Performance in practice of a ventilation system with thermal storage in a computer seminar room

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Abstract

Computer classrooms present challenges for cooling because internal heat gains higher than typical classrooms. Focused on thermal comfort, this paper presents the results of a field and computational study of a computer seminar room in west England. A mechanical ventilation system with phase change materials thermal storage has been installed in the room to provide thermal comfort and indoor air quality. Monitored data of internal air temperature, CO_2 and humidity were analysed and compared with current requirements for indoor air quality and comfort. The analysis indicates that good internal environmental conditions are provided by the system. To better understand the ventilative cooling performance of the system a week in early September was chosen and analysed in detail. In addition the hottest hour of the week was chosen for further analysis using CFD using air temperature monitored data for calibration. Results show that even for the most extreme external conditions of the monitored period, the seminar room has a uniform temperature distribution within thermal comfort requirements and air velocity ranging between 0.11 to 0.17 m/s close to the students and will not cause uncomfortable draughts.

Keywords - ventilative cooling; thermal comfort; phase change material; thermal storage; school buildings

1. Introduction

PCM thermal batteries incorporated in ventilation systems to reduce cooling demand have been studied during the last 20 years. The impact of a packed bed of granules containing PCMs on the supply temperatures in a ventilation system for houses in Japan investigated through experiments and simulations [1]. It was found that depending on the location 42-62% reduction of the ventilation load was achieved. A room ventilation system incorporating heat pipes embedded in PCM thermal battery was tested experimentally for applications in the UK [2, 3]. Heat transfer rates of up to

200 W were measured under simulated UK summer conditions comparing the system favourably to conventional air conditioning and other technologies such as cooled beams.

A numerical study of the free cooling of a low-energy residential building using a thermal energy storage device filled with spheres of encapsulated RT20 paraffin integrated into a mechanical ventilation system has shown that it is an effective cooling technique with a melting temperature between 20 and 22 ^{o}C in the case of a continental climate [4]. PCM heat exchangers in the ventilation system can also provide heating power [5].Optimization of the PCM-air heat exchanger integrated into the ventilation system to provide thermal comfort and indoor air quality with reduced energy costs by shifting space heating electrical consumption from peak to off-peak period is the focus of current research [6]. Numerical studies for integration of PCM in ventilation systems for large spaces have also shown reduction of energy consumption [7].

Two recent reviews [8,9] on PCM integration into buildings and HVAC systems points out that there is a 'scarcity of data published on actual performance in real life applications' and real case studies are essential to document performance and potential of PCM products in real operation conditions' as well as addressing costs. This paper attempts to fill part of this gap by presenting field measurements from a computer seminar room ventilated and cooled through a mechanical ventilation system incorporating a thermal battery with phase change materials (PMC). Simulation is also used to supplement discussions on monitored data.

2. Description of the Case-study and Ventilation System

The content of this section first appeared in [10] and is included here for completeness. The case-study is a computer seminar room at a university campus in West England. The room has a floor area of 117 m^2 and includes 26 desk top computers, peak occupancy of 26 students, and artificial lighting comprising of 24 luminaires each equipped with one 48 W lamp. The total internal heat gain in the room is 60 W/m^2. The room has one external wall facing west with U-value of 0.56 W/m^2 K while 23 % is glazing (U-value 1.82 W/m^2 K) with internal blinds. Ventilation and cooling is provided via a 8kW Cool-Phase® unit. Heating is provided through perimeter hot water radiators and windows are operable. Climate is temperate maritime with 2684 Heating Degree Days and 196 Cooling Degree Days; 20 year average, base 15.5 ^{o}C, south west England [11].

The Cool-Phase® system by Monodraught Ltd was installed in May 2013 to provide ventilation for indoor air quality and cool the air for thermal comfort. The Cool-Phase® system uses the concept of a thermal battery consisting of Phase Change Material (PCM) plates within the ventilation path to capture and store heat. Therefore, the thermal batteries use the latent heat property of materials to store energy, which is charged and discharged by passing air through a heat exchanger. A diagram of the system is shown in Figure 1 where the principle of the PCM thermal battery function is shown. The system is concealed in the false ceiling and its appearance to the user is that of a conventional ventilation system with two air supply terminals and one air extract terminal. Air is drawn from outside or the room using a variable speed fan. During operational hours and depending on internal air quality (monitored through CO_2 sensors) the air is mixed with recirculated air from the room to conserve energy. The air is then directed through the PCM thermal battery to be cooled if necessary (determined by air temperature sensors and control rules) or by-passes it if cooling is not needed. Outside operational hours, ambient air is used to recharge the PCM thermal battery the duration of which is determined by air temperature sensors and control rules according to the season.

The system performance for a year has been presented in [10] based on data from the system sensors and was shown that thermal comfort is provided during summer and IAQ is maintained throughout the year with a small energy consumption by the fan (0.77kWh/m^2/annum).

This paper presents monitoring carried out during August-November 2015 with purpose installed sensors distributed within the computer seminar room to evaluate environmental conditions and distribution within the space. CFD modelling was carried out to further examine thermal comfort within the space.

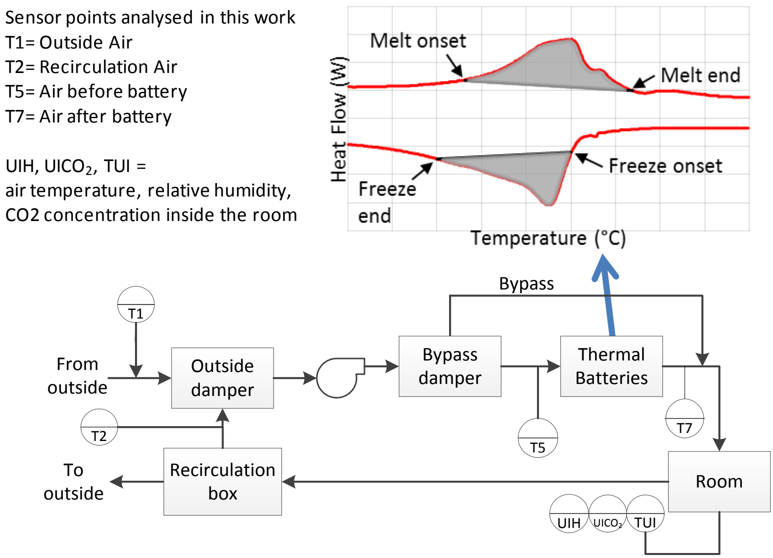

Fig 1 Schematic of Cool-Phase system with a graphical explanation of the PCM thermal battery principle of operation.

3. Description of Monitoring and Modelling

Sensors were installed on 19 August 2015 measuring air temperature, relative humidity and CO_2 as shown in Figure 2.

Fig 2 - Photos and layout of the computer seminar room showing position of sensors (H=HOBO, i=i-button).

Eight HOBO UX100-003 measured air temperature and relative humidity at 5 min interval. H1, H2, H3 and H4 are at seating person height (0.70 m from the floor), H5 and H6 at 1.80m, H7 at the same level as Cool-Phase® wall mounted user control (1.5m) and H8 close to exhaust grille (on the ceiling). Four i-button DS1922L were installed at the four faces of the air inlet diffuser with a 20 min interval. In addition, CO_2 was measured at two locations in the room on two consecutive days using Telaire sensors through a HOBO logger. Monitoring results presented in this paper are for the period 19 August to 27 November 2015, covering a warm period of the year as well as the autumn period when the room was fully used for classes. Monitoring continues and later results will cover conditions for a whole year.

To investigate further the environmental conditions distribution in the room a CDF model was developed using ANSYS – FLUENT® [12]. A 3D model was constructed and simulation results were compared with monitoring data. This model is then used to investigate a range of boundary conditions at steady state for the whole room.

4. Monitoring Results and Discussion

Figure 3 shows air temperature and relative humidity during the monitoring period at 0.7m height averaged from the 4 monitoring locations together with upper adaptive thermal comfort limit [13] for air temperature and the system setpoints for summer (22 °C) and autumn (23 °C). Average of the four sensors are presented because analysis of hourly monitored data during operational hours (8:00-21:00) indicate uniform air temperature (difference less than 0.5°C) and relative humidity (difference less than 1%). Air temperature at 0.7m did not exceed the upper limit for thermal comfort during the monitoring period of four months. Relative humidity higher than 70% and below 30% was observed on some occasions (20 hours or 2.19% and 3 hours or 0.33%, respectively). During the summer period analyzed, 360 hours (89.33%) were below the Coolphase setpoint, indicating good operation; it should be noted that occupancy was lower than capacity as formal classes start in September. During autumn, air temperature is always lower than the thermal comfort upper limit and for 315 hours (61.64%) of the period lower than the setpoint.

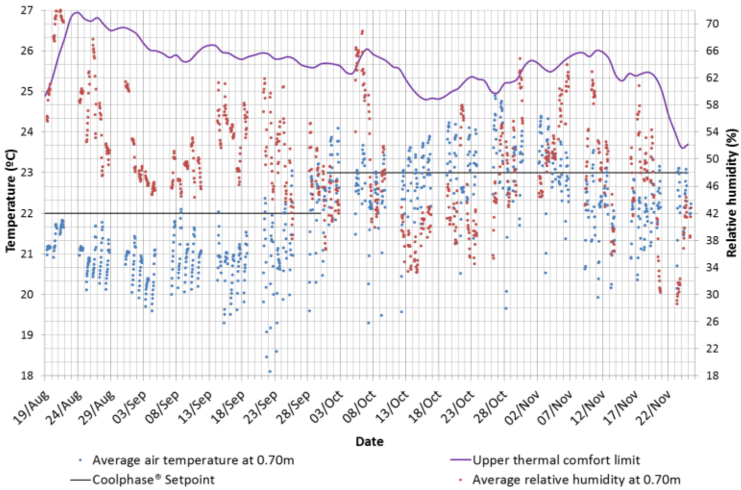

Fig 3. Hourly air temperature and relative humidity between 8:00 and 21:00 during the monitoring period at 0.7m averaged for the four sensors

Figure 3 presents monitored data for a typical week in the beginning of September. Maximum external temperature is 21 °C on Thursday 10 September. During working days the system starts with a charging-purge mode between midnight and 1:00 and continues with charging mode from 1:00 to 7:00am; this has an impact on the inlet air temperature. The system is off between 7:00 and 8:00am when the cooling mode is initiated and continues until 21:00. If the temperature outside the intake damper is lower that the set point for summer (22°C) the PCM thermal battery is by-passed. If the temperature outside the intake damper is higher than the summer setpoint the inlet air is directed to the PCM thermal battery through recirculation. At 21:00 the system is turned off until midnight.

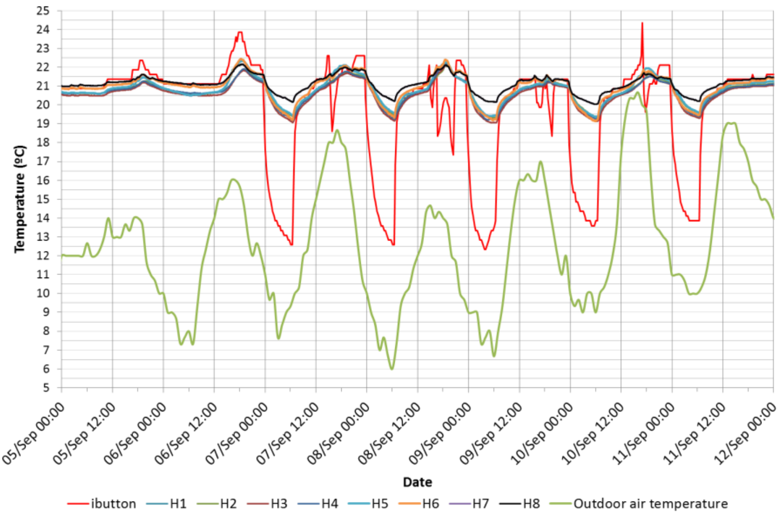

Fig 3. Air temperature at 0.70m, exhaust, diffuser and thermal comfort limits

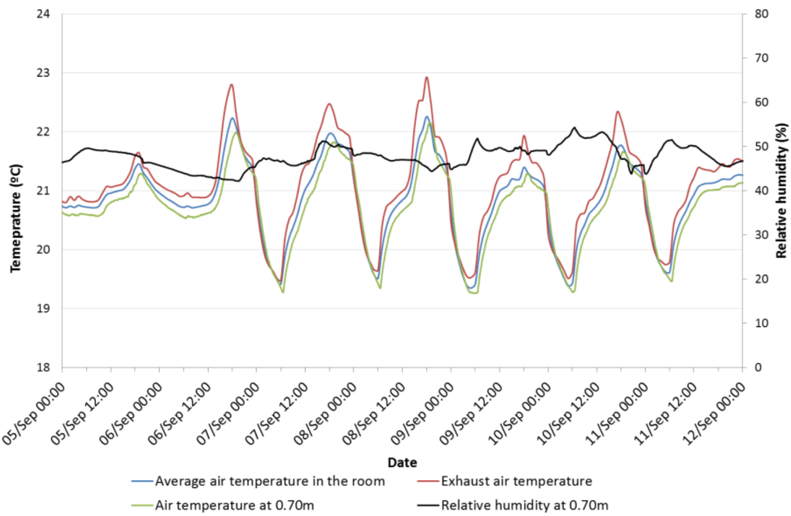

Fig 4. Air temperature and relative humidity at different points in the seminar room.

This operation is indicated with the variations of room inlet air temperature in Figure 3. Internal temperatures in the room are maintained below the maximum thermal comfort limit. There are occasions during early morning when air temperatures at 0.7m (desk height) are just lower than the lower thermal comfort limit. However, air temperature higher in the room and the sensor next to the equipment room sensor are within thermal comfort range. The internal air temperature profile is presented in more detail in Figure 4 where stratification of air temperate is observed with a maximum of 1^oC. Relative humidity is also maintained within acceptable range.

As this is a seminar room, IAQ considerations are important especially during the heating period. CO_2 concentrations at two monitored points (CO_2-1 and CO_2-2 on Figure 2) during November 2015 are presented in Figure 5. Average CO_2 concentration is 963 on the first day and 895 ppm on the second day. The limit of 1500ppm was not exceeded for more than 20mins. It should be noted that the two sensors were placed well within the occupant zone and the rooms was fully utilized for classes.

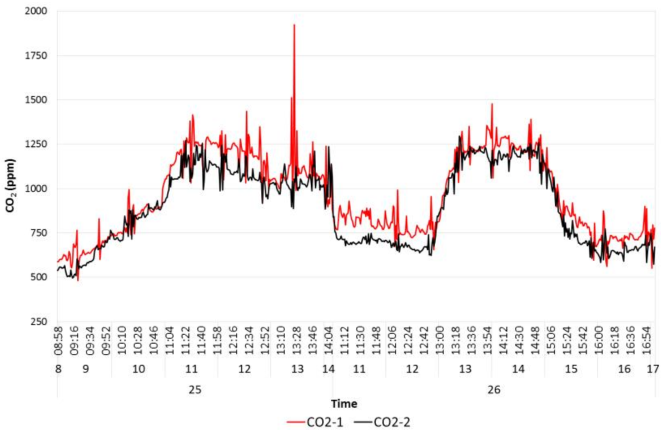

Fig 5. CO_2 concentration on two consecutive days during late November 2015.

5. CFD Modelling Results and Discussion

Figures 6-8 present the air temperature distribution within the seminar room as well as the air velocity on Thursday 10 September which is the weekday with the highest external temperatures presented in Figures 3 and 4.

The CFD model was created within ANSYS-FLUENT to examine the room conditions on the hottest hour of the day (16:00). Temperature results were compared with the eight locations of monitored data to give confidence on the predictions validity. The average difference between simulation and monitored measurement is 0.3K (or 1.42%) which shows that the simulation is well calibrated.

Air temperature simulation results presented in Figure 6 confirm that near uniform temperature distribution within thermal comfort range is achieved at seating level. The CFD model indicates a stratification range between seating level (0.7 from floor) and near the ceiling (0.30 from ceiling) of about 4 K. This is wider than the monitored data (see Figure 4) and will be investigated to improve the CFD model.

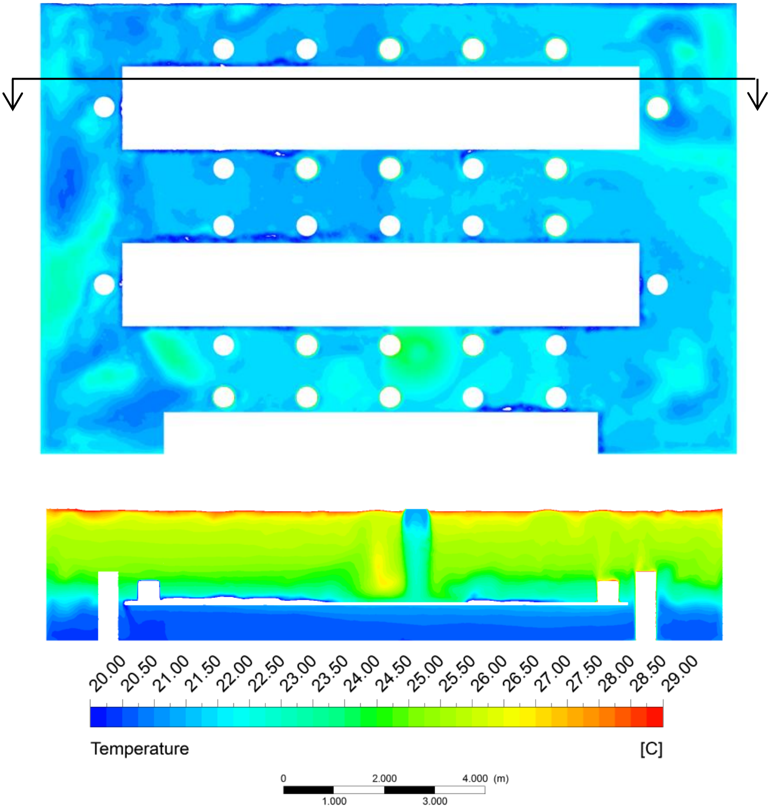

Fig 6. Air temperature in two sections of the seminar room at 16:00hrs on 10 September 2015 with full occupancy and internal gains.

Air velocity simulation results are presented in Figures 7 and 8. They show that the velocities close to the students are between 0.11 to 0.17 m/s and will not cause uncomfortable draughts. They also show an air velocity uniform when the areas close to the Cool-Phase® diffuser are excluded and present velocities below 0.11 m/s and an average of 0.034 m/s.

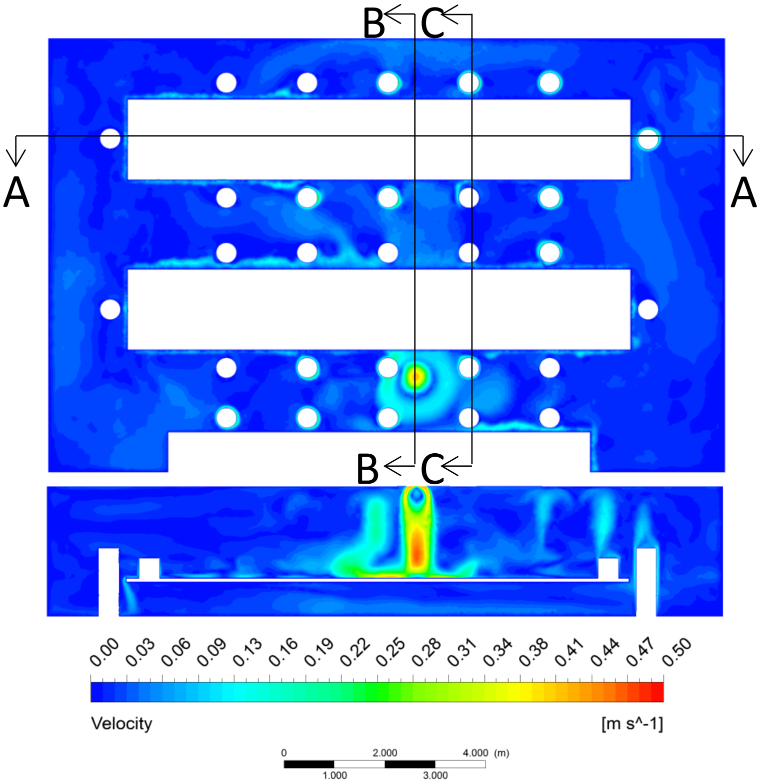

Fig 7. Air velocity distribution in the room in two sections of the seminar room at 16:00hrs on 10 September 2015.

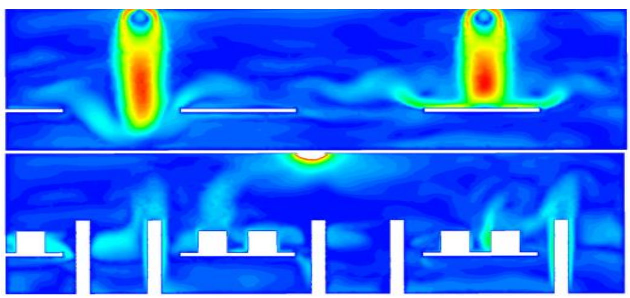

Fig 8. Cross sections (BB- diffuser level and CC – exhaust level) of the room (see Fig 7) showing air velocity distribution

6. Conclusions and further work

Analysis of three months in-situ monitoring within the space of an IT intensive seminar room equipped with a Cool-Phase® system to provide cooling indicate that thermal comfort and IAQ are maintained throughout the space at occupant level. CFD modelling indicates uniform conditions within the room. Monitoring is continued and will be compared with the system's recorded data to propose improvements such as location of set-point sensor in the occupied zone. In addition an occupants' survey will be carried out to gauge satisfaction. The work is part of a case-study being developed for EBC Annex 62 on Ventilative Cooling.

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