HYBRID VENTILATION IN RETROFITTED BUILDINGS – CONCEPTS, STRATEGIES AND MEASUREMENTS

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ABSTRACT

How can hybrid ventilation and natural ventilation significantly improve the indoor climate in retrofitted office and education buildings? During the last 5 years hybrid ventilation and natural ventilation have increasingly been utilised in refurbished and retrofitted buildings with great results. Utilising a newly developed system solution concept, it is illustrated how intelligent control of buildings can establish a good indoor climate with satisfied users. This article contains results from 4 building cases including two schools and two office buildings in Denmark and Switzerland.

KEYWORDS

Hybrid ventilation, natural ventilation, refurbishment, indoor climate, schools, offices, natural cooling.

1. INTRODUCTION: VENTILATION CONCEPT OF NON-DOMESTIC BUILDINGS

A complete ventilation concept has been developed by WindowMaster A/S in co-operation with building owners, architects and engineers. The concept includes a system solution for the building design with focus on a control system for hybrid ventilation (natural ventilation with mechanical assistance). The main variables in such a system solution include the ventilation strategies for each individual building as determined in the design phase, which are subsequently developed and implemented into a control system. In order to create a good indoor climate together with high energy efficiency the control is adaptive to the building depending on the indoor and outdoor climate.

In the next two sections 2 and 3, experiences and measurements from building cases with reference to the integrated control system are illustrated. Common to all the buildings is that they are serviced with internal sensors and a weather station on top of the building. The weather station gives information about the current outside temperature, wind velocity, wind direction and rain. Along with CFD-calculations of the wind pressures on the building envelope for different wind directions this information is used in determining of how much the windows should open.

Based on the empirical experiences and measurements the paper concludes in section 4 that the developed concept successfully can be utilised in retrofitted buildings.

2. SCHOOL BUILDINGS

General experiences

Generally school buildings are characterised with a very high people load in the lessons and lower people load in the breaks. Besides temperature sensors CO_2-sensors are therefore often integrated. In the summer period the required fresh air exchange can easily be achieved by natural ventilation alone, but during the winter season it may be necessary to support the natural ventilation system by mechanical ventilation.

For a large part of the year, the required ventilation for cooling is often higher than the required fresh air change. From practical experiences cooling by natural ventilation is very effective, and it is possible to lower the operative temperature by 2-3°C because of the air movements by natural ventilation.

Noerremark School

The Noerremark School is a Danish school from 1955, which has been utilized one year after the refurbishment in the spring of 2003. Since the school had problems with mould and bad indoor climate the ceilings and roof insulation were changed, and the school was serviced with automatically controlled windows for natural ventilation.

The school has around 440 students divided into 24 classes and the size of the classes varies from 13 to 21 students. Each classroom is 60 m^2 and has an adjacent corridor. The floor to ceiling height in the zones 1-13 varies from 2.4–3.7 m and is constantly 3.5 m in the rest of the zones. The building is constructed of bricks and the thermal mass judged to be medium to high.

Ventilation principles and strategies

In Figure 1 the ventilation principles in the school can be seen. In connection with the renovation the windows were renewed and atomised windows positioned highly in the façades were installed.

Every classroom has four windows: two façade windows and two skylights in zone 1-13 and two windows in the internal walls of zone 14-20. In addition the corridors have automatically controlled windows resulting in an effective cross ventilation and a more even indoor climate in the entire building.

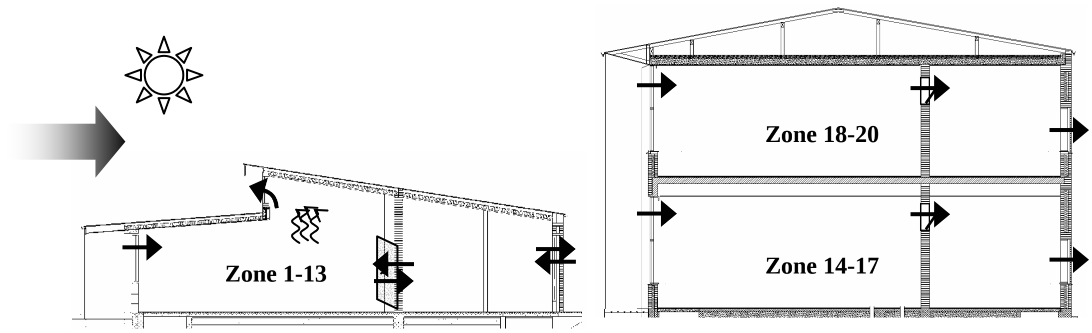

Figure 1: Ventilation principles of the natural ventilation in the school. Zone 14-20 have openings in the internal walls facing the corridors in order to provide cross ventilation.

During the heating season the zones are pulse ventilated automatically every half hour in order to secure a fresh indoor climate. According to the building manager of the school the users do not notice the pulse ventilation. The window operators operate very slowly automatically and almost soundlessly.

During the summer season the zones have comfort ventilation during the daytime and optimised night cooling during the night. During comfort ventilation the windows are more or less opened constantly automatically in order to secure a comfortable thermal indoor climate without overheating.

Results of temperatures

The school has just had the one year examination with a very positive result. The users are very satisfied with the indoor climate and natural ventilation during the year.
In Figure 2 the annual number of hours above 26 and 27°C in the different classrooms can be seen during the occupancy time (all weekdays from 8AM-3PM).

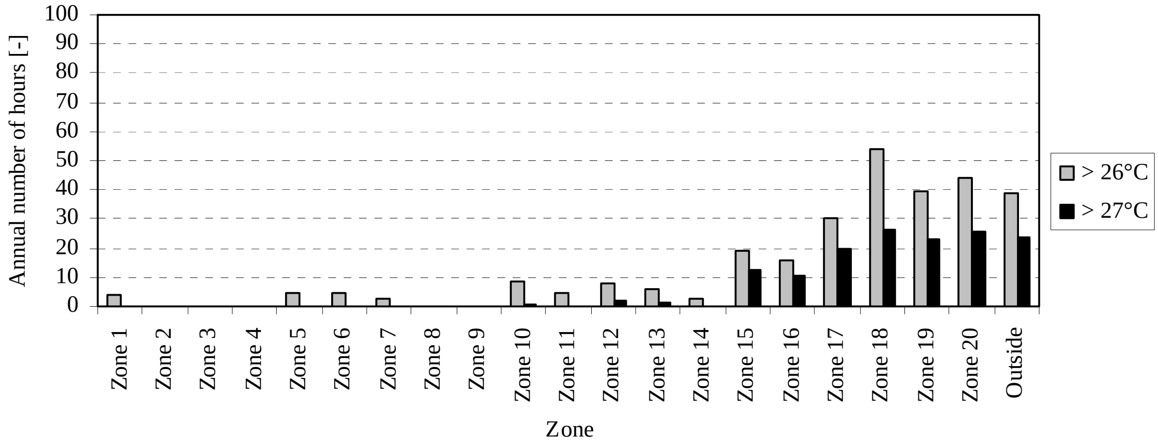

Figure 2: Annual number of hours above 26 and 27°C in the occupancy time in the different classrooms and outside.

In Figure 3 the temperature variations during a summer and a winter week can be seen in three different zones in school.

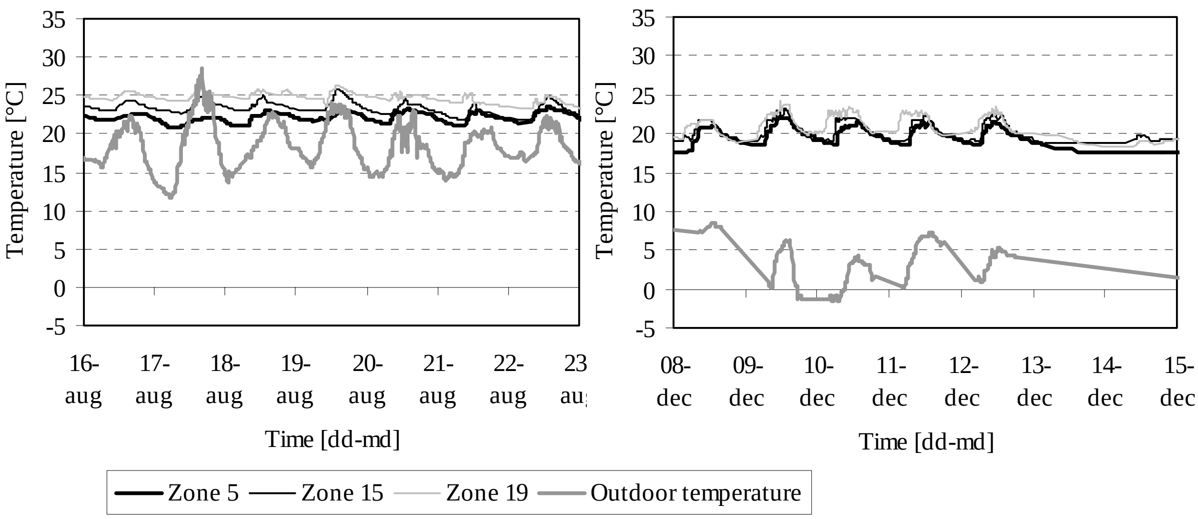

Figure 3: Temperature variations outside and in three different zones.

Dyssegaard School

The Dyssegaard School is a Danish school situated close to Copenhagen. In conjunction with a refurbishment of the building, natural ventilation was installed in the winter 2003/2004. The building is from 1932 and is characterized by a big assembly hall in the middle surrounded by classrooms. The assembly hall reaches from the ground floor through all the storeys up to the roof, where day light pours down to the assembly hall through rows of roof lights.

In the natural ventilation system the assembly hall and the roof lights provide excellent conditions for thermal buoyancy, where the used and warm air can rise and leave through the roof lights. Cool and fresh air is provided through façade windows in each classroom. Between the classrooms and the assembly hall large sliding doors ensures air flow with minimum pressure loss. In Figure 4 the ventilation principle is illustrated for part of the building. During classes the sliding door can sometimes be closed and the classroom will then be ventilated by single sided ventilation.

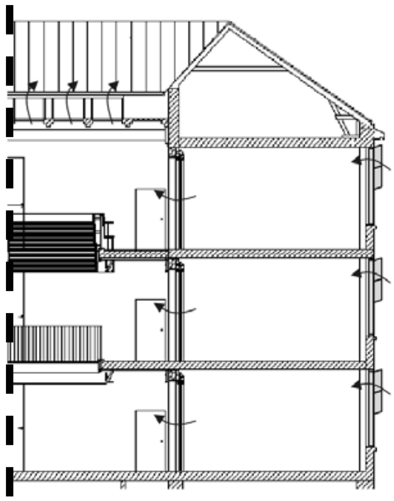

Figure 4: Ventilation principles of the natural ventilation in the Dyssegaard School.

For the natural ventilation the building is divided into a number of zones (one per classroom) where the opening degree of the windows is controlled according to measurements of temperature and CO_2-concentrations in each zone.

In the wintertime the main purpose of ventilation is to preserve a good air quality in the building during the whole day, whilst in the summertime the air change will be dictated by the thermal climate in order to maintain comfortable temperatures indoors. In the summer time the windows will therefore be more or less open all day, and the indoor air quality will be very high.

In Figure 5 the temperatures of the indoor air in zone 3, 15 and 25 can be seen for a cold winter week and the CO_2-concentrations during a cold winter day. The zones all have façade windows to the west and are situated on the ground floor, the 1st floor and the 2nd floor respectively.

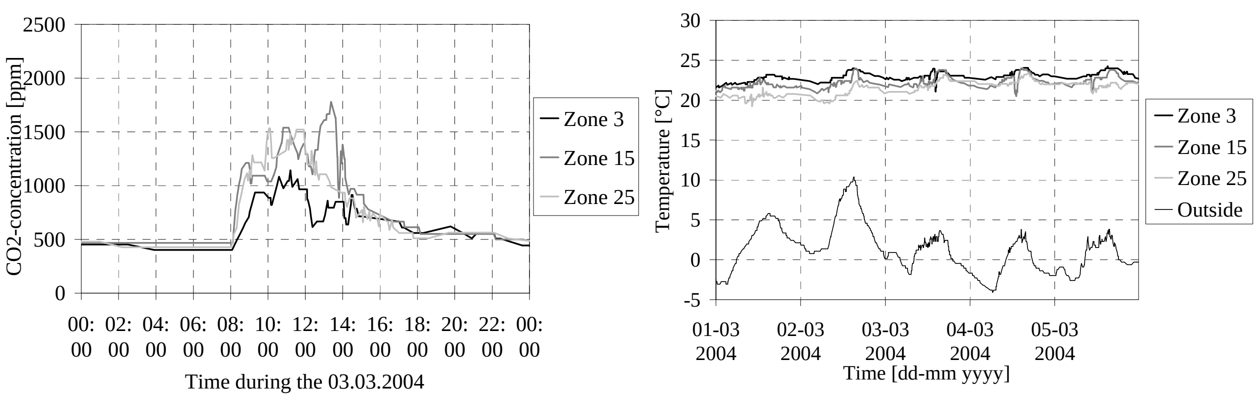

Figure 5: CO_2-concentrations and temperatures during a winter day respectively wither week for zone 3, 15 and 25.

In the graph showing the CO_2-concentrations it is easily seen at which hours the rooms are occupied. In the winter period the ventilation strategy for the natural ventilation is pulse ventilation as in the Noerremark School. The pulses are mainly placed in breaks, where the children move around and most of them leave the room. It is seen on the temperature graph that the pulse ventilation only causes small drops in the indoor temperature in spite of the low outdoor temperatures.
Generally the mean CO_2-concentration in the occupancy hours from 8 AM to 2 PM is around 1000 ppm in the three zones during the week shown in Figure 5, and only for short periods it has exceeded 1500 ppm. The good indoor air quality is partly due to the assembly hall, which has a great air volume and functions as a buffer for the classrooms. However with mechanical assistance the developed CO_2-concentration in the Dyssegaard School can be lowered further.

3. OFFICE BUILDINGS

General experiences

Office buildings are in general very suitable for hybrid ventilation and natural ventilation. The cooling obtained by natural ventilation is very high, which is positive for the indoor climate and the performance of the users. In many cases dynamic calculations are pessimistic about natural ventilation being able to create a stable indoor climate. Practical experiences from many different office buildings give another picture. Hybrid ventilation and natural ventilation work when an advanced control is used and provide a good indoor climate.

The Bodum Head Quarters, Switzerland

The Bodum Head Quarters is situated in the middle of Switzerland and contains two buildings – one refurbished and one new. The two buildings are very similar and were built/refurbished together in the year 2000-2001. Each building is 1100 m^2 distributed on 4 levels. Due to the large window sections the solar heat gain is the largest heat load in the buildings.

Ventilation principles and strategies

Both buildings have open plan offices built around an open stairwell/atrium in the middle of the building. In Figure 6 the ventilation principle of the hybrid ventilation can be seen.

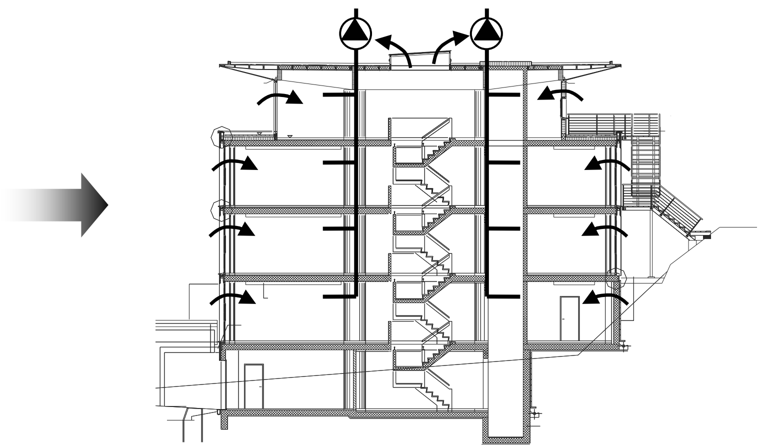

Figure 6: Ventilation principle of the natural ventilation with assisting mechanical exhaust from each level when necessary.

The mechanical exhaust is integrated in the bearing columns in connection with the stairwells. The mechanical exhaust is activated automatically when the temperature in the individual zone gets too high.

Results of temperatures

In Figure 7 the annual temperatures above 26°C outdoors and inside the new and refurbished building can be seen during the occupancy time (all weekdays from 8AM-4PM). All zones have hybrid ventilation except the attic floor in the refurbished building. All zones shown have open plan offices except the ground floor in the refurbished building, which is a reception and show room.

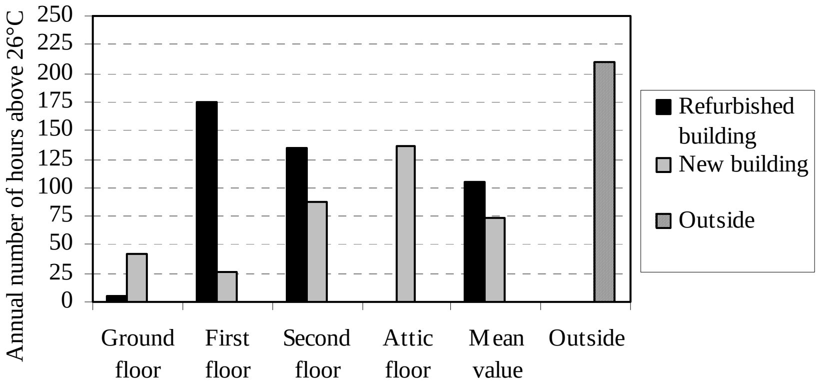

Figure 7: The annual number of hours above 26°C during the occupancy time based on measurements.

According to the user response and the results in Figure 7 it is possible to establish a stable indoor climate in the buildings. Due to the air movements that are possible to create with natural ventilation the operative temperature is lowered 2-3°C, which is very positive during the warmer periods.

In Figure 8 the percentage and variation of the time with mechanical assistance can be seen.

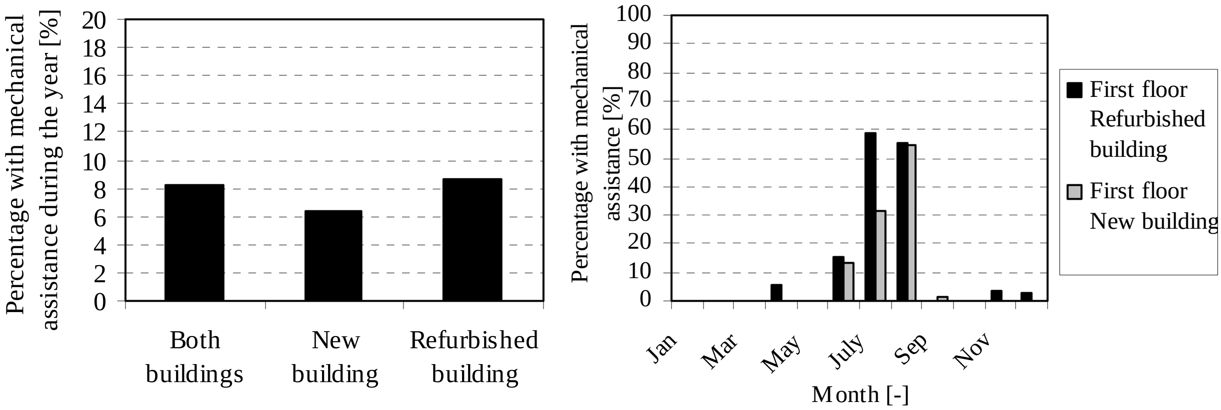

Figure 8: To the right: The annual percentage of the time with mechanical assistance in both buildings. To the left: The monthly variation of the mechanical assistance on the first floors.

The need for mechanical assistance is 8% on average varied from 7-14% in the different zones - smallest on ground level and similar on the other floors. The mechanical assistance in all zones is mainly utilized during the summer months as illustrated in the figure. The mechanical assistance is mainly utilized during the night for night cooling. During the daytime the natural ventilation has been sufficient to create a stable thermal indoor climate.

VOLVO Headquarters

In the spring of 2002 Volvo moved into a refurbished industrial building from 1949. The building was built for production of colours and had been unused for 7 years before the refurbishment. The building has natural ventilation in the offices on the ground and first floor and mechanical ventilation in the canteen. The ventilation principles vary depending on where you are in the building and the usage of the building. In Figure 9 the basic ventilation principles can be seen.

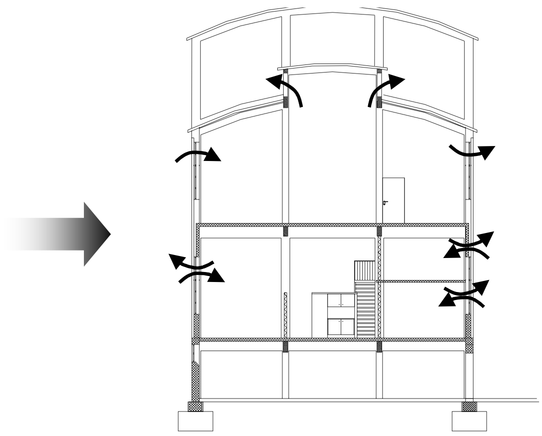

Figure 9: Typical ventilation principles of natural ventilation in Volvo: single-sided, cross and stack ventilation.

In Figure 10 the annual number of hours above 26 and 27°C can be seen in the different zones together with a comparison of the measurements and calculations in a specific zone. The number of warm hours is in the occupancy time (all weekdays 8AM-4PM).

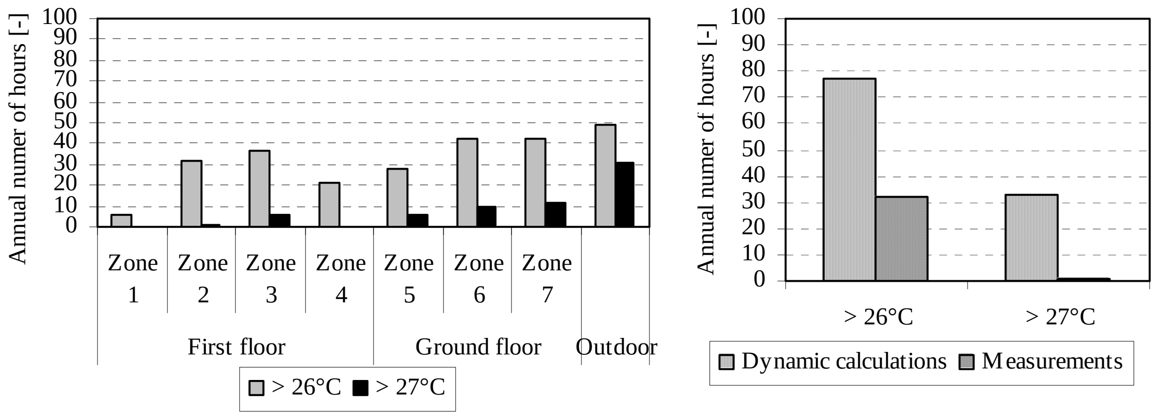

Figure 10 To the left: The measured number of hours above 26 and 27°C in the occupancy time. To the right: Comparison of dynamic calculations and measurements of a specific zone (zone 2).

Based on Figure 10 (to the left) and the users the thermal indoor climate has been very stable in the building. The comparison with the dynamic calculation (to the right) shows that the predicted number of hours above 26°C is higher than the measurements. The difference is mainly because the effect of the thermal mass and natural ventilation in the building had been underestimated. However relative to the total occupancy time the difference is small.

4. CONCLUSION

In connection with refurbishments of existing buildings, hybrid and natural ventilation can successfully be integrated in the design on an aesthetic basis as well as on a performance basis. This paper is based on four different building cases which illustrate how hybrid and natural ventilation with great results can be implemented in retrofitted buildings. Common for all cases is that they have undertaken an integrated system solution concept. This has proven to be important for a good indoor climate and satisfied users when hybrid or natural ventilation is applied. Those results are also in accordance with our experiences from a range of other building references across Europe, which have utilised the same concept of a system solution. In connection with this concept, a control system with focus on hybrid ventilation has been developed.

In section 2 two examples of refurbished schools are given. Based on the measurements from these schools it can be seen how it is possible to create a stable indoor environment by means of both thermal and atmospheric indoor climate. Due to the high people loads in schools it may be necessary with assisting mechanical ventilation during the winter season in order to lower the concentration of CO_2. However in the school example with CO_2-measurements the concentration is low with natural ventilation, which is partly due to the usage of the classrooms and the opening areas into the assembly hall in the middle, which has a great air volume and functions as a buffer for the classrooms.

In section 3 two examples of refurbished office buildings are given, one with natural ventilation and one with hybrid ventilation located in Denmark and Switzerland, respectively. Based on the user response and the measurements the indoor climate has been very good in both cases despite the very different conditions of the outdoor climate and annual number of hours above 26°C inside the buildings. However relative to the total occupancy time the difference numbers of hours is small. Due to the air movements that are possible to create with natural ventilation, the operative temperature can be lowered by 2-3°C, which is especially an advantage for the building located in warmer climate conditions. Based on the temperature statistics and the user response the cooling by natural ventilation is significant. Similar to the office building in Switzerland the need for mechanical assistance in connection with cooling is often limited due to the obtained cooling effect by natural ventilation. Since cooling by natural ventilation is a passive cooling technique this lowers the energy consumptions.

In order to develop a good indoor climate together with good energy efficiency of the building it is important with an intelligent control system. In order to utilise the natural driving forces as much as possible it is, besides many other factors, important that the control considers the actual wind pressures on the building. The wind is a strong driving force and important to consider in order to obtain a comfortable indoor climate and thereby utilisation of natural ventilation. By CFD-calculations the wind pressure coefficients of the individual buildings are determined for different wind directions and implemented in the control system.