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An evaluation on the effect of night ventilation on thermal mass to reduce overheating in future climate scenarios

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Abstract

The aim of this study was to evaluate the influence of night ventilation on thermal mass benefits, with a view to alleviating the impact of future climate scenarios in terms of overheating.

Dynamic thermal simulations were used to analyse the overheating performance of a test room with exposed thermal mass. A range of night ventilation rates were simulated to evaluate their effect on thermal mass behaviour with regard to overheating according to different future climate and emission scenarios for London Islington.

The study shows that night ventilation rates of at least 8 acph are needed to provide significant overheating reductions. In the long term, ventilation rates under 10 acph will have little effect, allowing overheating reductions of less than 3% for high emissions scenarios and less than 8% for medium emissions scenarios. Different strategies must be in place if overheating is to be avoided due to warmer outdoor temperatures.

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Keywords: climate projections; dynamic simulation; ventilation; overheating; thermal mass

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1. Introduction

Thermal mass has the benefit of regulating energy in buildings and generates potential savings in energy and CO_2 emissions. The benefits of coupling thermal mass and ventilation in housing to avoid overheating have been already presented in the literature [1, 2]. According to the Zero Carbon Hub [3], thermal mass and purge ventilation have a beneficial effect on reducing overheating. This study focuses on non-domestic buildings, where normally the thermal mass is hidden behind a compressed mineral wool suspended ceiling. This suspended ceiling produces a blocking effect for the use of the thermal mass to regulate the indoor conditions, avoiding the loading and unloading process of the thermal mass to be used as a regulatory mechanism for comfort indoor temperature. Exposure and use of the building thermal mass can reduce overheating in summer and minimize the need for cooling energy, reducing energy consumption and CO_2 emissions [4]. According to data collected by Santamouris [5], air change rates per hour in commercial buildings range from 2 to 30. Blondeau et al [6] found that ventilation rates above 8 or 10 acph had little effect on comfort improvement.

As a result of the effect of climate change, temperatures in summer will be higher and longer periods of summer heat waves will be expected [7]. Previous work has presented the issue of overheating in future weather conditions for non-domestic buildings [8]. Exposure of the building thermal mass combined with a night ventilation strategy can reduce overheating in current weather conditions [4], furthermore, the same thermal mass effect and reduction in overheating can be achieved in future climate change scenarios although the benefits are vastly reduced and further strategies must be sought [9].

The aim of this study was to evaluate the influence of night ventilation on the thermal mass benefits to alleviate the impact of future climate scenarios in terms of overheating.

2. Method

An exemplar test room, as shown in Figure 1, was modeled with dimensions 7.5m x 7.5m x 3.5m. The test room was dynamically simulated using energyplus in DesignBuilder software. U-values for internal floors hidden (with suspended ceiling) were 0.739 W/m^2K and exposing (without suspended ceiling) the thermal were 1.523 W/m^2K as previously published [4,9]. The test room was naturally ventilated and a night cooling ventilation strategy was used to cool down the thermal mass and discharge the heat accumulated during the day. Five night ventilation rates were simulated as 2, 4, 6, 8 and 10 acph, following previous published work results [5,6]. No cooling and no solar protection were used in the simulations to be able to isolate and specifically quantify the benefits provided by the thermal mass to reduce overheating on its own. The simulated test room results were audited to confirm corroboration of results with building physics principles.

The dynamic computational simulation in DesignBuilder had the following parameters:

- Simulated location in London (Islington).
- Medium weight construction according to Part L2 2010 (UK).
- All surfaces adiabatic apart from south wall being external with a U-value of 0.26 W/m2K.
- 50% glazing in south wall with a U-value of 1.978 W/m2K and g-value of 0.687.
- Office equipment load of 10 W/m2.
- Lighting load of 0 W/m2.
- People density of 0.111 people/m2, following an occupancy schedule from 9:00 to 17:00
- Constant infiltration of 0.5 air changes per hour (acph).
- Natural ventilation rate of 1.5 acph, following a schedule from 8:00 to 19:00
- Night ventilation rates ranging from 2 to 10 acph, following a schedule from 24:00 to 6:00
- Simulations run for a full year.

The test room was dynamically simulated using the weather files produced as part of the Prometheus project, which are based on UK Climate Projections 2009 (UKCP09) data to provide weather projections in future climate [10]. This study used Design Summer Year (DSY) weather files with a probabilistic prediction for the 50^{th} percentile reflecting climate change for a medium and high emission scenarios. The exemplar test room was simulated with and without suspended ceiling for the baseline (1970s), 2030s, 2050s and 2080s weather files to compare the effect on overheating hours and for the range of thermal mass thicknesses.

The overheating limit was set to 28ºC in accordance with CIBSE definitions [11, 12].

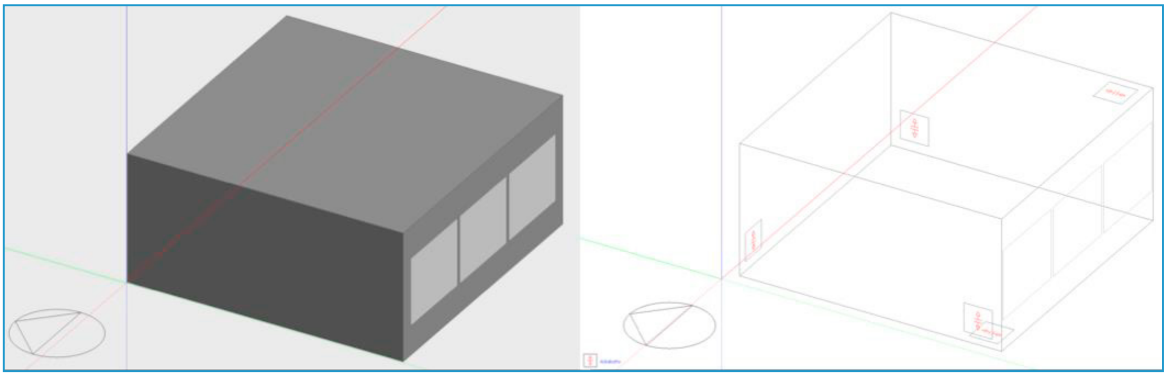

Fig. 1. Exemplar room for simulation.

3. Results

In terms of assessing the overheating performance with and without the suspended ceiling for the range of ventilation rates, thirty-five simulations were solved in total using the dynamic Energyplus engine in DesignBuilder without the use of any cooling preventing overheating and only allowing the thermal mass and night ventilation to control the overheating. Two simulations were performed for each weather file, each night ventilation rate and each emission scenario, medium emissions (ME) and high emissions (HE), for London (Islington), simulating the exemplar test room with suspended ceiling and non-suspended ceiling.

Temperature distribution results for London (Islington) with the use of a non-suspended ceiling, exposing the thermal mass, were collected for every simulation and results can be found in previous work [4,9]. The final results for overheating hours above 28ºC are presented in Figure 2 for the high emission scenario and in Figure 3 for the medium emission scenario.

As expected and in accordance with Pfafferott et al. [13], the night ventilation effect increases with higher air change per hour providing a higher reduction on overheating when the thermal mass is exposed. As outdoor temperatures are getting warmer according to weather projections, the reduction effect of exposing the thermal mass is reduced further and further as shown in Figures 2 and 3 and the results presented in Table 1.

Exposing the thermal mass by elimination of the suspended ceiling reduces the overheating hours above 28°C in most of the future weather simulations compared to the same room featuring a suspended ceiling with isolation of the thermal mass from the ambient temperatures. Night ventilation has no effect at all in simulation for the 2080s under high emissions when air change rates per hour are 6 or less. This is expected due to the higher night temperature with climate change and lower ventilation rates not allowing the thermal mass to cool down during the night.

As expected, overheating hours above 28°C are higher for the high emissions scenario than for the medium emissions scenario, as higher emissions will accelerate the global warming effect of climate change, producing warmer and longer summers.

As previously presented, overheating hours above 28°C will increase with the simulation of future weather for all simulations; by the 2080s they will be roughly between two to three times the baseline levels in the 1970s for both, medium and high, emissions scenarios [9].

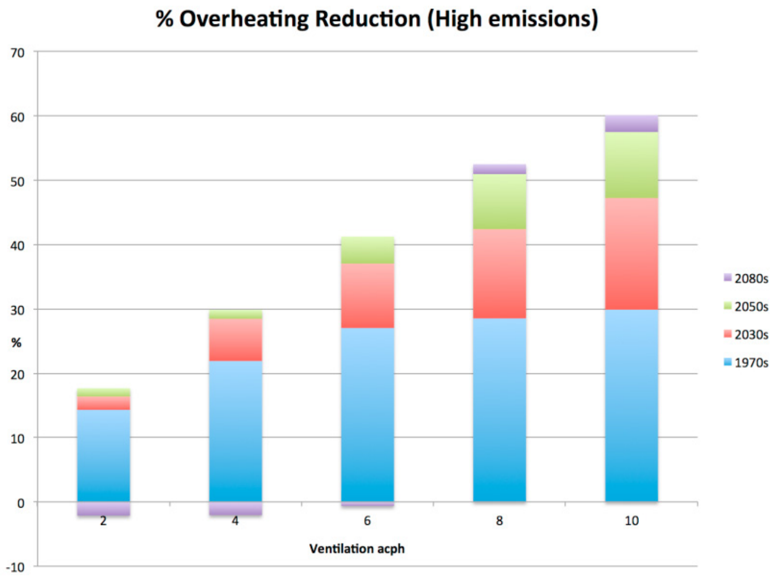

Fig. 2. Overheating percentage reduction due to exposing the thermal mass for high emissions.

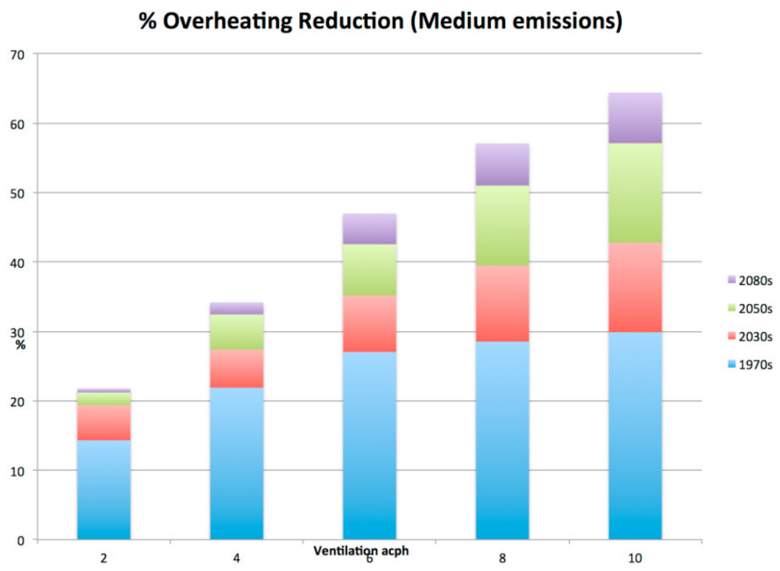

Fig. 3. Overheating percentage reduction due to exposing the thermal mass for medium emissions.

Table 1. Overheating hour and percentage reduction due to exposing the thermal mass for high and medium emissions.

		HE - Overheating Hours (% Reduction)					ME - Overheating Hours (% Reduction)				
	acph	2	4	6	8	10	2	4	6	8	10
1970s	S	932.5	783	730.5	683.5	662.5	932.5	783	730.5	683.5	662.5
	NS	799 (14.32)	611.5 (21.90)	533 (27.04)	488.5 (28.53)	464.5 (29.89)	799 (14.32)	611.5 (21.90)	533 (27.04)	488.5 (28.53)	464.5 (29.89)
2030s	S	1295.5	1167.5	1105.5	1058	1031.5	1225	1090.5	1025.5	976	958.5
	NS	1269 (2.05)	1091 (6.55)	995 (10.00)	911.5 (13.85)	852.5 (17.35)	1163 (5.06)	1031 (5.46)	942 (8.14)	869 (10.96)	835 (12.88)
2050s	S	1412.5	1260.5	1209.5	1157.5	1135	1398.5	1266.5	1211	1146.5	1122
	NS	1394 (1.31)	1243 (1.39)	1158.5 (4.22)	1058 8.60)	1018.5 (10.26)	1373 (1.82)	1202 (5.09)	1121.5 (7.39)	1014.5 (11.51)	961 (14.35)
2080s	S	1753	1650	1610.5	1568.5	1542	1565.5	1464.5	1417	1363	1326.5
	NS	1790.5 (-2.14)	1684 (-2.06)	1621 (-0.65)	1544.5 (1.53)	1501.5 (2.63)	1556.5 (0.57)	1439 (1.74)	1354.5 (4.41)	1280 (6.09)	1230 (7.27)

The reduction in overheating hours as a benefit of using the thermal mass became smaller and smaller as the weather files approached the simulation for 2080 of the emission scenario, when the effect of climate change is higher. Variations on thermal mass benefit in relation to the thermal mass thickness are quite small, in the region of 3% for high emissions and 2% for medium emissions. This effect is due to the outdoor temperature being much higher in the 2080s than in the reference simulations of the 1970s, reducing the night cooling effect on the thermal mass and limiting the saving in overheating hours previously presented in the literature [14].

The number of overheating hours correlates with the need for cooling in a building and subsequently with the energy use and carbon emissions that cooling would incur. The higher the number of overheating hours, the more energy consumption and carbon emissions will be driven by cooling to alleviate overheating.

4. Discussion

Exposing the thermal mass by removal of the suspended ceiling in non-domestic buildings can reduce the overheating hours above 28ºC in all future weather simulations in London (Islington) compared to the same room featuring a suspended ceiling with accompanying (simulated) isolation of the thermal mass from ambient temperatures. These results agree with previous research highlighting the benefits of exposing the thermal mass and the use of night ventilation [1,2,15].

The number of overheating hours correlates with the need for cooling in a building and subsequently with the energy use and carbon emissions that cooling would incur. The use of cooling is driven by the number of overheating hours in the building, which will affect the thermal comfort of the occupants, so the higher the number of overheating hours, the more energy consumption and carbon emissions will be generated and the more probable the high emission scenario will be.

As previously reported [9], the simulation results show that by exposing and making use of the room thermal mass, the number of hours above 28ºC can be reduced but the beneficial effect of the thermal mass is very much reduced in subsequent simulations for 2030s, 2050s and 2080s with a bigger detrimental reduction for the high emission scenario, due to an increase in outdoor temperatures [13].

The effect of the ventilation rate to reduce overheating hours is directly proportional to the ventilation rate as already reported [13]. The effect of weather projections on the overheating reduction is inversely proportional, to the point that exposing the thermal mass in high emissions for 2080s has no reduction effect at all. In terms of emissions scenarios, higher overheating reductions are possible with medium emissions than higher emission, which corroborate the expectations of warmer temperatures.

While this study supports the use of thermal mass and purge ventilation as a mechanism to avoid overheating [1, 2, 3] in the short term, a different strategy must be applied to reduce overheating in the long term (2050s and 2080s) [9] and furthermore, the study supports the use of night ventilation rates of at least 8 acph to provide significant overheating reductions.

Under low night ventilation rates, the reduction of overheating hours will be minimal to achieve thermal comfort to the occupants and father measures must be put in places to reduce the use of cooling if a reduction in energy and CO_2 emissions must be achieved.

These results should be taken into account in the design of new buildings and refurbishment work to avoid overheating in the future due to climate change due to the long life of buildings. This study highlights the need of further understanding on the performance of thermal mass, its relation to night ventilation rates and its effect to reduce overheating in future climate by quantifying the benefit of energy efficient measures in the long term to avoid the need to refurbish in the short to medium term due to the higher temperatures in future climates.

5. Conclusion

This study shows that the use of thermal mass and night ventilation can provide a reduction in overheating in the short term. Furthermore, it shows that the use of night ventilation rates of at least 8 acph is needed to provide significant overheating reductions. In the long term, the 2080s, the use the ventilation rates under 10 acph has as little effect as overheating reductions of less than 3% for high emissions scenarios and less than 8% for medium emissions scenarios. Further considerations and a different strategy must be in place if overheating needs to be avoided due to warmer outdoor temperatures.

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