Experimental Study of Overheating of an Unglazed Transpired Collector Façade under Southern European Summer Conditions for Four Modes of Operation

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Abstract:

The use of unglazed transpired collector (UTC) façades for air preheating in buildings has been proved to be an energy saving solution for refurbishing old buildings. However, not all climates are appropriate for the installation of this type of façade, and in some cases their benefits in winter can be counterbalanced by the negative effects during summer. There is a risk of overheating and façade cooling load increase if the system is not operated appropriately in summer. In this study, a UTC façade cooling load increase was measured in real weather conditions in four different operating modes. Ambient temperature and solar radiation values were monitored. Surface and air temperatures were measured in the different layers, and the heat flux through the test cell wall was registered in two cases, both with and without UTC. The four operation modes combined mechanical or natural ventilation and air flow direction. Results showed that not ventilating the façade or using natural ventilation increased the façade cooling load by around 45 %, whereas outdoor mechanical ventilation produced an increase of 23%. Ventilating with indoor air reduced heat transfer compared to a non-UTC façade but only when it is integrated into an existing ventilation system. Cooling load increase due to overheating in the UTC façade was low in all four modes of operation. UTC façades must be integrated into the building ventilation system to avoid a cooling load increase during summer, or they must be ventilated with outdoor air if there is no ventilation system to reduce the impact of overheating.

Keywords: Unglazed Transpired Collector, Ventilated façade, air preheating, ventilation.

1. Introduction

Over the last few years, more and more renewable energy sources have been incorporated to construction to reduce the energy consumption from other polluting energy sources. In many cases, solar energy is the most available source and it can be absorbed and used in many ways: thermal solar collectors, photovoltaic panels, green roofs, green façades, or simply through glazed façades. The surface area available in roofs may not be sufficient to take advantage of the solar irradiance on the building. Thus, it is necessary to also use the building façades.

However, some of the currently proposed solutions to incorporate solar collectors or other elements to building façades present important drawbacks when the objective is to refurbish an existing building or implement an economically viable system. These problems have been mentioned by various authors (Zhou & Chen 2010; Kalyanova 2008). In the case of opaque ventilated façades, their cost is low, and their installation does not require a profound intervention on the building. An opaque ventilated façade is essentially a solar collector where the absorber is an opaque steel or aluminium plate, and ambient air is introduced in some way inside the façade, preheating the air as it flows through the layers into the building. The main disadvantage of this system is that the collector is directly exposed to ambient air on its outer surface and so it has a high convection heat loss. An unglazed transpired collector, UTC, system was proposed and patented to mitigate this negative effect (Hollick 1994).

A UTC façade is basically an opaque perforated solar collector. A schematic of a UTC is shown in figure 1. Solar irradiance is absorbed by the outer layer of the collector, which is made of steel or aluminium and whose surface is painted in a dark colour to achieve a high solar absorptance. In order to minimize the heat loss by convection to the exterior, the collector is perforated, and a low-pressure space is created in its plenum using a fan located downstream. In this way, the external heat boundary layer is sucked through the pores. Therefore, heat loss is reduced almost to long wave radiation interchange with the surroundings, which can also be decreased by using a low emissivity coating (Bokor et al. 2017).

UTCs have been widely studied by many authors in the available literature. UTC heat loss due to natural convection to the ambient air was analysed and found to be negligible, (Kutscher et al. 1993). One of the most influential variables on the performance of a UTC was found to be wind velocity and many authors have studied its effect on the efficiency of the UTC as a solar collector (Al-damook & Khalil 2017; Fleck et al. 2002; Vasan & Stathopoulos 2014). UTC façades installed in residential buildings have also been studied, for instance by (Hollick 1996; Brown et al. 2014).

The performance of UTC collectors depends on the climate. In (Peci et al. 2018), the best location to install UTC façades was found to be in regions with mild winter climates, with many hours of sunlight and quite high daytime peak temperatures. However, some of these locations also have dry and hot summer climatic conditions. In these cases, the behaviour of a UTC façade could be counterproductive during summer because the heated air must be evacuated to avoid overheating and to avoid an increase in the façade cooling load. Therefore, an appropriate operation mode should be implemented.

Although buildings can benefit from the installation of solar façades in winter, the main problem arises when the solar collector is working during summer. The air inside the collector can reach high temperatures (Yu et al. 2017), increasing the heat flow through the insulation wall. Ventilation of heated air is not required and if not ventilated the air inside the collector increases its temperature to the point of overheating, and if the existing insulation is poor, the cooling requirements increase(Stazi et al. 2012). Some authors have studied this effect for other solar walls, such as

Trombe walls. However, there are no empirical data in literature regarding the quantification of overheating in hot climates during summer for UTC façades. If this is not dealt with adequately, it represents an important drawback for its use in building refurbishment. Solutions have been proposed by some authors. For example, an increase in the façade insulation was recommended by (Long et al. 2018), while ventilation of the collector cavity was the solution proposed by (Stazi et al. 2012). Another solution is to take advantage of the heat absorbed and use it to heat water or in a heat driven cooling system, such as in an absorption cycle or in a desiccant cooling system (Peci et al. 2018). In (Soussi et al. 2013), simulations were performed to assess several techniques to prevent overheating during summer. However, these solutions lead to increased costs and the benefits of preheating air during winter may be exceeded by the initial installation cost.

In the present study, an experimental UTC module was built and installed on the façade of a test cell under summer weather conditions in Cordoba, Spain. In this location, maximum ambient temperatures of around 40 ˚C are typical. The aim was to quantify the cooling load increase due to the UTC façade overheating, comparing with a non-UTC façade. The effects of using four different modes of operation to avoid overheating were also evaluated in terms of cooling load decrease.

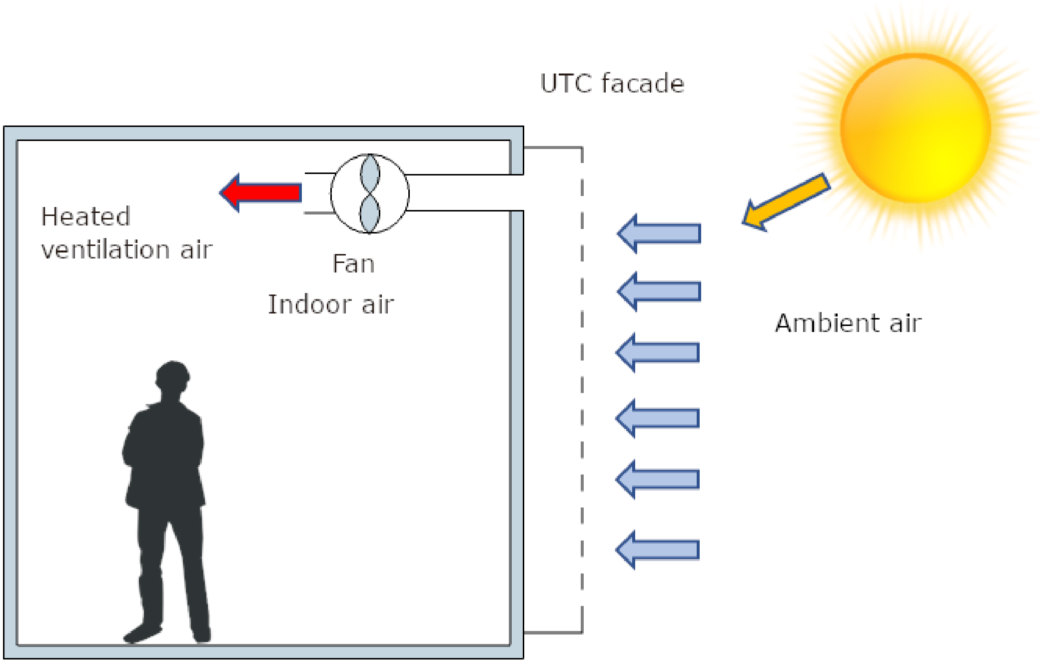


Figure 1. Schematic of UTC façade system

Nomenclature:

E_{daily} daily façade cooling load per unit collector area (J)

$E_{daily,UTC}$ daily UTC façade cooling load per unit collector area (J)

$E_{daily,Non-UTC}$ daily non-UTC façade cooling load per unit collector area (J)

$\dot{q}_i$ Heat transfer through the façade (W/m^2)

t time (s)

2. Experimental setup

An experimental UTC module was manufactured, installed on the south wall of a test cell under real weather conditions and monitored. This orientation was chosen because the high number of hours of solar irradiance. Nevertheless, the performance of UTC façades for other orientations was studied by (Peci et al. 2018). The location of the test cell was Cordoba, in the south of Spain, coordinates 37˚54’51.19’’N 4˚43’34.8’’W. The climate in this location is representative of a southern European continental climate, with mild winters and very hot and dry summers (Beck et al. 2018).

The test cell consisted of a modular site office of 6x2x2.5 m insulated with 3 cm sandwich panels, see figure 2. The cell had a door and a small window, both closed during the experiments. An air conditioning system was installed to maintain the indoor temperature within the range of normal conditions inside a real room. The indoor air temperature was set to 23 ˚C.

Figure 2. The test cell.The position of the UTC façade module, the surface temperature probes and the protected ambient temperature probe (right) can be seen.

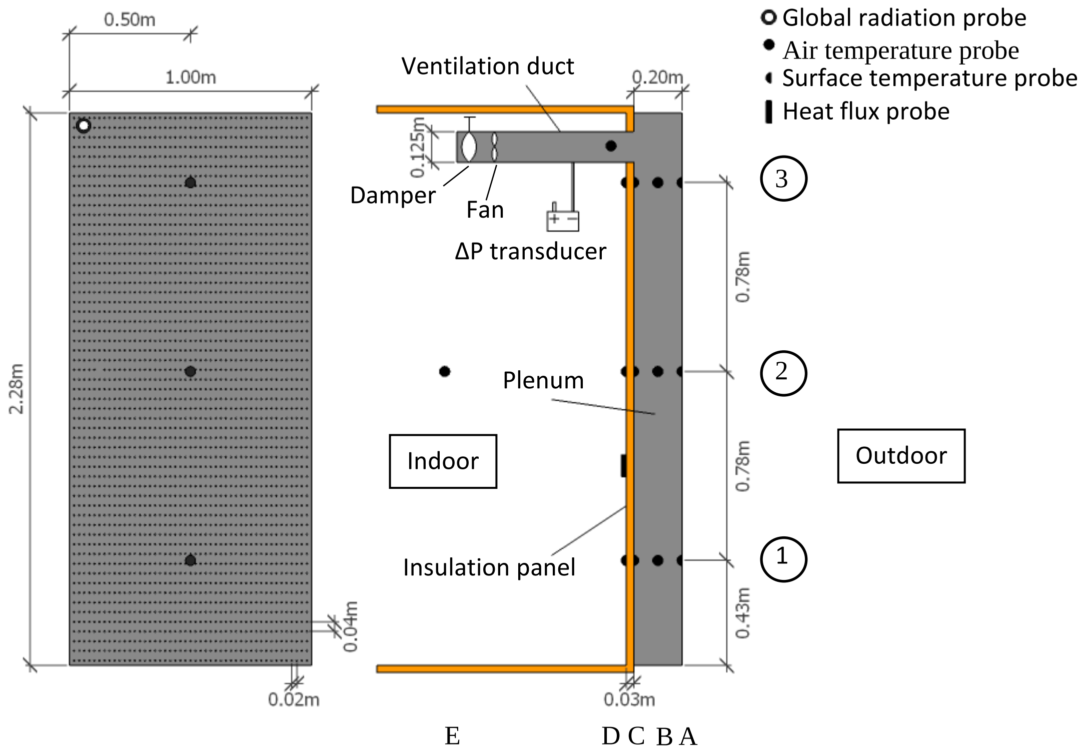


Figure 3. UTC experimental module dimensions and temperature probe locations. Probes were installed at three heights (1,2 and 3) in the steel plate (A), the plenum (B), the outer sandwich panel surface(C) and the inner sandwich panel surface (D).

The dimensions of the UTC module are shown in figure 3. The galvanized steel thermal conductivity was approximately 60 W $m^{-1}K^{-1}$, its specific heat 470 J $kg^{-1}K^{-1}$, and its density 7800 kg m^{-3} The test cell insulation consisted of a 0.03 m-thick sandwich panel with a U-value of 0.901 $Wm^{-2}K^{-1}$ and a weight of 13.1 kg m^{-2}. The module was tightened with nuts and bolts to the sandwich panel of the south façade of the test cell, and its perimeter sealed with silicone to prevent air leakage. A circular hole was made in the upper part of the sandwich panel behind the UTC module which connected with the ventilation fan through a 125 mm diameter duct. The fan discharged inside the test cell through an open damper.

The configuration of the collector plate was chosen based on the data found in literature. Several arrangements of plates and perforations can be found in literature (Van Decker et al. 2001; Li et al. 2013; Badache et al. 2012). The basic arrangement consists of a metal plate, galvanized steel or aluminium, and an array of circular perforations, covering between 0.8 % and 5 % of the collector surface (Love et al. 2014; Badache et al. 2013). The thickness of plenums varies between 50 and 300 mm (Badache et al. 2013; Chan et al. 2014), and the insulation layer can be either an additional insulation panel or the existent façade of the building. The latter is frequently the case when refurbishing an existent building. An outlet ventilation opening in the upper part of the insulation panel connects the plenum with the ducts and the fan that introduces the air stream into the indoor space. The normal operation is winter mode, when hot air is introduced directly into the building or as preheated air through an existing HVAC system.

Air and surface temperatures were measured using DS18B20 temperature probes, with a maximum error of ±0.5 ˚C. Both the façade with UTC and without UTC were monitored in the same way simultaneously to evaluate the effect of adding a UTC to the test cell façade. The positions of the temperature probes can be seen in figure 2. Two heat flux plates Hukseflux HFP01, (Hukseflux Thermal Sensors n.d.), were installed in the centre of both façades on the inner side of the insulation panel, figure 3.

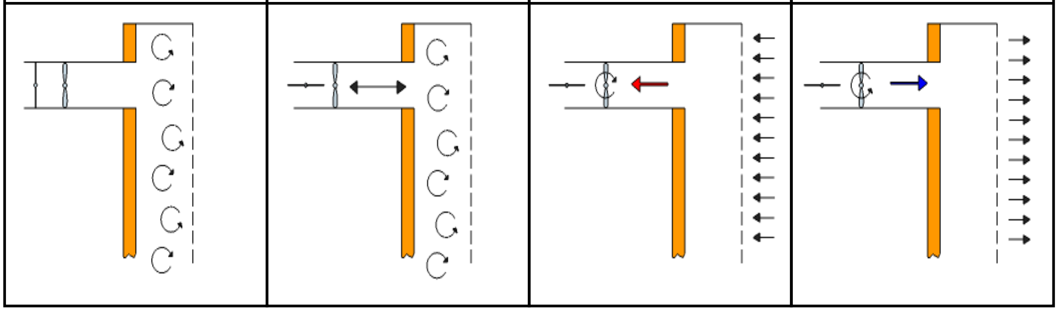
The weather variables were measured in situ. The ambient temperature was measured just in front of the test cell, see figure 3, and the probe itself was protected against solar radiation. The global solar radiation on the façade surface was measured with a global radiation pyranometer located on the upper right corner of the collector as can be seen in figure 3.

Four operation modes were tested depending on the type of ventilation of the UTC module, see table 1. Modes 1 and 2 corresponded to two situations, one in which the UTC façade is not ventilated, and the other naturally ventilated. This could happen in real-life situations due to a UTC fan failure or a misuse of the system. In modes 3 and 4, the UTC was ventilated, from outdoor to outdoor in the former case and from indoor to outdoor in the latter. In both cases overheating of the façade is prevented. In mode 3 the air was exhausted back to outdoor after removing heat from the collector surface. In mode 4 the intake air entered the space through cracks in the test cell: door, window, joints, etc.

The airflow rate in modes 3 and 4 was estimated from the air velocity measured with a hot wire anemometer in the centre of the duct. Although there were small fluctuations, the flow rate was considered constant with an average value of 220 $m^3\ h^{-1}$ for both directions. The average electric fan power consumption during modes 3 and 4 was 34 W.

Table 1. UTC operation modes tested

Mode 1	Mode 2	Mode 3	Mode 4
Fan: off Damper: closed Flow: natural	Fan: off Damper: open Flow: natural	Fan: on Damper: open Inlet flow	Fan: on Damper: open Outlet flow



Tests were carried out over a period of four weeks of measurements between 13 June and 12 July, one week for each of the operation modes tested. Samples were taken every 10 s and their values were averaged and stored every 60 s. The results were smoothed with a one hour moving average algorithm.

The daily cooling load per unit area due to the heat transfer through both façades was evaluated using equation 1, where the heat transfer values $\dot{q}_i$ were measured with one heat flux probe in each case, located in the centre of the façade areas. Since only one probe was used for each façade, the results were significant only for comparison studies. The cooling load increase percentage when using the UTC façade was calculated with equation 2.

$$E_{daily} = \sum_{i=1}^{i=1440} \dot{q}_i \cdot t \qquad (1)$$

$$\Delta E_{daily} = \frac{E_{daily,UTC} - E_{daily,Non-UTC}}{E_{daily,Non-UTC}} \cdot 100 \qquad (2)$$

Where E_{daily} is the integration of the experimental heat transfer through the insulation panel and t is the sample time step. Since quick temperature variations did not occur, transient phenomena can be neglected and equation (1) could be considered a good approximation.

3. Results and analysis

The values of the main weather variables, global irradiance on the façade and ambient air temperature, during the tests can be seen in figures 4 and 5, respectively. They correspond to typical summer weather in the continental dry climate of the south of Spain. The global irradiance on the UTC surface showed that the measurements were taken, in general, during hot sunny days, figure 4. The peak values during the 28 days of measurements were quite uniform, around 350 W/m^2. The effect of the peak irradiance will be discussed later.

In figure 5, the indoor temperatures and the ambient temperatures just outside the UTC module registered during the tests are shown. These temperature values are typical for this location at this time of the year. The ambient air temperature measured corresponded to the temperature of the air entering the UTC module in mode 3. The peak values were quite uniform, around 40 ˚C, during all the tests except for the third week, which was more cloudy and peak temperature values dropped to around 35 ˚C. The effect of ambient peak temperatures on the increase of heat transfer through the façade will be dealt with later. The indoor temperatures oscillated around 24˚C during the day when the air conditioning system was operating. However, during the night there was no heating system, so the temperature fell naturally to values between 15 ˚C and 20 ˚C.

From the weather data, it can be concluded that the testing period is appropriate to obtain data of the UTC performance under unfavourable conditions.

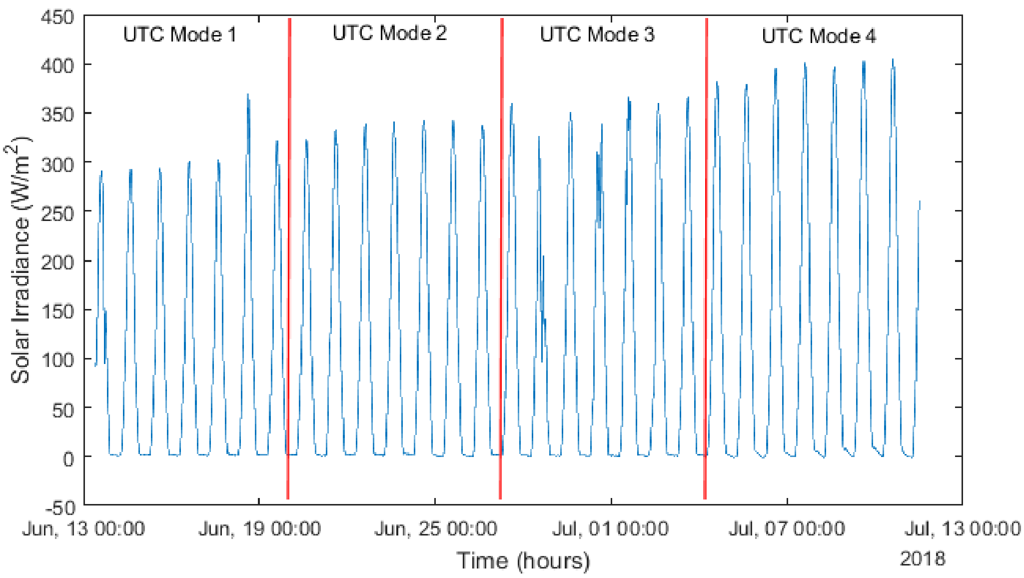


Figure 4. Solar irradiance on the UTC during the tests

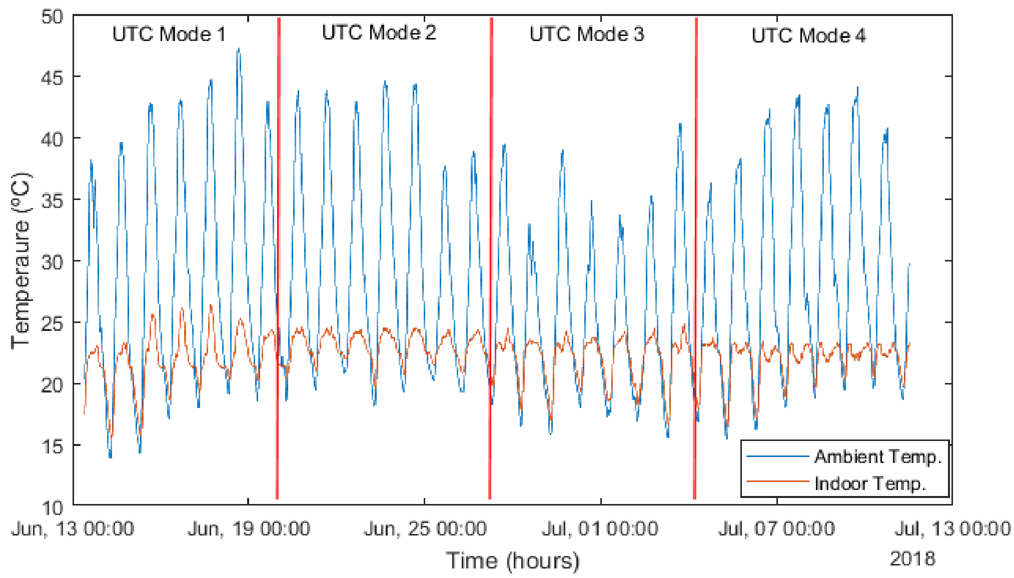


Figure 5. Ambient and indoor temperatures during the tests

UTC temperature profiles

The temperature profiles across the UTC façade for the maximum and minimum ambient temperatures are shown in figures 6 and 7. These temperatures were averaged for heights 1, 2 and 3, see figure 3. Similar values of indoor and ambient temperatures and solar radiation were selected for comparison purposes. Modes 1 and 2 showed similar temperature gradients inside the plenum and in the insulation layer, thus leading to similar values of heat flux, as figure 6 also shows. Therefore, the heat transfer from the air in the plenum was not influenced by the opening of the damper. The reason for this is the small duct diameter compared to the cross section of the UTC plenum. Natural convection of air through the duct was negligible. The result was that the air in the plenum was overheated and that caused the heat flux to increase over that of the non-UTC façade, especially when solar radiation and ambient temperature were at their peak values. Modes 3 and 4 presented more moderate UTC temperatures, as heat was being removed from it due to the circulation of air through the UTC holes. Therefore, the air temperature inside the plenum did not reach such high temperatures as in modes 1 and 2. In the case of mode 4 the inverse flow of air through the façade caused the UTC plate temperature to match approximately the ambient air temperature. In this case, the plenum air coming from indoors absorbs heat from the UTC and is then exhausted. Very low air temperatures were obtained in the plenum and the heat flux values were the lowest. It should be noted that in order to balance the airflow in the test cell, hot air from the ambient air is introduced through windows and door cracks, thus increasing the cooling load of the room. This case is only considered if the room ventilation rate is higher than the UTC ventilation rate, otherwise the increase in cooling load would have to be accounted for in the general balance.

Regarding temperature profiles during the night, figure 7, operation modes 1 and 2 presented similar behaviour with the UTC acting as a radiation shield. In these modes plenum temperatures were lower than in modes 3 and 4, in which the temperature profiles were flatter. The temperature differences between modes were not significant but modes 3 and 4 had the advantage of being able to remove cooling loads during the night through ventilation with fresh air, also known as free cooling.

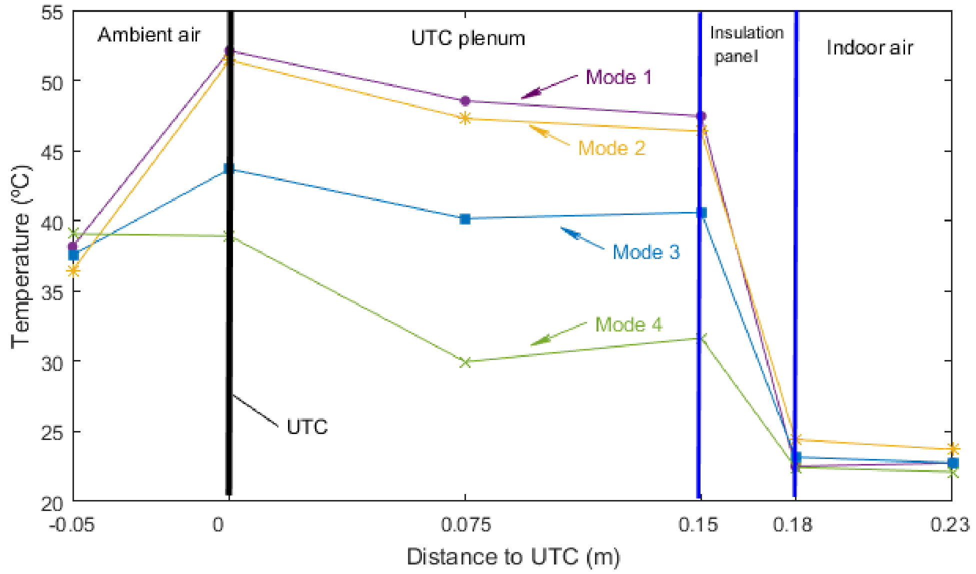


Figure 6. Temperature profile across the UTC and insulation panel at maximum day temperature in the four modes tested

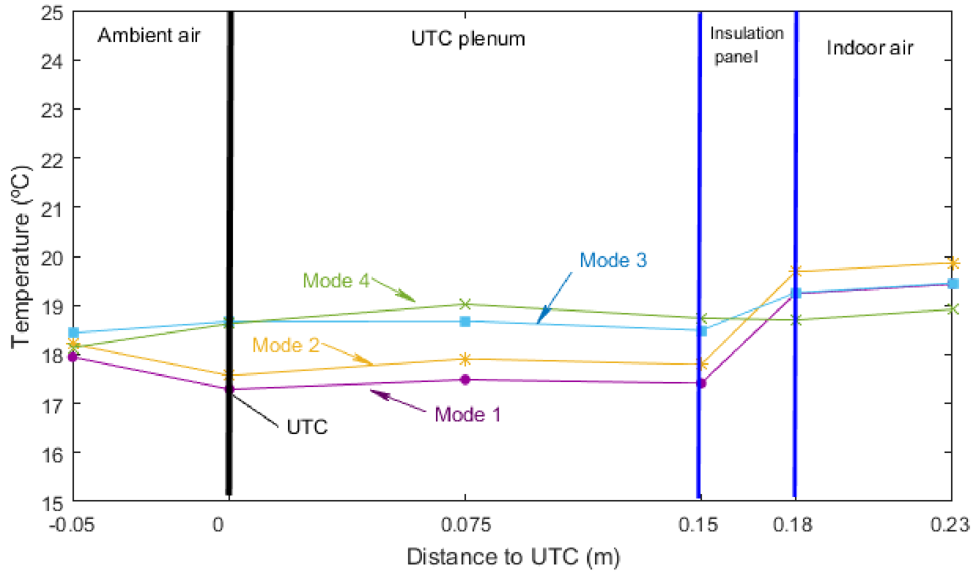


Figure 7. Temperature profile across the UTC and insulation panel at minimum day temperature in the four modes tested

Heat flux increase

a. Mode 1

Figure 8 shows the heat flux into the test cell through the UTC façade and the non-UTC façade. Since the façade was closed and there was no mechanical ventilation, the air in the plenum was heated by the UTC plate and temperatures reached high values during peak solar radiation values. For this reason, heat flux values for the UTC façade were up to 8 W/m^2 higher than in the case without UTC, as can be seen in figure 9. In this mode, the only heat transfer mechanism to evacuate the heat absorbed by the UTC was natural convection from the outer surface of the collector, as the plenum is sealed. During the night, temperature difference between ambient air and plenum air was almost negligible, and heat flux values were similar in both cases.

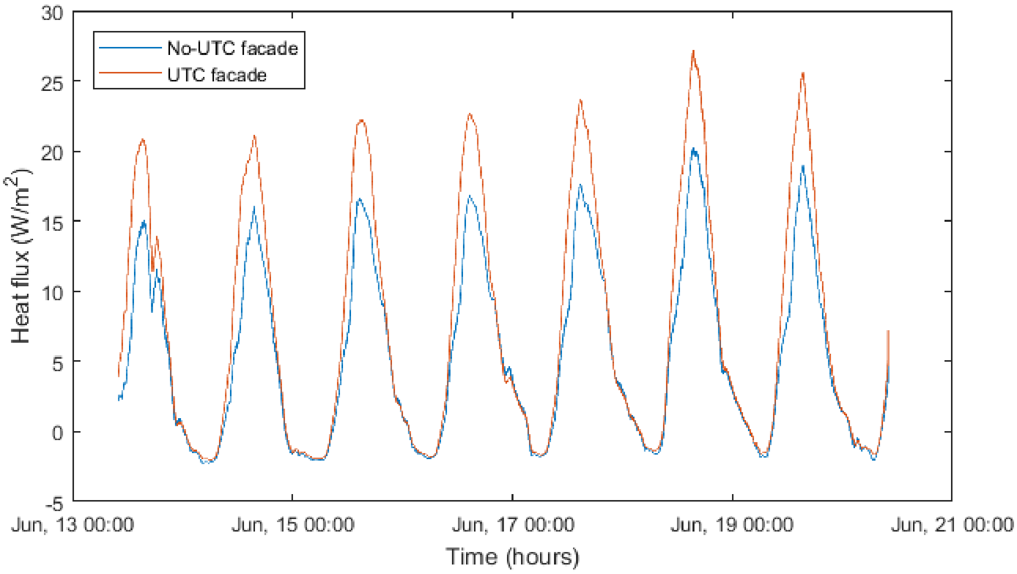


Figure 8. Heat flux across the module wall for the UTC and non-UTC façades in mode 1

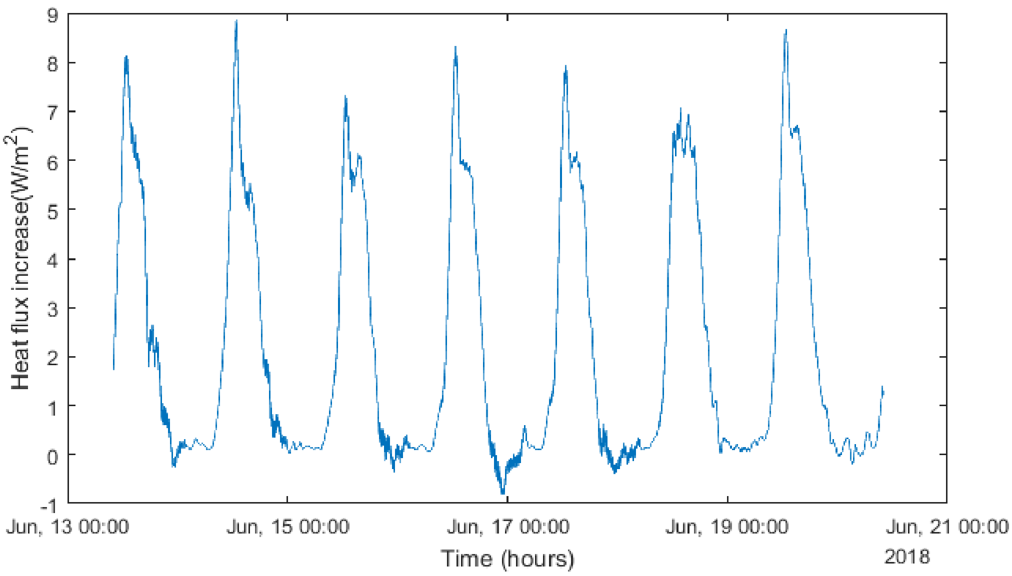


Figure 9. Heat flux increase when using the UTC façade in mode 1

b. Mode 2

There were no significant differences between this operation mode and mode 1. High temperatures were found inside the UTC and the heat flux values were similar to those in mode 1. Peak and daily values were found to be similar too, figures 10 and 11. In this mode, natural convection evacuates heat from both surfaces of the solar collector layer, and hot air in the plenum is exhausted due to buoyancy, although the results show this effect to be negligible.

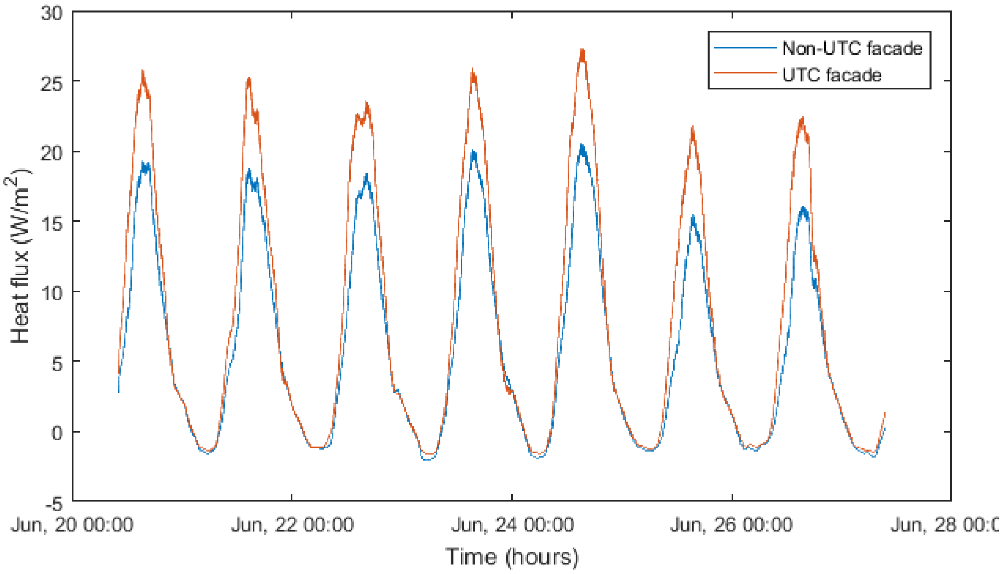


Figure 10. Heat flux across the module wall for the UTC and non-UTC façades in mode 2

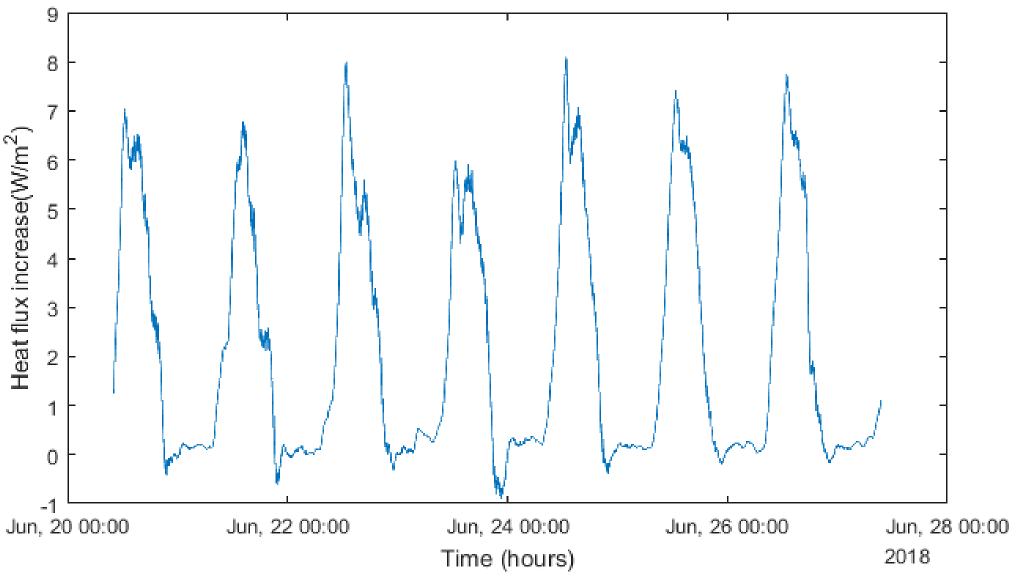


Figure 11. Heat flux increase when using the UTC façade in mode 2

c. Mode 3

In operation mode 3, figures 12 and 13, the heat flux values presented significantly lower values than in modes 1 and 2. The maximum heat flux peak values were around 2.5 W/m^2 during the day. The daily cooling load increase was between 2.2 % and 13.3 %. In contrast, night values were found to be lower in the case of the UTC façade. Forced convection through the façade increased dramatically the heat removal from the collector layer. The plenum air temperature was still higher than outdoors, but considerably lower than in modes 1 and 2.

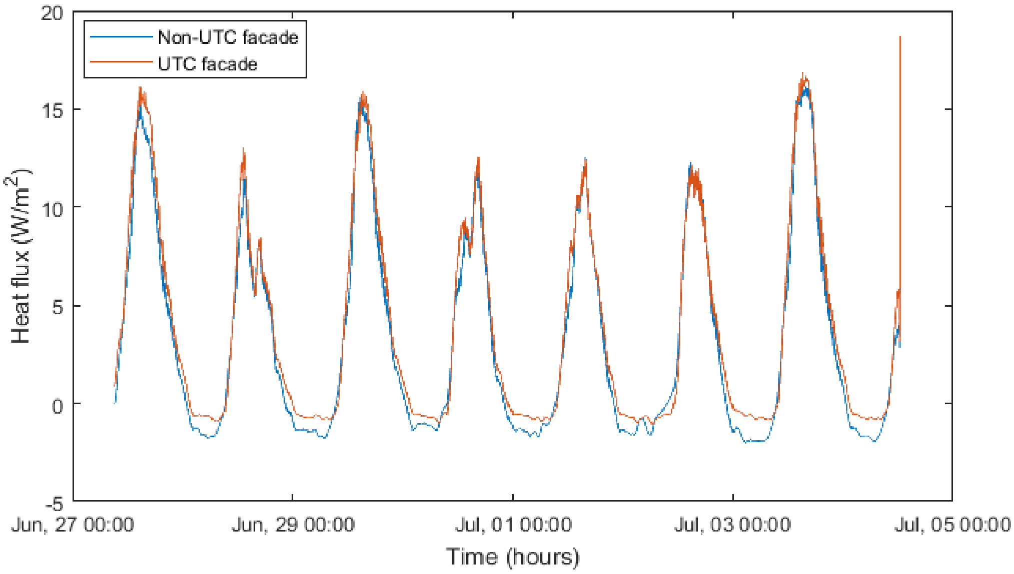


Figure 12. Heat flux across the module wall for the UTC and non-UTC façades in mode 3

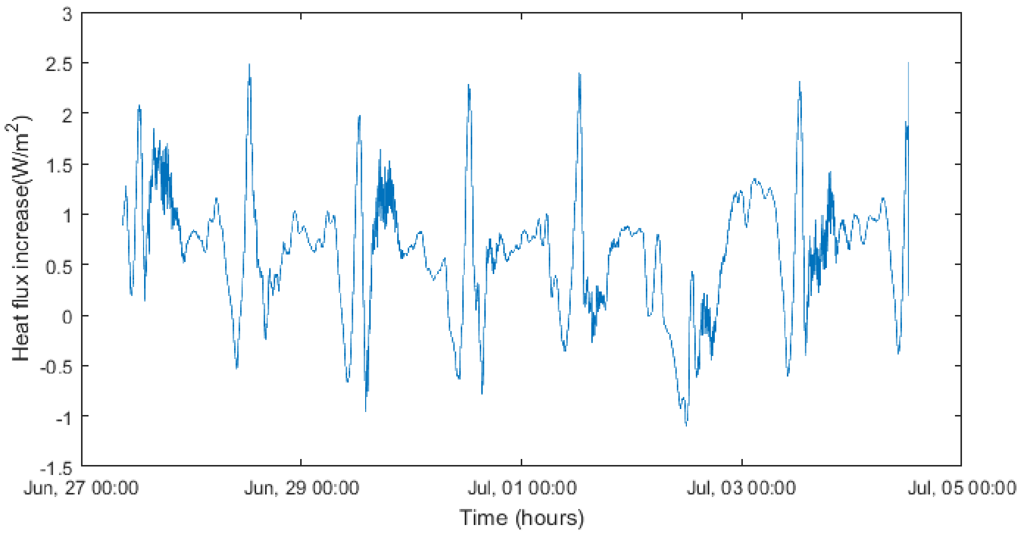


Figure 13. Heat flux increase when using the UTC façade in mode 3

d. Mode 4

In mode 4, heat flux values were lower in the case of the UTC façade during the day, figure 14. A maximum heat flux decrease of around 11 W/m2 was measured, figure 15. Daily cooling load values varied between 13.2 kJ/m2 and 43.2 kJ/m2. Heat flux was reduced to almost zero during the night in the case of UTC. Peak values did not follow the same trend as solar irradiance values. In modes 4, convection heat transfer was in this case to indoor air, which was at a lower temperature than outdoors. Moreover, heat was removed after passing through the plenum, so temperatures on either side of the insulation panel were almost the same, leading to very low heat transfer rates through it.

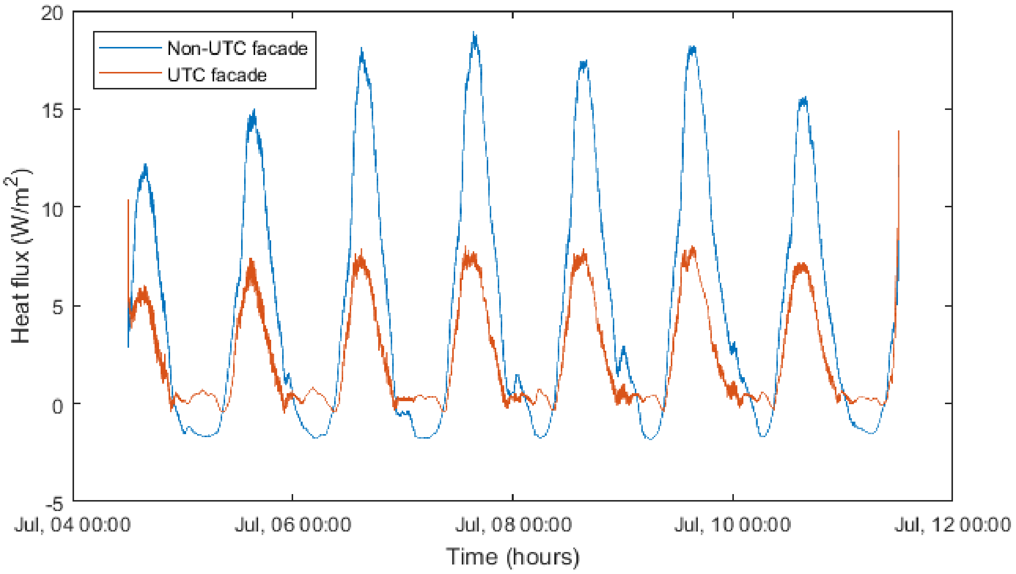


Figure 14. Heat flux across the module wall for the UTC and non-UTC façades in mode 4

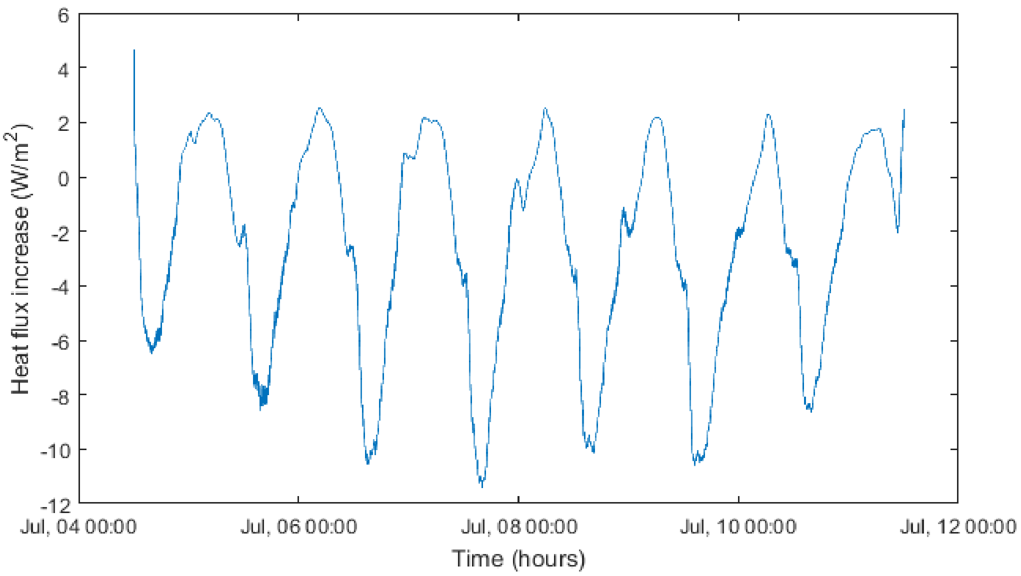


Figure 15. Heat flux increase when using the UTC façade in mode 4

In conclusion, modes 1 and 2 would be the inadequate modes of operation for a UTC façade, or when mechanical ventilation fails in unfavourable climatic conditions. These operation modes should not be used in normal operation during summer. Mode 3 reduces the overheating and does not have any drawbacks, providing the hot air from the UTC is exhausted to the exterior. Mode 4 is more efficient, and even reduces the cooling load of the façade. The reduced cooling load is only possible if there is an existent ventilation system whose exhaust stream is directed through the UTC façade. If a ventilation system were not present, a new cooling load would be created and the decrease in heat flux through the façade would be balanced with the additional ventilation heat gain created.

Daily energy gain

Figures 16 to 19 represent the daily integrated energy transferred through the test cell façade, which was evaluated using equation 2, for all four operation modes, both with and without UTC. The energy increase, equation 1, is expressed above each bar as a percentage of the energy transferred through the façade without UTC.

Regarding modes 1 and 2, figures 16 and 17, despite the fact that the ambient temperature was different for each test, the energy increase values were very similar, between 30 % and 45 %. It can also be noted in these modes that the absolute difference between the daily energy values was not significantly affected by the meteorological variables. The explanation for this similar behaviour in these two cases could be the null effect of the aperture of the exhaust damper on the natural convection air movement inside the UTC plenum, as the duct section area was four times smaller than the plenum horizontal section. Moreover, the interior room did not have any openings to create a pressure gradient negative enough for the airflow rate to increase. Nevertheless, the increase in cooling loads did not reach excessively high absolute values.

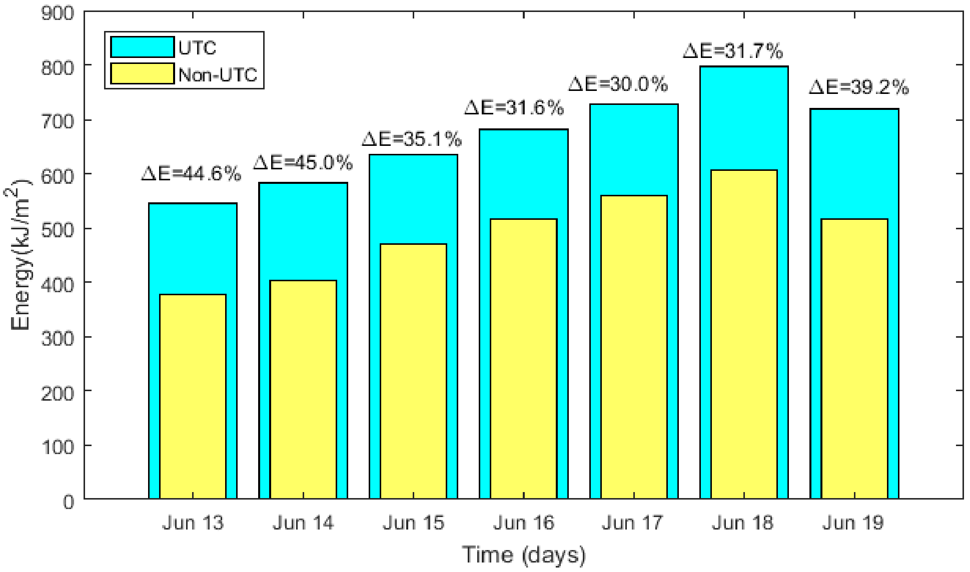


Figure 16. Daily energy gained through the wall for the UTC and non-UTC façades for mode 1

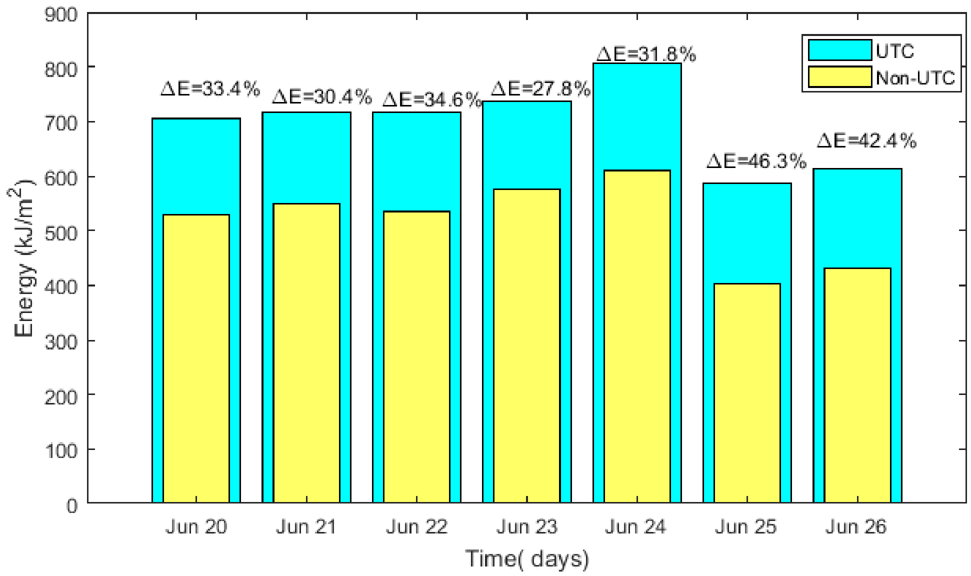


Figure 17. Daily energy gained through the wall for the UTC and non-UTC façades for mode 2

In contrast, modes 3 and 4, figures 18 and 19, which used mechanical ventilation, showed improved behaviour compared to modes 1 and 2, from the façade cooling load point of view. In the case of mode 3, figure 18, ventilating the UTC module by suctioning the air through the collector plate and then exhausting the air back to the exterior through the duct, produced values of daily energy transfer increase between 2.2 % and 13.3 %, lower than in modes 1 and 2. The absolute values were correlated to the ambient temperature, as can be seen comparing figure 5 with figure 16. However, the energy increase didn't seem to be clearly related either to ambient temperature or to solar radiation.

In mode 4, figure 19, there was a decrease of energy transfer when using the UTC façade, as the UTC ventilation air was indoor air at temperatures around 25 ˚C, while the ambient temperature reached a maximum of around 40 ˚C. The decrease in energy transfer was clearly correlated with the ambient temperature, see figure 5. The ventilation air intakes were cracks in the door, the window and other elements of the test cell, so ventilating in this way leads to an increase in ventilation cooling load. this option is only justified if an existent ventilation system is present. The estimation of the daily cooling load increase due to the infiltration air intake is represented in figure 20. It shows that the cooling load due to heat transfer through the façade was negligible compared to the ventilation cooling load. Therefore, the only case in which ventilation through the façade with indoor air would be viable is when there is an existent ventilation system. If there is no ventilation system, there would be an unnecessary increase in the building cooling load.

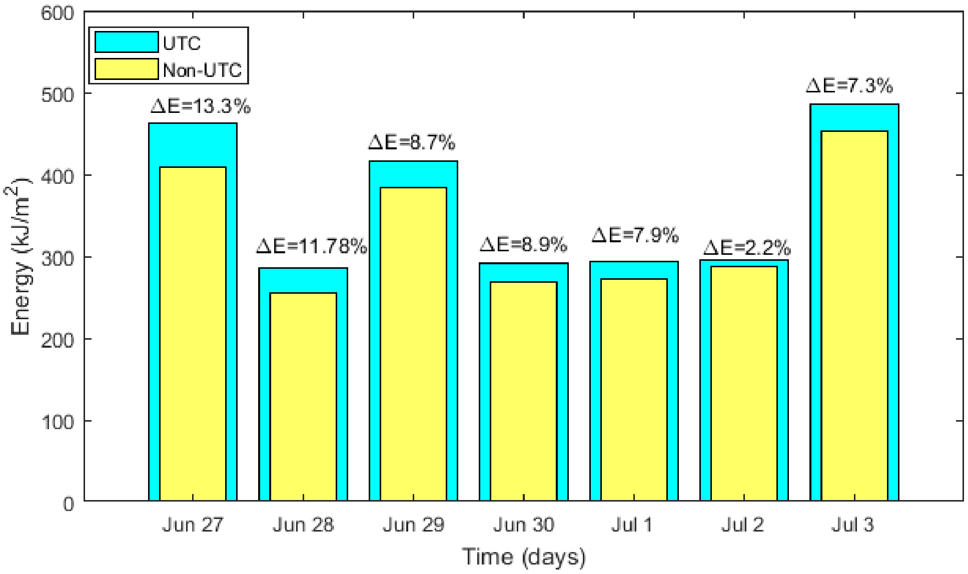


Figure 18. Daily energy gained through the wall for the UTC and non-UTC façades for mode 3

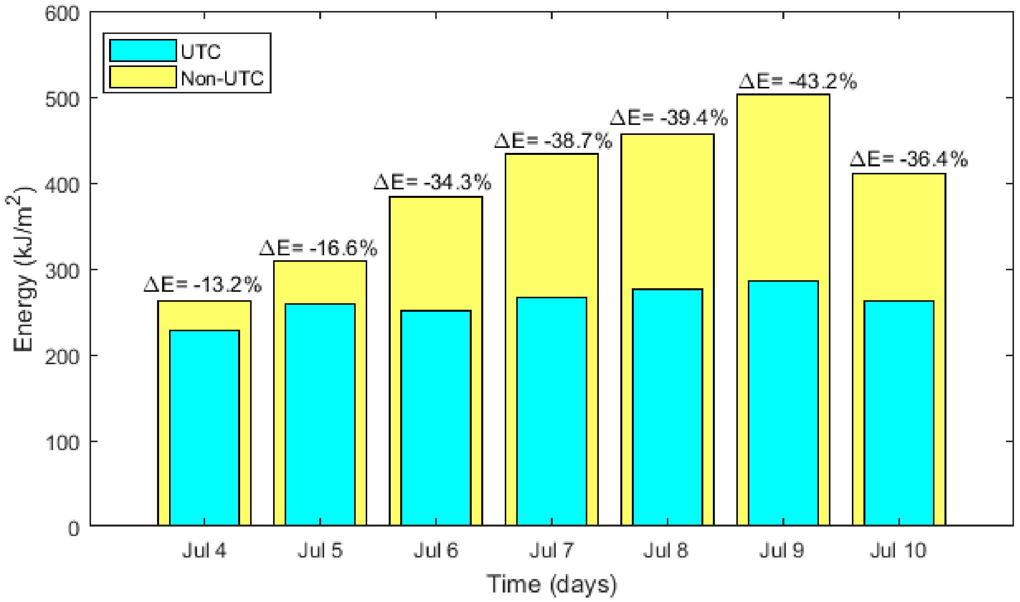


Figure 19. Daily energy gained through the wall for the UTC and non-UTC façades for mode 4

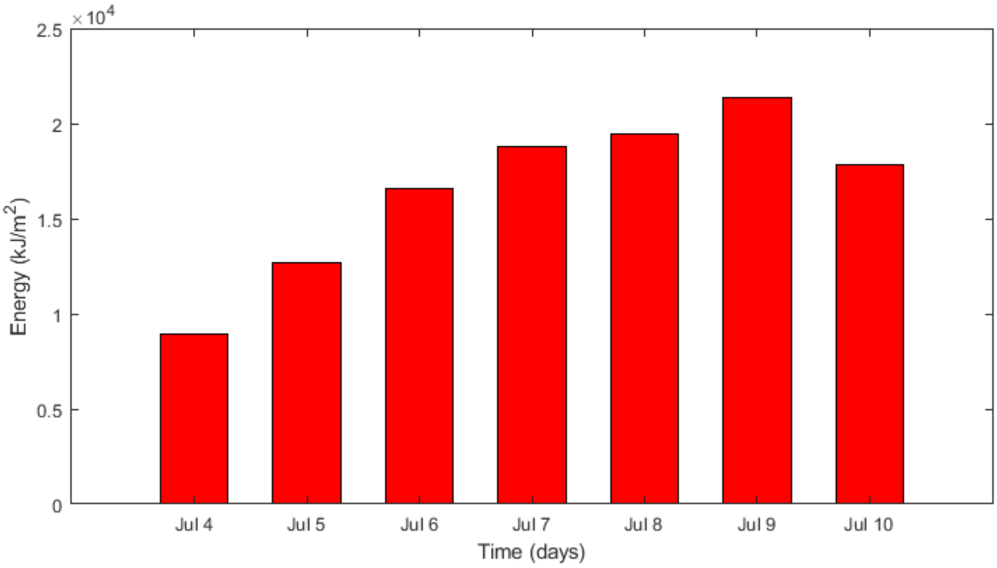


Figure 20. Daily ventilation cooling load increase due to the infiltration air intake in mode 4

Table 2 shows the average temperature and global solar radiation for each operation mode together with the total cooling load increase due to the UTC façade, the total cooling load in the case of non-UTC façade and the percentage of energy increase. Average temperatures and solar irradiation were of the same order of magnitude, so comparison between these cases was possible. To confirm this point, figure 21 shows the average heat flux through the non-UTC and UTC facades within an interval of high solar irradiation and temperature values for the four weeks of measurements. It can be seen that in the case of non-UTC façade the heat flux is independent of modes of operation, whereas in the case of UTC heat flux follows the same trend that has been observed in the previous results. Non-ventilation of the UTC façade increases the cooling load by up to 39.4%. Ventilating the façade with ambient air increased the cooling load by 17.2 %, and the fan energy consumption is taken into account in the total energy balance. Ventilating with indoor air reduced the cooling load, but only in the cases where mechanical ventilation was legally required, otherwise the ventilation cooling load is 40 times higher than with the non-UTC façade.

The electric power rate of the inline fan was measured, and its mean value was 34 W. In modes 1 and 2 the fan was off, and this value was irrelevant, but in modes 3 and 4 the energy that the fan consumes must be considered. The fan power rate per unit area for the module tested was 14.9 W m^{-2}, which was of the same order as the maximum heat transfer through the façade at midday, see figures 12 and 14. Therefore, preventing overheating through ventilation in mode 3 would not be justified, because the decrease in façade cooling load is lower than the total energy consumption of the fan. In the case of mode 4, as mentioned above, it is assumed that an existent ventilation system was present, so the fan energy consumption would not add any additional energy consumption to the system.

Table 2. Total weekly integrated energy increase for each operation mode and averaged ambient air temperature and solar irradiance during the total test period

Mode	T_{avg} (˚C)	I_{avg} (W/m^2)	ΔE (MJ/m^2)	E Non-UTC (MJ/m^2)	Δ E (%)	ΔE(%) Including ventilation cooling load	Fan energy consumption (MJ/m^2)
1	33.1	150	1.27	3.22	39.4	39.4	0
2	33.4	172	1.27	3.46	36.7	36.7	0
3	28.7	170	0.34	1.98	17.2	17.2	1.4
4	32.9	196	-1.58	2.92	-54.1	4009*	1.4

*only in case of non-existing ventilation system

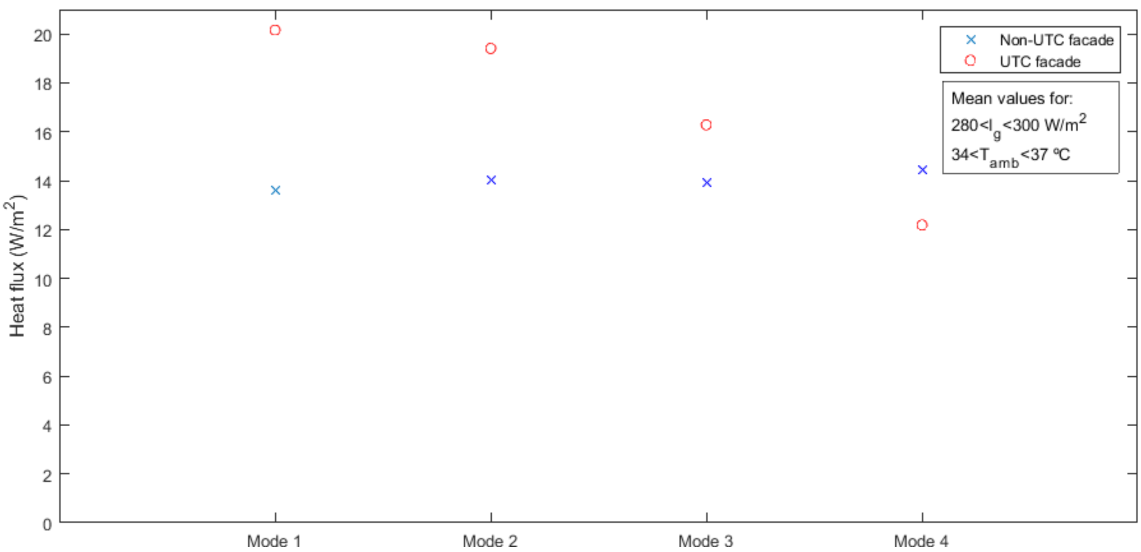


Figure 21. Average heat flux for high temperature and irradiation values during the four weeks of measurements

4. Conclusions

In this study, experimental data were obtained to quantify the influence of a UTC façade on the façade cooling load during hot weather conditions. Four operation modes were tested to quantify the cooling load reduction and to find the most effective. Temperatures and heat transfer through walls, with and without a UTC façade, were measured to obtain comparative results. High ambient temperatures and high values of solar radiation were reached during the tests, which resulted in overheating of the plenum of the UTC façade

During the day, it was found that not mechanically ventilating the UTC, modes 1 and 2, increased the plenum air temperature and therefore the heat transfer through the building wall, increasing the cooling load of the building. Natural ventilation was found not to be enough to reduce this effect. At night the effect of the UTC on the different surface temperatures was negligible.

Ventilating the UTC façade reduced the cooling load notably during the day. In the case of mode 3, ventilating with ambient air reduced the façade load increase, but required the additional energy consumption of the fan. Ventilating to the exterior, mode 4, was found to reduce the façade cooling load, but as in case 3, the fan energy consumption must be considered in the energy balance. Furthermore, the ventilation cooling load was very high, so this mode can only be considered when a ventilation system already exists in the building.

Finally, assuming that the building façade is well insulated, the cooling load increase found in this study due to the installation of a UTC façade may not justify the use of a fan, so mode 3 is not recommended. Modes 1 and 2 are recommended, as the overheating was found not to be high enough to cause a high cooling load increase. Mode 4 is only recommended in the case of an existing ventilation system.

For future work, it would be interesting to study the minimum airflow rate needed to nullify the cooling load increase for a particular insulation wall, as in this paper the nominal air flow rate for winter was used.

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