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Evaluating the impact of Ventilation strategy and Window Opening Area on Overheating Issues

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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. The result of the effect of climate change will be more intense and longer periods of summer heat waves. Use of the building thermal mass can reduce overheating in summer and minimise the need for cooling energy, reducing energy consumption and CO_2 emissions. Night ventilation is one of the key factors to maximise the benefits of thermal mass in buildings but due to issues in security and pollution, in many situations windows can only be effectively opened during occupied hours. Cross ventilation provides gains versus the use of single side ventilation but it is not always possible to have it. The main aim of this study was to evaluate the influence of window opening area and night ventilation on the thermal mass benefits to overheating by exposing the thermal mass. A second aim was to understand the further benefits that could be obtained by using cross ventilation in reducing overheating This study was based on dynamic thermal simulations to analyse the overheating performance of a test room with covered and exposed thermal mass. The testing room was simulated for a range of window openings from 5% to 40% area opening with single-sided and cross natural ventilation. Fifthteen 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 opening areas during occupied hours in two different natural ventilation conditions. The simulation results show that by exposing and making use of the room thermal mass, the number of hours above 28ºC can be reduced with the reduction being proportional to the window opening area. The CIBSE TM52 overheating assessment is only passed by using window opening areas above 20% with a cross ventilation strategy, but they could generate occupants discomfort.

1. Introduction

Thermal mass has the benefit of regulating energy in buildings and generates potential savings in energy and CO_2 emissions. Some of these benefits are well understood in the literature in terms of domestic properties and coupling with ventilation to reduce overheating [1,2]. The result of the effect of climate change will be more intense and longer periods of summer heat waves affecting the majority of buildings with overheating issues [3]. Previous work has shown that the issue of overheating in future weather conditions for non-domestic buildings will be on the rise [4]. It has been already presented in the literature that the combination of thermal mass and night ventilation can reduce overheating in summer and minimise the need for cooling energy, reducing energy consumption and CO_2 emissions [5]. Night ventilation is one of the key factors to maximise the benefits of thermal mass in buildings but due to issues in security and pollution, in many situations windows can only be effectively opened during occupied hours.

In office environments, the thermal mass is normally hidden under a layer of compressed mineral wool forming a suspended ceiling. This suspended ceiling will have a detrimental effect on the regulation activities performed by the thermal, as the thermal mass will be blocked and unable to absorb excess heat from the indoor environment and to release it during cooling periods [5].

Cross ventilation provides gains versus the use of single side ventilation but it is not always possible to achieve it, although much higher and effective ventilation rates are possible. According to data collected by Santamouris et al [6], air change rates per hour in commercial buildings range between 2 to 30. Blondeau et al [7] found that ventilation rates above 8 or 10 acph had little effect on comfort improvement, mostly due to the discomfort due to higher ventilation rates.

Although the coupling of thermal mass combined with a night ventilation strategy can reduce overheating in current weather conditions [5], a similar effect can be achieve to reduce overheating in future climate change scenarios although the benefits are vastly reduced and further strategies must be sought [4].

Naturally ventilated buildings should follow CIBSE TM52 for overheating assessment [8]. The CIBSE TM52 overheating assessment is comprised of three criteria during the non-heating season, between 1st May and 30th September:

- Criterion 1. Hours of Exceedance of the threshold comfort temperature.
- Criterion 2. Daily Weighted Exceedance for severity of overheating.
- Criterion 3. Upper Limit Temperature for unacceptable overheating.

The main aim of this study was to evaluate the influence of window opening area and night ventilation on the thermal mass benefits to overheating by exposing the thermal mass. A second aim was to understand the further benefits that could be obtained by using cross ventilation in reducing overheating.

2. Methodology

A test room, as shown in Figure 1, was modeled with dimensions 7.5m x 7.5m x 3.5m. This test room was created in DesignBuilder software and dynamically simulated using energyplus. The internal floor was simulated as a suspended ceiling by hidden the thermal mass with a U-value of 0.739 W/m2K and another model was created simulating the exposure of the thermal mass (non-suspended) with a U-value of 1.523 W/m2K as previously published [4,5]. The test room was having a combination of natural ventilation and a night cooling ventilation strategy during the summer to cool down the thermal mass and discharge the heat accumulated during the day. Five window opening (WO) areas were selected for simulation, 5%, 10%, 20%, 30% and 40%, to generation the ventilation rates during office hours and night ventilation. No cooling and shading were used in the simulations to be able to isolate and specifically quantify the benefits provided by the thermal mass and the cross ventilation 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:

- 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 in winter follows a schedule from 8:00 to 19:00
- Night ventilation rates are used to supplement natural ventilation during summer (1st May to 31st September), following a schedule from 24:00 to 6:00
- All ventilation is performed through the windows opening and all windows are top hung awning windows, providing bottom opening.
- Simulations run for a full year.

The test room was dynamically simulated using the control weather file produced as part of the Prometheus project, which are based on UK Climate Projections 2009 (UKCP09) data to provide weather projections in future climate [9]. This study used Design Summer Year (DSY) weather files located in London (Islington. The test room was simulated with and without suspended ceiling all the different window openings during single side ventilation. Furthermore, the test room was simulated under cross ventilation conditions for the different window openings.

The overheating limit was set to 28ºC in accordance with CIBSE definitions [8, 10]

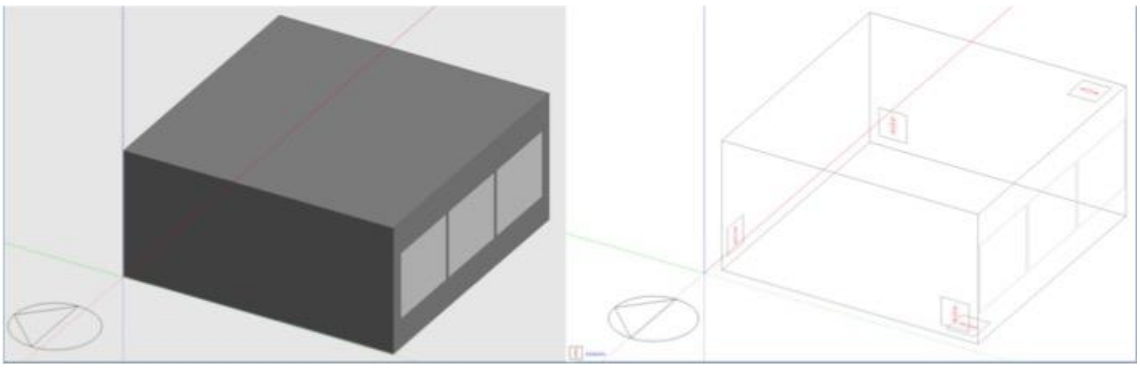

Figure 1. Simulated test room showing single side ventilation strategy

3. Results

In terms of assessing the overheating performance with and without the suspended ceiling for the range of windows opening area in a single side ventilation approach, 10 simulations were calculated in total using the dynamic Energyplus engine in DesignBuilder without the use of any cooling preventing overheating and only allowing the thermal mass and natural ventilation to control the overheating. A further five simulation were calculated to simulated cross ventilation without suspended ceiling (non-suspended), to further evaluate the potential benefits of increasing the ventilation effect on reducing overheating.

Figure 2 and Figure 3 present the ventilation rates generated for each window opening area and ventilation strategy (single side or cross). The use of cross ventilation almost quadruple the ventilation rates achieved by single ventilation during winter, while during summer, cross ventilation rates are massively high, well above those values indicated by Blondeau et al [7] and resulting in discomfort due to the high ventilation rates.

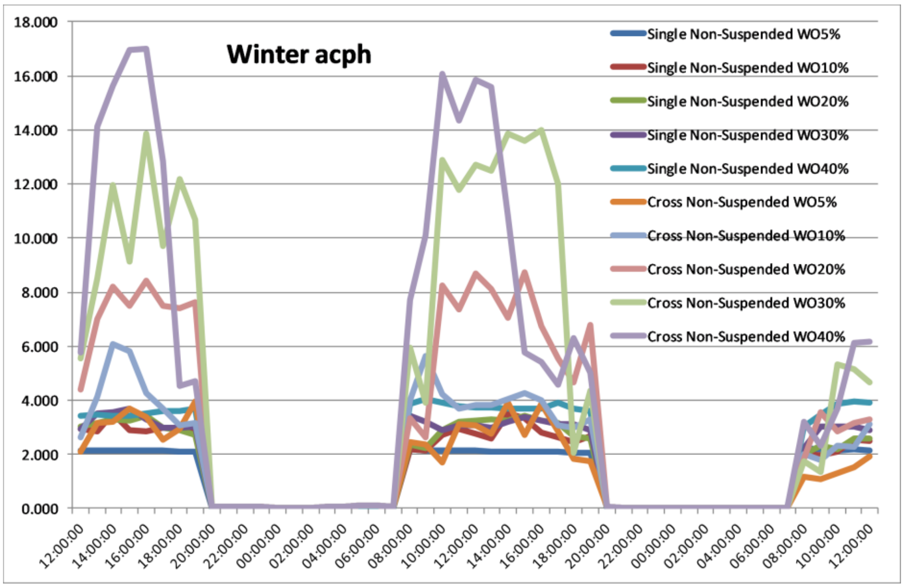

Figure 2. Ventilation rates (acph) during winter in accordance to windows opening (WO) area and ventilation strategy

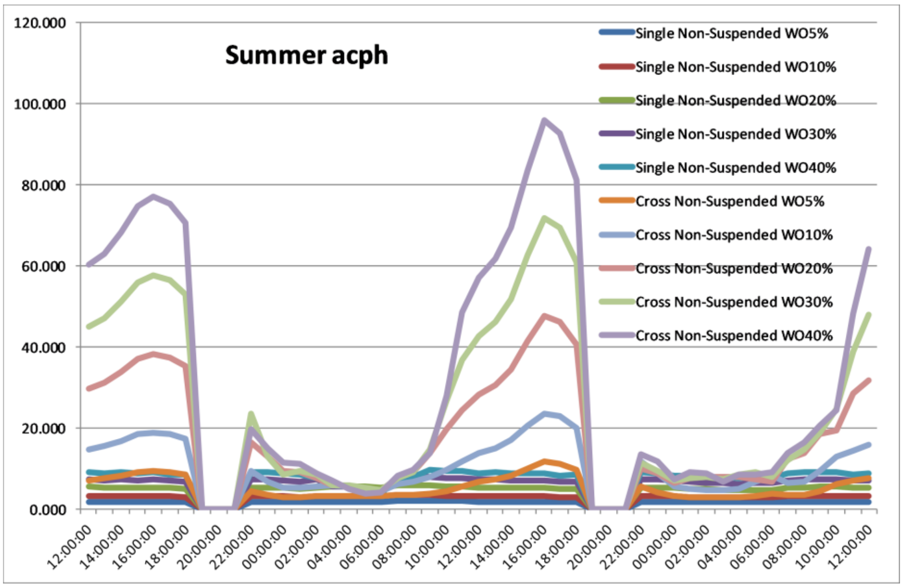

Figure 3. Ventilation rates (acph) during summer in accordance to windows opening (WO) area and ventilation strategy

3.1. Overheating hours

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 [4,5]. The final results for overheating hours above 28ºC are presented in Figure 4 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. The use of cross ventilation will further greatly reduce the overheating hours due to high ventilation rates achieve in cross ventilation as presented in Figure 4. All the overheating hours above 28 degree centigrade are presented in Table 1.

Table 1. Overheating hours above 28 degrees centigrade according to window opening area, thermal mass and ventilation strategy

Occupied hours about 28 C			
Window opening [%]	Single Side Ventilation		Cross Ventilation
	Suspended	Non-Suspended	Non-Suspended
5	2150	1858.8	371.2
10	1187.5	916.5	121.5
20	518	328.8	39.5
30	299.2	168.3	23.8
40	199.8	101.3	18.7

Exposing the thermal mass by elimination of the suspended ceiling reduces the overheating hours above 28°C in all the window opening area settings but the higher reductions can be achieved once a cross ventilation strategy has been implemented, with higher reduction at small window opening areas.

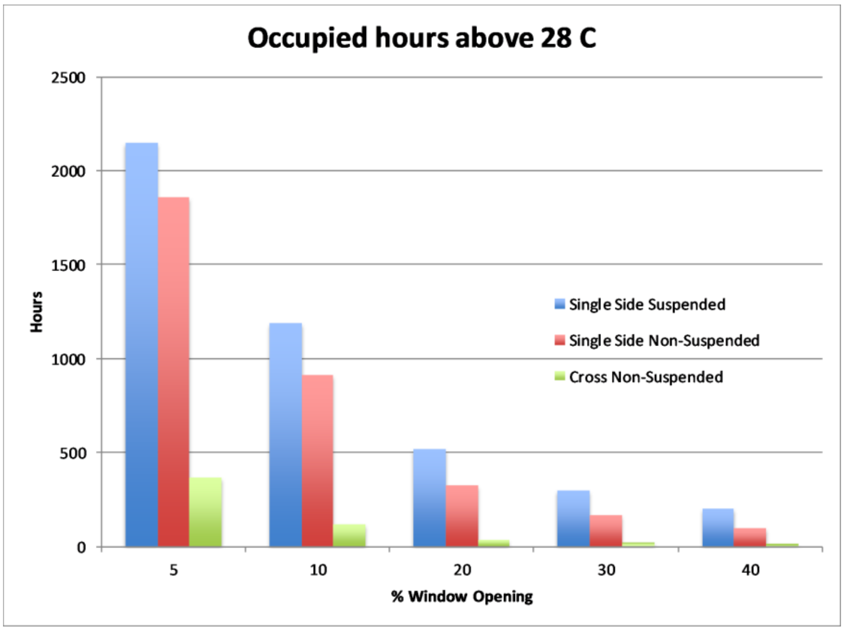

Figure 4. Overheating hours above 28 degrees centigrade according to window opening area, thermal mass and ventilation strategy

Figure 5 shows the percentage of overheating reduction that can be achieved by first making use of the available thermal mass by not having a suspended ceiling and secondly by using a cross ventilation strategy as opposed to single side ventilation. On the one hand, the percentage reduction due to exposing the thermal mass is proportional to the window opening area, increasing the reduction as the window area increase from 5% to 40%. On the other hand, moving from single side ventilation to cross ventilation provide a much bigger reduction in overheating hour, above 80%, but this reduction is similar for each window opening area.

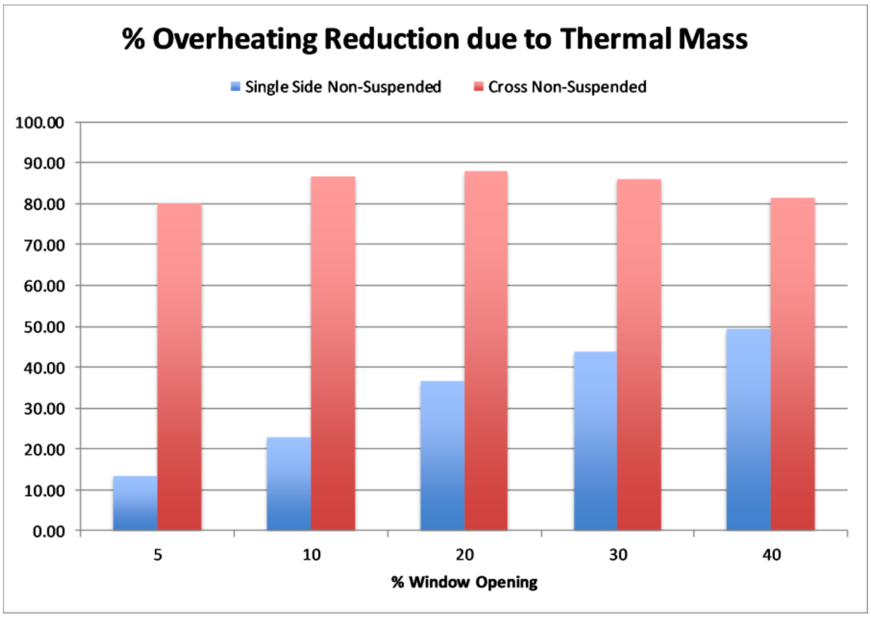

Figure 5. Overheating reduction according to window opening area by exposing the thermal mass and using cross ventilation.

The number of overheating hours during occupied periods, as presented in Figure 4 and Table 1, can be correlated with an expectation of the use of cooling in the building and then it will have repercussions on a higher energy use and carbon emissions, due to the use of cooling to mitigate overheating. The correlation between higher the number of occupied overheating hours and the increase of energy consumption and carbon emissions, driven by cooling to alleviate overheating, is the relationship to be mitigated by the use of thermal mass and ventilation strategy.

3.2. CIBSE TM52

As presented in the introduction, all the simulations were assess for the thermal comfort overheating following the CIBSE TM52 overheating assessment, which is based on three criteria as explained previously in the introduction in Section 1. Table 2 presents the results of the CIBSE TM52 overheating assessment, showing firstly the results of the test room with singe side ventilation and using a suspended ceiling, no benefit from thermal mass, for the range of window opening area. All the simulations with this strategy failed the overheating assessment, only able to satisfy criterion 3 on unacceptable overheating temperatures with a window opening of 30% or higher. Secondly, using a non-suspended ceiling approach and making the most of the available thermal mass for all the window opening area options. While the criterion values improved in general, the end result was still failing the overall overheating assessment. Criterion 3 is in this case successful for a window opening of 20% or higher. Thirdly, the simulations change ventilation strategy from single side to cross ventilation coupling with the use of thermal mass for all window opening area options. The CIBSE TM52 overall overheating assessment is only passed by making use of window opening areas above 20%, even that criterion 2, related to the severity of the overheating, is not satisfied in any of the window opening simulations. This shows that to achieve a Pass in the TM52 thermal comfort overheating assessment, only criterion 1 and 2 must be achieved. In the case of a cross ventilation strategy with a window opening area of 10% and only achieving a pass in criterion 3, it is not enough to achieve an overall pass in the overheating assessment, stressing the importance of criterion 1, which relates to hours of Exceedance of the threshold comfort temperature, for the overall CIBSE TM52 thermal comfort overheating.

Table 2. CIBSE TM52 overheating assessment.

<table>
<tr><th colspan="2">CIBSE TM52</th><th>Window Opening</th><th>Criterion 1 (%)</th><th>Criterion 2 (K.hr)</th><th>Criterion 3 (hr)</th><th>Pass/Fail</th></tr>
<tr><td rowspan="10">Single Side Ventilation</td><td rowspan="5">Suspended</td><td>5</td><td>97.13</td><td>164.33</td><td>970.5</td><td>Fail</td></tr>
<tr><td>10</td><td>72.57</td><td>88</td><td>308.17</td><td>Fail</td></tr>
<tr><td>20</td><td>37.55</td><td>40.67</td><td>34.67</td><td>Fail</td></tr>
<tr><td>30</td><td>22.97</td><td>28.33</td><td>2.83</td><td>Fail</td></tr>
<tr><td>40</td><td>15.29</td><td>22.67</td><td>0</td><td>Fail</td></tr>
<tr><td rowspan="5">Non-Suspended</td><td>5</td><td>94.75</td><td>144.33</td><td>715.17</td><td>Fail</td></tr>
<tr><td>10</td><td>57.64</td><td>73.83</td><td>83</td><td>Fail</td></tr>
<tr><td>20</td><td>23.78</td><td>27.83</td><td>0</td><td>Fail</td></tr>
<tr><td>30</td><td>12.62</td><td>19</td><td>0</td><td>Fail</td></tr>
<tr><td>40</td><td>7.34</td><td>14.33</td><td>0</td><td>Fail</td></tr>
<tr><td rowspan="5">Cross Ventilation</td><td rowspan="5">Non-Suspended</td><td>5</td><td>28.49</td><td>39</td><td>14.5</td><td>Fail</td></tr>
<tr><td>10</td><td>8.23</td><td>22.17</td><td>0</td><td>Fail</td></tr>
<tr><td>20</td><td>2.88</td><td>12.67</td><td>0</td><td>Pass</td></tr>
<tr><td>30</td><td>1.85</td><td>8.67</td><td>0</td><td>Pass</td></tr>
<tr><td>40</td><td>1.58</td><td>6.33</td><td>0</td><td>Pass</td></tr>
</table>

4. Discussion

Using the thermal available by exposing it, with the removal of suspended ceilings in non-domestic settings, can generate good reductions on occupied overheating hours above 28ºC in all the dynamic simulations for London (Islington), in comparison to the same test room featuring a suspended ceiling for single side ventilation. These results, highlighting the improvements due to the thermal mass exposure coupled with natural and night ventilation, agree with previous research on the area [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.

As previously reported [4,5], the simulation results show that by exposing and making use of the room thermal mass, the number of hours above 28ºC can be reduced with the reduction being proportional to the window opening area. In practical terms, perhaps not all simulated window opening area stages can be achieved and in same extreme cases, there could be restrictions to opening windows completely, due to noise, air pollution or security. Some of the issues on opening windows are due to discomfort by occupants during the building occupied hours, but then the night ventilation strategy will became a main mean to charge and discharge the thermal mass of the building without affecting the thermal comfort of occupants, as it will be performed during unoccupied periods.

The effect of the ventilation rate strategy to reduce occupied overheating hours provided huge reduction of above 80% for all window opening area simulations as previously reported in the literature [11]. The overheating hours reduction, due to the transfer to cross ventilation from single side ventilation, is not proportional at all with the amount of window opening area but seems to be mostly driven by the much bigger air change per hours rates generated by cross ventilation as shown in Figure 2. These much higher rates of ventilation would not be adequate during occupied periods in the building , as it would generate discomfort on the occupants as previously pointed out [7], but cross ventilation rates for cross ventilation with a window opening area of 10% are still inside the ventilation rate values reported by Santamouris et al [6].

Focusing on the CIBSE TM52 overheating assessment, shown in Table 2, the exposure of the thermal mass with single side ventilation is unable to pass the overheating assessment. With the effect of climate change, outdoor temperature will become even higher, limiting even more the beneficial effect of night ventilation [13], so further alternatives much be investigated to achieve the CIBSE TM52 overheating assessment by natural means.

One of the alternatives, as presented in this paper, could be a move form single side ventilation to cross ventilation, which would generate higher ventilation rates under similar conditions. The CIBSE TM52 overheating assessment is only passed by using window opening areas above 20%, but they will generate ventilation rates outside the scope measured by Santamouris et al [6], which could generate occupants discomfort of its own by much higher ventilation rates. These high ventilation rates would not be any issue during the night ventilation strategy, as the building will be unoccupied.

The results presented in this paper should provide guidance in the design of new buildings and refurbishment work to avoid overheating in the future by coupling thermal mass benefits with ventilation strategies. This study highlights the requirement of further analysis to understand the mechanism driving the performance of thermal mass, its interrelation with natural and night ventilation strategies and its effect to mitigate overheating issues in non-domestic buildings during occupied hours.

5. Conclusion

This study shows that the use of thermal mass and night ventilation can provide a reduction in overheating for a range of window opening areas. Furthermore, it shows that overheating hours reductions are proportional to the window opening area for single side ventilation strategies. While in the case of cross ventilation strategies, the main driver of the overheating reduction is the ventilation rate, which could generate discomfort during occupied periods. A move to much higher ventilation rate strategies during night ventilation should be further studied to evaluate if the thermal mass mechanism could be performing adequately under this conditions.

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