Energy savings and thermal comfort with ventilation radiators – A dynamic heating and ventilation system

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SUMMARY

Studies indicate that a high ventilation rate with fresh air supply directly from outdoors gives better thermal comfort conditions, less SBS (Sick Building Syndrome) symptoms and increased work productivity. The drawbacks with a high ventilation rate in natural or exhaust ventilated buildings are normally increased energy use for heating and cold air draught. Such problems may be minimized with ventilation radiators, radiators where cold ventilation air is brought directly from outdoors through a wall channel into the radiator where it is heated before entering the room.

This paper discusses advantages with ventilation radiators in comparison to those of traditional heating systems. Focus has been on energy aspects and thermal comfort. The main conclusions are that ventilation radiators may give a stable and uniform thermal indoor climate. The high thermal gradient between cold ventilation air and the radiator surface inside the ventilation channel also makes the ventilation radiator more efficient than other systems. A method to vary indoor climate on a daily basis according to where people stay is proposed for additional energy savings with ventilation radiators. The deductions were based on results from CFD simulations in a well validated office model.

INTRODUCTION

A CFD (Computational Fluid Dynamics) model of an office room was made to simulate and investigate thermal climate and energy aspects with different heating systems. The goal of the project was to find ways to improve the thermal efficiency of water-based space heating, mainly radiators, and adapt them to low systems temperatures. Low-temperature heating, either by heat pumps or district heating systems, have several positive environmental and economical aspects. Some of them are more efficient energy use, decreased thermal losses in distribution and improved thermal comfort [1-3].

During the study interaction between heating and ventilation systems proved to be an important factor for controlling the thermal climate. Cold draught tends to be the largest hazard, especially in low-temperature systems. The reason is because low temperature systems such as floor and wall heating have weak buoyancy power to counteract cold down-flow from air inlets and windows. With ventilation radiators, on the other hand, the ventilation air is already heated to room air temperature when it enters the room after passing through the radiator. This secures stable indoor climate. The ventilation radiators even proved to perform better in terms of thermal efficiency compared to the other heating systems tested. That is why the focus of the project turned to the evaluation and development of ventilation radiators.
There are still great possibilities for improvement. This paper deals with experiences from the study and explains some advantages with ventilation radiators that can be utilized further in the future.

**PRINCIPLE OF VENTILATION RADIATORS**

A ventilation radiator is a combined ventilation and radiator system where cold ventilation air passes through the gap between the radiator panels before entering the room. The mean temperature gradient, $\Delta \theta_m$, between the radiator surface and the passing air is larger than in other low temperature radiator systems, just as the heat transfer coefficient, $k$. The radiator efficiency is improved as heat is more easily extracted from the radiator surface. Figure 1 shows the principle of a ventilation radiator.

![Illustration of a ventilation radiator](image)

**Figure 1. Illustration of a ventilation radiator**

Cold ventilation air (blue arrows) enters a gap in the wall because of pressure differences between outdoors and indoors. The air stream is directed between the parallel radiator plates and rises as it is pre-heated to room air temperature.

Because of high efficiency with ventilation radiators (the product of parameters on the right hand side of Equation (1)) the temperature difference between incoming and outgoing water in the radiator circuit, $\Delta \theta$, automatically becomes larger. The water leaving the radiators, $\theta_{water, out}$, may theoretically achieve temperatures similar to that of the room air where the radiators are placed, or even lower, depending on the mass flow rate, $\dot{m}$, inside the circuit. This is impossible with conventional radiators and very interesting in terms of energy savings and environmental aspects.

$$\dot{m} \cdot c_p \cdot \Delta \theta = k \cdot A \cdot \Delta \theta_m, \quad (1)$$

where $c_p$ and $\Delta \theta$ are the specific heat capacity of water and temperature difference between water entering and leaving the radiator, $\theta_{water, in}$ and $\theta_{water, out}$. The terms on the right hand side, $k$ and $A$, are the total heat transfer coefficient and the area of the radiator surface, respectively. The mean temperature difference, $\Delta \theta_m$, is given below.
\[ \Delta \theta_m = \frac{\theta_{\text{water, in}} - \theta_{\text{water, out}}}{\ln \frac{\theta_{\text{water, in}} - \theta_{\text{air}}}{\theta_{\text{water, out}} - \theta_{\text{air}}}} \quad (2) \]

where \( \theta_{\text{water, in}}, \theta_{\text{water, out}} \) and \( \theta_{\text{air}} \) are the water temperature in and out of the radiator and the temperature of ambient air.

**METHODS**

A CFD model was made as a reproduction of a real life test lab where Olesen et al measured thermal comfort [4]. Even the characteristics of building materials and heating and ventilation systems were replicated. The room, which resembles an office, had an exhaust ventilation system and a window, but no furniture. It was exposed to an outdoor climate similar to that of a normal winter day in Stockholm, Sweden. A sketch of the office is shown in Figure 2 below. The same model was used in two previous studies at the KTH School of Technology and Health. These papers are referred to for more details of the model and simulations [5,6].

![Sketch of the CFD model](image)

Figure 2. Sketch of the CFD model

About 450 W of heating power was needed to heat the room to a desired comfort temperature. Different heating systems were tested, among them ventilation radiators and a conventional radiator. All radiators had the same size. The heating systems were initially adjusted to give a comfort temperature of 21.0 °C at 1.1 m above floor level in the centre of the room. This did not necessarily mean that the thermal climate was similar for all cases. The aim of the study was to map differences in thermal climate and compare the performance of each heating system. The thermal comfort results were evaluated according to recommendations in ISO 7730:1994, an international standard that specifies conditions for thermal comfort [7].

The water flow situation inside the heat emitters was not reproduced. Instead a fixed mean temperature was set for the whole heated surface. This simplification was made to make the CFD simulations less complicated even if a certain margin of error would occur according to theory. In reality the temperature variations over heated radiator surfaces are in linear relation to \( \Delta \theta_m \), the mean temperature difference of water entering and leaving the radiator. The size of \( \Delta \theta_m \) and the margin of error depend on the mass flow through the radiator. Higher mass flow means more uniform surface temperature.
RESULTS

Figure 3 displays simulated thermal comfort results with different heating methods. Comfort temperature is, like the more commonly used operative temperature, a variable used to obtain an understanding of the perceived thermal climate. It considers the balance between radiant heating or cooling and the draught-induced air temperature effects on the perceived air temperature. Table 1 shows various data achieved during the simulations with three different ventilation radiators and a conventional radiator.

![Ventilation radiator A, surface temp. 34.5 °C](image1)

![Floor heating, surface temp. 26.0 °C](image2)

![Conventional radiator, surface temp. 42.3 °C](image3)

Figure 3 a-c. Comfort temperature with different heating methods

The illustrations are from the XZ plane at Y = L/2. Cold areas are represented by blue colours, while the warm areas are shown in red.

Table 1. Simulation results

<table>
<thead>
<tr>
<th></th>
<th>Vent. radiator Case A</th>
<th>Conventional radiator</th>
<th>Vent. Radiator Case B</th>
<th>Vent. Radiator Case C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature of heated surface, °C</td>
<td>34.5</td>
<td>42.3</td>
<td>38.0</td>
<td>34.5</td>
</tr>
<tr>
<td>Comfort temp. at Z = 1.1 m and X = L/2, °C</td>
<td>21.0</td>
<td>21.0</td>
<td>21.0</td>
<td>23.2</td>
</tr>
<tr>
<td>Flow rate of ventilation air, l/s</td>
<td>7.0</td>
<td>7.0</td>
<td>7.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Channel width in ventilation radiators, m</td>
<td>0.015</td>
<td>-</td>
<td>0.04</td>
<td>0.015</td>
</tr>
<tr>
<td>Air temp. at Z = 1.1 m and X = L/2, °C</td>
<td>21.3</td>
<td>20.8</td>
<td>21.4</td>
<td>23.8</td>
</tr>
<tr>
<td>Total heat output from radiator, W</td>
<td>435</td>
<td>483</td>
<td>445</td>
<td>335</td>
</tr>
<tr>
<td>Conv. heat output between panels, W</td>
<td>230</td>
<td>138</td>
<td>196</td>
<td>155</td>
</tr>
<tr>
<td>Total heat transfer coefficient, W/(m²·°C)</td>
<td>9.6</td>
<td>6.7</td>
<td>7.8</td>
<td>8.8</td>
</tr>
<tr>
<td>Mean air speed in ventilation channel, m/s</td>
<td>0.93</td>
<td>-</td>
<td>0.35</td>
<td>0.4</td>
</tr>
</tbody>
</table>
DISCUSSION

The following discussion is based on simulation results from our low temperature heating project.

THERMAL COMFORT

Because the ventilation air had already been heated to about 18 °C before entering the room no areas inside the room had problems with cold air draught when using the ventilation radiator in case A. The temperature gradients between floor and ceiling, and between the walls, became smaller than with the other systems for the same reason. Small temperature differences in the room resulted in less air movements caused by buoyancy forces.

RADIATOR EFFICIENCY

The total heat transfer coefficient was 9.6 W/( m²·°C) for the ventilation radiator used in case A and 6.7 W/( m²·°C) for the conventional radiator. It is obvious that a large thermal gradient between radiator walls and cold air in contact with the panels boosts convection heat output. The convection heat emitted from between the radiator panels was 67 % higher for the ventilation radiator compared to the conventional radiator.

In case B and C adjustments were made to the ventilation radiator. The heat transfer coefficient decreased considerably when the channel width was enlarged or the air velocity was decreased in the ventilation channel. As expected from theory the degree of turbulence inside the ventilation radiator was crucial for the heat output. No radiator with convection fins were tested in the study.

THERMAL RESPONSE TIME

The heat output from a ventilation radiator is strongly dependent on the air temperature and air velocity of air passing in the ventilation channel. As a consequence a ventilation radiator has super-short response time and regulates its heat output automatically according to the ventilation rate in the room or changes in outdoor climate. In other water-based heating systems the need for manual adjustments of valves is much greater and the response time is much longer.

EXAMPLE:

When the outdoor temperature and the temperature of air entering the ventilation channel decrease the thermal efficiency of the ventilation radiator automatically increases simultaneously. The ventilation radiator emits more heat as the need for heat in the building increases.

A WAY TO CREATE A DYNAMIC HEATING AND VENTILATION SYSTEM

The super-short response time of ventilation radiators may be used to create a dynamic heating and ventilation system where the radiator heat output is controlled by the ventilation rate in the room.
EXAMPLE:

The ventilation rate in different parts of a house is varied automatically on a daily basis depending on where people tend to stay, sleep and where fresh air and heat is needed. The heat output from the ventilation radiators increases and decreases in perfect synchrony with the variation in ventilation rate. All the time a desired thermal climate is kept where people stay. In the rooms where there are no people the ventilation rate is lower. Here the ventilation radiators do not emit as much heat, but still the room temperature is kept at an acceptable level. This renders energy savings. The example is illustrated in Figure 4.

Day

Night

Figure 4. A dynamic heating and ventilation system with ventilation radiators is shown above

The ventilation rate was changed according to where a person stayed. Each illustration shows ventilation air flow, corresponding heat output from the radiator and comfort temperature in the centre of the room at Z = 1.1 m. The upper illustrations show the situation during daytime, while the lower illustrations show the same at night. Heat emitted by the person, 93 W when the person did office work and 70 W when sleeping, was included in the estimations. The radiator had a constant surface temperature of 31.7 °C.
CONCLUSIONS

The thermal climate proved to be more stable and uniform with ventilation radiators than with floor heating and the conventional radiator. Because the ventilation air was pre-heated before entering the room a high ventilation rate could be kept without any hazard of cold draught, even if the temperature of the supply air was below freezing. With conventional heating systems cold draught is often a major problem in wintertime, especially in naturally or exhaust ventilated buildings.

The ventilation radiators had higher thermal efficiency than the conventional radiator. In practice this means that a lower water temperature may be kept in the radiator circuit with the same heat output. This results in energy savings in heat production and distribution. Even more energy may be saved if the short reaction time of ventilation radiators is used to balance the need for heating and ventilation on a daily basis.

The ventilation radiator with the narrowest ventilation channel between the radiator panels had a larger total heat transfer coefficient and thus a better thermal performance than the other ventilation radiators. The reason was higher air velocity and a more turbulent flow inside the channel. This knowledge may lead to development of ventilation radiators with design differing from that of traditional radiators. It is likely that new types of slim double panel ventilation radiators attached close to the wall may be interesting both in terms of energy usage and visual aspects. To find the ideal geometries for increased convection heat output the degree of turbulent air flow in the ventilation channel should be optimized in relation to pressure losses and noise. This process should include calculations that show whether convection fins would be functional to have inside the ventilation channel.

ACKNOWLEDGEMENT

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REFERENCES

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