Experimental Study of the Temperature Distribution inside Two Zones Separated by an Air Curtain System

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Abstract

To increase the usage of renewable energy in residential buildings, wood stoves appear as an attractive alternative for space-heating. However, it remains unclear if one wood stove can efficiently heat up the whole building without a risk of reducing the thermal comfort level of the occupants. The question arises whether the high power of current stoves may cause unacceptable overheating in the room where the stove is located while other rooms remain heated insufficiently. In order to achieve a proper indoor thermal environment inside the entire dwelling, the heat transfer between the rooms should be well understood and enhanced. This paper investigates these aspects by combining passive and active heat distribution solutions. The objective of this study is to examine the effect of the airflow distribution from a downward plane jet on the heat distribution inside and between zones with temperature differences. Air temperature measurements were carried out to discover the effect of the air curtain system operation on the heat distribution. Measurement results were obtained with various airflow distribution conditions generated by the slot diffuser located above the doorway between the two zones. The experimental results show that the air distributed by the slot diffuser provides better mixing inside both zones, minimizing the vertical temperature stratification inside zones. Moreover, this study shows that supplying the warm air through the air curtain system may decrease the period of time needed to achieve a satisfactory thermal environment inside both zones.

Keywords - indoor air; active heat distribution; high performance buildings
1. Introduction

High energy consumption in the building sector has led to a great need for energy saving and energy efficient solutions for buildings. Low-energy buildings have a highly-insulated envelope and very energy efficient windows. They are characterized by a high level of air tightness [1]. These features lead to a decrease of energy used for heating. In consequence it can be assumed that it is no longer required to place a heat emitter in each room of the building, so the space-heating distribution system can therefore be simplified [2][3]. Reducing the energy needs in high-performance buildings encourage simplification of the space heating system, e.g. with a wood stove or a radiator. However, a reduced space heating system leads to temperature differences and lower temperatures inside rooms that are not directly heated. In addition, depending on the geometry of the building, there is a risk that the room equipped with a heating device may be overheated while the rest of the building may be heated too little [4]. Another problem may be the draught risk in the lower part of the room with the heater as warm air moves up due to buoyancy force [5]. The question arises as how can one space-heating emission system ensure thermal comfort in the entire building. This still remains unclear due to lack of understanding of some fundamental aspects, including heat transfer within or between different zones and temperature stratification inside zones. The challenge is to decrease the risk of overheating in the room in which the additional heat source is located. This study assumes that a better heat distribution may be achieved through the optimum passive and active method.

The air curtain may be considered as a downward plane jet discharged from a narrow slot diffuser. The theoretical basis for air curtain analysis is a theory of a free stream jet [6]. Except very small velocities of flow, it is found that the jet becomes completely turbulent at a short distance from the point of discharge. While forming the jet, discharged fluid partly mixes with the surrounding fluid at rest. Particles of fluid from the surroundings are carried away by the jet so that the mass-flow increases in the downstream direction. Concurrently the jet spreads out and its velocity decrease but the total momentum remains constant [6][7]. Properly designed air curtain produces a pressure drop which forbids transversal flow through the opening. However if the outlet velocity is high enough the air curtain can increase the heat and mass transfer through itself. This phenomena depend also on blowing angle. The main aim of the research is to investigate the performance of the air curtain system for improving indoor air distribution and heat distribution inside a highly-insulated building.

2. Methods

Study design

The active heat distribution method uses an air curtain system, which is located above the doorway between two zones. The system does not require an extensive system of ventilation ducts, but needs an extra fan. The warm air inside the heated zone rises and is at the same time distributed by the slot diffuser along the downward plane
The created jet impinges the floor and enters both zones at the ground level. Figure 1a. shows the schematic airflow distribution through the door opening between the cold and the warm zones. Convective flows due to buoyancy forces may cause the warm air to occupy the upper part of the room and it takes longer time to distribute heat to the lower part of the room [4]. It can lead to a large temperature stratification inside zones. Thermal comfort cannot be obtained while the lower part of the room, which contains also the occupants zone, stays cold. Large temperature differences between zones may induce airflows with a high velocity appearing in the vicinity of the doorway. Draught risk may rise, especially at the lower part of the cold zone and the warm zone.

Fig. 1. Schematic airflow distribution through the door opening between warm(1) and cold(2) zones: a) without the air curtain system; b) with the air curtain system.
The airflow pattern produced by the downward plane jet is presented in Figure 1b. It is assumed that warm air distributed along the downward plane jet can provide a higher temperature in the lower part of the doorway. The room air from both zones will be mixed with the downward jet. The plane jet force the air downward and provide a better mixing condition of the air inside both zones. The warm air is supplied into the lower part of the cold and the warm zone. Distributing the air downward with the plane jet may help to reduce the temperature difference between the two zones. In addition, it takes less time to achieve the uniform thermal parameters inside the whole building.

**Measurement conditions and setup**

The experimental measurements have been conducted in the climate chamber equipped with an internal heating device that simulated a real room with a wood stove. The chamber consisted of two zones – a heated zone and a zone not heated. Air temperature measurements were carried out to examine the effect of air curtain operation on the airflow distribution inside and between the two zones together with temperature differences. Measurement results were obtained with various airflow distributions generated by the slot diffuser. Three different discharge velocities from the slot diffuser were used during the experiments: 3.5, 5.3, and 8.5 m/s. To measure the temperature of the room air, twenty PT-100 sensors were used. Two poles with the temperature probes were placed at a distance of 1.8 m from the door opening in each zone. The sensors were located at five levels: 0.15, 0.75, 1.35, 1.95, and 2.55 m above the floor. Additionally, temperatures inside the cold zone were measured in a distance of 0.9 m from the doorway at ten levels: 0.13, 0.26, 0.46, 0.66, 0.86, 1.06, 1.26, 1.46, 1.66, and 1.80 m. The measured temperature values were averaged over a period of ten minutes of measurement.

<table>
<thead>
<tr>
<th>Location of probes:</th>
<th>Target:</th>
<th>Type:</th>
<th>Number of probes:</th>
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<tbody>
<tr>
<td>Cold zone</td>
<td></td>
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<td>1.8 m from the door opening</td>
<td>air temperature</td>
<td>PT-100</td>
<td>5</td>
</tr>
<tr>
<td>0.9 m from the door opening</td>
<td>air temperature</td>
<td>PT-100</td>
<td>10</td>
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<tr>
<td>Warm zone</td>
<td></td>
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<tr>
<td>1.8 m from the door opening</td>
<td>air temperature</td>
<td>PT-100</td>
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Due to the fact that it is hard to predict the airflow distribution, smoke visualization was performed to identify the airflow pattern and to determine the optimum sensor locations. The room air with smoke was supplied to the air curtain system and was discharged from the slot as the downward jet. The smoke test was conducted with three different supply velocities from the slot: 3.8, 5.3, and 8.5 m/s.
3. **Results and discussion**

*Visualization results*

Figure 2 presents the location of the slot diffuser. The slot diffuser is located in the upper right corner of Figure 2, the doorway is located below. Figure 3 shows the airflow distribution inside the cold zone for different supply velocities from the slot diffuser. The red arrows indicate the direction of airflow as was observed while conducting the experiment with the smoke. The blue arrows indicate the air inside the cold zone. The airflow pattern can be seen in the initial phase (10 s). After that time, in a short time (20-30 s) the distributed air mixed with the cold air and the smoke was distributed evenly inside the zones. With a velocity of 8.5 m/s, the smoke concentrated and remained longer at the ground level. For velocities of 3.5 and 5.3 m/s, the air rose up but to a lower height.

![Image of airflow distribution inside the cold zone with location of the slot diffuser](image)

Fig. 2. Photos of the airflow distribution inside the cold zone: location of the slot diffuser.
Fig. 3. Photos of the airflow distribution inside the cold zone with the downward plane jet.

**Temperature measurements results**

Figure 4 shows the temperature distribution in the cold zone with a distance of 0.9 m from the doorway while releasing air with different velocities. In the case with a supply velocity of 3.8 m/s, the lowest temperature value was obtained by two sensors located at levels of 0.15 and 0.26 m from the floor. It shows that the temperature increased with increasing altitude. An inverted situation can be seen in the case with a supply velocity of 8.5 m/s, with which the highest temperature value was obtained at the level of 0.15 m. For this condition, the temperature decreased with altitude. Increasing the supply velocity of the air curtain system may increase the temperature values at lower levels inside the cold zone when using the air curtain system. This means that it is possible to distribute warm air with the jet into the cold room and to assume that it may lead to reduction of the draught risk in the cold room. However, it should be noted that the draught discomfort is determined by the combination of air velocity and air temperature (ISO 7730). Therefore air velocity needs to be investigated in order to define the local discomfort risk.
However, the temperature of the warm room with the heating device may depend on the supply velocity and the geometry of the slot diffuser.

Figure 4. Temperature distribution inside the cold zone at a distance of 0.9 m from the doorway.

Figure 5 and 6 show the temperature distribution inside the cold zone (Fig. 4) and the warm zone (Fig. 5) at a distance of 1.8 m from the doorway. According to the temperature measurements, the results reveal that increasing the supply velocity of the slot diffuser may decrease the temperature stratification significantly in the warm zone. The experimental results show that the air distribution by the slot diffuser provides better mixing inside both zones, minimizing the vertical temperature stratification. The stratification inside the cold zone was 1.9°C without using the air curtain system, 1.8°C with a discharge velocity of 3.8 m/s and 1°C for a discharge velocity of 8.5 m/s with the air curtain system. The temperature stratification inside the warm zone was 5.6°C without using the air curtain system, 5.2°C for a discharge velocity of 3.8 m/s and 1.8°C for a discharge velocity of 8.5 m/s with the air curtain system. The results were analyzed regarding vertical temperature gradient and not individual temperature values due to the fact of initial parameters differences.
Fig. 5. Temperature distribution inside the cold zone at a distance of 1.8 m from the doorway.

Fig. 6. Temperature distribution inside the warm zone at a distance of 1.8 m from the doorway.

4. Practical limitations

There are some practical limitations in the presented study, e.g. the effects of the discharge velocity from the slot diffuser. Moreover, an improperly designed air curtain system may have a negative impact on heat transfer between zones. Therefore, more studies should be carried out regarding the effect of the airflow distribution on the heat transfer.
distribution through a doorway and heat transfer between zones while supplying air with a slot diffuser needs to be investigated.

5. Conclusion

Reduced space-heating needs in residential buildings has a potential for energy saving. Space heating of a high performance residential building using a wood stove can be an attractive solution. However, placing only one wood stove inside the whole dwelling tends to overheat the zone with the wood stove while other rooms that are far from the stove could experience unacceptable low temperatures. As a consequence, the air movement due to the buoyancy force may lead to a significant vertical temperature difference inside rooms. The use of a downward plane jet from a slot diffuser directly affect the performance of the airflow and heat distribution inside and between zones. The airflow distribution with the slot diffuser located above the doorway may reduce the vertical temperature stratification inside both zones. Moreover, supplying the warm air through the air curtain system may decrease the period of time needed to achieve a uniform thermal environment inside both zones. One of the advantages of distributing air with the air curtain system is that the warm air is quickly well mixed, in particular in the lower part of the zones.

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References