An Evaluation of the Combined Effect of Window Shading and Themal Mass to Reduce Overheating

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Abstract. Thermal mass has the benefit of regulating energy in buildings and generates potential savings in energy and CO_2 emissions. Window and local shading can provide shelter and reduce the severity of overheating during the year and mostly during the summer period.

The aim of this study was firstly to evaluate the influence of window shading to reduce overheating and secondly to assess the thermal mass benefits in the presence of shading devices to alleviate the impact of overheating.

This study was based on dynamic thermal simulations to analyse the performance of different window and local shading devices to avoid overheating. Twenty building simulation models were performed using the Energyplus plugin in DesignBuilder to evaluate the effect on the thermal mass behaviour to mitigate overheating according to different window shading devices.

This study confirmed, as expected, that the use of window shading helps to alleviate the overheating hours in the test room and as such, improving the thermal comfort and reducing the need for cooling. Furthermore, when the window shading devices are coupling with thermal mass and night ventilation, the reduction on overheating hours achieved will reach a reduction of over 50% with respect to not exposing the thermal mass. In conclusion, exposing the thermal mass coupled with a night ventilation strategy provides a reduction on overheating hours, which is increased by using different window shading devices. Exposure of the thermal mass provides a good strategy for reducing the need for cooling and increasing thermal comfort.

Keywords: Window Shading, Overheating, Dynamic Simulation, Thermal Mass.

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]. A combination of thermal mass and night ventilation provide a beneficial effect on reducing overheating as proposed by the Zero Carbon Home [3]. 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].

Furthermore to the use of thermal mass coupled with night ventilation, shading should be use to control and reduce solar gains through glazing helping to reduce overheating issues by excluding or minimizing the effect of solar radiation in the indoor environment [5, 6, 7]. The importance of adequate shading is even more relevant in well insulated buildings, in which overheating issues are happening during the summer months [8].

Regarding provision of shading, several options are available:

- Window shading by blinds, which could be internal, external or midpane [5].
- Use of electrochromatic glazing for window shading [5].
- Integrating overhangs into the design to provide local shading [3]

The aim of this study was firstly to evaluate the influence of window and local shading to reduce overheating and secondly to assess the benefits of using thermal mass in conjunction with the shading devices to alleviate the impact of overheating.

2 Method

An exemplar test room, as shown in Fig. 1, was modeled with dimensions 7.5m x 7.5m x 3.5m. The test room was dynamically simulated using energyplus in Design-Builder software. U-values for internal floors hidden (with suspended ceiling) were 0.739 W/m^{2}K and exposing (without suspended ceiling) the thermal mass were 1.523 W/m^{2}K as previously published [4]. 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 in accordance to the conditions presented below. No cooling was 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.

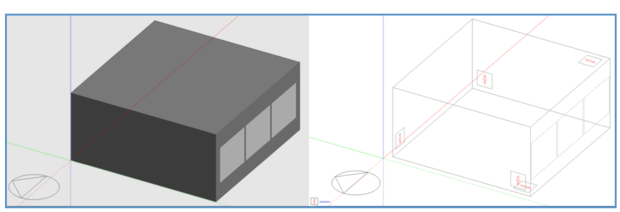

Fig. 1. Test room for dynamic building simulation.

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/m^{2}K.
- 50% glazing in south wall with a U-value of 1.978 W/m^{2}K and g-value of 0.687.
- Office equipment load of 10 W/m^2.
- Lighting load of 0 W/m^2 to focus on the performance of the thermal mass.
- People density of 0.111 people/m^2, following an occupancy schedule from 9:00 to 17:00
- Constant infiltration of 0.5 air changes per hour (ACH).
- Natural ventilation rate of 1.5 ACH, following a schedule from 8:00 to 19:00
- Night ventilation rates of 6 ACH, following a schedule from 24:00 to 6:00
- Heating by gas boiler.
- Heating setpoint temperature of 20ºC and set back temperature of 12ºC.
- No active cooling.
- Simulations run for one year (8760 hours).

The following window and local shading devices were simulated with and without suspended ceiling to compare the effect on overheating hours:

- No shading
- Window shading (implemented according to office occupancy schedule by the UK's National Calculation Method for Non Domestic Buildings)
  - Inside blind with high reflective slats
  - Outside blind with high reflective slats
  - Midpane blind with medium reflective slats
  - Inside shade roll light translucent
  - Inside shade roll light opaque
  - Electrochromatic reflective 6 mm glazing
  - Electrochromatic absortivetive 6 mm glazing
- Local shading
  - 0.5 meter overhang.
  - 1 meter overhang.

The overheating limit was set to 28ºC in accordance with CIBSE definitions [9, 10].

3 Results

In terms of assessing the overheating performance with and without the suspended ceiling for the range of window and local shading devices, twenty dynamic building simulations were solved in total using the dynamic Energyplus engine in Design-Builder 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 window and local shading device, simulating the test room with suspended ceiling and non-suspended ceiling, exposing the thermal mass.

Temperature distribution results for London (Islington) with the use of suspended ceiling and non-suspended ceiling, exposing the thermal mass, were collected for every simulation and results can be found in previous work [4]. The results for overheating hours over 28ºC are presented in Table 1, providing the total number of overheating hours with suspended ceiling and non suspended ceiling by using different window and local shading and no shading.

Table 1. Overheating hours over 28ºC for non-suspended ceilings (thermal mass exposed) and suspended ceilings from simulation results.

Shading type	Non-Suspended ceiling [hours]	Suspended ceiling [hours]
No Shading	533	730.5
Inside Blind	83	229
Outside Blind	5	14.5
MidPane Blind	161.5	334
Inside Shade Roll Translucent	112	302.5
Inside Shade Roll Opaque	56.5	171.5
Electrochromic Reflective	7	30
Electrochromic Absorbtive	7	39
0.5m Overhang	189	387
1m Overhang	42	56

Fig 2. presents a comparison of percentage reduction on overheating hours over 28ºC due to the influence of window shading versus no shading for a suspended ceiling and non-suspended ceiling scenario. The percentage is calculated from the baseline of no shading at all to the reduction in overheating hours above 28ºC due to the use of window and local shading devices as presented in Table 1. Very high overheating reductions, close to 100%, can be achieved by using electrochromatic glazing or outside blinds, while the smallest reductions are achieved by the use of midpane blinds and a 0.5 meter overhang. Regardless being the smallest reduction,

they still achieve reduction around 50%. It must be noted that in all cases, the use of the thermal mass provided a bigger reduction in overheating, much more pronounced with the use of internal and midpane blinds, as well as shade rolls.

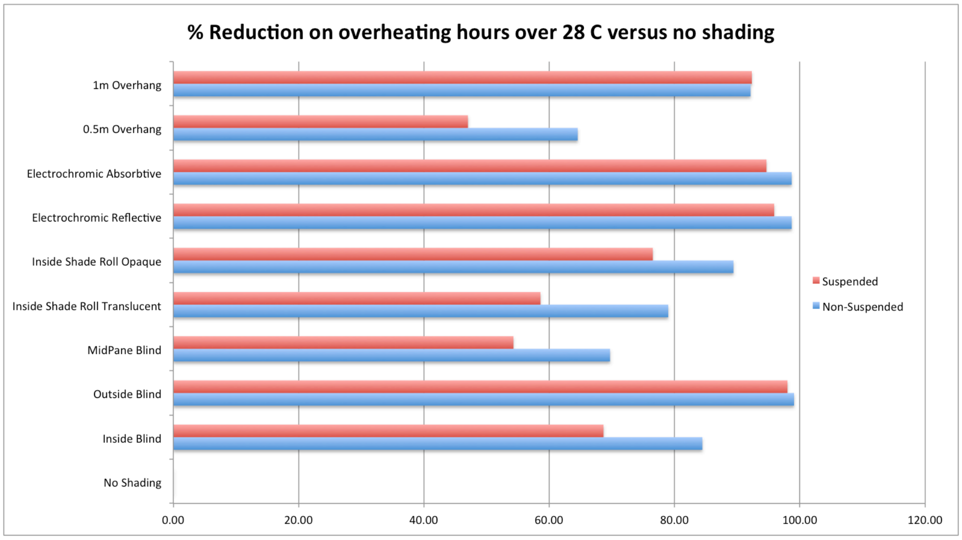

Fig. 2. Comparison of percentage reduction on overheating hours over 28ºC by window and local shading versus no shading for suspended ceiling and non-suspended ceiling scenario.

Fig. 3 presents the percentage reduction on overheating hours over 28ºC due to exposing the thermal mass in non-suspended ceilings. This percentage reduction is calculate based on the overheating hours above 28ºC when having a suspended ceiling and the overheating hours resulting from exposing the thermal mass (non-suspended ceiling) for each window and local shading devices as presented in Table 1. Overheating reductions above 70% can be achieved by using electrochromatic glazing, while the use of blinds and rolls allow reductions above 60%. Little benefit is appreciated by the use of a 1 meter overhang but this is due to the overhang already providing a massive reduction of overheating hours by blocking the solar radiation from reaching the glazing, so minimising any radiation effect in the inside room which would be charging the thermal mass and overheating hours being mostly driving by internal gains, form people and equipment. In the case of the smaller contribution of exposing the thermal mass for the case of "no shading", the issue for the thermal mass is completely the opposite. In this case, the thermal mass is fully loaded early in the day, as the number of overheating hours are above 700 hours a year. When the thermal mass is fully loaded, it will have no benefit for reduction until the heat contained in the thermal mass is discharged with the night ventilation strategy.

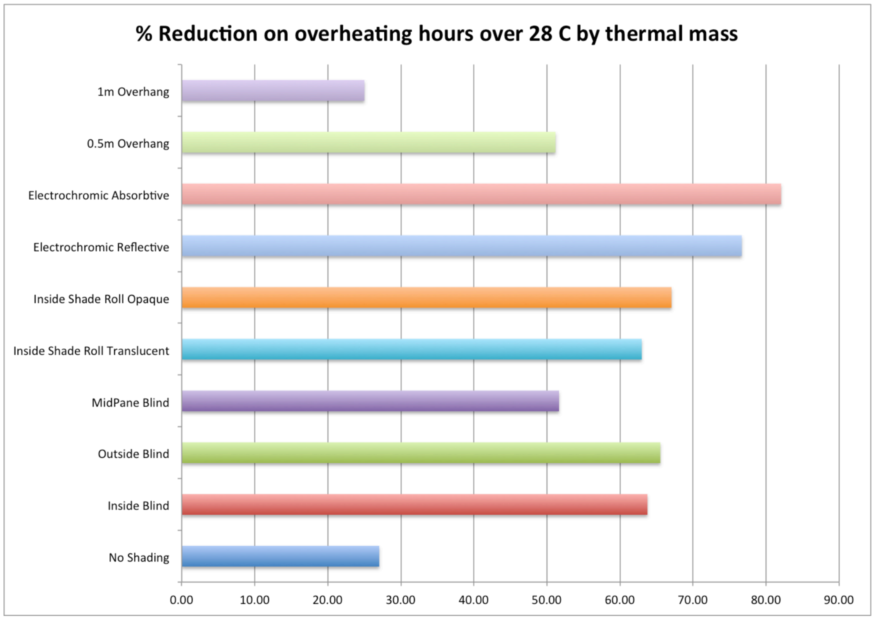

Fig. 3. Percentage reduction on overheating hours over 28ºC by using thermal mass (non-suspended ceiling) versus a suspended ceiling scenario.

4 Discussion

The use of window or local shading devices to control the solar gain transmission in window can greatly contribute to a reduction of overheating hours over 28°C as supported by this study and the literature [5, 6, 7]. As expected, external or outside blinds provide one of the highest overheating reductions, which agree with the literature [3, 5, 8]. A design limitation on the use of external or outside window shading devices in the United Kingdom is the practice of installing windows, which open outward [3, 11]. On the one hand, electrochromatic glazing provides high overheating reductions, similar to the use of external blind, but avoiding the limitation on opening outwards. On the other hand, electrochromatic glazing has the highest economic cost in terms of new build and retrofit [5], making it the least likely option for window shading regardless of the very good performance.

As well as using window or local shading, exposing the thermal mass by removal of the suspended ceiling in non-domestic buildings can reduce further the overheating hours above 28ºC in all window and local shading device 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, the use of night ventilation and implementation of window shading [1, 2, 5, 6, 7, 12].

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.

While this study supports the use of thermal mass and purge ventilation as a mechanism to avoid overheating [1, 2, 3] on its own, the benefits of thermal mass can be further extended when window shading devices and local shading is used to limit the solar transmission through glazing [5, 6, 7].

These results should be taken into account in the design of new buildings and refurbishment work to avoid overheating and to provide mitigating options to deal with overheating. This study highlights the importance of the thermal mass performance, night ventilation and its effect to reduce overheating also when window shading or local shading is impemented to limit and reduce overheating.

5 Conclusion

This study confirmed, as expected, that the use of window shading helps to alleviate the overheating hours in the test room and as such, improving the thermal comfort and reducing the need for cooling. Furthermore, when the window shading devices are coupling with an optimised used of the thermal mass and night ventilation, the reduction on overheating hours achieved will reach a reduction of over 50% with respect to not exposing the thermal mass. In conclusion, exposing the thermal mass coupled with a night ventilation strategy provides a reduction on overheating hours, which is increased by using different window shading devices. Exposure of the thermal mass provides a good strategy for reducing the need for cooling and increasing thermal comfort

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