Results of Monitoring a Naturally Ventilated and Passively Cooled Office Building in Frankfurt a.M., Germany

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SUMMARY

In this article the concept of a new energy-efficient office building and results of a 3-year monitoring are described. The monitoring was performed within the German funding programme EnOB [1]. In this building most of the offices are naturally ventilated and passively cooled. One aspect of the passive cooling is the nocturnal ventilation operated automatically by the building's control system. Another focus of the energy concept is on regenerative heating with wooden pellets.
Monitoring results show that the integrated planning enabled a very low consumption of energy for heating, ventilation, cooling and lighting. The monitoring could help to reveal operating problems and to lower the usage of energy. Though passively cooled, the rooms provided good thermal conditions. The given limits of room temperatures were exceeded only in an acceptable manner. Good air quality could be achieved just by natural ventilation.
In this article first the building and energy concept is described. Then results of the monitoring are shown, with a focus on the passive cooling concept and the achieved user comfort.

INTRODUCTION

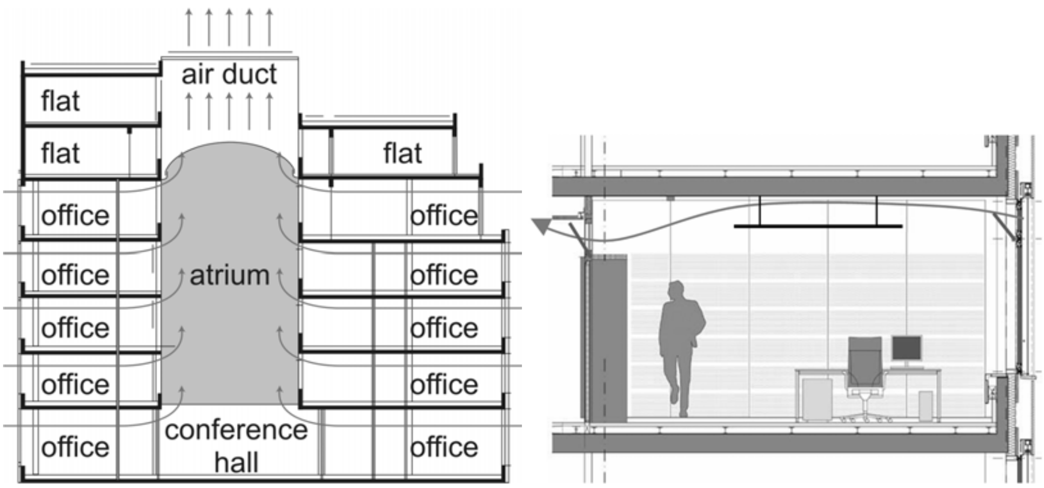
Air-conditioning and active cooling contribute significantly to the energy consumption of a lot of existing office buildings, particularly if primary energy is taken into account. Passive cooling strategies can diminish the energy consumption for cooling.
In new office building "East Arcade" of the KfW bank group (Figure 1) passive cooling and nocturnal ventilation are main aspects of the energy concept. The building is a demonstration project within a German funding programme by the Ministry of Economy and Technology. To apply for the programme the anticipated total annual primary energy use (heating, ventilation, cooling and lighting) had to be below 100 kWh per m² net floor. This was an ambitious aim but it could be achieved, as examination of 25 buildings has shown [2].

Building and Energy Concept

In order to achieve the strict given criteria an integrated architecture and energy concept had been designed. The new building was completed in 2002 and has space for 300 employees. Five of the seven floors are used as offices and the two top floors as apartments. The offices are arranged around an atrium which plays a central role in the passive cooling concept as it is used for night venting the building. It also increases the compactness of the building (area-volume ratio is 0.25 m^{-1}) and - combined with a good insulation - minimizes the heat loss through the façade. The energy for heating is provided by a pellet boiler and a condensation boiler handling peak loads. The pellets cover about 75% of heating energy throughout the year. The offices are heated by radiators mounted on the balustrade.

Figure 1. The south-elevation of the new KfW building

Moderately glazed areas with high selectivity and an efficient automatic external shading system help to reduce the ambient heat loads during warm weather conditions. Only rooms with high heat gains are conditioned by active cooling. For that purpose a heat exchanger derives part of the cooling energy from the fresh water supply.
However the majority of the offices is cooled passively by nocturnal ventilation and activating the building's thermal mass. Thereby the natural ventilation concept utilizes the stack effect in the central atrium (Figure 2a). For this purpose the skylights in the façade and towards the hallways are opened automatically during night. The concrete ceiling is exposed (without suspended ceiling) for optimal heat exchange with the air (Figure 2b).
In addition to the night venting option the rooms offer the opportunity for day-time (single-sided) natural ventilation by manually operable windows and skylights. Here the user can determine the opening times of the skylights himself or choose a short-term ventilation on the control panel, lasting for 3 minutes.



a) b)

Figure 2: a) Cross section of the KfW building with the central atrium, showing air flow pathway during night ventilation. b) Section through an office.

Two main objectives were defined. According to the EnOB-programme the total primary energy use should be lower than 100 kWh/m².
Furthermore the temperatures in the offices should not exceed a defined upper temperature limit during more than 60 hours a year, which is 60 hours with the attendance of the user. According to the decision of a German regional court in 2003 [3] the temperature in offices should not rise over 26 degrees until ambient reaches 32 degrees. Over 32°C outside there should be a minimum difference of 6 Kelvin between ambient and inside temperature.

METHODS

In this project energy consumption, operation of the technical equipment and the occupants' comfort conditions have been monitored since May 2003, using about 300 sensors. One main focus was to check whether the real measured values would match the planned and predicted energy consumption of the building. Therefore the circuits for heat and cold supply were equipped with heat meters. Facilities using much electric energy were stocked with electric meters. For examining the user's comfort room air temperature and CO_2-concentration in some representing offices have been recorded. Additionally the state of the sun blinds, the windows and the window skylights were stored to provide information about the user's behaviour and the function of the automatic building control. Also the efficiency of the passive cooling concept was observed, completed by temperature sensors mounted into the ceiling. Continuous data were recorded in 10-minute-intervals, event data like the opening of a window were recorded in real-time. Every night the data was exported by the control system into different text files on a computer on site and transferred to a database on a server at university.

RESULTS

Energy Consumption

Regarding the final energy usage of the building the energy for heating was detected as the major part. To this point constantly high supply temperatures for the heating circuits of up to 90°C were measured even during summer. The reason was that two supplemented hot water boilers needed permanently high temperatures. The high supply temperatures and active heating circuits lead to heat losses even during summer.
High exhaust temperatures of the pellet boiler revealed a further problem. An expert report indicated that the efficiency of the boiler was too small which led to a higher consumption of the wooden pellets.
Regarding primary energy heating has less influence, as wooden biomass is regarded with a primary energy ratio of only 0.2 whereas electric power is multiplied by 3.0.
The mechanical cooling for the IT and technical service rooms used a big amount of primary energy. The cooling machine runs with electrical power, its COP (coefficient of performance) is only 2.6. In the beginning in a lot of IT rooms set temperatures of 20°C made the cooling run even 24 hours a day. Changing the operation rules and rising the set temperatures to 26°C helped significantly to save both electrical power for ventilators and energy for cooling.
This is just an example of how monitoring can help to reveal problems and reduce and optimise the energy consumption of a building. Thereby the main problem weren't necessarily conceptional flaws but an improper operation of the technical equipment.

Figure 3 shows the total primary energy consumption of the building for 3 measured years and expected values for the 4th year.

During the three years of monitoring not only problems could be found but it also was shown that the building had a very low energy consumption compared to usual office buildings. The performance of ventilation and lighting turned out to be very good and user comfort could be achieved without active cooling.

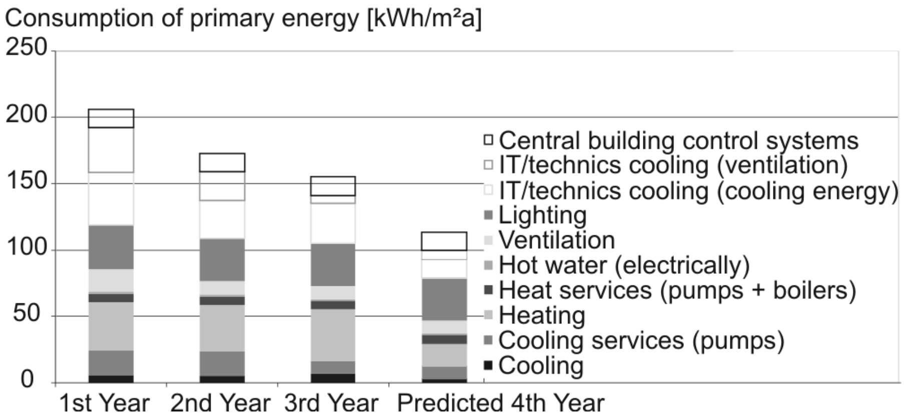


Figure 3: Primary energy consumption during the 3 years of monitoring including a prediction for the fourth year, all according to criteria of the funding programme. Energy for building control and IT-cooling is marked differently as it is not included in each of the compared buildings from the programme.

Passive Cooling

In addition to a glazing of low energy transmission and reduced internal heat loads an automatic shading system supports the passive cooling concept during summer days. For every room an integrated shading calendar of the control system calculates whether the sun hits the façade and whether the blinds have to be closed. The user is able to override the automatic regulation by the control panel in his room.

Within the monitoring project the positions of blinds have been recorded in 30 different rooms on all sides of the building. Looking at the average time that a blind is closed one can see that during summer the rooms are shaded up to 6 hours a day (Figure 4). The blinds are regarded as closed if more than 50% of the window is covered. From November until the end of February the average closing time is less than one hour a day.

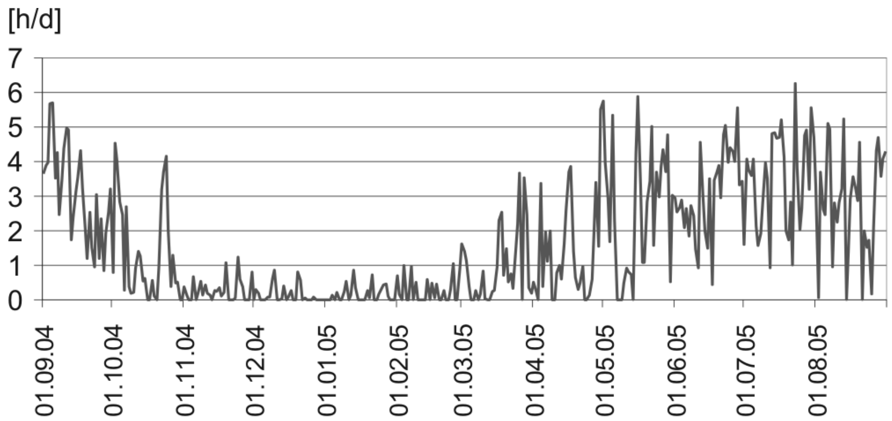


Figure 4: Average closing time of blinds during the day in all 30 measured offices

If you consider the percentage of rooms with closed blinds during a day separated by the orientation you can find out if the shading calendar is working properly. In Figure 5 it is evident that blinds on the eastern façade move down much earlier than the southern or western ones. Shading of each orientation is stopped automatically at a fixed time when the sun cannot hit the façade anymore. Beside a small number of western offices being regulated like southern rooms the function of the shading calendar does not reveal any remarkable failures. During winter it is only the southern façade with blinds being closed.

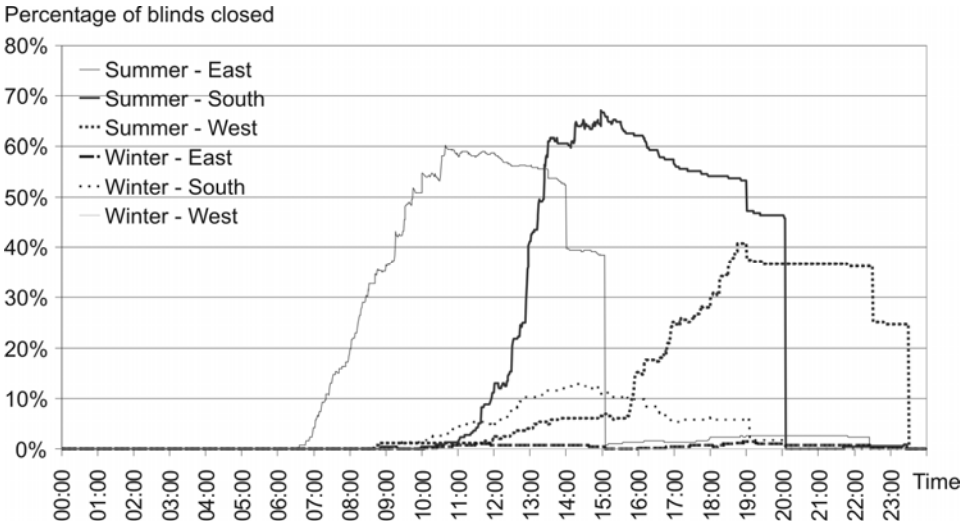


Figure 5: Average percentage of rooms with the blinds closed during a typical day in summer and winter

In order to obtain information on the effect of room air temperatures on the thermal behaviour of the concrete ceilings during night ventilation the temperatures of the ceiling (on the surface and in a depth of 4 cm) were recorded in ten offices.

In rooms featuring exposed concrete ceilings there was a pronounced effect of the room air temperature on the ceiling temperatures. Figure 6 shows how the cooler air temperature reduced the ceiling temperatures. On the other hand, some offices had suspended ceilings in which case there was no correlation between the room air and the ceiling temperatures.

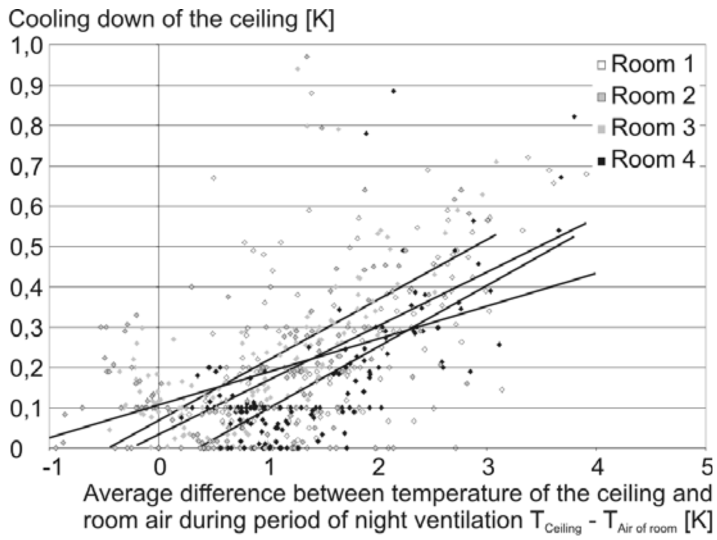


Figure 6: Cooling of the ceiling during the night ventilation from 21 p.m. until 6 a.m. depending on the average difference between the ceiling and the air temperature.

Thermal Comfort

In order to evaluate the thermal comfort conditions in the offices, air temperatures and the attendance were recorded in 10 rooms (out of 200) since 2003 and in 20 further rooms from autumn 2004 on.

The room temperature limit for acceptable conditions had been defined to 26°C for ambient temperatures up to 32°C and with a minimum temperature difference of 6 Kelvin between the indoor and ambient air temperature when the ambient temperature exceeded 32°C (referred to as 32/6-limit). Even during the hot summer of 2003 the room temperatures of frequently used and passively cooled rooms in average surpassed this limit by only 2.1% (32 hours) of the overall attendance time [4]. The maximum temperature in these offices reached 29.6°C with the outdoor air temperatures reaching 40°C (Figure 7).

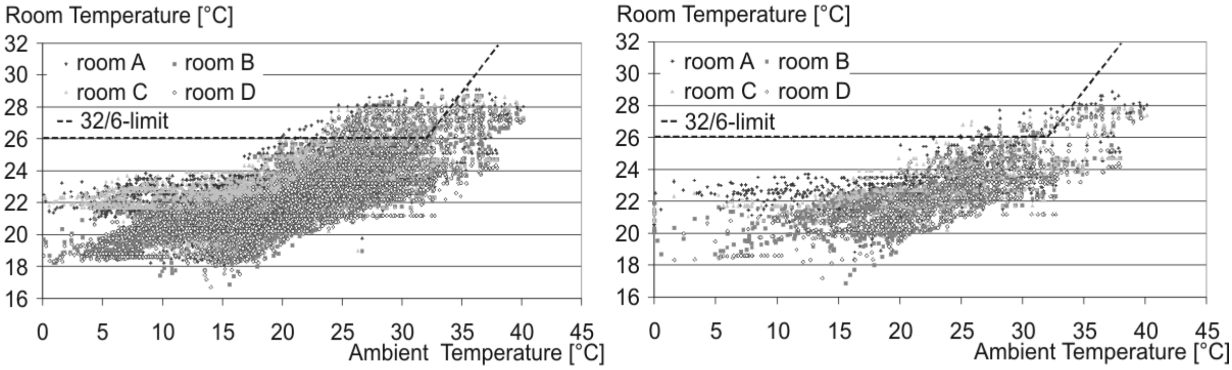


Figure 7: Average hourly air temperature of four passively cooled offices from May 2003 to October 2003 plotted over the actual ambient air temperature. Data including all recorded hours (left) indicate a number of hours when the comfort limit was exceeded. When considering the attendance times (right) there were rarely any temperatures above the limit. The left picture also shows the lower limit of 18°C for the night cooling.

In 2004 the average time above the limit conditions was 0.4% (9 hours), in 2005 2.1% (38 hours) of the total attendance time (Figure 8). The maximum temperature recorded in these offices was 27.2°C during the summer of 2004 and 28.2°C in the summer of 2005.

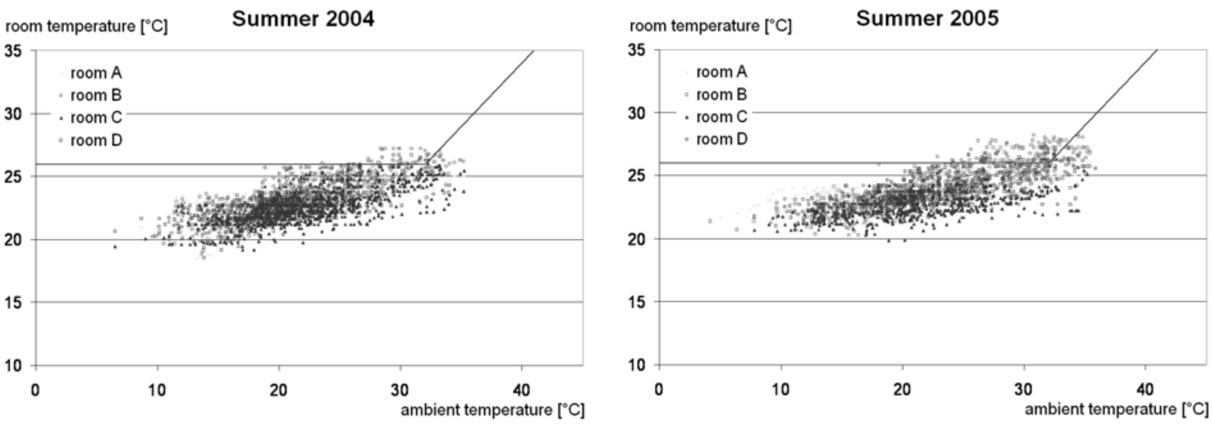


Figure 8: The average exceeding hours for the same four rooms are 9 in summer 2004 and 38 in summer 2005

In summer 2006 however the 60 hour limit was exceeded in different rooms. The reasons were malfunctions of the atrium lid and therefore a failure of the night ventilation. In combination with the very warm nights during June there had been one week with temperatures up to 30°C in the offices. This shows how important the proper operation of the building is if there is no active cooling system for backup.
Though being just a spot sample, the results of the four rooms showed that passive cooling is possible even with extreme weather like in 2003 if the building is operated in the right way.

Air quality

In 5 rooms CO_2-concentrations have been measured additionally for checking if sufficient air quality was achieved just by natural ventilation. Two of these offices were ventilated by air conditioning, the other three by natural ventilation. The results of more than two years monitoring showed that the limit of 2000 ppm was never reached, the limit of 1500 ppm was exceeded just for a few hours - independent of the type of ventilation [5].
On average, the CO_2-concentration was below 1500 ppm for 99.8% and less than 1000 ppm for 98.6% of attendance time. Figure 9 confirms that in every room the concentration was below 800 ppm at least in 90% of the attendance time. There was no significant difference between naturally and mechanically ventilated spaces
The analysis showed that the employees' manual use of the skylights did not depend on the ambient temperature. As an example, on average the skylights were open as often in January 2005 as in June 2005. In contrast, the manual opening of windows was dependent on the outside climate. In June 2005 occupants used the windows more than three times as often for ventilation as in January 2005. With a decreasing frequency of opening the windows in winter, the chance to measure higher CO_2-concentrations rose (Figure 10).

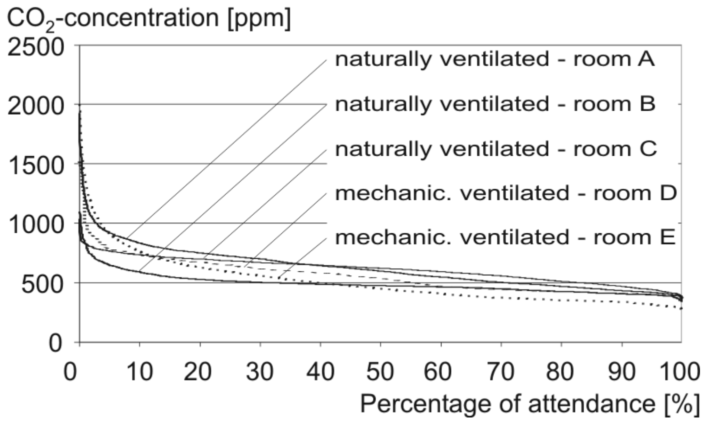


Figure 9: Cumulative frequency distributions for hourly averaged CO_2-concentration of air in 3 naturally and 2 mechanically ventilated offices. Data for one year, only hours with attendance of the occupant

DISCUSSION

The 3-year monitoring of the KfW bank building showed that the ambitious target of a primary energy consumption of 100 kWh m^{-2} a^{-1} was almost reached after the third year with a prediction to fall below this value in the future. Compared to conventional office buildings in Germany this building shows an outstanding energy performance.
Not conceptual errors but failures in operating the building's facilities caused the higher energy consumption in the beginning. This is in accordance to the results of the other

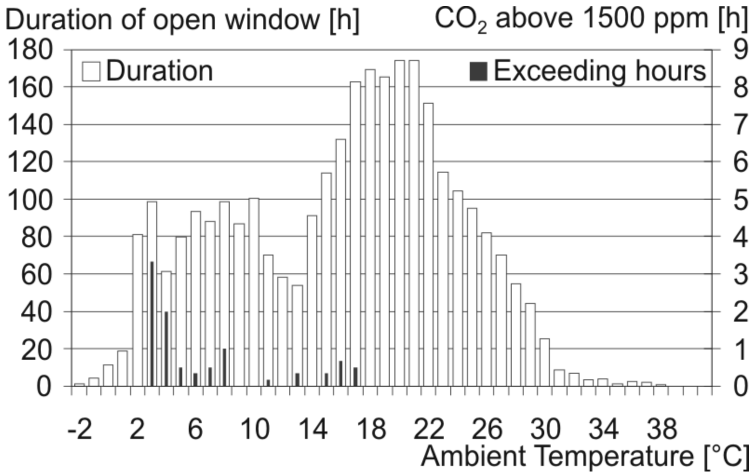


Figure 10: Total time of window opened with CO_2-concentration exceeding 1500 ppm for an office over one year, classified in steps of ambient temperature

demonstration buildings of the programme and underlines the importance of a continuous monitoring of a building. Important preconditions for this are appropriate data management and visualisation as well as experienced facility managers who are familiar with energy performance issues.

It could also be proved that even under extreme climate conditions – like summer 2003 – acceptable thermal conditions in the passively cooled offices could be achieved. The proper operation of the shading system and the night cooling are important to keep the room temperatures within the required limits.

Examinations on the CO_2-concentration in sample rooms have shown that without mechanical ventilation good air quality was obtained.

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REFERENCES

1. Funding programme of Federal Ministry of Economics and Technology (BMWi), http://www.enob.info
2. Voss, K., Löhnert, G., Herkel, S., Wagner, A., Wambsganß, M., (2006). Bürogebäude mit Zukunft (Office buildings with future), Solarpraxis GmbH
3. Regional Court, Bielefeld, Germany (2003). Judgement of the Regional Court Bielefeld, 16. April 2003
4. Wagner A., Kleber, M., Rohlffs, K., (2005). The Passively Cooled KfW Building in Germany - Monitoring Results. Proceedings of PALENC Conference, Santorin
5. Kleber, M., Wagner A., (2006). Results of Monitoring a naturally ventilated and passively cooled Office Building in Frankfurt a.M. Proceedings of EPIC Conference AIVC, Lyon.