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ENERGY CONSERVATION IN BUILDINGS WITH INTEGRATION OF ADVANCED VENTILATED WALL COMPONENTS

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Synopsis

The performance of a Ventilated wall component under real weather conditions was tested, during two weather seasons, winter and summer. The component was built in a 1:1 scale, consisting of two equal area parts, a Ventilated wall with and without a radiant barrier. It was installed at the South façade of a PASSYS outdoor Test Cell at CRES. Air openings were located at the bottom and top of each wall component in order to facilitate the air movement through the air gap. Simultaneous measurements were carried out at both wall components in order to perform a comparative study of their performance. Different configurations were tested on both wall parts, namely: different air inlet and outlet areas, by changing the number of openings, natural and mechanical ventilation of the air gap, controlled and floating room air temperature. Results showed that the application of this technique in the building's structure is beneficial in terms of reducing the cooling load. This paper describes the design, construction, experimental testing and results drawn out of this experimental study for the summer period.

1. Introduction

Over the last decade, the focus of ecological architecture moved beyond the narrow scope of energy efficiency, towards a growing attention to human comfort and a healthy working environment. The double skinned building has been recognised as an option for removing the definitive barrier that a sealed building creates between the occupant and the outdoor environment. To date double skinned buildings have tended to be large scale prestige projects, many of them quite often use energy intensive materials such as metal and glass.

Specially designed building structures can contribute to reduction of their energy needs. In regions with high levels of solar radiation, Ventilated structures maintain the temperature of the outer shell of double skinned buildings at a temperature close to the ambient, reducing significantly the impact of incident radiation into the interior of the building. By effectively applying this technique over the entire building envelope, it is possible to significantly reduce envelope gains [1]. The technique can also be beneficial during the heating period by either maintaining the surface of the envelope at close to ambient temperatures or reducing radiation losses or by creating a blanket of insulating air around the building, depending on its mode of operation. The aim of the work carried out was to acquire more knowledge on the performance of ventilated building components and to investigate alternative solutions that will assist to new generation of products with improved performance.

The aim of this paper is to present the experimental work carried out at a Ventilated wall component under summer conditions. The wall was installed at the South facade of the PASSYS Outdoor Test Cell at CRES. The Ventilated wall's performance was investigated through the effect of several parameters, like air inlets and outlets, natural and forced ventilation, application of a radiant barrier, different heating modes in the testing room [2].

2. Description of the component

The total dimensions of the wall in the Test Cell were 2.75 m width and 2.75 m height. The component consisted of two parts of the same area, the Ventilated wall (henceforth called *Typical Ventilated wall*) and the Ventilated wall with a radiant barrier (henceforth called *Upgraded Ventilated wall*). The two components were separated by an insulation layer of 8 cm, in order to avoid heat flow between them, and were tested under actual outdoor conditions. The structure and dimensions of the wall parts can be seen in Figures 1 and 2. Simultaneous measurements were carried out at both wall components in order to perform a comparative study of their performance. Air openings were located at the bottom and top of each wall component in order to facilitate the air movement through the air gap.

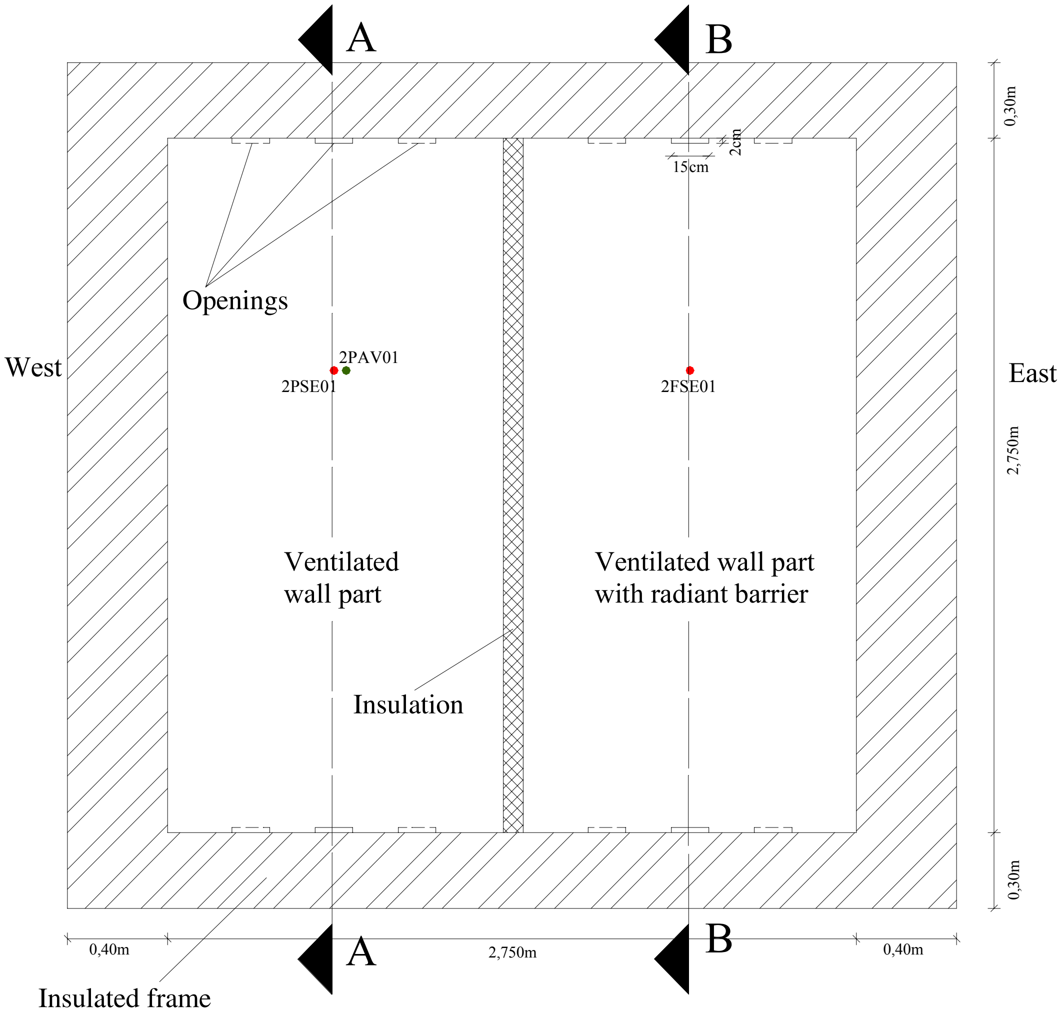


Figure 1. Total dimensions of the Ventilated wall component.

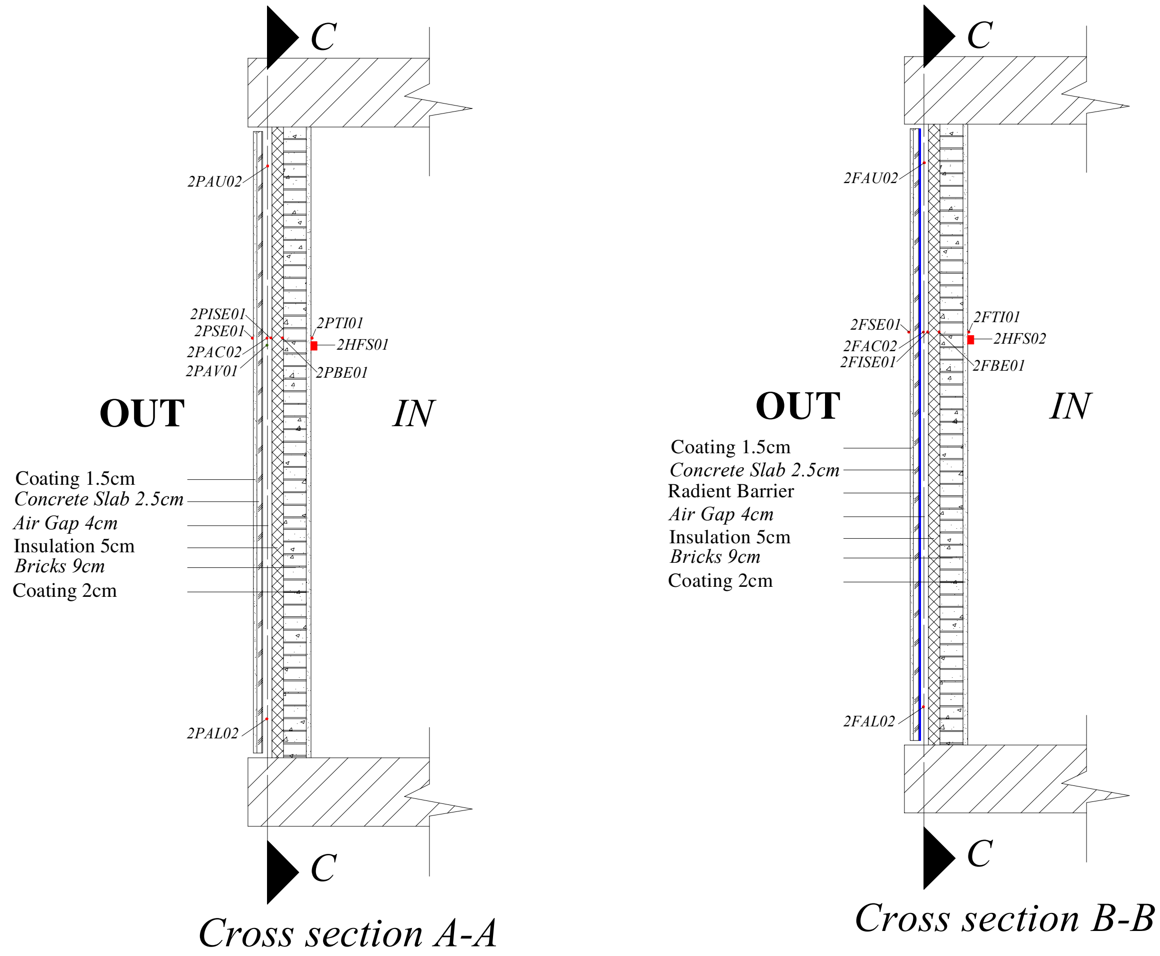


Figure 2. Cross sections of the Ventilated wall parts - Sensors position.

The wall structure, of total wall thickness of 24 cm, consisted of :

- a 2 cm thickness coating layer in the interior of the room,
- a 9 cm thickness brick layer made of 9 x 6 x 19 cm bricks,
- a 5 cm thickness of rockwool insulation layer in contact with the bricks,
- an air gap of 4 cm width,
- a 2.5 cm thickness of prefabricated reinforced concrete slab and
- a 1.5 cm thickness of mortar on the external, exposed to the environment surface.

A radiant barrier in contact with the prefabricated concrete slab was positioned at the *Upgraded* V*entilated wall part.* The radiant barrier had a very small thickness (0.1mm) so it does not contribute to any increase in the total thickness of this wall part.

3. Experimental procedure and instrumentation

Different configurations were tested simultaneously on both wall parts :

- different air inlet and outlet areas by changing the number of the openings,
- natural and mechanical ventilation of the air gap,
- controlled and floating room air temperature

The constant test room temperature was set at 27 ± 0.2 ^{o}C, controlled by combining heating/ cooling mode. The settings for each individual phase are summarised in Table 1.

Table 1. Experimental phases and settings.

Phase Nr.	Opening area Inlet/Outlet	Air Flow mode	Control scheme
1	1 / 1	Natural flow	Constant indoor temperature
2	2 / 2	Natural flow	Constant indoor temperature
3	3 / 3	Natural flow	Constant indoor temperature
4	2 / 3	Forced ventilation 0.5 m/s	Constant indoor temperature
5	3 / 3	Forced ventilation 1.4 m/s	Constant indoor temperature
6	3 / 3	Natural flow	Constant heating power 150W

Apart from the standard instrumentation of the Test Cell, additional sensors were installed to measure the performance of the roof components:

- Prefabricated reinforced concrete slab: 1 T-type thermocouple on the external surface of the wall part, firmly attached with two layers of tape, one of them thermal insulating covered with an external reflective tape.
- Air gap: 9 T-type thermocouples at 3 different heights, in the middle of the air gap width of each wall part.
- Air gap velocity: 1 low velocity hot wire anemometer in the middle of the air gap of the Typical Ventilated wall part.
- Insulation, brick, mortar: 1 T-type thermocouple at the same height, on each wall part.
- Wall component heat flux: 2 heat flux meters, one installed in each wall part.

The positions of the sensors on the test component can be seen in Figures 1, 2 and 3. The data from all sensors were collected at the Test Cells Data Acquisition System (DAS).

4. Experimental results

The study of the performance of the different experimental layouts was based on the examination of the temperature of the exposed, prefabricated layer as well as the external surface of the insulation layer of the different wall constructions.

The analysis of the collected data aimed to assess:

- The performance of each Ventilated wall, with and without a radiant barrier (Qualitative assessment). To obtain confidence on the results of the comparison, the analysis was performed for selected representative days for the summer season with weather conditions unfavourable for the performance of a wall component (reduced heat losses and increased heat gains).
- The impact on the performance of the two Ventilated wall components of the different parameters, namely, air inlet/outlet area, air flow mode in the gap (forced or natural) as well as indoor temperature control scheme (Quantitative assessment). The comparison was made for days with comparable climatic conditions during the testing period, since identical days although desirable, could not be found during the testing period.

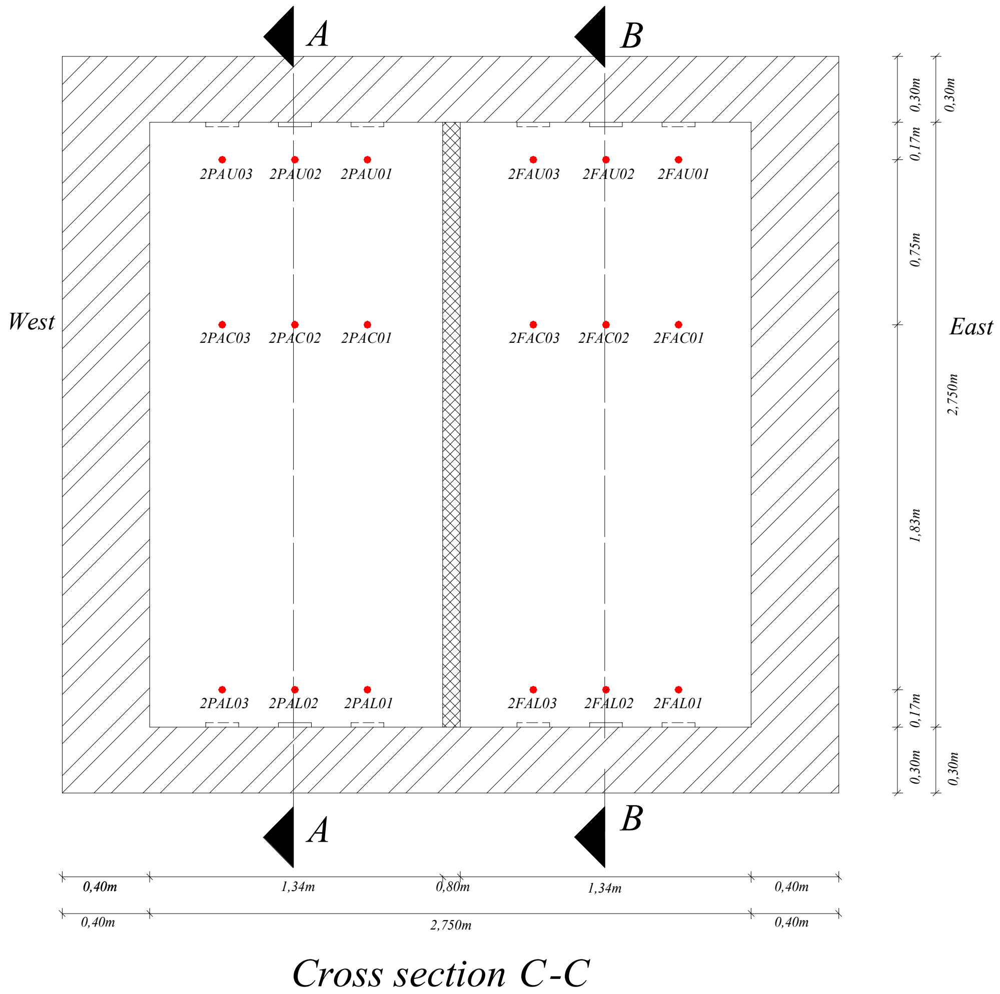
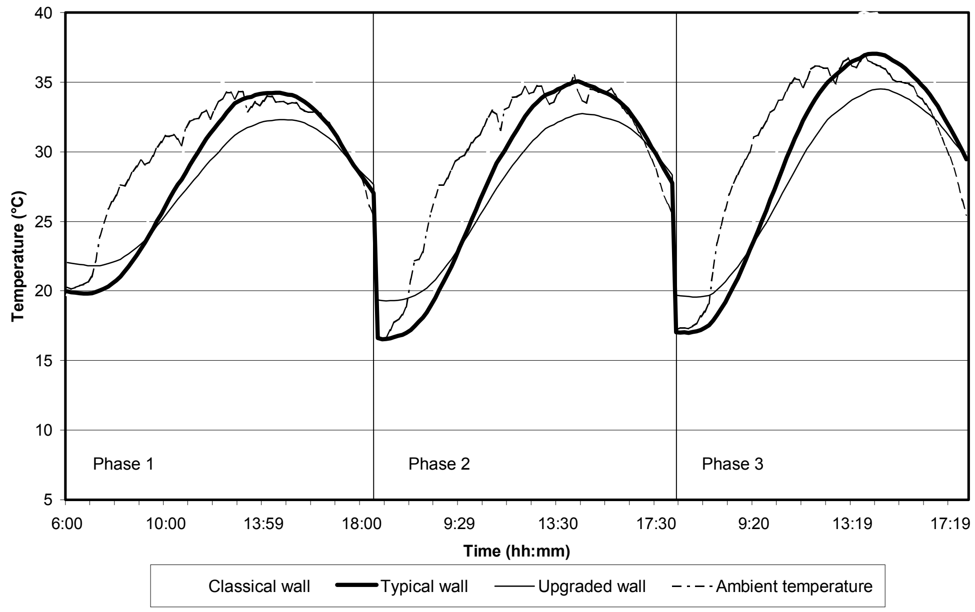


Figure 3. Sensor positions on the Ventilated wall component.

It must be noted that a conventional wall, i.e. without a ventilation air gap, was not utilised in this experimental sequence. According to the findings of the Ventilated roof experiments [3], the outer slab temperature of the Ventilated and the Conventional roof - a roof without a ventilation gap - were very close throughout the day. More specifically and as expected, during daytime, the Ventilated component with the radiant barrier matched the Conventional slab's temperature better (RMSE 3.4%), while during night-time the best match was observed for the simple Ventilated component without a radiant barrier (RMSE 3.5%). Moreover, the Conventional roof's outer insulation surface temperature is very close to that of the respective outer slab (maximum observed differences of the order of 1K). It was therefore decided to use the outer slab temperatures of the Ventilated wall with the radiant barrier (Upgraded Ventilated wall) for day and without it (Typical Ventilated wall) for night as indicators of the respective upper insulation surface temperature of a potential conventional wall without an air gap, henceforth called *Classical wall*.

4.1 Qualitative Assessment

The temperature distribution of the external surface of the insulation layer for the Typical, Upgraded and Classical wall together with the ambient temperature for the daytime summer period during the different Phases can be seen in Figures 4 and 5. Figures 6 and 7 show the same temperatures for the night-time summer period. It can be seen that the insulation temperature, unlike the slab's one, is clearly differentiated between the two Ventilated walls and the similar temperature of the Classical wall. Beyond mid-morning (9:00-10:00), the Upgraded wall insulation is always cooler, by 2-3K, than the Typical wall insulation, and the Typical wall insulation is cooler, by 2-3 K, than the assumed Classical wall insulation. During night-time, the Typical and the Classical wall insulation layers are at a temperature very close to that of the ambient air, while the Upgraded wall insulation remains at 2-3 K warmer.



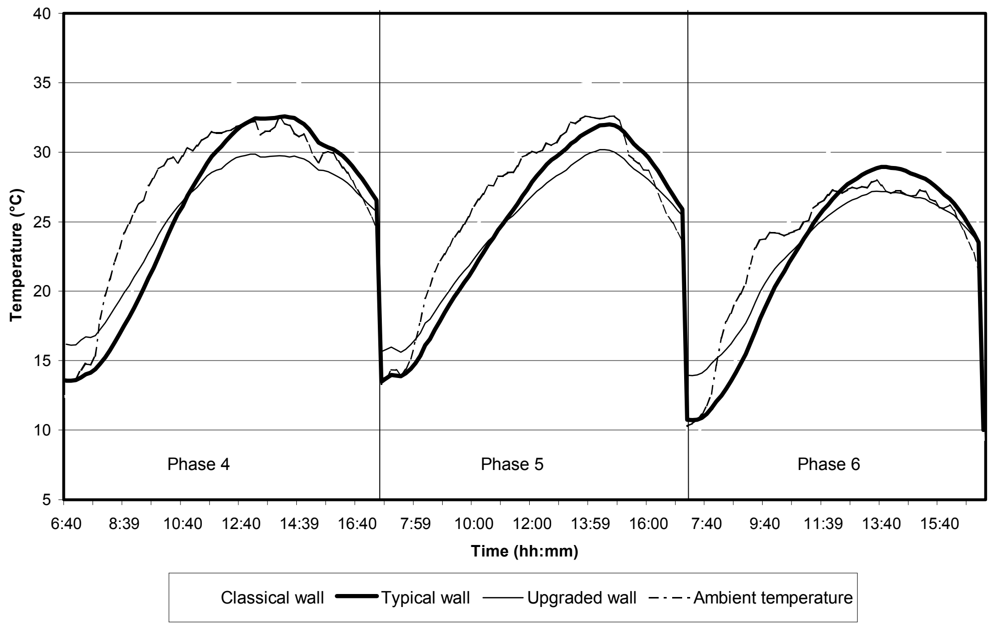


Figure 4 -5. Insulation exterior surface temperature of the Typical, Upgraded and Classical wall during phases 1, 2 and 3 (Figure 4) and during phases 4, 5 and 6 (Figure 5)- Summer daytime.

The radiant barrier seems to perform equally well with the air gap, providing extra cooling of similar magnitude to the Upgraded wall insulation, during daytime. The barrier keeps the thermal radiation of the outer slab from entering the air gap, resulting in lower temperatures of both the insulation and the air inside the gap. During night-time, it prevents the radiative cooling of the insulation layer thus, resulting to higher insulation temperatures.

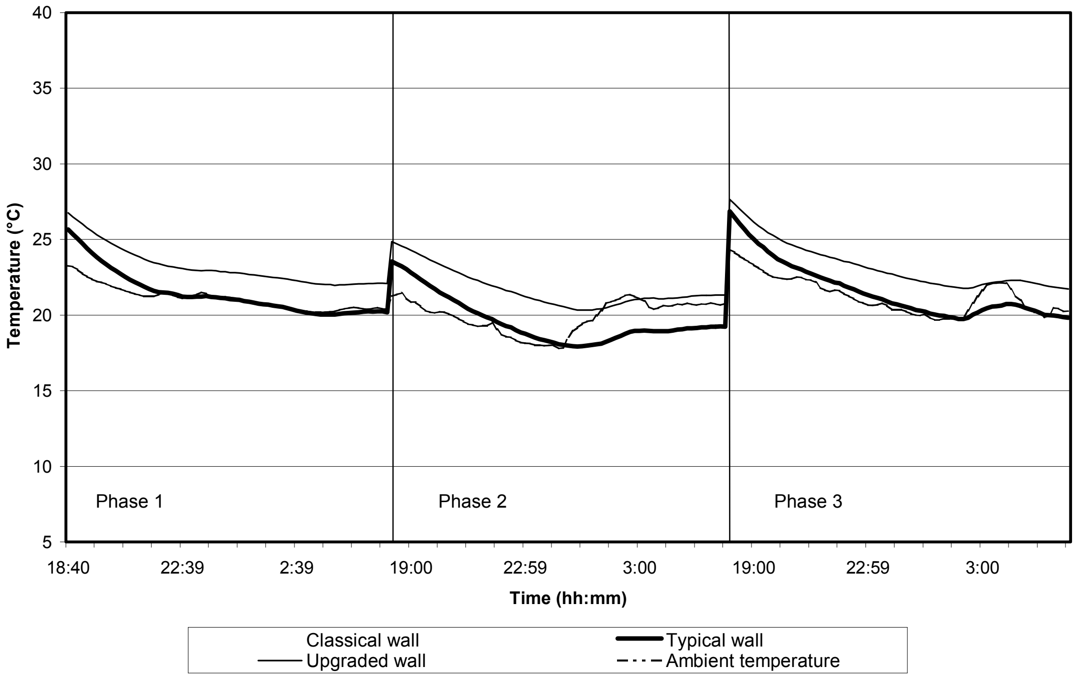


Figure 6. Insulation exterior surface temperature of the Typical, Upgraded and Classical wall during phases 1, 2 and 3 – Summer night-time.

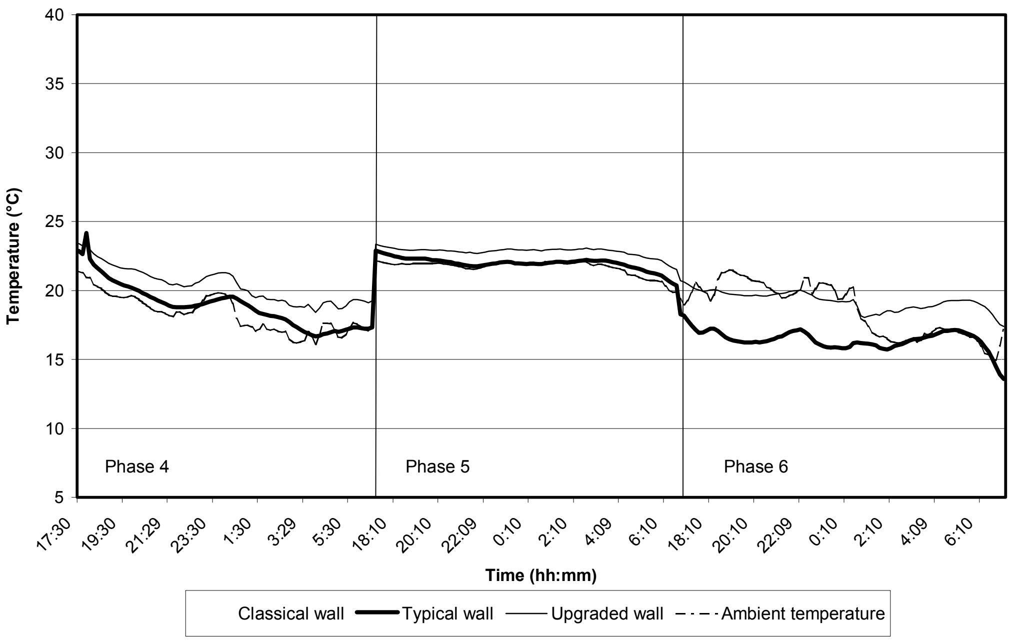


Figure 7. Insulation exterior surface temperature of the Typical, Upgraded and Classical wall during phases 4, 5 and 6 – Summer night-time.

The overall performance of the Upgraded Ventilated wall can be considered as efficient, since during daytime, it provides a significant insulation cooling by 4 to 6 K as compared to a Classical wall construction, double that for a Typical Ventilated wall. On the other hand, the higher night-time insulation temperatures correspond to warming comparable in magnitude to the daytime cooling. Since this warming is observed for the whole duration of the night, while the daytime cooling only for about 2/3 of the daytime, the overall result could even be a net heat gain instead of the desired heat loss. Nevertheless, during night-time, other means of passive cooling could be used to balance the heat load, rendering the daytime performance as the only one significant.

4.2 Quantitative assessment

The effect of the inlet and outlet area on the wall performance is shown in Figure 8, which depicts the temperature difference between the different Wall types for the insulation layer and the outer prefabricated layer for Phases 1, 2 and 3 (1, 2 and 3 open slots respectively) during summer daytime conditions. It was found that when the number of the air openings increases, the performance of the system under summer daytime conditions improves. The Upgraded walls' insulation layer was kept at slightly lower temperatures in Phase 3 than in Phase 1 as compared to the corresponding component of a Classical wall. The improvement during daytime can be attributed to the larger heat losses to the air inside the gap, as the larger the open slot area allows the air to circulate and mix with the ambient air.

The addition of the radiant barrier in the Upgraded wall clearly improves its performance during daytime by blocking the thermal radiation emitted by the outer slab towards the insulation. During night-time though, the radiant barrier does not allow the radiative cooling of the insulation thus, leading to worse performance of the Upgraded wall as compared to the Typical and the Classical ones.

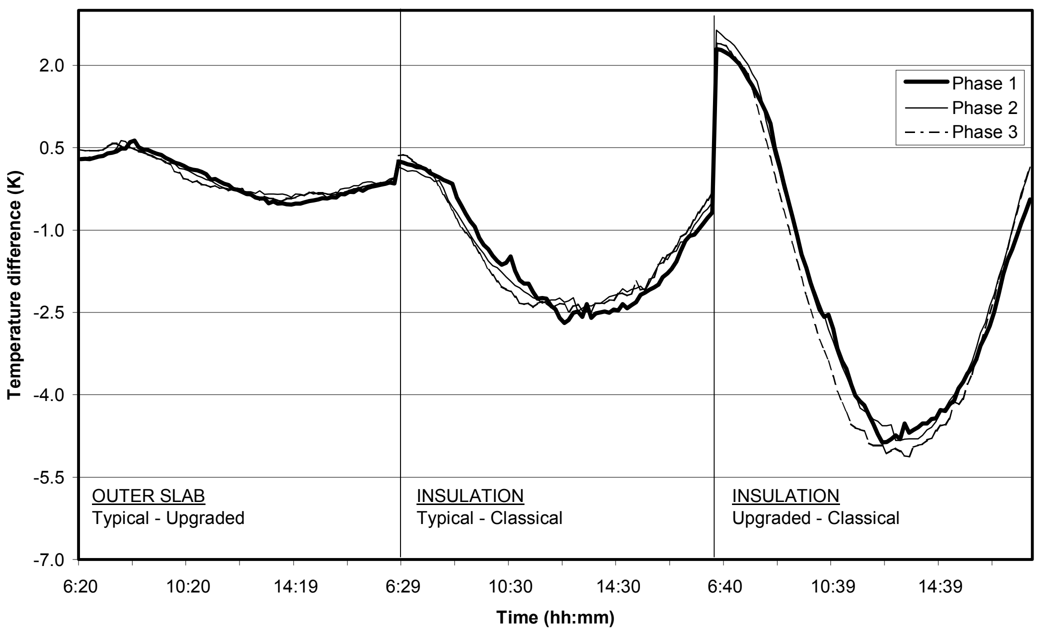


Figure 8. Daytime temperature differences between the Upgraded, Typical and Classical walls.

4.3 Results summary

The above analysis indicates that during summer, the use a radiant barrier may yield up to 5 K lower insulation temperatures during daytime, but also 2.5 K higher temperature during night-time. The use of forced ventilation at 1.4 m/s, may provide a reduction of the insulation temperature by up to 1.5 K or even more, and relieve the night-time thermal accumulation when a radiant barrier is used. Finally, during summer the fixed temperature control leads to up to 3 K lower insulation temperatures.

To demonstrate the overall performance of the various Ventilated wall layouts, the expected heat fluxes were calculated. In order to enable direct comparison with the respective fluxes of the conventional assumed wall (Classical wall), only the inner part of the wall consisting of the insulation and the inner brick wall, that is common in both the Upgraded and Typical Ventilated walls and the Classical wall, was considered. In this way, it is also possible to reduce the ambient induced variation.

The heat fluxes for a given period, t, through this part of the Upgraded wall is:

$$Q_U = \sum_t U_U \cdot \left(T_{insulation} - T_{room}\right)\Big|_U = U_U \cdot \sum_t \left(T_{insulation} - T_{room}\right)\Big|_U$$

Similarly for the Typical and Classical walls:

$$Q_T = \sum_t U_T \cdot \left(T_{insulation} - T_{room}\right)\Big|_T = U_T \cdot \sum_t \left(T_{insulation} - T_{room}\right)\Big|_T$$

$$Q_C = \sum_t U_C \cdot \left(T_{insulation} - T_{room}\right)\Big|_C = U_C \cdot \sum_t \left(T_{insulation} - T_{room}\right)\Big|_C$$

A performance indicator was taken in order to examine the relative difference of the heat fluxes in the different layouts represented by the ratios (for thermal transmittances: $U_U = U_T = U_C$):

$$A = (Q_U - Q_C) / |Q_C| \qquad \text{and} \qquad B = (Q_T - Q_C) / |Q_C|$$

When the Upgraded or Typical walls present higher heat losses or lower heat gains than the Classical one, then *A* or *B*, respectively, are negative. Correspondingly, positive *A* or *B* values represent lower heat losses or higher heat gains from the Upgraded or Typical roofs, respectively. According to the above, positive *A* or *B* values during summer means that the Upgraded or Typical walls perform better. Negative *A* or *B* values mean that the Upgraded or the Typical walls, respectively, outperform the Classical one, while positive *A* or *B* values mean that the Classical is better.

The heat fluxes and ratios calculated for the day, night and 24 h periods of the different Phases are presented in Table 2.

Table 2. Heat flows on the wall components.

Summer	Day					Night					24 h				
	Q_C (W/m²)	Q_T (W/m²)	Q_U (W/m²)	B	A	Q_C (W/m²)	Q_T (W/m²)	Q_U (W/m²)	B	A	Q_C (W/m²)	Q_T (W/m²)	Q_U (W/m²)	B	A
Phase 1	212	106	65	-50%	-70%	-434	-427	-293	2%	33%	-222	-321	-228	-45%	-3%
Phase 2	173	69	29	-60%	-83%	-559	-557	-390	0%	30%	-386	-489	-361	-27%	6%
Phase 3	304	198	135	-35%	-56%	-538	-536	-372	0%	31%	-233	-338	-237	-45%	-2%
Phase 4	52	-80	-102	-252%	-296%	-825	-810	-662	2%	20%	-773	-890	-765	-15%	1%
Phase 5	-40	-201	-226	-398%	-460%	-854	-843	-716	1%	16%	-894	-1044	-942	-17%	-5%
Phase 6	-616	-682	-521	-11%	15%	-1725	-1691	-1270	2%	26%	-2341	-2373	-1791	-1%	23%

The results obtained from the different comparisons can be summarised as:

- the ventilation gap is a significant feature, enhancing the overall thermal performance of a wall during the summer period,
- the addition of the radiant barrier improves the performance of the Ventilated wall in all Phases except for summer night-time conditions,
- smaller openings at the edges of the ventilation gap improve the performance of the wall during summer nights, but reduce it under summer daytime conditions,
- the use of forced ventilation greatly improves the performance of the wall under summer daytime conditions,
- a steady temperature control scheme is preferable over a constant indoor power one, during summer.

According to the above Table, during summer daytime, the ventilation gap provides significant cooling of the insulation while during night-time it has a relatively indifferent effect. On a 24h basis, the ventilation gap enhances the performance of the wall during summer.

The addition of the radiant barrier improves the performance of the Ventilated wall in all Phases except for summer night-time conditions. On a 24h basis the radiant barrier is favourable under transient and winter conditions, while during summer the barrier presents an ambiguous behaviour with half the Phases favourable and the rest not.

The size of the opening has a distinct effect on the performance of the Ventilated walls. For the Typical wall, a small opening is not favourable under summer daytime conditions, while for night-time there is no clear evidence that the area of the opening exercises a significant effect. On a 24h basis, the large opening is better for summer. For the Upgraded wall the best performance is obtained using the intermediate opening area (Phase 2) for summer day and night.

Forced ventilation greatly improves the performance of the wall under summer conditions, while it partly compensates for the adverse effect of the radiant barrier during summer night-time. The higher the flow velocity inside the gap, the larger the improvement is.

5. Conclusions

An advanced Ventilated wall component in full-scale dimensions was tested at CRES's test. The tested Ventilated wall component showed a good performance in terms of cooling demand and it can significantly contribute to building's energy conservation. Air circulation inside the air gap enhances the heat removal and contributes to reduced heat gains through the wall during summer. The use of a radiant barrier was found to ameliorate the performance of the component. The use of mechanical ventilation improves the performance of the wall, especially under summer conditions. In conclusion, Ventilated wall components can be regarded as a promising application that can contribute to reduction of buildings' cooling demands.

Acknowledgments

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