Heating and Cooling of the Supply Air in Fan-Assisted Natural Ventilation System

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ABSTRACT

In schools the temperature of the indoor air is one of the most important factors in terms of the indoor climate. The resulting indoor air temperature is depending on many factors; the temperature of the supply air being one of the more significant one. One fan-assisted natural ventilation system includes a supply air system where the outdoor air should be passively heated respectively cooled when passing components in the ground before it is supplied to the classrooms. The objective is to examine the ability of the supply system to transfer heat to/from the outdoor air. This has been studied by measurements of the air temperature at several measurement points in a real school building. The results show that the supply air system has an ability to heat respectively cool the outdoor air. The heat transfer results in a supply air temperature within a rather narrow interval, regardless of outdoor air temperature. The consequence of cooling hot humid air leads to high relative humidity which means that a risk for mould growth may occur which should be avoided. This must be observed and handled if designing this form of system.

KEYWORDS

Supply air, temperature, passive heating, natural ventilation

INTRODUCTION

In schools the temperature is one of the most important factors in aspects of the indoor climate and of the well-being and performance of the children. Wargocki et al (2005) among all have shown that the temperature have an effect on the performance of school children.

The resulting indoor air temperature is depending on many factors. The temperature of the supply air is one of most significant factors. Especially concerning fan-assisted natural ventilation this temperature must be given attention. During periods with cool outdoor air temperature, a risk of draught may occur if the outdoor air enters the room directly without being preheated. During periods with high outdoor air temperatures too high supply air temperature may occur leading to insufficient ventilation and air quality. If the supply air temperature is higher than the room temperature there is a risk that the air will not reach the volume where the pupils are but will flow directly to the exhaust air devices. The natural ventilation system must deal with this issue.

The temperature of the supply air is also important in aspects of thermal comfort and ventilation need. This is especially important in classrooms where a high heat supply will take place due to the high density of people. The supply air temperature should therefore allow a transport of heat from the room implying that the supply air temperature should be some degrees lower than the room temperature.

One configuration of a school building with fan-assisted natural ventilation addresses these goals for indoor climate and energy, by trying to minimize the energy use for ventilation while maintaining or even improving the indoor climate, by including a supply air system where the outdoor air should be passively heated during wintertime and cooled during summertime by the soil and a culvert system before it is supplied to the classrooms. Besides the preheating of the outdoor air which may be advantageous for comfort and air quality reasons this type of supply system may imply that energy can be saved and is therefore intended to be energy-efficient.

The objective of the study is to examine the ability of this type of supply system to passively transfer heat to/from the outdoor air when passing through the supply components.

Studies of supply air temperature in natural ventilation system includes studies by for example Sikander et al (1999) where the temperature was one of the parameter required to together with the relative humidity evaluate the risk of mould growth in this type of supply system which was the objective of the study. It must be emphasized that this solution of supply system may mean high relative humidity and condensation in the system with a risk for mould to grow which should be avoided. The type of ventilation system has been studied by for example of Hult (1998) and Blomsterberg et al (1998). Other studies of the supply air temperature have been performed for mechanical ventilation by for example Engdahl and Johansson (2004), where the energy need was in focus.

METHODS

The ability of the studied type of supply system to passively transfer heat has been studied by measurements in a real school building situated in Malmö, Sweden. A more thorough presentation of the school is made in (Nordquist, 2007) where other aspects of the ventilation system such as the possible driving pressure, and amount and movement of air flow are studied.

Description of the supply air system and the measurements

Outdoor air enters six parallel circular concrete ducts with a diameter of 400 mm and a length of about 20 m lowered in the ground. The air then enters a concrete culvert which has a length of 60 m, a width of 1 m and a height of 2,1 m. This culvert is situated below the building following the length axis of the building. The air then enters a culvert from which vertical brick ducts leads the air to each classroom. After passing through the vertical brick ducts and the supply air devices, the supply air enters the classroom about 3,5 m above the floor level.

Measurements of the air temperature have been made at several points in a school with this design. The values were sampled each 15 minutes. The measurement period which has been analysed here covers a period from June to November. The outdoor air temperatures vary between -5 to +30ºC which is about the interval that can be expected at this location for most climate periods.

RESULTS - MEASURED TEMPERATURES IN THE SUPPLY SYSTEM

The temperature of the air at some interesting point in the supply system is presented. The measured temperature at the entering of the culvert after passing 20 m concrete ducts in the ground is presented in Figure 1. The temperature after passing concrete ducts in the ground and 55 m of culvert is presented in Figure 2. They are all shown as a function of the measured outdoor air temperature.

At the entering of the culvert a fan and a damper are placed. The damper is closed during nights and weekends. The effect the closed damper has on the heating and cooling can be seen in Figure 2 at the measurement point at the end of the culvert before entering the supply brick ducts to the classrooms. When examining the measurement data a picture emerges. When looking at outdoor temperatures mainly below 10 ºC two clusters can be identified. When the damper is closed during the night the air temperature at this point is higher; between about 18-20 ºC and when the damper is open during school time the temperature is somewhat lower; about 14-17ºC. This is logical as the supply air can be assumed to be stationary when the damper is closed and the heat will be transferred to a larger amount than when the air has a higher velocity as for daytime. This effect is not that clear at the other measurement points earlier in the supply system. The fan is working when the outdoor air is above 10 ºC during daytime.

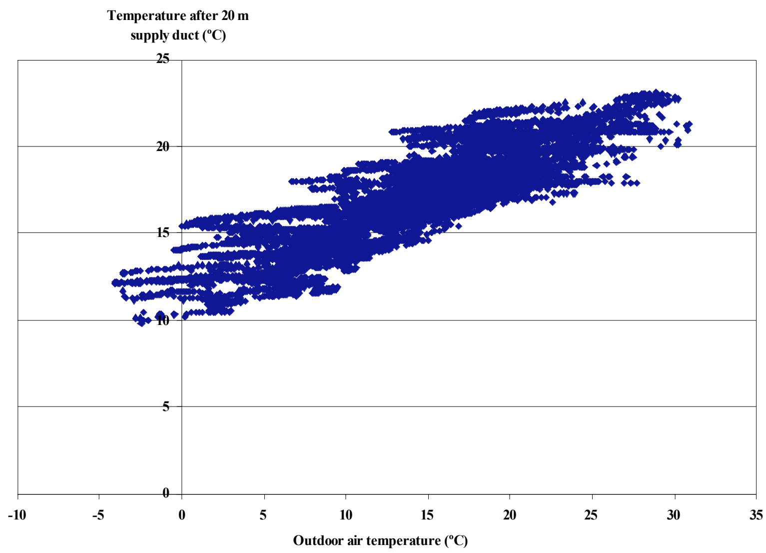

Figure 1. The measured temperature at the entering of the culvert after passing 20 m concrete ducts in the ground as a function of the measured outdoor air temperature.

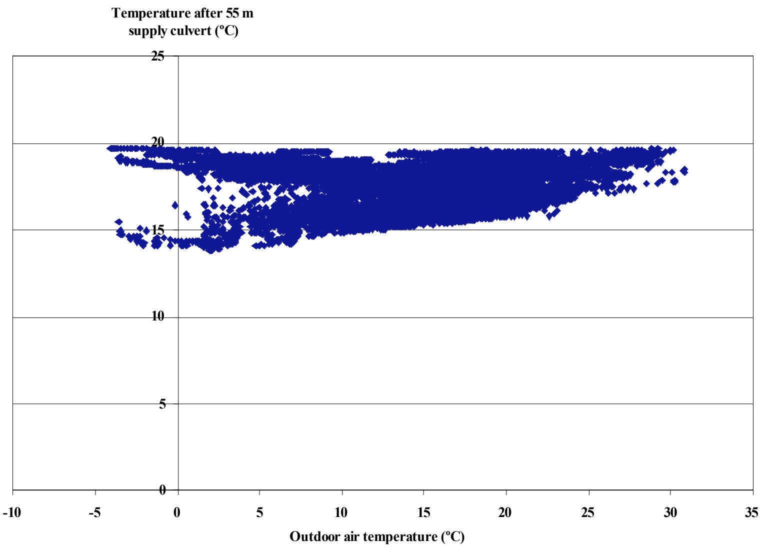

Figure 2. The measured temperature after passing 20 m concrete ducts in the ground and 55 m of culvert (whole culvert) as a function of the measured outdoor air temperature.

A relation between the outdoor air temperature and the temperature at each measurement point was calculated by linear regression and the following expressions were obtained.

$$T_{ground\ duct}=0{,}36\ T_{out}+11{,}8 \qquad (1)$$

$$T_{15\ m\ culvert}=0{,}10\ T_{out}+15{,}7 \qquad (2)$$

$$T_{whole\ culvert}=0{,}01\ T_{out}+17{,}2 \qquad (3)$$

where T_{out} *is* the outdoor air temperature, $T_{ground\ duct}$ is the temperature after passing through the ground ducts, $T_{15\ m\ culvert}$ is the temperature after passing the ground ducts and 15 m of culvert and $T_{whole\ culvert}$ is the temperature of the air after passing through the ground duct and the culvert before entering the vertical supply brick ducts leading to the classrooms.

With these linear regression equations the mean temperature, and the maximum and minimum temperature and the reduction of the outdoor temperature interval can be calculated. The interval of the outdoor air temperature is chosen between -5ºC and +30ºC. These parameters are presented in Table 1.

In Table 1 it can be seen that the ducts in the ground heats the air temperature to 10ºC when its it -5ºC and cools the air when the outdoor air is 30°C to 22,7°C. For an outdoor air temperature interval of 35°C (-5°C to 30°C) the temperature interval after the ground ducts is 12,7°C (10,0 to 22,7ºC). The interval between the minimum and maximum temperature after the ground ducts is reduced 64% in relation to the interval of the outdoor air. The corresponding values for the points 15 m inside the culvert and after the culvert are 90% respectively 99%.

Table 1. Calculated minimum and maximum temperatures and mean temperatures at different points in the supply system.

	Outdoor air temperature	*Temperature after 20 m duct in ground*	*Temperature efter 20 m duct in ground och 15 m culvert*	*Temperature efter 20 m duct in ground och 55 m culvert*
Studied interval Minimum-maximum temperature	-5- +30ºC	10,0-22,7ºC	15,2-18,5ºC	17,2-17,5ºC
Mean temperature	12,5±17,5ºC	16,3±6,4ºC	16,9±1,7ºC	17,3±0,2ºC
Reduction of the outdoor air temperature interval	-	64%	90%	99%

DISCUSSION

In terms of energy the heating/cooling of the outdoor air which passively takes place in the ground supply system can be viewed upon as positive. However some energy from the building above will contribute to the heat transferred from the supply system to the outdoor air, which means that some of the heating energy can not be viewed upon as passive. The system creates a supply air temperature which is some degrees below room temperature thus enabling a moderate thermal climate, positive for the students and a prerequisite for a sufficient air movement in the room.

A large part of the heat transfer takes places in the ducts in the ground. The heat transferring area of the six ducts, about 150 m^2, is considerable in relation to the heat transferring area of 55 m culvert which is about 115 m^2, explaining this large contribution to the heat transfer. When discussing this type of supply system the ducts should accordingly be considered and acknowledged thus not thinking of the culvert as the main contributor to the heat transfer.

The measurement data has been presented and then analysed with a linear regression. The finding of the two clusters of data imply that a next step to take could be to divide the temperature data in one daytime group respectively one night time group and to calculate different regression equations for the two suggested groups which may increase the accuracy. The temperature difference between the two groups is however only some degrees and the analyse so far, shows the order of magnitude for the present configuration.

The heat transfer is considered in this study. There is however other aspects of this type of supply system that needs to be considered. When hot air is cooled, high relative humidity and condensation may occur which may create a moisture problem. Depending on the conditions and material mould may grow. This area has been studied by Sikander (1999) and Hult (1998). This is very important and the author want to lay emphasize on this. The choice of material, design and maintenance must be carefully considered. It should also be taken into account that, for the studied configuration, as a large part of the heat transfer, two thirds, takes place in the ducts prior to the culvert, risk for high relative humidity in this part also is possible. These ducts must also be addressed. For the studied configuration, these ducts are rather long and rather narrow ducts which may imply a disadvantage in terms of this problem. Another solution that can be considered could be to avoid the outdoor air to pass through the culvert system during periods when a high relative humidity will occur, in others words only to use it for heating during the cold season and not for cooling the air during the summer season.

Future research

A theoretical model describing the heat transfer has been developed. This will be validated with the measurements giving a model to apply in the design stage making it possible to decide on a sufficient configuration. Then it should be possible to attain the length and other dimensions required to attain a sufficient heat transfer.

CONCLUSIONS

The results show that the ducts in the ground gives a significant contribution to the heating/cooling of the outdoor air. About two thirds of the heat is transferred in the ground ducts. The results also show that the studied supply system in terms of ducts and culvert heat respectively cools the outdoor air to a rather narrow temperature interval. The conclusion can be drawn that the studied supply duct system has a significant ability to heat/cool the outdoor air.

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