Ventilative cooling of a seminar room using active PCM thermal storage

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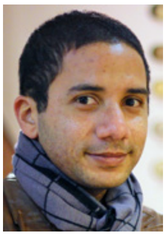

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One-year monitoring results of environmental conditions in a UK seminar room where the Cool-phase® ventilation and PCM battery system has been installed indicate thermal comfort and good indoor air quality throughout the year. CFD analysis indicates that air temperature and air distribution is uniform at occupants' level.

Keywords: ventilative cooling, seminar room, thermal comfort, thermal storage, phase change materials, operational data.

Thermal comfort and indoor air quality requirements for the case-study

Thermal comfort evaluation is usually based on current guidance on avoiding overheating in buildings. In the UK, current guidance for schools is provided by the Education Funding Agency [1]; it includes guidelines on ventilation, thermal comfort and indoor air quality, including the Services Output Specification [2], the Baseline Design Environmental Services and Ventilation Strategy [3] and the Building Bulletin 101 [4]. These documents are aligned with CIBSE's guidance on prevention of summertime overheating [5,6 ,7 ,8] which refer to calculations according to European Standard BS EN 15251 and UK Building Regulations Parts L (Conservation of Fuel and Power) and F (Ventilation) [9].

Until recently overheating criteria for schools were based on fixed air temperature (28°C which can be exceeded for 120 hrs and 32°C not to be exceeded) outside the heating season and during the occupied period from 1st May to 30th September.

Currently, the adaptive thermal comfort approach is used which follows the methodology and recommendations of European Standard EN 15251 to determine whether a building is overheated, or in the case of an existing building whether it can be classed as overheating. The new criteria are based on a variable (adaptive) temperature threshold that is generated from the outside running-mean dry-bulb temperature. There are three criteria, two of which must be met for compliance, as follows [3]:

(a) Hours of Exceedence: The number of hours operative temperature exceeds the maximum acceptable operative temperature (θmax) by 1K, must not exceed 3% of the total occupied hours or 40 hours, during the five summer months.

(b) Weighted Exceedance: The sum of the weighted exceedance for each degree K above θmax (1K, 2K and 3K) is ≤ 10.0.
(c) Threshold/Upper Limit Temperature (θupp): The measured/predicted operative temperature should not exceed the θmax by 4K or more at any time.

The case-study analysed in this paper was built to comply with the older requirements so operational data are analysed following both approaches.

In terms of IAQ based on CO_2 concentration, until recently the guidance was that when measured at seated head height, during the continuous period between the start and finish of teaching on any day, the average concentration of carbon dioxide should not exceed 1,500 parts per million (ppm). This criterion is changed to the following criteria [3]:

(a) Ventilation should be provided to limit the concentration of carbon dioxide measured at seated head height in all teaching and learning spaces.
(b) Where mechanical ventilation is used or when hybrid systems are operating in mechanical mode, i.e. the driving force is provided by a fan, sufficient fresh air should be provided to achieve a daily average concentration of carbon dioxide during the occupied period of less than 1,000 ppm and so that the maximum concentration does not exceed 1,500ppm for more than 20 consecutive minutes each day.

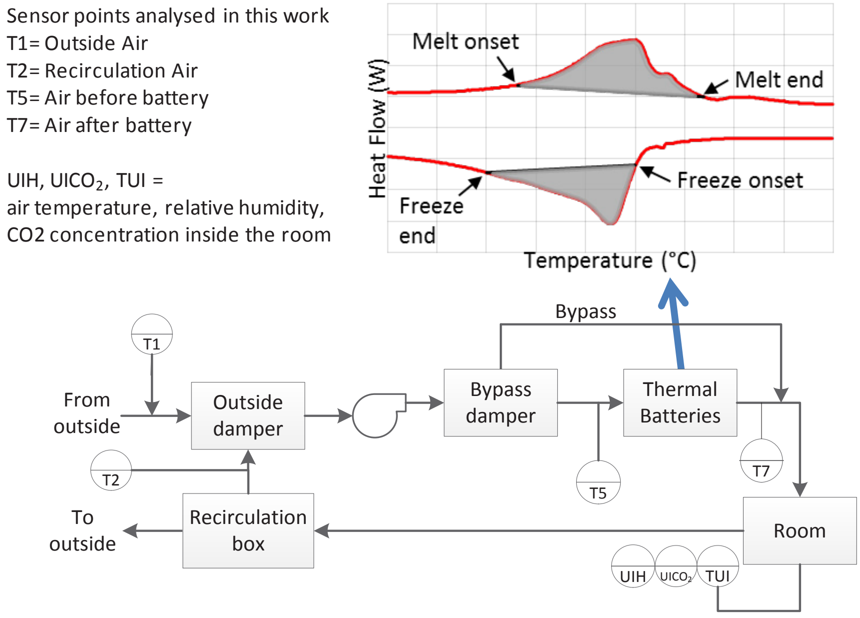

Figure 1. Schematic of Cool-Phase system with a graphical explanation of the PCM thermal battery principle of operation.

Description of the case-study computer seminar room

The case-study is a seminar room at a university campus in West England. Cool-Phase® systems have been installed in other spaces of the university but the seminar room was chosen because of its use (computer laboratory) with higher internal heat gains than other spaces. 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 8 kW Cool-Phase® unit. Heating is provided through perimeter hot water radiators and windows are operable. Climate is temperate maritime with 2,684 Heating Degree Days and 196 Cooling Degree Days; 20 year average, base 15.5°C, south west England [10].

Description of the ventilative cooling system

A 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.

Figure 2 shows how the system works based on monitored data during one day in August 2013. The system starts with a charging-purge mode between midnight and 1:00 and continues with charging mode from 1:00 to 7:00 am. Inlet and outlet temperatures through the PCM thermal battery are decreasing with a temperature difference between them indicating the battery is charging. The system is off between 7:00 and 8:00 am when the cooling mode is initiated and continues until 21:00. In the morning (8:00-~13:00) the temperature outside the intake damper is lower than the set-point for summer (22°C) so the PCM thermal battery is by-passed. At around 13:00, set-point temperature is exceeded and the inlet air is directed to the PCM thermal battery through recirculation. Inlet air is cooled to below room temperature until shortly before 21:00 when the system is off until midnight. Maximum temperature in the room is 24.5°C below max external temperature.

System performance

Figure 3 shows temperatures in the case-study room during operational hours in the summer of 2013 (May – September). According to adaptive thermal comfort criteria, it can be observed that the system has achieved internal temperatures within the upper and lower limits and therefore complies with all conditions. Also, air temperatures do not exceed 28 or 32°C and daily average inside/outside temperature difference is less than 5°C and therefore achieves comfort according to static thermal comfort criteria.

An analysis of monitored room CO_2 concentration was carried out for the whole year that data are available. **Table 1** presents the results. Daily average concentration during the occupied period is always less than 1.000 ppm and the 1.500 ppm limit was not exceeded with the exception of one occasion for 22 min when occupancy was higher than designed and there was a conflict between IAQ and thermal comfort.

The fan energy used by the system for the year was calculated to be 90 kWh. This equates to 0.77 kWh/m²/annum. Annual electricity energy use intensity for secondary schools has a median of 51 kWh/m² [8]. This increases by 5 kWh/m² when moving from 'heating and natural ventilation' to 'heating and mechanical ventilation' buildings. CIBSE TM57 [8] presents good case-studies with cooling energy intensity of 12.5 kWh and 3.5 kWh/m².

Room temperature and air velocity distribution using CFD

In the previous section average environmental conditions in the room were reported. However, the distribution is also important to examine whether there are areas within the room that deviate from thermal comfort requirements. This was investigated using a CDF model of the room. A 3D model of the room was constructed with summer boundary conditions; the hour in July with the highest internal temperature was selected as the worst case scenario and a steady state simulation was performed with full occupancy and internal heat gains. **Figure 4** shows the air temperature at 1.2 m height (student sitting plane) and velocity fields at the plane of one air inlet.

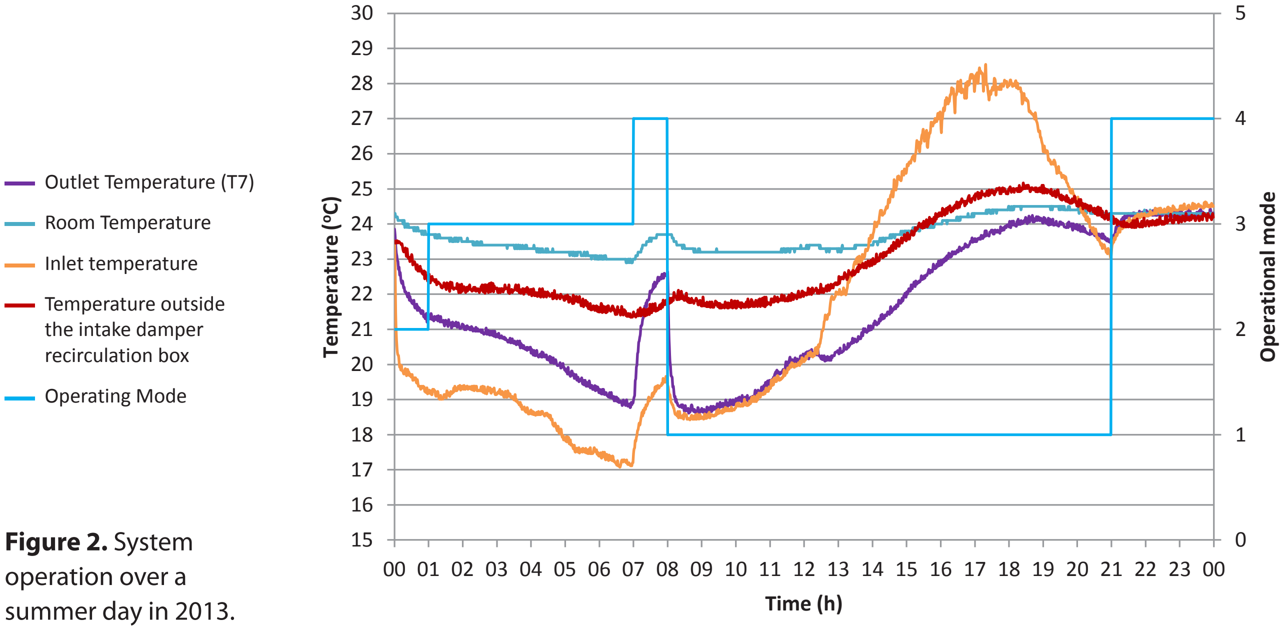

Figure 2. System operation over a summer day in 2013.

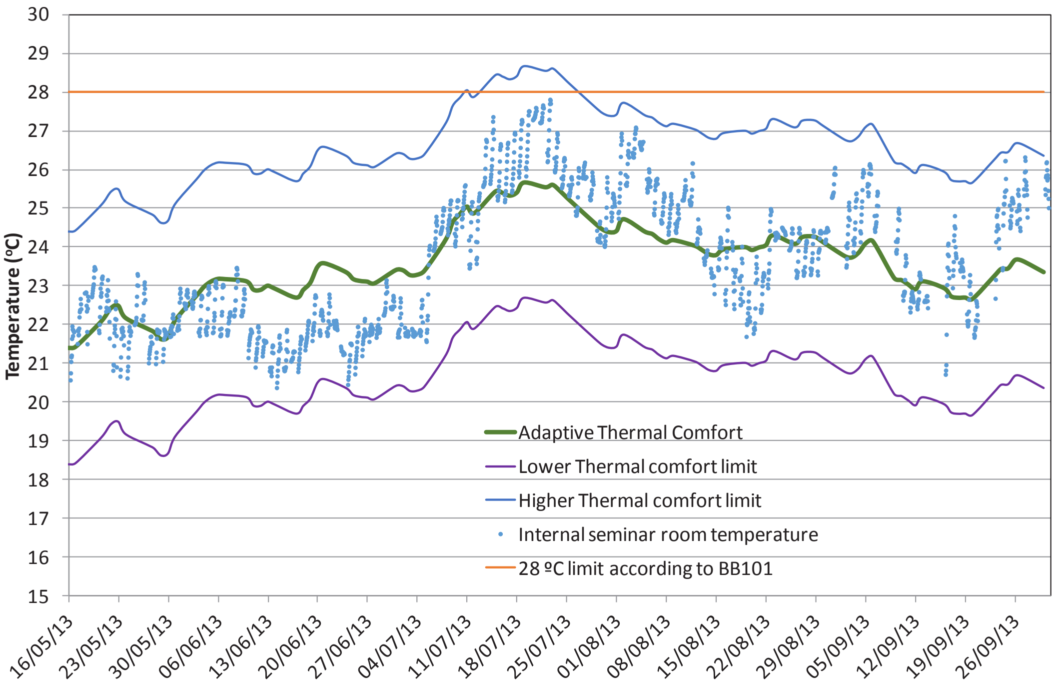

Figure 3. Thermal comfort performance over the summer months.

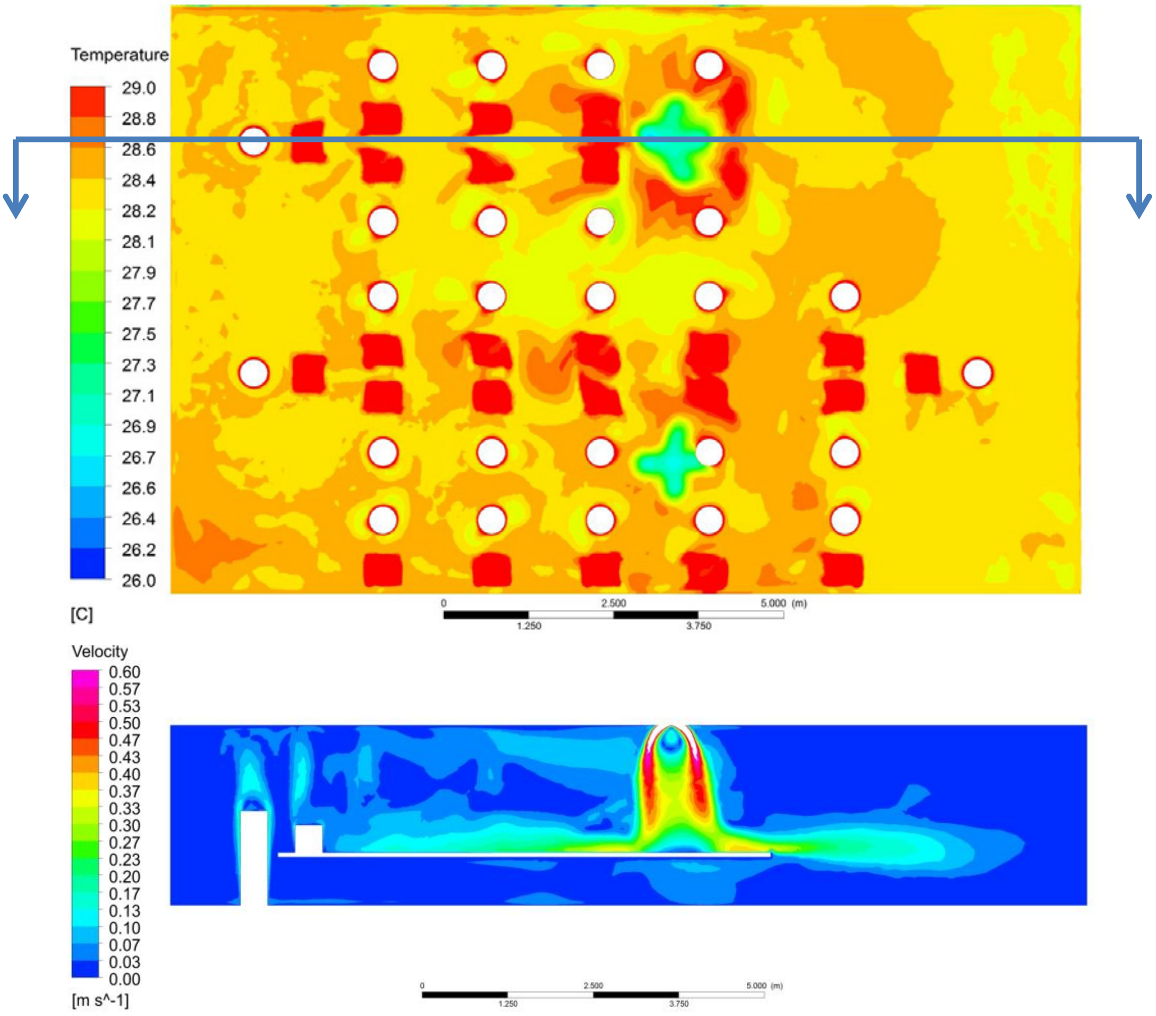

Figure 4. Air temperature and velocity in two sections of the seminar room during the hour with highest internal temperature (see **Figure 3**) and full occupancy and internal gains.

It can be observed that air temperature is uniform across the room and there are no areas with much higher air temperature which will cause discomfort. The air velocity contours indicate that at occupancy level underneath the air inlet velocity is in the range of 0.1–0.2 m/s with some small areas reaching 0.37 m/s Air velocity is lower in the rest of the room. Changing the direction of inlet louvres would reduce air velocities if this is required although higher velocities might aid thermal comfort.

Concluding remarks

Analysis of one-year operational environmental data for a seminar room equipped with a Cool-Phase® system to provide cooling indicate that the system performs well throughout the year in terms of IAQ and thermal comfort for an IT intensive seminar room. Further analysis of a second year of operational data plus additional monitoring to study the distribution of environmental conditions in the room and feedback by users is under progress and will be reported in a case-study being developed for EBC Annex 62. ■

Table 1. CO_2 concentration (ppm): daily average and exceeding 1500 ppm for more than 20 consecutive minutes.

Month	Average	> 1,500 ppm
May	502	0
June	423	0
July	413	0
August	416	0
September	500	0
October	595	0
November	741	0
December	566	Once*
January	601	0
February	719	0
March	695	0
April	579	0

* CO_2 concentration exceeded 1,500 ppm for 22 min on mid-morning on 6 Dec 2013 when occupancy in the room was more than its maximum and external air temperature at ~7°C. The control system restricted outside air to the room to less than maximum capacity to avoid thermal comfort issues.

References

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