

USE OF MULTI-ZONE AIR FLOW SIMULATIONS TO EVALUATE A HYBRID VENTILATION SYSTEM

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ABSTRACT

This paper describes how a multi-zone air flow simulation program has been used for the evaluation of the performance of a hybrid ventilation system in a Swedish school. The idea was also to determine whether it is feasible for an HVAC consultant to apply a multi-zone air flow simulation program in a straight forward way. Before the analysis the tool was used to simulate the present state i.e. checked against measured data.

First the checked model was used to evaluate the sensitivity of the system to wind fluctuations, then to study air flows as a function of temperature and finally to evaluate the performance of the solar chimney. Multi-zone air flow simulations can be very useful for the design of hybrid ventilation and the chosen program can most likely be used by competent HVAC designers.

INTRODUCTION

In an air distribution system, the fans are big users of electrical energy. To deliver 1 m³ of air result in a use of more than 3.5 MWh (depends on the efficiency of the fans) of electrical energy during one year if the pressure drops in the system is 400 Pa. To minimize the use of energy the pressure drops in the air distribution system must be lowered and the forces created by thermal buoyancy and wind applied. To accomplish this, filters are removed, larger ducts are used and no heat recovery is installed. The problems that rise when the pressure drop is lowered are due to the fact that the ratio between outside pressure fluctuations and the system pressure drop becomes large, the authority of the system decreases. When the authority is small, any change in outside pressure due to changes in the wind speed and wind direction will create large variations in the airflow.

The Swedish participation in the IEA Annex 35 Hybrid ventilation in New and Retrofitted Office Buildings was mainly focused on a pilot study, which meant refurbishing a school. An important part of the refurbishment was the implementation of a system for demand controlled hybrid ventilation. After the refurbishment the school was extensively and

continuously monitored for 1.5 years (Blomsterberg 2002). To further evaluate the monitoring results, simulations of air flows, energy use and indoor climate were carried out. These simulations were also carried out during the design to support the design team. In this paper some of the air flow simulations are presented.

SIMULATION TOOL

There are several advanced programs for multi-zone air flow modelling available e.g. COMIS (Feustel 1998), IDA (Sahlin 1995), CONTAMW (Dols 2002). For this study the last program was chosen, as being a user-friendly and free alternative. CONTAMW is a multizone indoor air quality and ventilation analysis program designed to help to determine: air flows and pressures – infiltration, exfiltration, and room-to-room airflows and pressure differences in buildings systems driven by mechanical means, wind pressures acting on the exterior of the building, and buoyancy effects induced by temperature differences between the building and outside; contaminant concentrations – the dispersal of airborne contaminants transported by these airflows and transformed by a variety of processes including chemical and radio-chemical transformation, adsorption and desorption to building materials, filtration, and deposition to building surfaces; and/or personal exposure – the prediction of exposure building occupants to airborne contaminants for eventual risk assessment.

CONTAMW can be useful in a variety of applications. Its ability to calculate building airflows and relative pressures between zones of the building is useful for assessing the adequacy of ventilation rates in building, to determine the variation in ventilation rates over time, to determine the distribution of ventilation air within a building, and to estimate the impact of envelope air tightening efforts on infiltration rates.

CASE STUDY

The Tånga School is a two-story building located in the city of Falkenberg and was built in 1968 containing 20 classrooms, 10 workshops, dining hall, kitchen, gymnasium and offices with a total floor

area of 9350 m². A principal sketch of the school is shown in figure 1.

Before the refurbishment the school was equipped with mechanical exhaust and supply ventilation without heat recovery in building B and C, and with heat recovery in building A (installed in 1993). The approximate specific use of electricity was 3 kW/m³/s and the mechanical ventilation was running between 7.00 and 17.00, with a ventilation rate of 6 l/(s and person) in classrooms. The total ventilation rate was approximately 84000 m³/h.

When retrofitting building B of the Tãnga School, the hybrid ventilation system and the Building Energy Monitoring System (BEMS) of the heating and ventilation system have been two important issues in the design. To achieve passive stack ventilation to a maximum extent, concern must be taken to the system pressure drop during operating conditions. Because of the absence of continuously working fans and the reliance mostly on stack effects, it is essential to reduce the total pressure drop through the distribution ducts. This requires large ducts with a minimum of obstructions. The necessity of controlling the airflows and to secure a good indoor climate under these conditions demands an advanced BEMS.

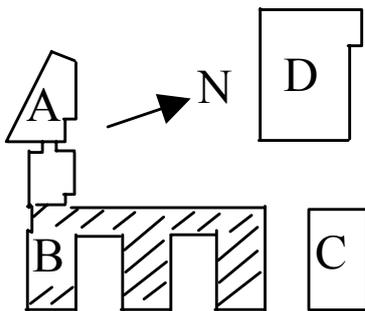


Figure 1 Principal sketch of the Tãnga School. The marked part of building B is equipped with the new hybrid ventilation system.

The main principle of ventilating the two stories high Tãnga School is by passive stack ventilation. When stack effects don't provide a sufficient differential pressure, assisting fans will maintain it at a sufficient level. In the Tãnga school the outdoor air is distributed to the rooms through several air intakes in the exterior walls into a stub duct from where it is distributed to the room. The fresh air is preheated using convectors under the stub duct. This provides mixing ventilation in the classrooms. As the school is situated in a quite clean environment it has been considered acceptable to use no filters, which decrease the pressure drop through the air intakes. Louvers and mosquito nets are however used to prevent rain and snow as well as insects and larger particles as leaves to enter the duct. The air intakes and

the stub duct are easily accessible and can be cleaned by hand.

To prevent air from going backward through the duct system the chimneys have their outlet leeward of the predominant wind direction. The extract air is evacuated through air terminal devices located on the opposite side of the air intakes of the room into vertical ventilation ducts. Local dampers are mounted both in the air intakes and in the exhaust duct, which allows individual control of the flow rate in each classroom. In figure 2, a measurement is shown regarding the capacity of the dampers at the air intake. Also, in the figure a regression model of the capacity as a function of the damper opening is shown.

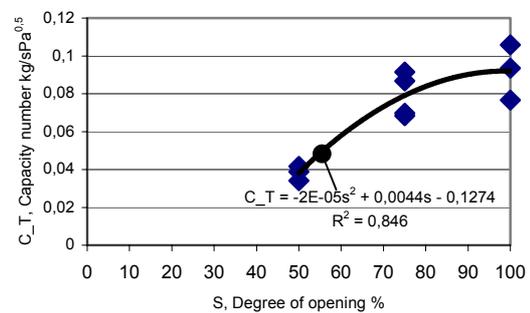


Figure 2 Measurements of the capacity of the air intakes. A regression model is added.

To increase the stack effect, 6 metre high solar chimneys have been installed on the roof with assisting exhaust fans and central dampers mounted in parallel. In addition to extending the length of the exhaust ducts, the solar chimneys consist of a flat plate solar air collector that heats the air in the chimney and increases the stack effect the last 6 metre of the exhaust ducts. There are in total three solar chimneys, each one serving a separate wing of the building. It is desirable to get equal stack effects on both floors and when needed having the exhaust fans working simultaneously.

CHECKING OF THE SIMULATION MODEL

The model is checked using data collected during the first year after the renovation. Two corner classrooms were studied, one on the ground floor and one on the first floor. The check was carried out for a variety of known boundary conditions during winter, when the fan is not needed. Each classroom was modelled separately. All air leakage paths to the outside, dampers, ducts, solar chimney were modelled. Measured data comprised continuous measurements of air flows in ducts for a range of

weather conditions, outdoor temperatures from -7 to $+5$ °C, wind speeds from 0.5 to 6.5 m/s, different wind directions, mostly cloudy days etc.. The pressure coefficients were obtained from wind tunnel measurements (Sandberg 2000).

The comparison shows reasonable agreement (see figure 3).

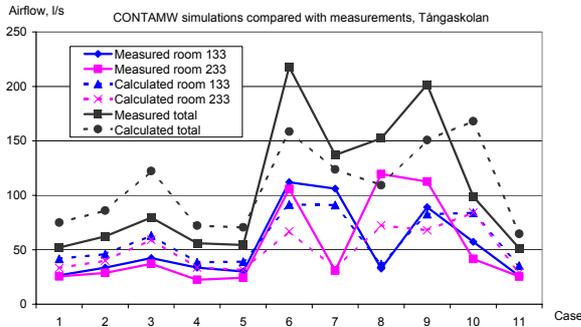


Figure 3 Comparison between calculated measured air flows.

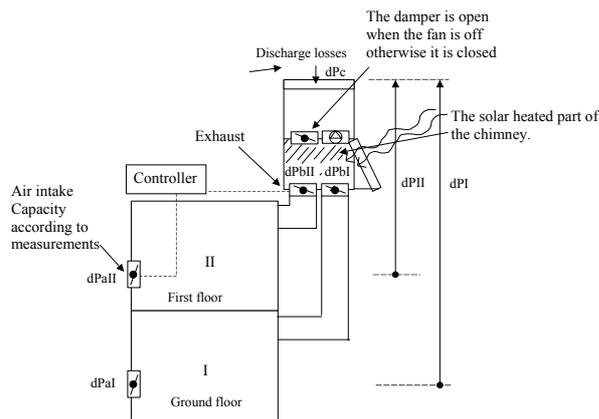


Figure 4 Principle of the hybrid ventilation system modelled.

RESULTS FROM CONTAMW SIMULATIONS

Sensitivity to wind fluctuations

To show the influence of the wind speed on the air flow rate simulations were performed for two classrooms, one on the ground floor and one on the first floor, assuming no air flows to adjacent rooms. The used pressure coefficients are from the wind tunnel measurements, where e.g. at the top of the solar chimney the value is -1 , which only varies slightly with the wind direction.

The ventilation rate increases with the wind speed, with a much higher ventilation on the ground floor (see figure 5 - 8). If the wind effect and stack effect

are combined i.e. assuming a temperature difference between inside and outside of 20 K, the ventilation rates are more than double for lower wind speed, where the stack effect is stronger than the wind effect. If we assume that a minimum ventilation rate is 4 l/s person and maximum ventilation rate is 7 l/s person i.e. total air flows between 100 l/s and 175 l/s, then there are cases with too low ventilation and cases with too high ventilation. The classroom in the ground floor will have inadequate ventilation during the summer at wind speed below 4 m/s and for wind directions $0 - 120$ and $300 - 360$ for wind speeds below 8 m/s. In winter the ventilation rate will be too high for wind speeds above 6 m/s coming from $150 - 240$ degrees. These result were obtained with fully open dampers. However the predominant wind direction is 170 degrees.

At the wind speed of 10 m/s, the flow in the summer varies 100 % depending upon the wind direction. A similar study for the same school simulating the whole wing i.e. six classrooms and ten other rooms showed that the total ventilation rate varies with 25 % depending upon the wind direction (Eriksson 2002). The Eriksson study also used a multi-zone air flow model, a research simulation program IDA MAE. The additional information that the Eriksson study presented was that for wind speeds higher than 3 m/s the air flow through the outdoor air intake can be reversed for certain wind directions. The Eriksson study also showed that the ratio between the exhaust air flow and the outdoor air flow is independent of the wind speed, but at a few specific wind directions, the ratio can deviate considerably from the mean.

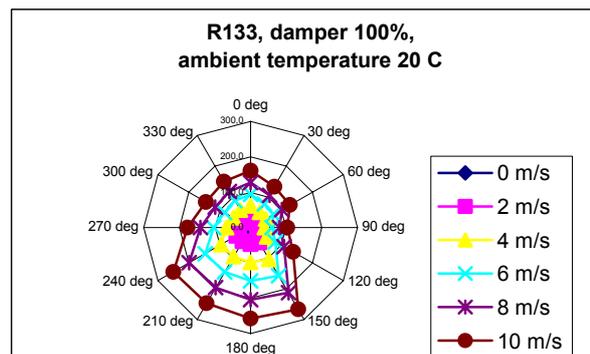


Figure 5 Simulated ventilation rates, l/s, for classroom 133 on the ground floor as a function of wind speed and direction.

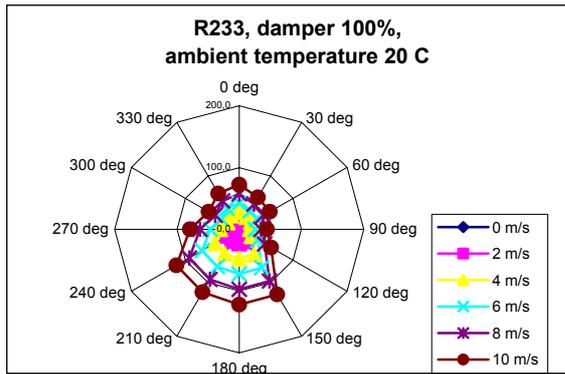


Figure 6 Simulated ventilation rates, l/s, for classroom 233 on the first floor as a function of wind speed and direction.

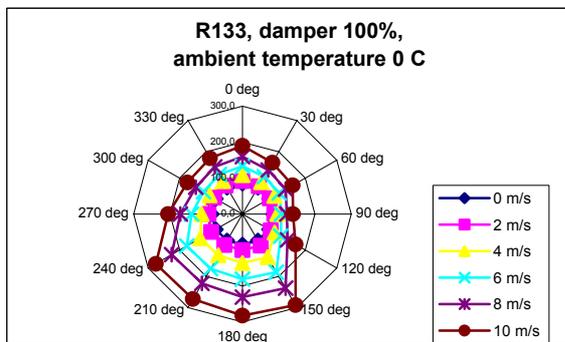


Figure 7 Simulated ventilation rates, l/s, for classroom 133 on the ground floor as a function of wind speed and direction.

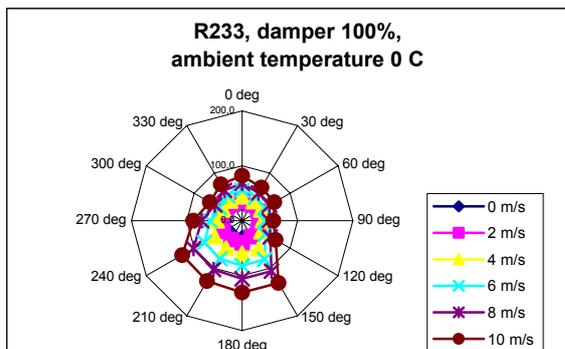


Figure 8 Simulated ventilation rates, l/s, for classroom 233 on the first floor as a function of wind speed and direction.

Sensitivity to stack effect

To show the influence of the stack effect on the air flow rate simulations were performed for two classrooms, one on the ground floor and one on the first floor, assuming no air flows to adjacent rooms and zero wind speed.

If we assume that a minimum ventilation rate is 4 l/s person and maximum ventilation rate is 7 l/s person

i.e. total air flows between 100 l/s and 175 l/s, then the classroom on the first floor would never be adequately ventilated and the classroom on the ground floor would be adequately ventilated if the outdoor temperatures are lower than -5°C (see figure 9 and 10). However most of the time there is some wind and the predominant wind direction causes the highest increase in ventilation, this means that the ventilation rates will be higher and the break point is likely to be above -5°C .

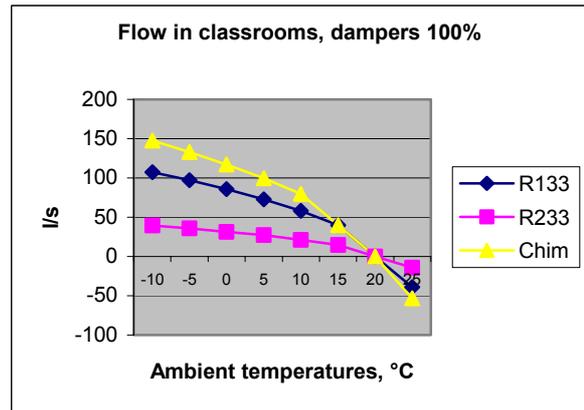


Figure 9 Simulated ventilation rates, l/s, for classroom 133 and 233 as a function of outdoor temperature.

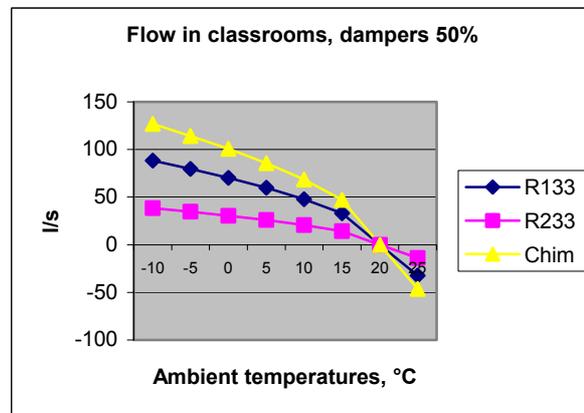


Figure 10 Simulated ventilation rates, l/s, for classroom 133 and 233 as a function of outdoor temperature.

Solar chimney

In the Tãnga School one solar chimney is installed at each wing of the B part of the building (see Figure 2 and 4). From the measurements can be seen that a typical raise of the temperature in the chimney thanks to the sun is to 5 K above the indoor temperature, during winter. It can also be seen that in the morning, with dampers open, the temperature in the chimney can be 10 K below the indoor temperature. Ideally

with the ventilation in operation the temperature in the chimney should be at least the same as indoors.

The first hours in the morning the ventilation rate can be rather low due to the cold air in the solar chimney, 10 – 40 % lower (see figure 11 and 12). It is not very likely that during the summer the starting temperature in the solar chimney is 10 °C only. The solar chimney can during winter (outdoor temperature less than + 10 °C) increase the air flow 5 – 15 %. In the summer the solar chimney can be rather useful, on the other hand the school is not used during the summer.

The Eriksson study also concluded that the solar chimney of Tångå school is not very effective. During sunny days, natural ventilation can be relied on longer. The temperature, at which the fan must be started, is raised about 5 K.

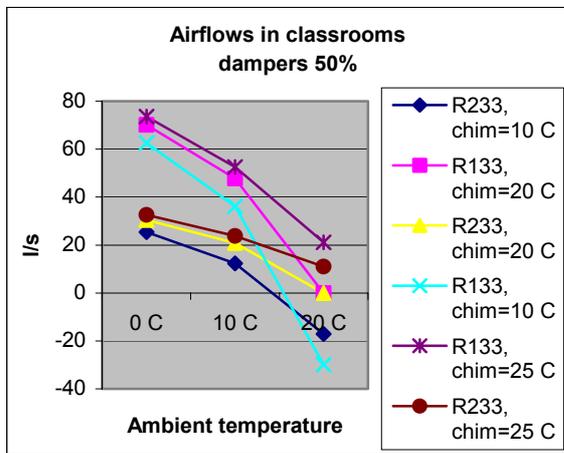


Figure 11 Simulated ventilation rates, l/s, for classroom 133 and 233 as a function of outdoor and chimney temperature.

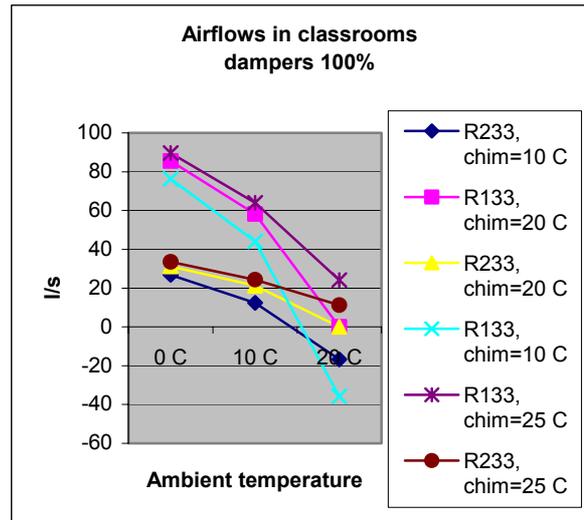


Figure 12 Simulated ventilation rates, l/s, for classroom 133 and 233 as a function of outdoor and chimney temperature.

DISCUSSION AND CONCLUSIONS

Sensitivity to wind speed and direction

Designing hybrid ventilation systems means reducing the pressure drops across the duct system, damper air intakes and outlets. This results in a less stable system, where the air flows are more sensitive to the variations in wind speed and direction. Before such systems are designed and built, the performance of the ventilation system must be studied carefully. The tool to be used is a multi-zone air flow model. A user friendly model, CONTAMW, has been used for the analyses. A competent HVAC designer can use CONTAMW on two separate classrooms and would for the Tångå school have determined that there is a strong dependence on the wind direction and that the highest ventilation rates for the two studied classrooms are for the predominant wind direction. The designer would also have determined that at low wind speeds the ventilation can be rather low and at high wind speed the ventilation can be too high. If the designer had simulated the air flow between rooms, then he/she would have discovered that there are cases when the air flow through the air intakes can be reversed. He/she would also have determined that the ratio between the exhaust air flow and the outdoor air flow is independent of the wind speed, but at a few specific wind directions, the ratio can deviate considerably from the mean.

Sensitivity to stack effect

The HVAC designer would discover that the classroom on the first floor would never be adequately ventilated and the classroom on the ground floor would be adequately ventilated if the

outdoor temperature is lower than $-5\text{ }^{\circ}\text{C}$. However most of the time there is some wind and the predominant wind direction causes the highest increase in ventilation, this means that the ventilation rates will be higher and the break point is likely to be above $-5\text{ }^{\circ}\text{C}$.

Solar chimney

To study a solar chimney is a more complex task than the other tasks described in this paper. The study done here was partly based on measurements and showed that the solar chimney in the Tånga school is not very effective and might for certain conditions even lower the ventilation rate. For detailed simulations of solar chimneys there is a need for a more advanced simulation tool. This tool should be able to couple thermal and air flow simulations. One example of this kind of tool is TRNFLOW, which the integration of the multi-zone air flow and pollutant transport model COMIS into the thermal multi-zone building module of the building and system simulation program TRNSYS (Weber 2003).

Use of multi-zone air flow simulation for the design of hybrid ventilation

It has been shown that the use of multi-zone air flow simulation for the design of hybrid ventilation can be very useful. The program CONTAMW can probably be used by HVAC designers for studying individual rooms. To simulate coupled rooms is a more demanding task, but will give more information. A problem will always be to determine some of the inputs e.g. pressure coefficients, air flow characteristics for dampers, the air leakage of the building envelope. For the Tånga school wind tunnel measurements were made of the pressure coefficients. The airtightness of classrooms were tested in the actual building. The air flow characteristics of the dampers were tested as well.

It is an even more difficult task to analyse a solar chimney for a designer, who will not easily have access to relevant inputs.

ACKNOWLEDGEMENTS

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