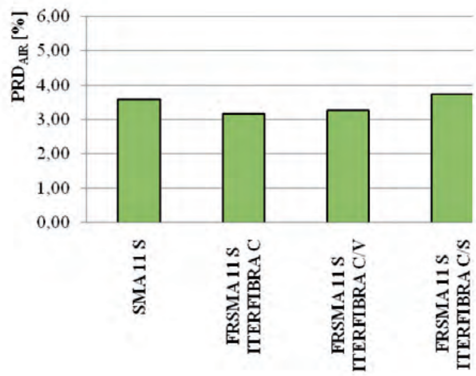


Figure 4: WTS_{AIR} of experimental SMA 11 S mixes (left)
Figure 5: PRD_{AIR} of SMA 11 S (right)

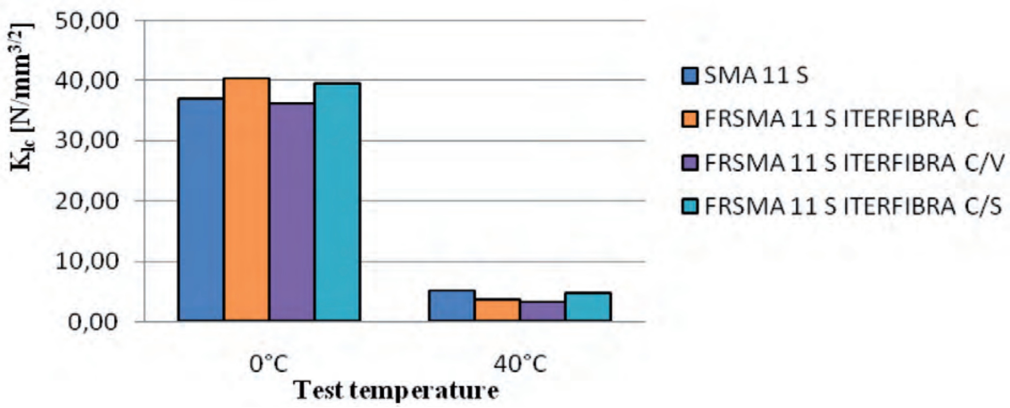


Figure 6: Characteristic K_{Ic} of SMA 11 S

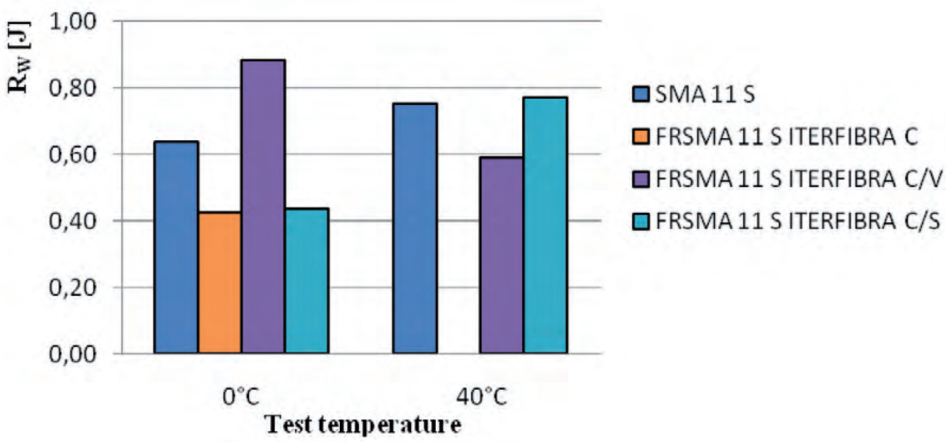


Figure 7: Characteristic R_W of SMA 11 S

with microfibers ITERFIBRA did not prove better resistance to crack propagation or crack creation as was expected on the basis of parameters under consideration (table 6 and 7). The residual strength of the microfibers type C by 40°C could not be measured because of device defect.

4 Summary

For individual microfibers ITERFIBRA [1] following recapitulation can be made:

Table 2: ITERFIBRA - Properties

Characteristic	Type C	Type C/V	Type C/S
Bulk density of hot mix asphalt specimen	any influence	lower bulk density	lower bulk density
Dynamic modules	any influence	slightly negative influence	slightly negative influence
Resistance to permanent deformation	any influence	any influence	slightly negative influence
Resistance to crack propagation	any influence	any influence	any influence

Acknowledgement

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Multiyear Underground Thermal Interaction Between the Soil, the Building and the Atmosphere

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Abstract

Generally, in situations where the initial ground temperature field is unknown or unsatisfactorily known, numerical simulations must be carried out for several years with an assumed initial ground temperature in order that the system defined by the building and the surrounding soil reaches equilibrium. Note that, equilibrium means that the grid nodes after a certain time point have approximately the same temperatures at the same corresponding hour every year. Sometimes it is of paramount importance to evaluate the thermal performance of a building at a specific location over a long period of time. The same applies for the calculation of soil's temperature due to the building's presence. Usually, an initial ground temperature must be assumed and the model run for a long period (e.g. 4 years), in order to approximate the thermal performance of the earth-contact domain. The duration of the period that the simulation must be carried out depends on how good the initial ground temperature has been approximated in relation to the meteorological conditions and the location. Basically, when a structure is constructed, the presence of the building in combination with the meteorological conditions tends to drive the ground temperature field below it after the system reaches equilibrium. In the present study, an effort will be carried out in order to predict soil's temperature due to the interaction between the atmosphere, structural components and ground for several years.

The two-day international conference “Climate and Constructions“ on 24 and 25 October 2012 covered the topics “Building Science“, “Construction Chemistry“, “Urban Climate” and ”Materials Technology and Construction Techniques“. Beside invited lectures and a workshop part about the interactions between climate and the construction sector, there was an open call to submit abstracts. The abstracts were assessed by an international advisory board. In the end, more than 30 articles were submitted, which were presented in two parallel sessions. About 80 people from over 20 countries worldwide attended the conference. Following the conference, various project ideas evolved of which several will start in the first year after the conference.

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