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Experimental investigation of the influence of different flooring emissivity on night-time cooling using displacement ventilation

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SUMMARY:
Night-time ventilation is a promising approach to reduce the energy needed for cooling buildings without reducing thermal comfort. The objective of the present paper is to determine how different emissivity of flooring influence the heat transfer in a room and the efficiency of night-time ventilation using displacement ventilation. Experimental work was conducted on the basis of the work performed by Artmann et al. (2009) in a similar previous study. An aluminum-foil floor cover was installed in a full scale test room. Experimental results obtained with aluminum flooring were compared to results obtained by Artmann et al. with a flooring consisting of expanded polystyrene (EPS). Results showed that the surface temperature of the floor decreased with decreasing emissivity. Mean convective heat fluxes were similar for experiments conducted with both EPS and aluminum-foil floor cover, but it was seen that the emissivity of the flooring affected the heat transfer ratio at the internal surfaces. The convective heat flux increased at the ceiling and decreased at the floor for experiments with aluminum flooring compared to the experiments with EPS floor. Temperature efficiency was slightly higher for experiments with aluminum flooring than for EPS floor. As the efficiency was only a bit higher with an extremely low emissivity of the floor cover, it was concluded that the influence of different emissivity of floor covers can be neglected concerning efficiency of displacement night-time ventilation.

1. Introduction

For many developed countries in the industrialized part of the world, it has been observed that the cooling demand in buildings has increased during the last few decades. Especially in commercial buildings, the cooling demand plays a significant role in the overall energy consumption of a building. This is a consequence of higher internal loads, modern buildings with extensive glazing which leads to higher solar gains, higher outdoor temperature due to climate change, better insulated buildings, and finally due to increased focus on thermal comfort. One promising approach to reduce the energy needed for cooling office buildings without reducing comfort is passive cooling by night-time ventilation. The basic concept of night-time ventilation is to cool the building structure overnight in order to provide a heat sink during the occupied period next day. Kolokotroni & Aronis (1999) investigated the potential energy savings by applying night-time ventilation strategy for typical air-conditioned buildings in United Kingdom (UK). Their results showed that the buildings would modestly benefit from natural night-time ventilation. Mechanical night-time ventilation would increase the energy consumption in many already existing buildings. However, if some building parameters were optimized in line with low energy design principles such as exposed thermal mass, reducing glazing ratio, reducing internal loads and increasing air tightness, the mechanical night-time ventilation would be a beneficial solution for reducing the energy use of a building.

Many studies have been carried out to evaluate the effect of different parameters on the indoor thermal environment and the efficiency of night-time ventilation. Night-time ventilation depends on the climatic conditions, as a significant temperature difference between ambient air and the building structure is needed during the night to achieve efficient convective cooling of the building mass. According to Givoni (1991), night-time ventilation is applicable in arid regions where the daytime temperature is between 30 and 36°C and the night temperatures are below about 20°C. Kolokotroni et al. (1999) investigated the suitability of night-time ventilation for cooling offices in UK, corresponding to moderate climates and concluded that night cooling is viable to increase thermal comfort in many UK offices. Artmann et al. (2007) have investigated the climatic potential for passive cooling of buildings by night-time ventilation in Europe with calculation based on a minimum temperature difference for night time cooling of ΔT_{crit} = 3K. Their results showed a high potential for cooling by night-time ventilation over the whole of Northern Europe and a significant potential in Central, Eastern and some regions of Southern Europe.

It is a general agreement that sufficient amount of thermal mass is needed to achieve effective night-time ventilation. Høseggen et al. (2009) investigated the effect of suspended ceilings on energy performance and thermal comfort. It was found that exposed concrete at the ceiling significantly increased the efficiency of cooling by night-time ventilation compared to a room with suspended ceiling. Artmann et al. (2008) evaluated outdoor climate, air change rates, thermal mass and internal heat gains in addition to the heat transfer coefficient on the effectiveness of night-time ventilation. They concluded that the climatic conditions and airflow rate during night-time ventilation are the most important factors, but also that thermal mass and internal heat gains have a significant effect on cooling performance and thermal comfort. Night-time ventilation is therefore suitable for office buildings which are usually unoccupied during the night so that relatively high air flows can be used to provide maximum cooling effect.

The experiments performed by Artmann et al. (2008) were carried out in an experimental room with internal wall and floor surfaces consisting of expanded polystyrene (EPS) and internal ceiling surface consisting of white paint, with emissivity of 0.73 and 0.90 respectively. In a real case scenario, the internal surfaces can have different emissivity in a wider range. Physical properties like emissivity will influence the radiation between elements present in the room. The objective of the present paper is to determine how different emissivity of flooring will influence the heat transfer in a room and the efficiency of night-time ventilation using displacement ventilation. This is assessed by experimental methods.

The experimental work presented in this paper is conducted on the basis of the experimental work performed by Artmann et al. (2009). The experiments were carried out in a full scale test room at Aalborg University during October 2009. In order to evaluate the influence of different emissivity, an aluminum-foil floor cover was installed in the test room used by Artmann et al. (2009). The results obtained by the experiments with aluminum-foil floor cover are compared with the results obtained by Artmann et al. (2009), who conducted the experiments when the internal floor surface consisted of EPS. This study provides a detailed analysis of convection and radiation during night-time ventilation depending on the emissivity, the air change rate (ACR) and the temperature difference between inlet air and room temperature.

2. Method

2.1 Setup of the test room

The test room used in this study is an insulated wooden construction located inside a laboratory at Aalborg University. The basic geometry of the test room is shown in figure 1. The test room has an internal volume of 24.52 m^3.

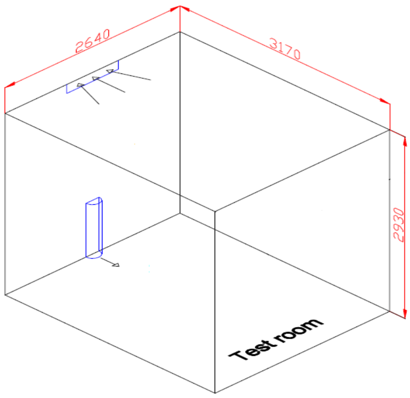

FIG 1. Basic geometry of the test room. Dimensions in mm.

Figure 2 shows the construction of walls, ceiling and floor in the test room. A detailed description of the construction of the test room can be found in a technical report written by Artmann et al. (2008). As seen from figure 2, the ceiling is the part of the test room construction with the greatest thermal mass.

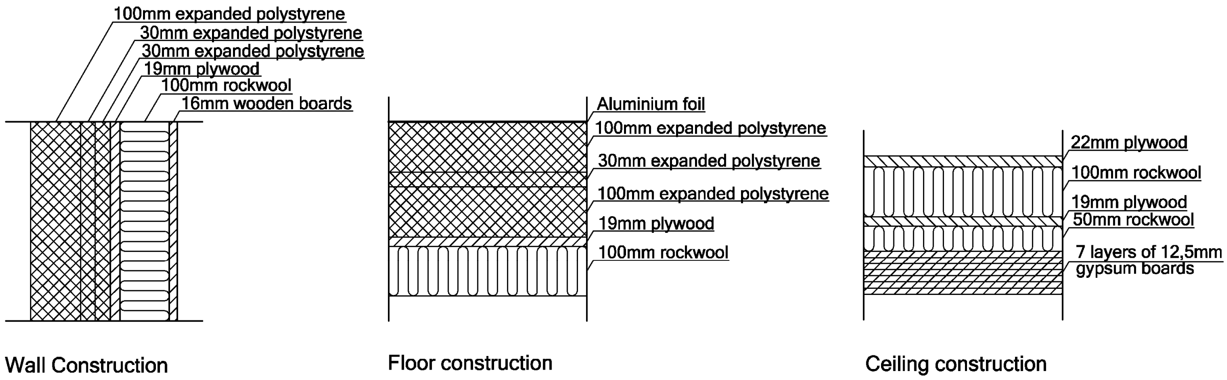

FIG 2. Wall, floor and ceiling constructions.

The thermal properties of the materials in the construction of the test room were based on a literature review and the emissivity of the aluminium-foil floor cover was obtained from the manufacturer. The values used for calculation are summarized in table 1.

TABLE 1. Material properties

Material	λ [W/m.K]	ρ [kg/m^3]	C_p [J/kg.K]	ε [-]
Wood	0.13	411	1800	-
EPS	0.037	16	1450	0.73
Rockwool	0.042	14	800	-
Gypsum board	0.28	1127	1006	0.9
Aluminium-foil	-	-	-	0.03

2.2 Ventilation of the test room

The test room is equipped with a mechanical ventilation system that supplies air at a defined temperature to the test room. The ventilation system consists of separate supply and exhaust systems. In order to obtain controlled conditions in the test room, the air to the supply system is taken from the laboratory since the temperature in the laboratory is more constant than the outdoor air temperature. A frequency transformer is connected to the fan in order to control the air flow through the system. The ventilation system is capable to perform an air flow from 56 to 330 m^3/h, corresponding to approximately 2.3 - 13.5 air change rate (ACR). The inlet air was supplied through a semi-circular displacement device placed at the floor in the middle of one of the short walls. The outlet air was exhausted through a rectangular opening of 870 mm width and 80 mm high located below the ceiling, see figure 1.

2.3 Location of thermocouples

Heat transfer in the test room was determined by temperature measurements. All thermocouples used in these experiments were made of type K thermocouple wires. The thermocouples were connected to two Fluke Helios Plus 2287A data loggers. The accuracy of the total temperature measurement system was estimated to be ±0.086 K. A detailed uncertainty analysis performed by Artmann et al. can be seen in the technical report dealing with temperature measurements (2008).

In order to systematically measure the temperature distribution in the test room and through the constructions, the surfaces were divided into sections and thermocouples were placed in each section. Figure 3 gives an illustration of this dismemberment. The crosses in figure 3 mark the positions of the thermocouples at the internal surfaces. It was assumed that the temperatures measured by the thermocouples were representative for the whole section. To determine the heat flow through the walls and the floor, the temperature difference over a 30 mm layer of EPS was measured. Thermocouples integrated in the ceiling construction were used to measure the temperature distribution through the ceiling. The thermocouples were placed in five layers in each of the 22 sections, resulting in a total of 110 thermocouples. Additional thermocouples were placed in the inlet where the pipe enters the room, in the displacement device and in the centre of the outlet opening.

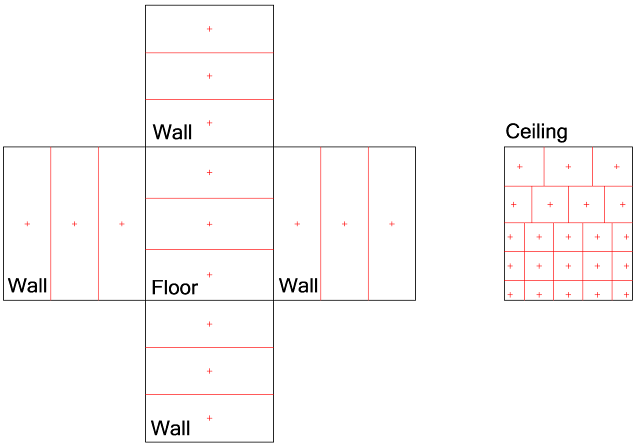

FIG 3. Subdivision of the surfaces into different sections.

2.4 Procedure for experiments

In order to observe the influence of a different floor cover emissivity, the air change rates and initial temperature differences were chosen similar to the one used by Artmann et al. (2009). Set-values for experiments are shown in table 2. ΔT_0 corresponds to the difference between the mean temperature of the ceiling before the experiment and the mean inlet air temperature measured during the ten last hours of the experiments T_{inlet}. In total nine experiments with the aluminium-foil floor cover were carried out in the test room. Each experiment lasted for 12 hours.

TABLE 2. Specification of the performed experiments

Experience number	Type of flooring	ACR	ΔT_0 (K)
1	EPS	3.1	10.1
2	EPS	6.7	5.8
3	EPS	6.7	11.3
4	EPS	12.6	3.6
5	EPS	12.6	6.0
6	EPS	12.7	12.7
11	Aluminium	3.1	5.0
12	Aluminium	3.1	6.7
13	Aluminium	6.7	2.8
14	Aluminium	6.7	5.2
15	Aluminium	6.6	8.9
16	Aluminium	6.7	9.6
17	Aluminium	13.1	3.1
18	Aluminium	13.2	5.9
19	Aluminium	12.8	7.6

2.5 Data evaluation

When using night-time ventilation, the only heat removed from the test room is the convective heat flow since radiative heat is only transported from one surface to another. The total heat flow removed from the room can be determined by two different methods:

- the inlet- and outlet temperatures can be measured to calculate the total heat flow removed by ventilation.
- or the convective heat flux can be calculated for each section and integrated over all surfaces to determine the total heat flow discharged from the room. The convective heat flux is determined from the difference between conductive and radiative heat fluxes. A one-dimensional finite difference model with an explicit scheme was used to determine the conductive heat flux at the surfaces. The radiative heat fluxes exchanged between surfaces were calculated for each surface according to the equation used by Artmann et al. (2009).

The uncertainties of calculating the convective heat flow is estimated to be ±12% with the first method and ±14% for the second one. By applying these two methods to the experimental results, it shows good results as the uncertainty bands are overlapping each other in all experiments.

3. Results and discussion

3.1 Internal surface temperatures

First of all it is of interest to investigate if the emissivity has an influence on the internal surface temperatures. To be able to compare surface temperatures in the test room during different experiments, the dimensionless temperature θ is introduced:

$$\theta = \frac{T - T_{inlet}}{\Delta T_0} \tag{1}$$

Figures 4 shows the comparison of the dimensionless temperature at the floor surface $\theta_{Surf,\ Floor}$ as a function of the time for all experiments conducted with EPS floor and aluminum-foil floor cover. The temperature at the floor surface declines when emissivity of the floor cover decreases using displacement ventilation. However the temperature at the ceiling is almost the same for different emissivity of the floor cover.

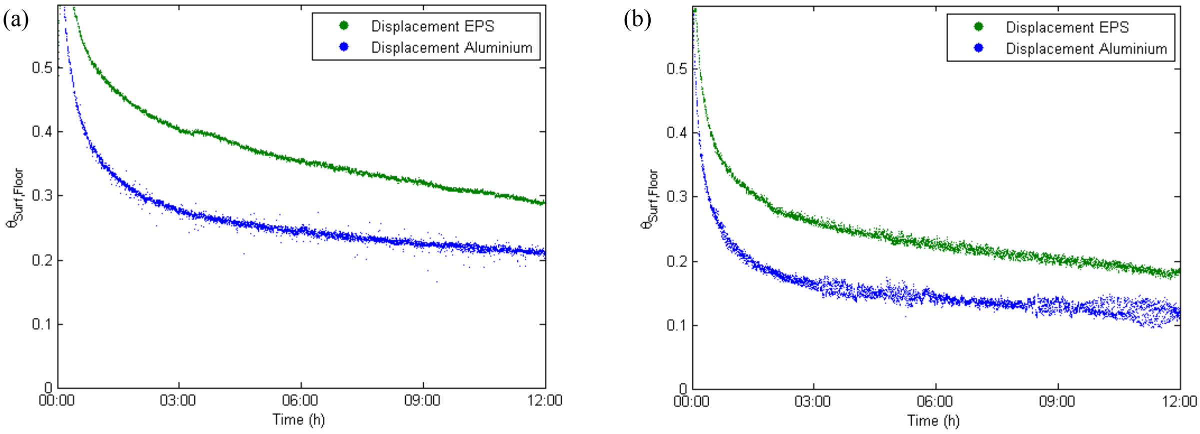

FIG 4. Dimensionless surface temperature at the floor for comparison of temperature development with EPS and aluminum flooring (left: 3.1 ACH; right: 6.7 ACH)

3.2 Heat flow in the test room

As it was seen that the emissivity of the floor has an influence on the surface temperatures, it is of great interest to see if this influences the total heat flow removed from the test room. Figure 5 shows the mean convective heat flux $q_{conv,\ tot}$ depending on the difference between the mean surface temperature $T_{surface}$ and the inlet air temperature T_{inlet} for both the experiments with aluminum-foil floor cover and the experiments with EPS floor. The relation is close to linear for experiments with same airflow rate and same flooring. It is also seen that experiments conducted with same ACR but different temperature differences follow the same line. The gradient of these lines is interpreted as average convective heat transfer coefficients, $h' = q_{conv,\ tot} / (T_{surface} - T_{inlet})$. It should be noted that this heat transfer coefficient can not be compared with the standard heat transfer coefficient, since h' is defined using the inlet temperature as reference instead of ambient room temperature. Figure 5 shows that the total convective heat flux is nearly the same for experiments conducted with EPS floor and for experiments conducted with aluminum foil floor cover. The small differences seen in figure 5 are within the range of measurement uncertainties and it is therefore impossible to assess if the differences are caused by temperature differences or accuracy.

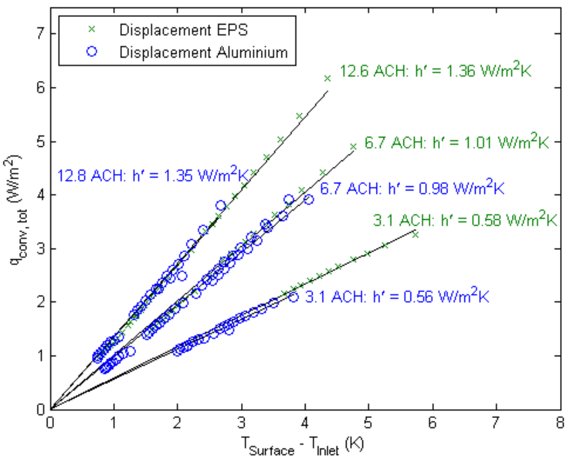

FIG 5. Mean convective heat flux from all surfaces as a function of the difference between the mean surface temperature and the inlet air temperature; hourly values, first hour excluded.

To investigate how the change of emissivity of the flooring influences the heat transfer in the room, heat transfers at the ceiling and at the floor are assessed separately. Figure 6 shows the convective heat flow from the ceiling, $q_{conv\,,\,Ceiling}$, and from the floor, $q_{conv\,,\,Floor}$, as a function of the difference between the mean surface temperature and the inlet temperature for all experiments with aluminum-foil floor cover and with EPS floor. It is seen that the convective heat flux is increasing at the ceiling with decreased emissivity of the flooring, whereas it is decreasing at the floor.

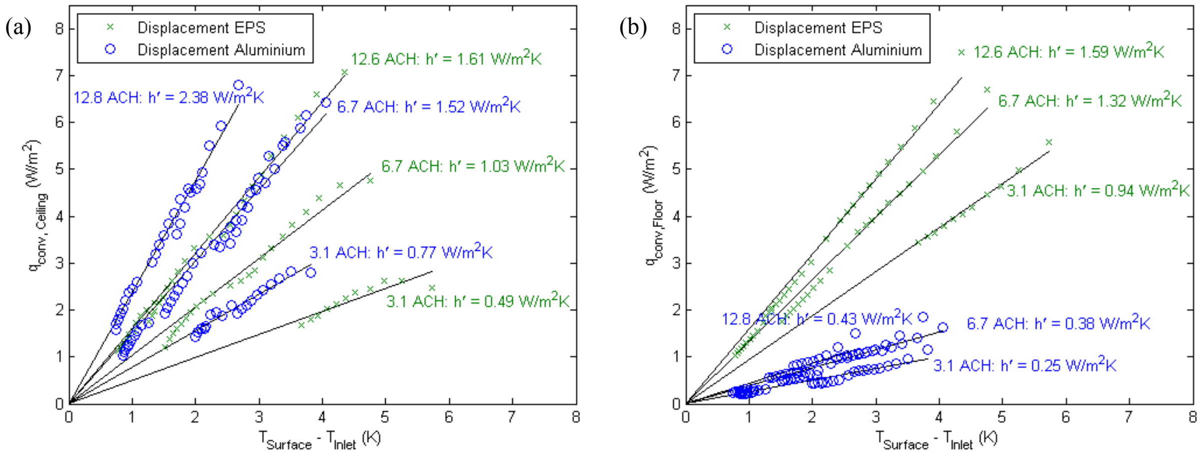

FIG 6. Mean convective heat flux from the ceiling (left) and from the floor (right) as a function of the difference between the mean surface temperature and the inlet air temperature; hourly values, first hour excluded.

3.3 Performance of night-time ventilation

The performance of night-time ventilation can be described by the temperature efficiency of the ventilation η according to equation 2:

$$\eta = \frac{T_{outlet} - T_{inlet}}{T_{surface} - T_{inlet}} \tag{2}$$

Figure 7 shows the relation between the temperature efficiency and the air change rate. It is seen that the temperature efficiency is higher for the experiments conducted with the aluminum-foil floor cover than for the experiments with the EPS floor. It is important to pay attention when assessing these results, since almost all results are within the range of the estimated uncertainty bands. However, when looking at figure 7, it is seen that all the results from the experiments with aluminum-foil floor cover are lying systematically above the efficiency of the experiments with EPS floor. Therefore it is likely to assume that the low emissivity of the aluminum foil floor cover is increasing the efficiency slightly. The higher efficiency for the experiments conducted with the aluminum-foil floor cover can probably be explained by investigation of the surface temperatures, see figure 4. The temperature at the floor is decreasing when the floor is covered with aluminum, which implies that the mean surface temperature decreases and this leads to a higher temperature efficiency.

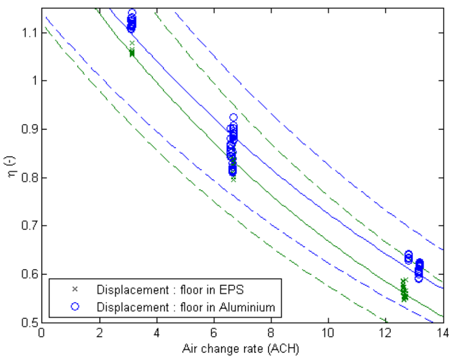

FIG 7. Temperature efficiency as a function of the air change rate for flooring made of aluminum and of EPS; hourly values, first hour excluded. Fitted curves with estimated uncertainty bands (±14%)

4. Conclusion

Experimental investigation of the temperature distribution at the internal surfaces in the test room revealed that the surface temperature at the ceiling was similar for both EPS and aluminum floor, while the surface temperature at the floor was decreasing with decreased emissivity, i.e. the surface temperatures depend on emissivity. Investigation of total convective heat flow in the test room showed that total convective heat flows were similar for experiments conducted with aluminum-foil floor cover and experiments conducted with EPS floor. This leads to the conclusion that changes in surface temperatures due to different emissivity of the floor have a minor or none impact on the total heat flow. When investigating internal surfaces separately, experimental results of the heat transfer at the ceiling and floor showed that the convective heat transfer increased at the ceiling and decreased at the floor for experiments conducted with aluminum-foil floor cover compared to the experiments conducted with EPS floor.

Results of temperature efficiency of ventilation revealed that the temperature efficiency was systematically slightly higher for experiments conducted with aluminum-foil floor cover than for the experiments conducted with EPS floor. The small differences may be correlated to estimated uncertainty, but it is likely to assume that the low emissivity of the floor is increasing the temperature efficiency slightly. It should be noticed that the value of floor emissivity used in this experiment is extremely low and is not common for a floor cover. Therefore, a real floor cover will always have a higher emissivity than the one used in this experiment, and the efficiency gain will not be noticeable.

References

Artmann N., Manz H. & Heiselberg P. 2007. Climatic potential for passive cooling of buildings by night-time ventilation in Europe. Applied Energy. Vol. 84. 187- 201 pp.

Artmann N. & Jensen R.L. 2008. Night-time ventilation experiments: Setup, data evaluation and uncertainty assessment. Technical Report 1901- 726X.

Artmann N., Manz H., Jensen R.L. & Heiselberg P. 2009. Experimental investigation of heat transfer during night time-ventilation. Energy and Buildings.

Givoni B. 1991. Performance and applicability of passive and low-energy cooling systems. Energy and Buildings. Vol. 17. 177-199 pp.

Høseggen R., Mathisen H.M. & Hanssen S.O. 2009. The effect of suspended ceiling on energy performance and thermal comfort. Energy and Buildings. Vol. 41. 234-245 pp.

Kolokotroni M. & Aronis A. 1999. Cooling reduction in air-conditioned offices by using night ventilation. Applied Energy. Vol. 63. 241-253 pp.