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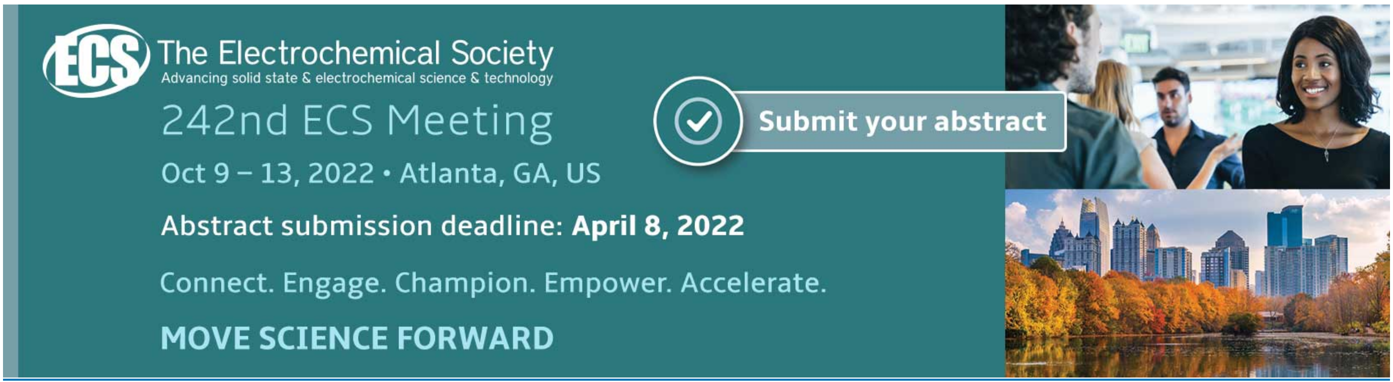

Performance analysis of a new system for night cooling of buildings on a full scale office room - CFD study

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Abstract. Night natural ventilation systems have been receiving increased attention in recent years because of their energy saving potential and environmental protection when used in passive instead of active cooling. A recently proposed novel system for cooling the building concrete slab is studied numerically in the present work. It consists of a new type of a Suspended Ceiling (SC) with a peripheral gap between it and the walls, combined with the positioning of the air supply and extraction grilles between the ceiling slab and the SC. The system relies only on night ventilation as a means for cooling down the structure of the building. This study focuses on the use of Computational Fluid Dynamics (CFD) to predict the airflow and thermal performance of this strategy and it is applied to a full scale office room. The calculations show that a SC with a gap can reduce the difference between the average temperatures at the end of the heating and the end of the cooling periods by 25% compared with the case of a full covered slab room scenario (tight SC). CFD proved to be a useful and accurate tool to predict indoor conditions in buildings.

1. Introduction

The use of thermal mass is generally thought of as a good practice in the sustainable building industry. Due to their ability to work as a heat reservoir, exposed structural elements may lead to an indoor temperature stabilization over a longer period of time, and can contribute to the existence of a time lag between the indoor and outdoor peak temperatures, making night cooling strategies more efficient [1], [2]. However, most of the office construction nowadays employs finishes made of light material (e.g. gypsum and wood based materials used in SC, interior partitions and/or raised floors), which prevent the effective use of thermal mass. These elements are necessary for today´s building paradigm as they enhance the acoustic performance and reduce the reverberation time, making the environment more comfortable. Recently, a novel strategy for night cooling in office buildings was proposed [3], which relies on the thermal mass stored during the day by the structure of a room. The proposed solution is based on the combination of a SC with a peripheral gap, such that the slab is only partially hidden, and on air supply and extraction slots placed above the SC. Experiments carried out in a reduced scale model demonstrate the ability of this solution to improve air cooling, allowing the reduction of the air temperature in the room during the occupation period, i.e., during the day. However, it is unclear whether the effectiveness of this cooling method is also achieved at full scale. A computational investigation of this problem was undertaken to address this issue. The accuracy of the predictions was firstly assessed at a reduced scale, using the experimental data from the previous work for validation purposes. Then calculations were performed at full scale to investigate the performance of this night cooling strategy in a real office room.

2. Numerical simulations

The commercial code Ansys-Fluent, release 17.0, was used in this study to predict the temperature distribution in a full-scale office room with a heat load, a SC and a pair of air slots, as schematically shown in Figure 1. The full-scale CFD model maintains the geometric proportions of the reduced scale model ($L_x \times L_y \times L_z = 0.75 \times 1.25 \times 0.43$ m^3), but the dimensions are 7 times larger. Table 1 shows the position of the openings and the size of the gap between the SC and the walls for the studied cases. The simulations were carried out for a period of 24 h, starting at 8:00 a.m. They comprise a heating period of 12 hours, during which an electrical resistance is turned on to simulate the heat load (50 W in the reduced scale model and 2450 W at full scale) due to occupants and electronic equipment in the real room, and a cooling period with the same duration, during which a fan placed at the extraction slot is switched on. The former period is characterized by natural convection induced by the heat load, and forced ventilation prevails during the latter period. Additional computational simulations were carried out for 72 hours.

The governing equations for mass, momentum and energy conservation were solved along with equations for turbulence closure to determine the temperature and velocity fields. Lateral walls, the top of the slab and floor were set as convection boundary conditions and the inlet and outlet as velocity-inlet and pressure-outlet, respectively.

Tetrahedral elements were used to mesh the fluid domain and the interior of the electrical resistance, and hexahedral elements were preferred for the solid domains of the slab and the SC. Refinement of the grid near the solid domains was also carried out. The calculations were performed using a mesh with around 2.5×10^6 control volumes (depending on the SC simulated) and a time step of 60 seconds. Additional calculations carried using a finer mesh or a shorter time step showed negligible differences.

3. Results and discussion

An example of the validation of the predictions for the reduced scale model is illustrated in Figure 2. It shows the predicted and measured time evolutions of the temperature along a period of 24h for a thermocouple located 60 mm above the floor at $x=L_x/3$ and $y=L_y/2$. Since each experiment took place in different days, laboratory temperatures also have varied. Thus, the temperature axis is not the same for all the tests. The heating rate in the initial period of the experiments in slightly overestimated in cases SC0 and SC2, and the predicted air temperature is also somewhat too high during the heating period. When the SC extends all over the ceiling (case SC0), the initial cooling rate is also slightly underestimated, being quite well reproduced in the remaining cases. The experimental data reported in Lança *et al.* [3] reveal that a gap of 5%×5% (case SC1) is adequate for cooling purposes and there is no advantage in the use of a wider gap.

Figure 3 shows the calculated temperature profiles at full scale for the first 4 cases presented in Table 1, along a vertical line at $x=2L_x/3$ and $y=3L_y/4$, after 8 hours of heating. It is clear that the profile for the case SC0–2450W presents the highest values of temperature among all cases. The SC attenuates the rate of heat transferred to the slab, which results in higher temperatures below the SC. At $z=1.6$ m, a temperature of 36.1°C was calculated at 4 p.m. for the case mentioned, while 29.9°C, 29.6°C and 29.7°C were computed for cases SC1–2450W, SC2–2450W and SC3–2450W, respectively.

Figure 4 shows the results of the calculated temperatures inside the slab and in the air, for a period of 72 hours, and cases SC0-2450W, SC1-2450W and SC0-2450W-LO. In the latter case, the air slots are placed below the SC. The evolution of the temperature at a point inside the slab, located at $x=L_x/2$, $y=L_y/3$ and 189 mm above the inner surface of the slab, is shown. The evolution of the air temperature is plotted at two locations along the same vertical line considered in Figure 3, one of them placed below and the other one above the SC, which are denoted by TC 64 and TC 61, respectively, in Figure 4.

Table 1 - Summary of the studied cases and the geometrical specifications.

	SC0-2450W	SC1-2450W	SC2-2450W	SC3-2450W	SC0-2450W-LO
Position of the air openings relative to the SC	above	above	above	above	below
Gap size (relative to model length, L_y)	0% × 0%	5% × 5%	7.5% × 10%	No SC	0% × 0%

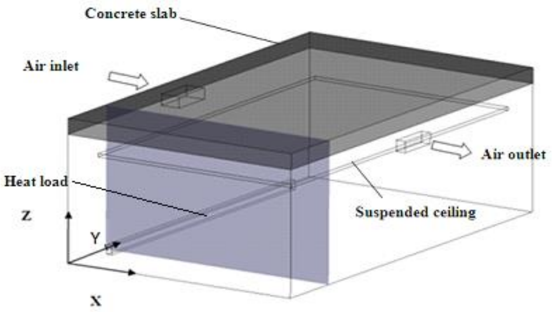

Figure 1. Schematic of the room office with SC and openings above the SC.

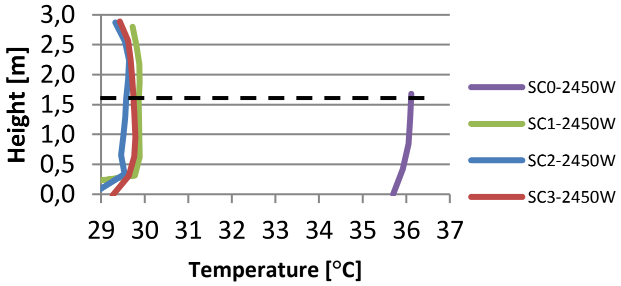

Figure 3. Calculated temperature profiles for cases SC 0–2450W to SC 3–2450 W. The dashed line represents the position of the SC.

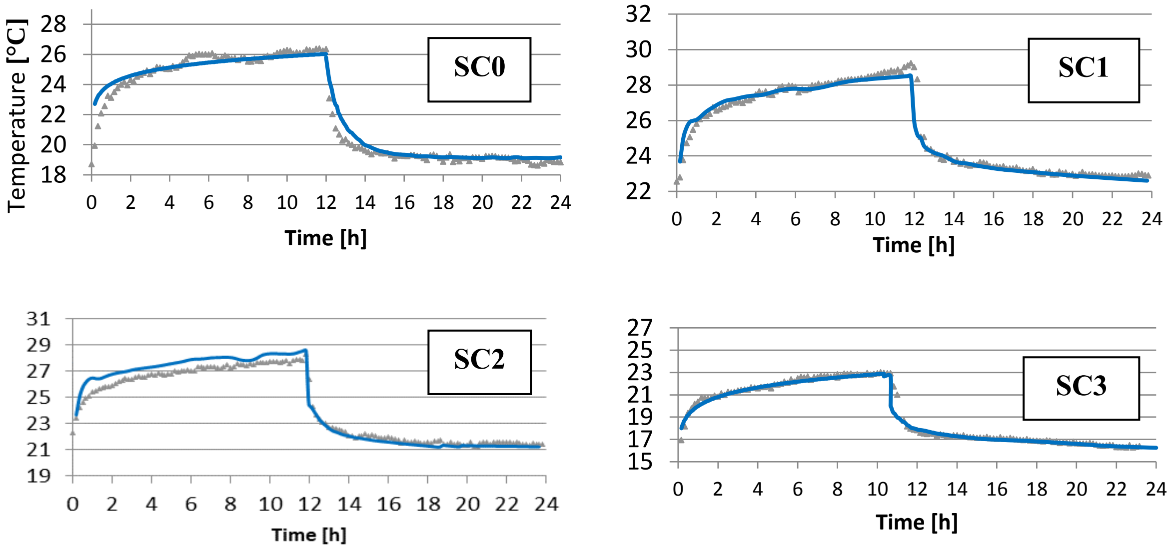

Figure 2. Predicted (solid lines) and measured (symbols) temperature profiles in the reduced scale model during a period of 24h for a thermocouple located 60 mm above the floor at $x=L_x/3$ and $y=L_y/2$.

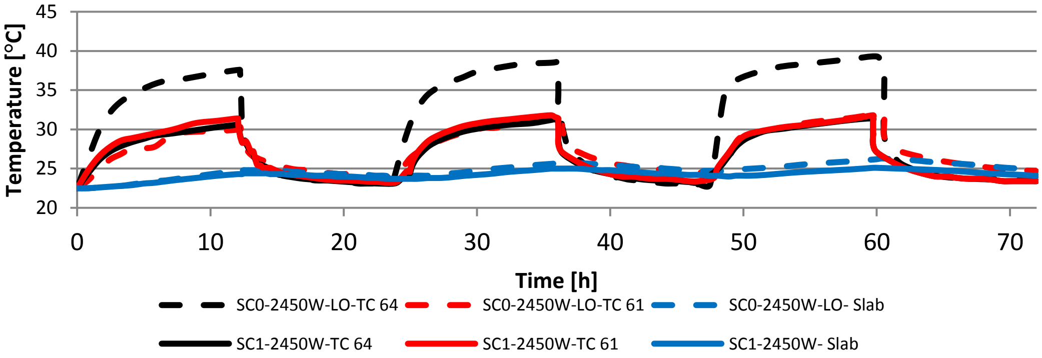

Figure 4. Evolution of calculated temperatures for cases SC0–2450W-LO (dashed lines) and SC1–2450 W (solid lines) inside the slab and in the air.

The maximum air and slab temperatures in the first and the third days of the simulations are a little different, and an increase is spotted over the simulation period, in contrast to what was observed at reduced scale [3]. This is expected because in a full-scale room the thermal mass is considerable and, consequently, it plays an important role when the analysis is extended to several days. This daily variation of the temperature occurs for both cases shown in Figure 4, although it can be barely noticed in the case SC1-2450W. The differences are more noticeable in the air temperature (TC 64), but they are also perceptible in the slab. This shows that the cooling of the thermal mass during the night is not completely achieved at the end of each cooling period (24h, 48h and 72h), especially in the case SC0-2450W-LO, i.e., the temperature of the slab is higher at those moments than at the beginning of the simulation. Therefore, the cooling efficiency is greatest when the openings are placed above the suspended ceiling, since the peak air temperature during the day is much lower than in the case of openings located below the SC. Figure 4 further shows that the temperature in the occupied zone (TC 64) is much higher for the case SC0-2450W-LO than in case SC1-2450W, at the end of the heating periods (12 h, 36 h and 60 h). In the former case, temperatures of 37.2°C and 39.3°C were found at 12 h and 60 h, respectively. This means that a rather uncomfortable environment for the occupants is likely to occur during the day when a SC with no gap is used.

4. Conclusions

The objective of this computational study was the investigation of a novel night cooling strategy in a full scale office room using a mathematical model validated for a reduced scale model. In the case of a SC with no gap, the temperatures are clearly the highest among the studied cases, since there is no heat and mass transfer between the plenum and the occupied zone. This reduces the heat transfer to the slab. The presence of a gap lets the rising air coming from the heat load to enter in the plenum, thereby lowering the temperature of the room. The combination of positioning of the supply and extraction slots above the SC and its peripheral gap allows for a more efficient cooling of the slab during the night and acts as a greater heat reservoir during the day. This innovative cooling strategy of office room buildings proved to be more efficient than the installation of a tight SC.

References

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