CONCEPT 2226, A NEW HIGH PERFORMANCE OFFICE BUILDING WITHOUT MECHANICAL HEATING, COOLING AND VENTILATION DEVICES

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ABSTRACT

Nowadays, building simulation tools have been proven to be very effective in the planning process of building projects to find optimal solutions for the building design. This paper has the goal to compare the simulation results and the measured data of the highly innovative office building named "2226" in Austria. Extensive research work have been done by using thermal simulation and CFD simulation tools to optimize a novel high performance office building concept without mechanical devices for heating, cooling or ventilation.

The first objective of the paper is to illustrate the feasibility to use the thermal simulation software TRNSYS for optimizing a novel strategy for building automation. The second objective is to compare results for the CO_2 concentration of simulation tools (TRNFLOW/COMIS and CFD simulation) to real measured data.

INTRODUCTION

In the last years, the discussion about sustainable building design has been focused on zero net emission buildings. Existing zero net emission building concepts have been proven to be technically efficient (Torcellini et al.,2006). However they are costly because they use cost intensive high efficient heating, cooling and ventilation systems and depend on onsite or grid storage systems (Voss et al.,2007).

The building concept of the "Concept 2226" goes beyond the conventional zero net emission building approaches by introducing an office building without any conventional active systems for heating, cooling and ventilation. The Concept 2226 was realized in July 2013 and is located in the cold climate of Austria. Fig. 1 shows the external of the Building 2226.

The innovative Concept 2226 rests on two strategies: (1) design of a state of the art high performance building envelope, and (2) integration of a novel building automation.

To meet the goal for the heating season, the Concept 2226 building is designed with a building envelope with an extremely low heat transfer. With a 72cm thick high-performance brick construction, it is well insulated and has an extremely high air tightness. The U-value of the envelope for example, is 0.08-0.1 W/m^{2}K. The huge time delay of the heat flow resulting from the 72 cm external wall construction helps to maintain comfortable conditions even in extreme cold time periods (Weller et al.,1996). A triple glazing system is used in combination with a high performance window frame. The U-value of the window is 0.6 W/m^{2}K.

Figure 1 The "Concept 2226" building in 2014 (Photo: E.Hoeber)

The novel building automation of the building is the heart of the innovative building energy concept. It controls the natural ventilation openings based on the internal carbon dioxide concentration, temperature levels and the occupant demands to assure comfortable room conditions in all seasons.

Providing a high level of indoor air quality in the wintertime without using any mechanical ventilation system. The only way to keep the indoor air quality on a comfortable and healthy level is to have a fresh air supply to reduce the internal contaminant concentration. In the heating season, this results in an additional cold external air supply into the room and the internal temperature will be reduced. To avoid too cool temperatures even in extreme situations, the concept 2226 building is equipped with a novel building automation logic that controls natural ventilation openings individually for each room, depending on the user demand and the weather condition.

SIMULATION AND MEASUREMENTS

Extensive simulation work were done prior to the construction to optimize the building envelope and the building automation logic. The development of a model predictive control system by using thermal simulation software including uncertainty estimation was an integral part of this research work. Fluid Dynamic Simulations were used to evaluate the CO_2 concentration in each room. The focus of this CFD simulation work was the optimization of the ventilation efficiency and the design of the natural ventilation openings.

Comfort Target

Comfort level for room temperature is defined by standard ASHRAE 55 (2010). The thermal comfort range is chosen with a minimal room temperature of 20 °C and a maximal temperature of 26 °C. The maximal acceptable relative humidity in the room is 60%. The maximal acceptable CO_2 concentration for permanently mechanically ventilated rooms is defined by ASHRAE 62.2 (2001); for a limited time period, the internal CO_2 concentration can be 800 ppm higher than the normal external CO_2 concentration. At an external CO_2 concentration of 400 ppm, the maximal acceptable CO_2 concentration is 1200 ppm.

The preliminary research work on the realized building was done in the year 2011 so that later versions of the building standards couldn't have been considered in this study.

Simulation tools

The software used for the building simulation and model setup was the multi zone dynamic thermal simulation software TRNSYS 17 (Klein et al.,1976). The single node airflow balance simulation software TRNFLOW was used to analyze airflow produced by natural ventilation and to predict the CO_2 concentration in the room. TRNFLOW is an extension of the TRNSYS simulation software, and it calculates data for air flow and contaminant concentration for the same simulation time step using the COMIS multi-zone single node air flow model. It was evaluated as part of IEA ECB Task 23 (Bossaer et al. 1995) and has been validated by Feustel (1999). As a single node multi zone airflow model, COMIS calculates the air temperature, humidity and CO_2 concentration for a totally mixed ventilation.

Thermal simulation to evaluate feasibility of the energy concept

A large number of more then 300 simulations were necessary to evaluate the influence of the user behaviour and to define uncertainties in internal heat loads and artificial lighting.

Thermal simulations have been done for the entire building with the goal of evaluating the feasibility of the novel building technology. The room temperature, CO_2 concentration and humidity were predicted by the thermal simulation tool by using extremely short time steps of 30 seconds. The short time steps were necessary to evaluate extremely short time periods where the natural ventilation is activated.

Development of the building automation system

The goal of the building automation design is to operate the natural ventilation openings to achieve a maximal comfort and indoor air quality without the use of conventional HVAC units.

A balance must be found between the amount of fresh air that must necessarily be supplied to achieve indoor air quality demands and the conserved heat in the room in the heating season (Heisselberg et al.,1999). A conflict arises in the transition period and the heating season when natural ventilation is used as the fresh air supply source and the external air temperature is below the minimal comfort indoor air temperature. However, natural ventilation in the heating season is a heat sink and the time period for natural ventilation should be as short as possible.

To maximize the performance of the automated natural ventilation openings, a control logic was developed and tested in the simulation model. The logic is based on the complementary mixed mode design strategy described by El Mankibi and Michel (2009). It uses an on-off controller with death band, (also known as hysteresis controllers) to actuate natural ventilation openings, mechanical ventilation, and heating and cooling devices.

The hybrid control logic is extended by the control parameters of external humidity and artificial lighting for the use in Building 2226. It ensures that the internal thermal comfort limit for relative humidity will not be exceeded and considers the internal humidity emission of occupants. The control of the artificial lighting ensures that the illuminance value will meet the required threshold value of 500 Lux at occupied working spaces. It will also provide additional internal heat gains in extremely cold situations in the heating season.

TRNSYS 17 is used in combination with the COMIS simulation model for ventilation is used to find optimal set-points for the building control. A simple enumerative optimization principle is used to find the optimal set-points for the room temperature, external temperature and CO_2 concentration. The combination of these simulation tools allows the evaluation of control algorithm. The proposed control algorithm is written in C++ and is integrated into the TRNSYS simulation environment.

A simple evaluation criterion is developed as an objective function to evaluate the outcome of the simulation results. It evaluates the set-points for the predicted CO2 concentration and the predicted room temperature by comparing the resulting building specific heating degree days and cooling degree days which are specific for each combination of set-points. An exclusion criterion is developed to avoid frequent operation of the automated window openers.

CFD simulation

The COMIS simulation program has advantages when it is used in combination with a dynamic thermal simulation tool. However, it has limitations as a mixed mode ventilation model because it cannot provide detailed information about local temperatures, air velocity and pollution concentration.

The computer aided fluid dynamic software tools ANSYS Fluent and OpenFoam are used to overcome the limitation of the COMIS model. These software tools are used to (1) validate the results of the COMIS model, (2) analyse the local CO_2 concentration and temperature in the room in different time intervals, and (3) assess the risk of cold air drag while natural ventilation is activated in the wintertime. The local CO_2 concentration and temperature are simulated for a completely airtight office space. The goal was to find out how long it would take to exceed the maximal acceptable CO_2 concentration. The results of the CFD simulation are compared to the result of the COMIS model to validate the correctness of the dynamic simulation predictions. The simulation results are validated with full-scale experiments.

The simulations to predict the risk of air drag are done at different external temperatures and different external air velocities.

Test condition

The figures in this paper are showing the simulation results for the west oriented office space. It is assumed to be occupied by 8 persons and has an internal heat gain of 15 W/m^2 for the electrical devices and 10 W/m^2 for the artificial lighting. The room has an area of 120 m^2 and a volume of 443 m^3.

Results for the CFD simulations and the real measured data are for a 10m^2 office space with one occupant. One occupant is assumed to produce 0.018 m^3/h CO_2. The height of the room in the realized building is 3.6 m.

RESULTS

Thermal simulation

Fig. 2 shows a representative example of the predicted room temperatures of a west-oriented office space in which the novel building automation is in operation. The room is assumed to have no HVAC systems and to have automated controlled window openers. The figure represents a simulation run with 9 occupants in the room. It shows that the temperatures are predicted to be in the comfort field in almost all time periods in the year. The simulation tool predicts temperatures for only 19 hours above the comfort temperature of maximal 26 C in the summer. These hours with temperatures above the comfort field are predicted for the week with extreme warm external temperatures.

Only 6 hours have been predicted to be below the comfort field in the wintertime. These temperatures below the comfort minimum are predicted for an operation without a back up system (additional internal load of artificial lighting or local resistant cooler).

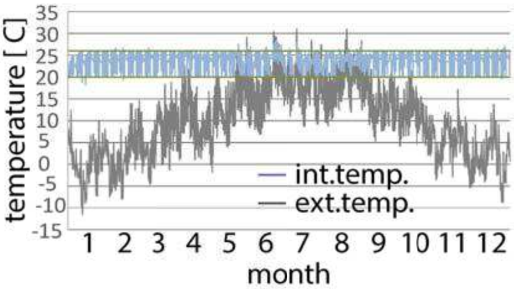

Figure 2 Results of the building simulation for the office space with west orientation

Fig. 3 and Fig. 4 show the predicted room temperatures in the west oriented simulated by Trnsys in the cold weather period in the winter (fig.3) and in the hottest weather period (fig.4) of the weather data.

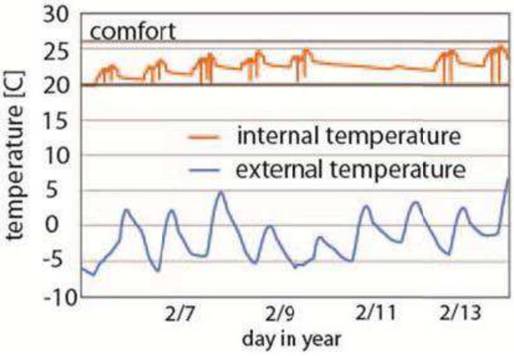

Figure 3 Simulated temperature data for the west oriented office space for the coldest week in the Test Reference Data (Dornbirn,AT).

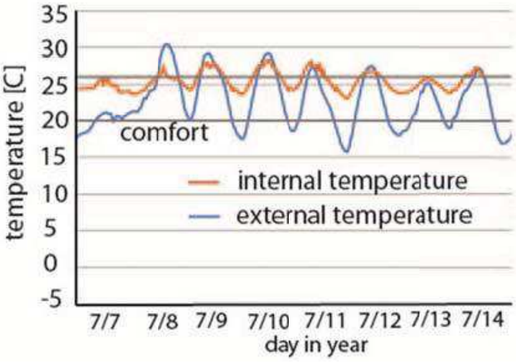

Figure 4 Simulated temperature data for the west oriented office space for the warmest week in the Test Reference Data (Dornbirn,AT).

Fig. 5 and Fig. 6 show the real measured temperature in the same west oriented office room at the most extreme weather period in the winter (fig.3) and in the summer (fig.4). The room occupancy and internal loads are similar to those in the simulation data in Fig.2.

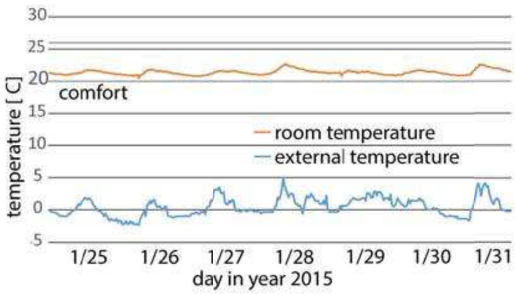

Figure 5 Measured temperature data for the west oriented office space for the coldest week in 2015 with occupation.

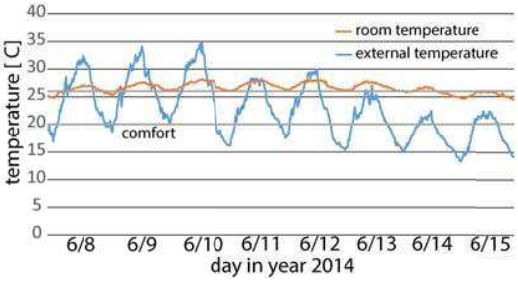

Figure 6 Measured temperature data for the west oriented office space for the warmest week in 2014 with occupation.

For the wintertime, the simulated internal air temperature shows temperature drops at time periods where the ventilation openings are open for fresh air supply. The room temperature will return very quickly to a higher level as soon the ventilation openings are closed. The measured data for the internal air temperature does not have these temperature drops. The real measured data does also not show temperatures below the target temperature of 20 C. An explanation for this difference is suggested by the differences in how the internal heat gains are distributed locally in the room. The assumption of a mixed mode ventilation in the COMIS model does not permit precise knowledge of the local temperature or the location of the temperature sensor.

A comparison of the simulated data (fig.4) to the measured data (fig. 6) at the hottest time periods shows that the room temperature predicted by the simulation software has the same thermodynamic behaviour then the real measured data. The real measured data illustrates that the room temperature occasionally rise to as much as 3 K above the temperature goal of 26 C. It also illustrates that the night ventilation effect is not always sufficient to cool the internal thermal mass to an appropriate level (Haase et al.,2009).

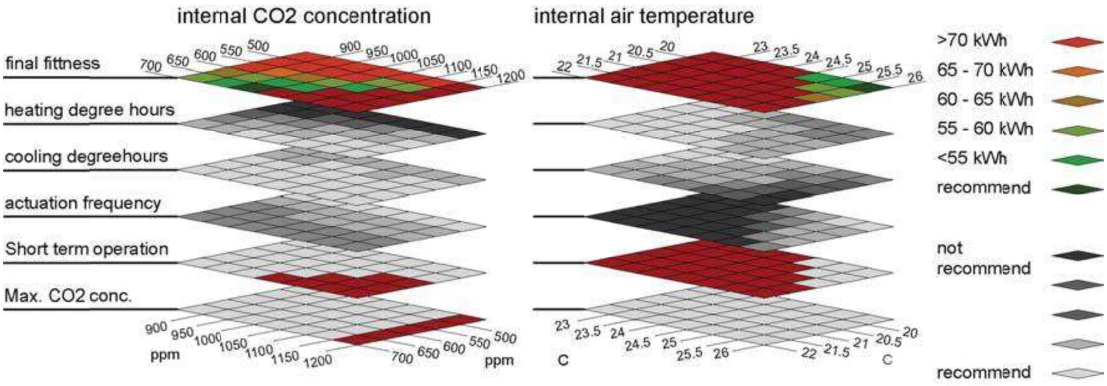

Figure 7 Illustration of the enumerative optimization process. Green areas are symbolizing optimal set-point combinations for the building automation.

Building automation

Results of the optimization process for the set points of the building automation have shown that the optimal set-points for the temperature are 22 C and 26 C for daytime operation to maintain comfortable conditions for most of the year. For the CO_2 concentration, the recommendation for the set-point is 600 ppm and 1000 ppm. The range of CO_2 concentration is necessary to assure short ventilation times in the winter. Fig.7 shows exemplary the result of the simulation based enumerative optimization process. Two matrixes are shown, where the x and y axis are the hysteresis set points of the CO_2 concentration and for the internal air temperature. The here illustrated diagram is for the heating period. Green areas are symbolizing solutions closer to the optimum. These optimal set-points are used in the realized building. An analysis of the measured data in Fig. 7 shows that the recommended set-points determined by the building simulation tool result in comfortable conditions. This indicates that the combination of TRNSYS with COMIS is a reliable tool for evaluating the feasibility of the proposed building automation logic. It gives useful recommendations for the planning process in form of a range of optimal control set-points. Although, because of uncertainties in the calculation process, it is not clear whether the set-points proposed by the simulation based optimization run are optimal, the measured data shows that they are effective.

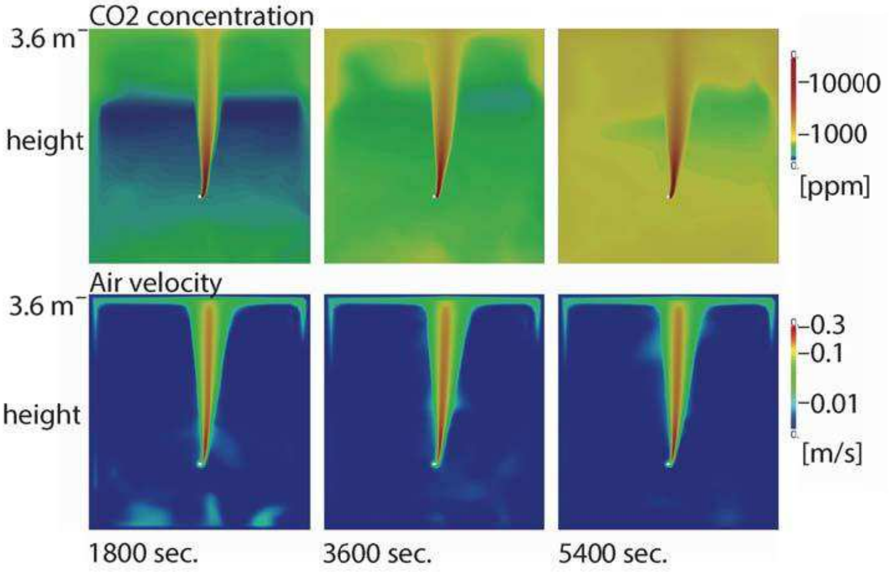

Figure 8 Simulation results of the CFD simulation in the section of the reference room. The CO2 concentration and the air velocity is shown in a function of time.

Fluid dynamics

Figure 8 and figure 9 are showing the predicted CO_2 concentration of the CFD simulation at different height levels at time steps of 30 minutes. The room is assumed to be not ventilated and to be occupied by 1 person. The room has a height of 3.6 m. The CO_2 production of the single occupant is in average 0.0167 m^3/h CO_2 and is therefore close to the estimations for the CFD simulations. The measurement result shows that the distributions of the CO_2 concentration follow a stratification principle. The figure shows that the highest CO_2 concentrations occur at heights above the height of the occupants in all time steps. It also illustrates that the CO_2 concentration close to the floor increases faster than it does in the occupied breathing zone at a height of 1.4 m. The lowest CO_2 concentration is for the simulated CFD results and for the real measured data at a height of 2 meters. It is not clear why the lowest concentration is on this height. There is a door in the test room, which could influence the result. However, the door was completely sealed for the experiments and the CFD simulations are assumed to be without this door.

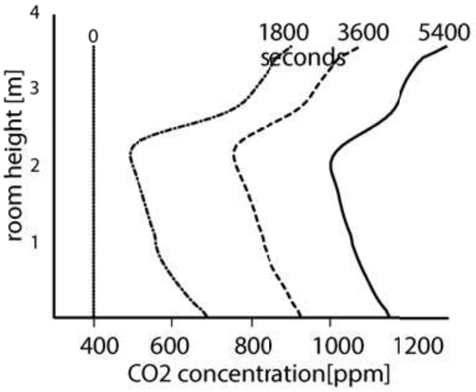

Figure 9 Simulated data for the CO2 concentration at different height levels in the room in different time steps.

Figure 10 shows the results of a full-scale experiment in a typical non ventilated office building with one occupant. Due to the elevated temperature, the exhaled gas mixture initially has positive buoyancy thereby producing a plume that is observed to extend from the occupant to the ceiling (Massman, 1998). The high- CO_2 plume mixes with ambient air during its ascent. Once the diluted plume reaches the ceiling, it cools as it flows along the ceiling and eventually descends along the vertical walls. As illustrated in Figures 8 and 9, a high-CO_2 layer develops and is maintained along both the ceiling and the floor.

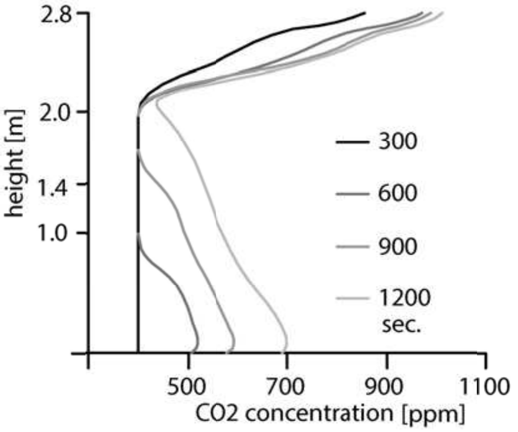

Figure 10 Measured data for the CO2 concentration at different height levels in the room in different time steps. (The CO_2 sensor does not illustrate data below 400 ppm)

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The full-scale experiment verifies the stratification behaviour of the CO^2 concentration in a non-ventilated room. The test room has a height of 2.8 m and has one occupant. Even when the absolute concentration levels are differing, it shows the same stratification effect like in the predicted data of the CFD simulation.

The reason for this stratification behaviour of the CO_2 concentration is the bonds between the air molecules and the CO_2 molecules (Tian et al.,2008). The CO_2, as a reactive acid gas bonds with the warmer air molecules of the exhaled air. Therefore, it follows the buoyancy effects and rises to the ceiling. When the air molecules are cooled, the CO_2 falls to the ground.

Figure 11 shows the CO2 concentration at breathing height produced by the CFD simulations in comparison to the completely mixed mode simulation proposed by TRNFLOW/COMIS. It illustrates that the data from the CFD simulation tool are more "optimistic" than the data from the TRNFLOW/ COMIS simulation tool. It is more optimistic because a longer time period is required to exceed the threshold value of maximal CO2 concentration. Currently, there is no existing simulation tool on the market which can calculate the stratification effect of the CO2 concentration in an timely manner. Therefore, the COMIS simulation tool is used for the optimization process of the building 22-26.

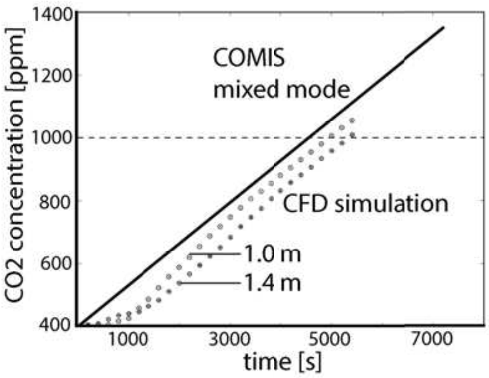

Figure 11 Simulation results for the CO2 concentration for the COMIS mixed-mode simulation tool and for a CFD simulation tool (OpenFoam).

A comparison of the measured data of the full scale experiment in figure 8 to the simulated results in figure 9 reveals that there is a stratification process of the CO_2 concentration at the observed time period.

The results of the CFD simulations and of the full-scale experiment have been useful in the planning process because they are illustrating that the TRNFLOW/COMIS model, which is used in the optimization process, is on the "save" side.

CONCLUSION

The measured results of the occupied building are illustrating that an office building can be operated without conventional devices for heating, cooling and ventilation. It also illustrates that the predictions of the thermal simulation tool for the room temperatures are close to the real measured data.

The results of the optimization process of the set-points for the building automation shows that the thermal dynamic simulation tool in combination with a mixed mode fluid dynamic simulation tool can be used to test a novel building automation algorithm.

The results of the CFD simulation are illustrating that the stratification effect of the CO_2 concentration is not considered in the currently available simulation tools. A fast calculating simulation tool, which provides reliable data for the stratification effect is proposed.

REFERENCES

ANSI/ASHRAE Standard 55-2010, Thermal Environmental Conditions for Human Occupancy, ASHRAE, Atlanta 2010

ANSI/ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality, ASHRAE, Atlanta 2001

Bejan A.. Convection Heat Transfer. John Wiley and Sons, 3rdedition, 2004.

Bossaer A., Ducarme D., Wouters P.(1995), Single sided ventilation in a 2-zone test cell, in: International Energy Agency, Multizone Air Flow Modelling, Evaluation of COMIS, Annex 23, Subtask 2 and 3, International Energy Agency Draft Final Report IEA.ECB.A23r95-4-27rJMF, 1995.

Brager, G.,Baker L., 2008, Occupant Satisfaction in Mixed-Mode Buildings, Proceedings, Air Conditioning and the Low Carbon Cooling Challenge, Windsor, UK

El Mankibi and Michel P.,2009, Hybrid ventilation control design and management" ASHRAE Transactions 2009

Feustel H.E. ,1999, COMIS—an international multizone air-flow and contaminant transport model" Energy and Buildings, 1999

Haase M., Amato A.,2009, An investigation of the potential for natural ventilation and building orientation to achieve thermal comfort in warm humid climates, Solar Energy 83 (3) (2009) 389-399

Heisselberg, P. and Tjelflaat P.O.1999, Design procedure for hybrid ventilation, Proceedings of HybVent Forum 1999, Australia

Klein S.A., Duffle J.A., Beckman W.A., TRNSYS-A transient simulation program, ASHRAE Transaction 1976 82 (1) 623-33.

Massman W. J.. 1998,A review of the molecular diffusivities of H2O,CO2, CH4, CO, O3, SO2, NH3, N2O, NO, and NO2, in air, O2, and N2 near STP. Atmospheric Environment, 32(6):1111–1127

Tian L., Lin Z., Wang Q.,E, 2011, Experimental investigation of thermal and ventilation performance of stratum ventilation, Building and Environment 46 (2011) 1309-1320

Torcellini P., Pless S., Deru M.,2006, Zero Energy Buildings: A critical Look at the Definition; Conference paper NREL CP 550 39833

Voss K., Herkel S., Pfafferott J., Lohnert G., Wagner A.,2007,Energy efficient office buildings with passive cooling – Results and experiences from a research and demonstration programme, Solar Energy 2007

Weller H. G., Tabor G.,Jasak H., and Fureby C.,1998, A tensorial approach to computational continuum mechanics using object oriented techniques. Computers in Physics, 12(6):620–631