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Effects of a Vertical Green Façade on the Thermal Performance and Cooling Demand

A Case Study of a Tube House in Vietnam

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Abstract
Traditional architecture has often applied greenery in the design to improve the thermal performance of indoor spaces. Such a bioclimatic approach is not often seen in the contemporary tube houses of Vietnam. Vietnamese architects recently started to focus more on greenery solutions for housing projects. However, the quantitative effects of plants on the building performance has not yet been investigated in Vietnam. This paper reports on an experiment to quantify the benefits of a vertical greening system for thermal performance and energy saving. A typical tube house in Hanoi was selected and two similar rooms were monitored during July and August, 2018. One of the rooms' façades was covered by the climbing plant Bougainvillea. Outdoor and indoor temperature and energy for air-conditioning were measured for the two rooms to quantify the effect of the greenery on the existing aluminium shading device and a bare window. Results for the green façade showed that the difference between outdoor and indoor temperature can be as high as 8°C. In addition, the climbing plants helped to reduce the indoor temperature by around 1°C and thus cooling energy was saved by up to 35%.

Keywords
Green façade, thermal performance, cooling demand

1 INTRODUCTION

Traditional Vietnamese architecture has often been designed with bioclimatic principles to maintain a good thermal environment without the help of a mechanical heating or cooling system. A Vietnamese proverb that describes green bioclimatic principles as follows: "to plant palm trees at the front (south) and banana trees at the rear (north)". The high palm trees at the front provide shading and at the same time enable the cool summer air to ventilate the house. On the other hand, the lower banana trees at the rear help to block the cold north-easterly wind in winter.

Despite its popularity in the past, plants and trees are limited around contemporary tube houses. A 'tube house' is a contemporary attached row house in Vietnam with a narrow width and long depth. The contemporary tube houses were built after economic reform in 1986. While one can easily find green aspects in a traditional rural house in Vietnam, high-density population and fast-growing urban development leave less room for trees to grow in the cities. Maintenance is also the reason for not having a lot of plants in and around the houses. The lack of greenery might not only negatively affect the energy and indoor climate performance of a single house but may also contribute to the urban heat island (UHI) effect (Szkordilisz, 2014).

FIG. 1 A housing refurbishment case in Vietnam. Left: old house. Right: refurbished house *(Vo Trong Nghia Architects, n.d.)*

Recently, with a clear aim to improve the aesthetic and thermal performance, more and more houses are built with integrated greenery. Such trends were applied by famous Vietnamese architects such as Vo Trong Nghia, Hoang Thuc Hao, and Nguyen Hoang Manh. Fig. 1 shows a housing refurbishment case by Vo Trong Nghia, where he redesigned the façade with a whole new layer of greenery. In Vietnam, such projects are collated under the term 'green buildings' or are sometimes also referred to as 'sustainable buildings'. However, there is little scientific evidence that shows the actual benefit of green solutions.

The research presented in this paper conducts an experiment of the greenery system on an existing tube house of Vietnam. The experiment investigates the effect of vertical greenery on the thermal behaviour and energy consumption and compares it with an aluminium shading device and a normal bare façade.

2 LITERATURE REVIEW

Green walls (GW) are categorised based on their construction and characteristics (Manso & Castro-Gomes, 2015).They can be classified into two main groups: green façades (GF) and living walls systems (LWS) (Dunnett & Kingsbury, 2004; Köhler, 2008) In green façades, walls and windows are often covered by climbing plants, whereas LWS often have integrated supporting materials and technology so greenery can grow uniformly on an extended vertical surface. There are direct green façades (plants grow directly on the wall surface) and indirect green façades (plants grow on a supporting system) (Manso & Castro-Gomes, 2015). Different types of green walls are shown in Fig. 2.

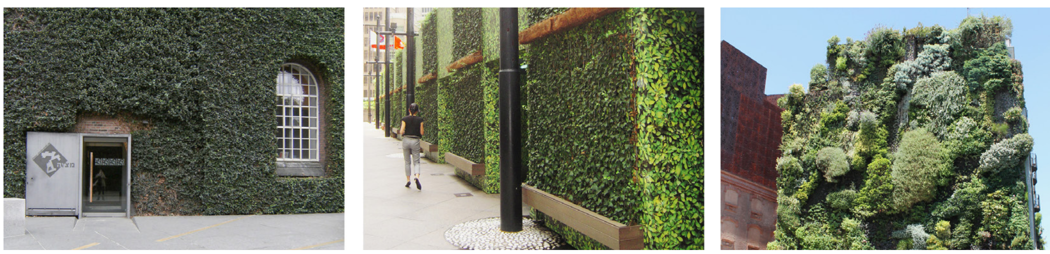

FIG. 2 From left to right: direct green façades, indirect green façades, living wall system *(Manso & Castro-Gomes, 2015)*

Previous studies have investigated the effects of green façades and living wall systems on the building environment and the energy performance. Vertical greenery systems work as a natural sun shading since, compared to a bare façade, they reduce the air surface temperatures behind the green layer (Perini et al., 2011; Kontoleon & Eumorfopoulou, 2010). Evapotranspiration effects of the plants were confirmed by a slightly lower air temperature and higher air humidity of the space between a normal façade and a green façade (Pérez et al., 2011). The maximum cooling effect of a greenery system is reported during the summer period, and better efficiency is found in locations with higher solar radiation. A greenery system also mitigates the urban heat island effect by lowering the air temperature in a large urban area (Wong et al., 2010; Alexandri & Jones, 2008). In terms of energy saving, a green façade has much potential to reduce the cooling load in both temperate and hot climatic regions (Coma et al., 2017; Haggag et al., 2014; Pérez et al., 2017). Effects of green façades on the thermal and energy performance in winter conditions are still debatable (Raji et al., 2015).

TABLE 1 Summary of previous experiments on green façades & living wall systems

#	LOCATION TIME	FACADE – PLANT TYPE	METHOD	KEY FINDINGS/ REFERENCE
1	Spain 2011 - 2013	Green façade Ivy, Honey suckle, Boston Ivy & Clematis	Experiment on 2 house-like cubicles (2.4x2.4x2.4 meter)	(Coma et al., 2014) Reduction of up to 14°C on outside wall surface temperature. No significant energy saving was found
2	Spain 2014	Green façade Boston Ivy	Experiment on 2 house-like cubicles (2.4x2.4x2.4 meter)	(Pérez et al., 2017) DSGF can provide comparable shadow factor values to other factors, such as façade setbacks, cantilevers, etc. Reduction of outside surface temperature Energy savings are dependent on orientation
3	Spain 2014 - 2015	Green façade Ivy Ever green	Experiment on 3 house-like cubicles (2.4x2.4x2.4 meter)	(Coma et al., 2017) Energy saving in summer: up to 58% (GW) and 34% (GF) Energy saving in winter: up to 4.2%
4	China	Living wall system	Experiment on 2 thermal labs	(Chen et al., 2013) Outside surface, inside surface and indoor temperature reduce by a maximum of 20.8, 7.7 and 1.1 Celsius degree respectively The LWS closer to the wall perform better in cooling effect.
5	Singapore 2010	Living wall system	Experiment on 8 living wall systems on a wall only	(Wong et al., 2010) Reduction in surface temperature
6	Hong Kong 2011–2012	Living wall system	Experiment on external wall of a n apartment	(Dahanayake & Chow, 2017) Reduction in surface temperature and outdoor mean radiant temperature during intense exposure period
7	UAE July	Planter boxes of vegetation	Experiment on an existing school building, 2 east-facing classrooms were selected.	(Haggag et al., 2014) Peak time indoor temperature is reduced by at least 5 Celsius degree Air-conditioning energy is reduced by 20%
8	Netherlands 2017	Direct GF & LWS based on planter boxes and mineral wools	Experiment on a climate chamber (1.1x1.4x1.4 meter)	(Ottelé & Perini, 2017) Due to the insulation layer, no difference in indoor temperature was found Green facades help bring surface temperature differences of up to 5.8°C in the summer and 2.1°C in the winter

Among the research on vertical greenery systems, many studies refer to physical experiments and measurements. Table 1 summarises the experiments on green façades and living wall systems. These experiments were located in Spain, the Netherlands, China, Singapore, Hong Kong, and the United Arab Emirates (UAE) in the period from 2010 to 2018. The three studies in Spain were carried out by the same authors. The plant species chosen for the Spanish studies was Boston Ivy, which grew in a double skin green façade. The studies in Asia had a more diverse selection of plants, with different plant types in a living wall system or in planter boxes. Most of the studies were conducted in a laboratory environment (Chen et al., 2013; Ottelé & Perini, 2017), or in a real outdoor context but with small-scale prototypes (Coma et al., 2017, 2014; Pérez et al., 2017; Wong et al., 2010). The main reason for this was the lack of greenery in the field and the diversity of the experimental outdoor conditions between the cases, such as orientation and environmental parameters (Ottelé & Perini, 2017). Furthermore, in a laboratory, boundary conditions are easily controlled and different types of greenery can be compared under the same environmental conditions. The most commonly measured value was the surface temperature of the external wall and the improvement in this regard was generally quite substantial. The experiment in China showed a significant reduction in outside surface temperature of 20.8°C. However, the living walls system in this case only helped to reduce the indoor temperature by 1.1°C.

Conclusions from these experiments show that, in general, green walls can help to reduce the surface temperature efficiently in both a temperate and warm tropical climate. However, the improvement of the indoor temperature is rather limited. The green wall only has a significant effect in the extremely hot climate of the UAE, where the peak indoor temperature was lowered by 5°C (Haggag et al., 2014). Nevertheless, the experiments showed considerable savings in air-conditioning consumption, 20% in the case of the UAE school and 34% and 58% in the case of the Spanish cubic units. The former case was less effective in energy saving despite its greater thermal performance. This could partly be because the former case was a real building experiment while the latter was a lab-based experiment.

No such experiment on green walls was found in Vietnam. Among the studies, Singapore is most similar to Vietnam in terms of climate conditions. However, that experiment was designed only for testing the surface temperature without any internal spaces.

3 EXPERIMENT DESIGN

3.1 CLIMATIC CONDITIONS

The experiment house is located in Hanoi, the capital city in the northern part of Vietnam, under the humid subtropical climatic conditions defined according to Koppen-Geiger climate classification (Kottek et al., 2006) as Cwa (warm temperate; winter dry; hot summer). Generally, Hanoi is affected by seasonal monsoon winds. It has a short cold and dry winter; the air temperature can reach as low as 5°C. Protection from the cold wind from the northeast is required. The summer is hot and the air temperature can reach up to 40°C. Annual precipitation is considerably high. The average rainfall in summer is approximately 300 mm per month (Nguyen et al., 2011)

3.2 EXPERIMENT SPACES

The selected rooms are a bedroom on the second floor and a living room on the first floor, both facing southwest, in a typical Vietnamese tube house. The dimensions of the rooms are 3.3 x 4.6 x 3.9 metres (w x l x h). The front façade consists of single lightweight masonry wall with a big window of 7.2 m^2 (56% of the external wall area) for each floor. The external walls are composed of 110mm brick work with 15mm of cement plaster on both sides. The U value is 2.57 W/m^2-K. The windows are composed of 6mm grey single glazing within an aluminium frame and a U value of 5.78 W/m^2-K. At the front, the first floor is covered with the climbing plants. The second-floor façade has an aluminium shading device, with a solar transmittance of 0 and a solar reflectance value of 0.5. The back side of the room is a glass wall with an aluminium frame that connects to the staircase. On both right and left sides of the rooms are single masonry walls adjacent to neighbouring walls. The two rooms are equipped with 12,000 Btu (British thermal unit) or 3.52 kWh air-conditioners which provide both cooling and (electric) heating. The existing building is presented in Fig. 3.

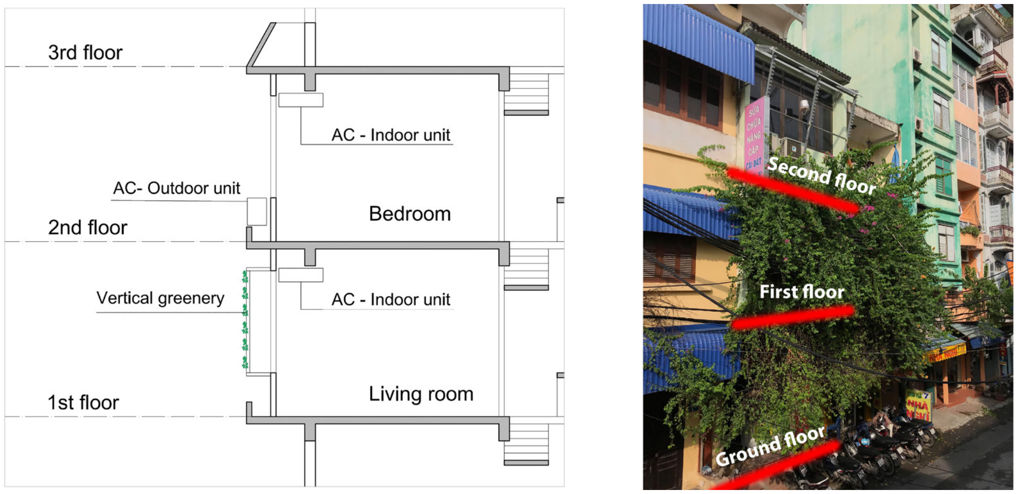

FIG. 3 Existing Vietnamese building for experiment. Left: cross section & floor plan, Right: outside view

3.3 THE PLANTS

In this study, the plant has already grown and covered most of the 1st floor façade. The other façade has an aluminium shading device. The plant type is Bougainvillea, a climbing tree that is regularly found in Vietnam thanks to its fast growth and low maintenance.

3.4 MONITORING EQUIPMENT

The performance of the two similar spaces is simultaneously measured. One of the spaces has a greenery system on the façade. There were eight measurement configurations in total, as listed in Table 2.

TABLE 2 Equipment names and measuring parameters

#	EQUIPMENT	SYMBOL	MEASURING
1	Sense 1	S1	Second floor outdoor temperature and relative humidity
2	Sense 2	S2	Second floor indoor temperature and relative humidity
3	Sense 3	S3	First floor outdoor temperature and relative humidity
4	Sense 4	S4	First floor indoor temperature and relative humidity
5	Sense 5	S5	Third floor outdoor temperature and relative humidity
6	Voltcraft	V	Solar radiation on the front southwest facade
7	Circle 1	C1	Electricity consumption of second floor air-conditioner
8	Circle 2	C2	Electricity consumption of first floor air-conditioner

Two sense data loggers (Plugwise) were put inside the rooms to measure the indoor temperature and relative humidity. Three other sense data loggers were installed just outside the windows to measure the outdoor temperature and relative humidity of the first, second and third floor. The temperature sensor has a range of 0 to 60˚C; the relative humidity sensor has a range of 5 to 95%. The accuracy of the data loggers is: temperature: 0.3°C at 25°C and 0.8°C at 60°C; relative humidity: 2.2% between

10%- 90%, 3.2% in other conditions. Two circle units (Plugwise, Type F) were connected to the two air-conditioners in the two rooms to measure electricity consumption. The accuracy is 5% ±0.5W for current usage and 1% ± 0.2W for cumulative usage. All of the Plugwise sensors were wirelessly connected to a computer and data was retrieved from the same software named Source. A solar data logger (Voltcraft) was used to measure the solar radiation on the façade. The sensor was oriented 45° from the horizontal plane and faced directly southwest. The reason for this was that the shading device and the leaves on the green façade have the same 45° inclined position, facing the sun directly in the afternoon. The sensor has a range from 0 to 1999 W/m^2 with an accuracy of 5% or 10W/m^2. All data is recorded at 15-minute intervals and presented in hourly intervals. The location of the equipment is presented in Fig. 4.

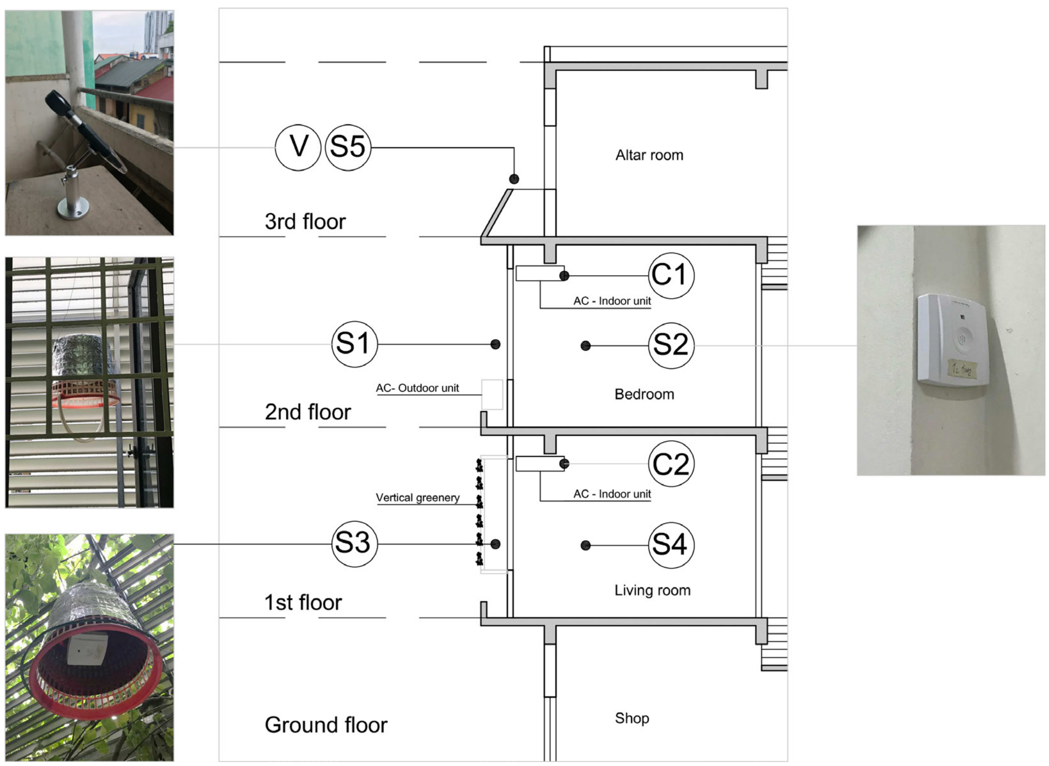

FIG. 4 Locations of the measurement equipment

3.5 MEASUREMENT PLAN

The experiments were conducted during the summer months of July and August, 2018. During this period, the two rooms were vacant to make sure that there would be no variation in heat gain from occupants and equipment. Details of the measuring schedule are shown in Fig. 5.

The first scenario aims to validate if the two rooms have similar thermal performance. From 9th - 15th August, both façades were bare and from 26th August - 3rd September, both façades were shaded.

FIG. 5 Three scenarios of the experiment

The second scenario in Fig. 5 compares the thermal performance and the energy consumption of the room with a green façade (first floor) with the room with a bare façade (second floor), from 27th July - 8th of August. From 10th of July - 24th July, the performance of the green façade room (first floor) and the shaded façade room (second floor) were compared under the third scenario.

The order of the scenario did not align with the time sequence because the experiments were conducted on a real building in which a green façade is a climbing plant. Once the plant was removed, it could not grow back in a short period of time.

Scenario 2 and Scenario 3 both lasted about 2 weeks. During the first week of each scenario, the rooms were naturally ventilated and only the temperature and humidity levels were monitored. During the other weeks, air-conditioners were used for 5 hours in the afternoon, and the energy for cooling was recorded. The air-conditioners were both set at the same cooling set-point of 27°C, based on a study of adaptive thermal comfort by Nguyen (Nguyen, Singh, & Reiter, 2012)effective temperature, standard effective temperature. Outside the air-conditioned periods, the rooms were naturally ventilated.

3.6 BOUNDARY CONDITIONS

This research specifically investigates the performance of an existing urban tube house in Vietnam. The energy consumption comparison is more valid in a real building case. The ideal setting was to compare two identical adjacent houses. However, it was not possible to have access to two such houses, so two similar rooms in one house were selected. The selected rooms were in two different levels of the house so the existing spaces may not have performed exactly the same. This limitation has been taken into account in the analysis and the presented result section.

The limitation of this experiment is that there were only two spaces available so we could only compare two different façade types at a time. Therefore, this study did not focus on comparing different greenery systems but mainly investigated the differences in performance between a room with a green façade and one without a green façade.

The experiment recorded both the temperature and humidity levels of the spaces. A green façade may impact the humidity level of the indoor spaces and hence influences the perception of the temperature. However, within the scope of this paper, the investigation of humidity is temporarily neglected.

Thermal inertia may have some effects on the performance of the rooms. However, as the rooms are of a lightweight construction, thermal inertia effects were not considered within the scope of this paper.

4 RESULTS

4.1 SOLAR RADIATION

Solar radiation was measured because it provides radiative energy and stimulates the evaporation process in the greenery system, see Fig. 6. Although July and August were hot months, solar radiation was not very high due to overcast skies and heavy rainfall during this period. The maximum and minimum daily solar radiation values were 1869 Wh/m^2 and 129 Wh/m^2, respectively. The average daily solar radiation was 921 Wh/m^2. During the period from 24th - 27th July and from 14th - 20th August, the measurement equipment was not working correctly and data is missing. Solar radiation often peaked at 15:00 because the main orientation of the house is South-West.

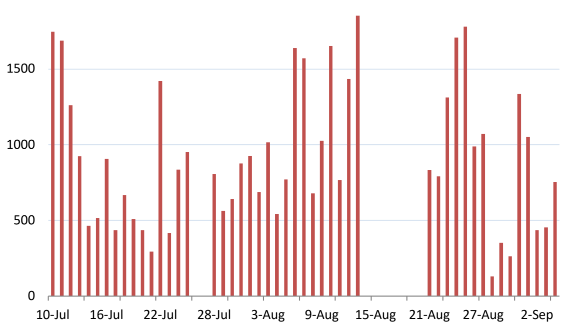

FIG. 6 Daily solar radiation during the experiment period (Wh/m^2)

4.2 THERMAL PERFORMANCE

4.2.1 Thermal performance of the two rooms

This part presents an overview of the thermal performance by showing the highest and lowest daily temperature of the two rooms during the whole period (Fig. 7) and on one of the hot days during this period, July 31st, in the cross section (see Fig. 8).

In general, the minimum outdoor temperature was not lower than 25°C. The maximum daily outdoor temperature varied during the period. Outdoor air could reach up to 42°C on the hottest day while the peak temperature on the coolest day was only 27°C. Although this was summertime, the rainfall could be really heavy and constant on some days, which caused a fluctuation in the temperature measured. The indoor temperature generally had a smaller fluctuation range and did not exceed 35°C. In all cases, the peak temperature of the second-floor room was generally higher than on the first floor room.

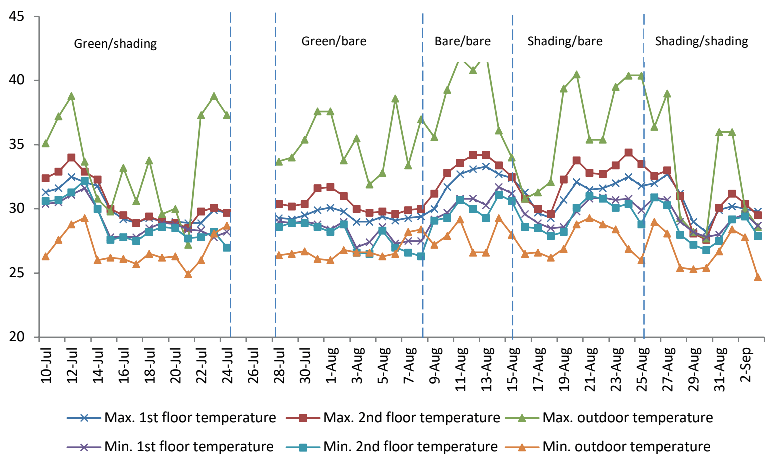

FIG. 7 Maximum and minimum daily outdoor and indoor temperature (°C)

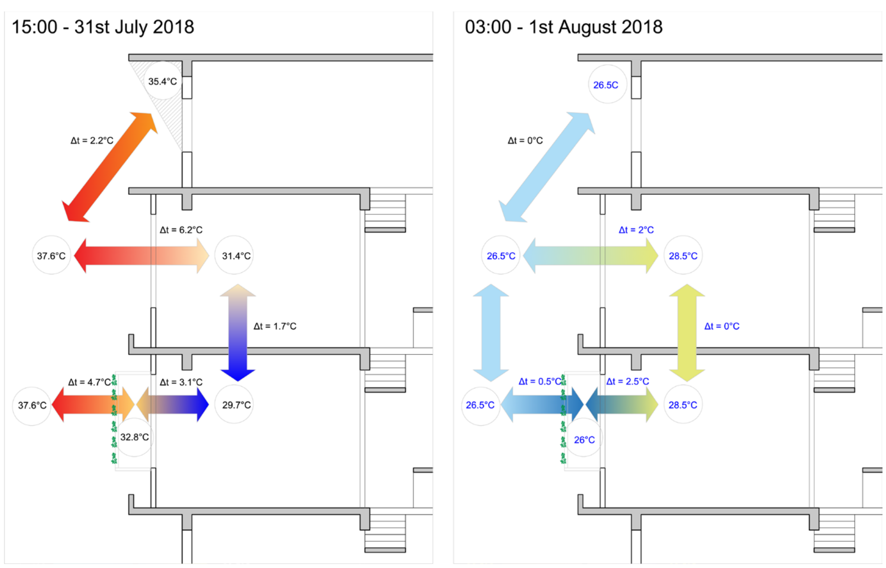

FIG. 8 Peak day time temperature at 15:00 on the 31/7/2018 and lowest night temperature at 03:00 on the 01/8/2018

Regarding the performance on 31st July, the outdoor temperature reached as high as 37.6°C at 15:00 and cooled down to 26.5°C at 03:00. A thermometer placed outside the 3rd floor showed that in the shaded area on the terrace the outdoor temperature was reduced to 35.4°C, which was 2.2°C lower than the temperature in the unshaded area. The climbing plants on the first floor provided significant cooling as the air temperature decreased 4.7°C to 32.8°C. The first-floor room was the coolest indoor space, where the temperature went down to 29.7°C, a 3.1°C further reduction behind the external wall with window glazing. Surprisingly, the indoor temperature of the second-floor room was also as low as 31.4°C, which led to a 6.2°C difference with the outdoor temperature, a relatively great difference compared to the expected outcome of a bare façade without shading or greenery. This also meant that the indoor temperature difference between the two floors was only 1.7°C. It is also worth noting that on 31st July, the maximum solar radiation was only 209 W/m^2, hence the effect of direct solar gain was not so significant. Such a minor difference was also believed to be due to the heat transfer between the floors. As the rooms accumulated heat during the day and peaked at 15:00, there was also a heat transfer through the slab between the floors which dragged the air temperature of the spaces closer to each other. The performance difference between the two façade types might be larger.

On the following night, the outdoor temperature lowered to 26.5°C. As can be seen from the figure, the indoor temperature was the same at 28.5°C, 2°C higher than outdoors, regardless of the façade type. The green façade in this case did not have much influence on the indoor temperature.

4.2.2 Temperature of a room over the course of a day

The relation between the indoor and outdoor temperature was examined by plotting the values against each other in different periods (see Fig 9). The measurement period was from 18th - 24th of August. Each of the colours represents temperature values over the course of one day, measures at 15-minute intervals. The two values do not have a simple linear relationship. The daily temperature pattern has a looped shape that comprises of two curves. The temperature often rises following the lower curve, peaks around early afternoon, and then slowly cools down following the upper part of the curve. For some days, although the outdoor temperatures were similar, the indoor values were different because the starting temperature of each day was different. In other words, the indoor temperature also depends on the average temperature of a longer period rather than just on one-day weather conditions. Internal heat gains accumulated after a few days could result in higher indoor temperatures compared to the first day. Therefore, analysing the thermal performance of the rooms should cover a longer period with constant microclimate conditions. A stable external environment in an extended period leads to more accurate performance of the internal space, enhancing the validity of the comparison.

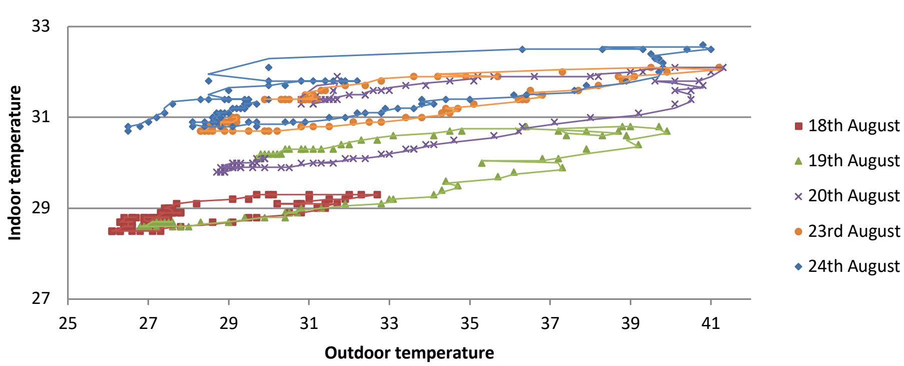

FIG. 9 Indoor and outdoor temperature of the first floor room with shading device (18th - 24th August)

4.2.3 Comparison of thermal performance for different scenarios

Scenario 1: Similar façade (9th – 15th August & 26th August – 3rd September)

Due to the fact that the experiment was based on a real case study, the experiment started with a comparison between two façade types (green façade & bare façade) and ended with a scenario in which the two floors had the same façade type. The latter period aimed at examining the similarity in performance of the two spaces by comparing thermal data. There were two periods in which the two floors had the same configuration. The first period was from 9th - 15th August, during which both façades were unshaded. During the last period, from August 26th to September 3rd, both windows were shaded by similar aluminium shading devices.

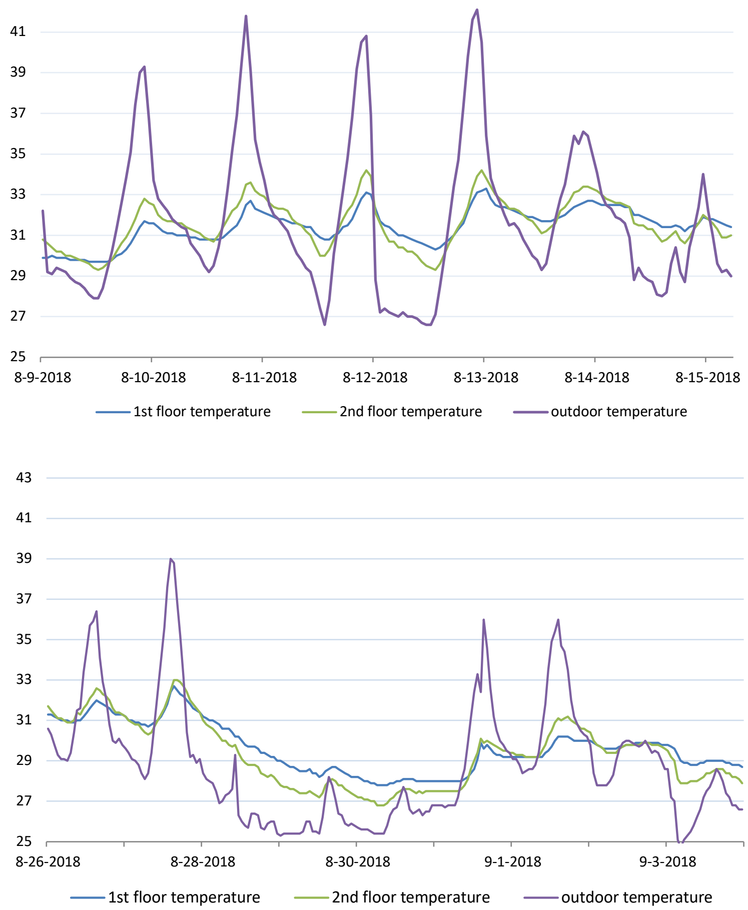

FIG. 10 Outdoor and indoor temperature of the two floors (°C) [above] 9th - 15th August (unshaded façade)[below] 26th August - 3rd September (aluminium shading devices)

Regarding the indoor temperature, although the shape of the graphs was similar, there were still differences of up to 1°C throughout the days (Fig. 10). During the days, the second-floor room was often slightly warmer during daytime and cooler at night, compared to first floor room. The correlation between the indoor temperatures of the two floors is shown in the scatter graph in Fig. 11 with R^2 values of 0.81 for the first period and 0.93 for the latter. However, the values deviate from the average fit lines. Such behaviour can be explained by the slightly larger exposure of the second floor; a part of the second-floor ceiling was the 3rd front balcony floor. Another reason could be the thermal mass effect of the floor layers. The second floor is closer to the roof and acts as an insulation layer for the first floor. Therefore, the upper room heated up at noon and cooled down at night more quickly than the lower one.

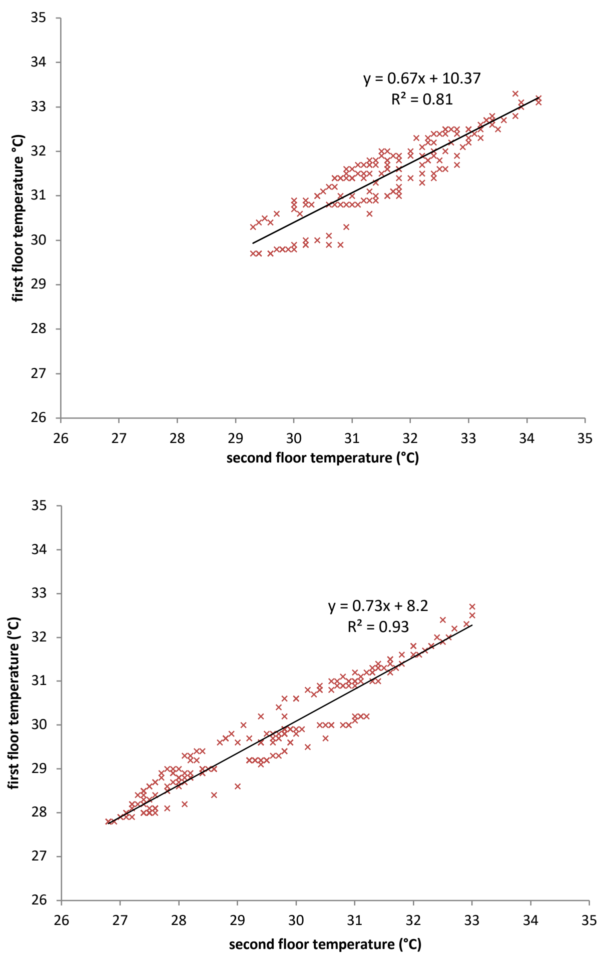

FIG. 11 Scatter plot of indoor temperature of the two floors (°C) [above] 9th - 15th August (unshaded façade)[below] 26th August - 3rd September (aluminium shading devices)

The thermal mass effect was also found while comparing the indoor temperature of the first floor, second floor, and third floor (top floor), as shown in Fig. 12. The lowest floor temperature, indicated by the blue line, did not vary and the top floor temperature (green line) fluctuated the most.

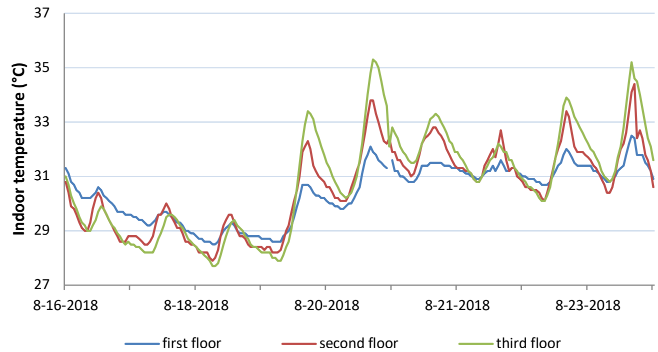

FIG. 12 Indoor temperature of the 1st, 2nd & 3rd floor during the period from the 16th - 24th August (°C)

Although the two rooms were configured similarly, it is important to note that indoor temperatures were not exactly equivalent. Nonetheless, the strong correlation in performance of the two spaces with same façade settings is significant enough to continue comparing the performance of the rooms in other scenarios.

Scenario 2: Green façade & unshaded façade

Throughout a two-week period, from 27th July - 9th August, the green façade on the lower floor was kept and compared to the unshaded façade on the upper floor. The rooms were naturally ventilated during the first week and air-conditioned during the afternoon of the second week. The thermal performances of the rooms were measured during the first week and are shown in Fig. 13.

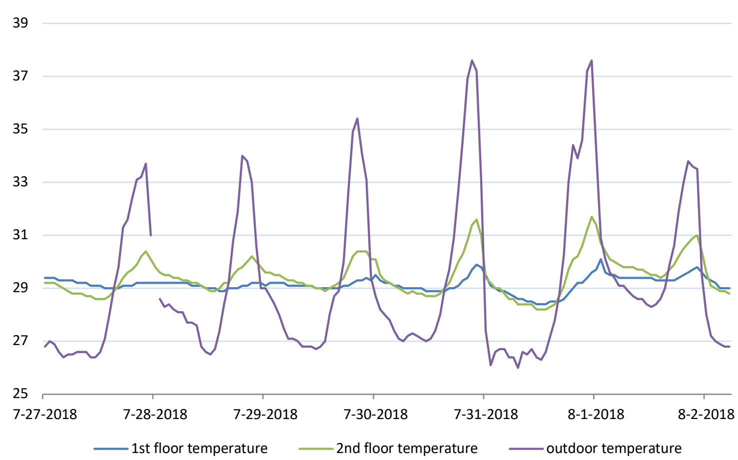

FIG. 13 Indoor and outdoor temperature measured on the 1st & 2nd floor from July 27th – Aug 2nd (°C)

At night, there was no temperature difference between the two spaces. The indoor temperature of the second floor rose more quickly during the daytime and peaked at around 2°C higher than the lower floor temperature.

Two ways are suggested to compare the performance of the two façade types. The first method is to directly compare the indoor temperature of the two rooms over the same period (27th July - 2nd August), when one room was unshaded (second floor) and the other room was covered with a green façade (first floor). With this method, the thermal mass effect or difference in the levels of the rooms need to be considered (see Scenario 1). With the second method, the thermal mass effect can be eliminated by comparing the performance of the same first floor room over two different periods, in which the room was unshaded (9th - 15th August) or equipped with a green façade (27th July - 2nd August). This method does not take into account the difference in other climate factors, such as solar radiation, wind speed, relative humidity or precipitation.

Comparing two rooms in the same period (27th July – 2nd August)

This part compares the thermal performance of the first floor (green façade) and the second floor (bare façade). Fig. 14 shows the indoor temperature difference between the two floors and the outdoor temperature over the same week. The climate condition of the week was stable as 4 out of 6 days the outdoor temperature ranged from 26 to 35°C. During those days, the temperature difference was around 1 - 1.2°C. The other two days had a higher peak temperature of 37.6°C resulting in a higher indoor temperature difference. The green façade room was up to 2.1°C cooler than the other.

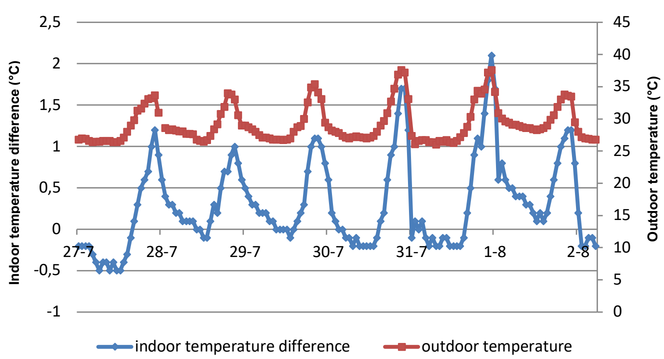

FIG. 14 The indoor temperature difference between first floor (green façade) and second floor (bare) and outdoor temperature (July 27th - August 2nd)

Taking into account the differences in the levels of the rooms (as discussed in Scenario 1), the temperature difference of the two rooms in the period 9th - 15th of August, when both rooms where unshaded, was plotted in Fig. 15. During the first four days, the maximum outdoor air temperature was high, ranging from 39.3°C to 42.1°C. However, the temperature difference was only around 1°C. On the 15th of August, when the maximum outdoor temperature was only 34°C, the indoor temperature of the two rooms were very similar, with the highest temperature difference only 0.1°C. Combining the results of the two periods, the green façade is shown to lower the indoor temperature by at least 1°C compared to the bare façade (temperature difference of 2.1°C compared to 1°C on warmer days, and 1°C to 0°C on cooler days). This result is similar to Chen's findings (Chen et al., 2013), where the living wall system helps to reduce the indoor temperature by 1.1°C.

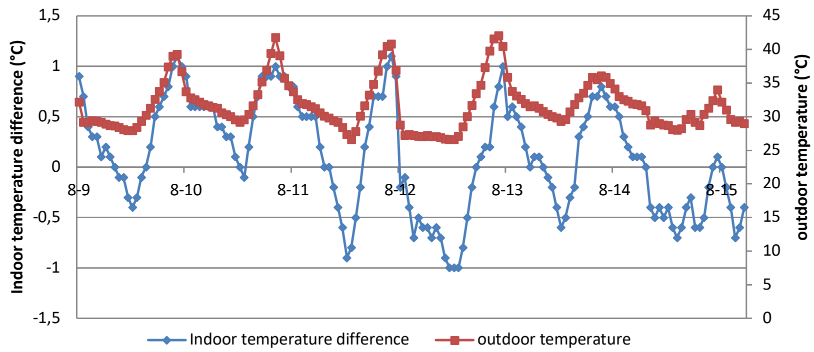

FIG. 15 The indoor temperature difference of the two floors (both bare façade) and outdoor temperature (09th until 15th of August)

Comparing the same room in two different periods

Fig. 16 shows the indoor and outdoor temperature of the first-floor room against each other during the two periods mentioned in the second comparison method. The differences in indoor temperature during the same outdoor temperature are visibly quite large (2°C on average). However, section 4.2.2 showed that indoor temperature also depends on the average temperature of the building over a longer period. The average indoor temperature in the two periods are not the same because the outdoor temperatures are not the same. Therefore, the benefit of the green façade over the bare façade cannot be proven if based solely on this comparison.

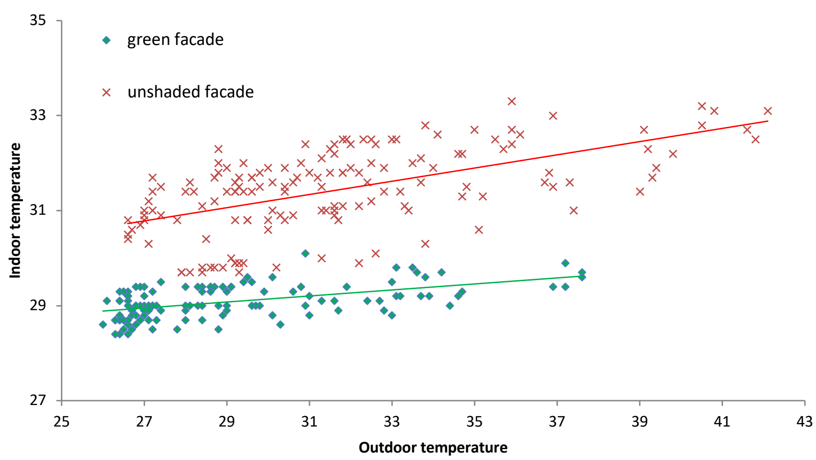

FIG. 16 Indoor and outdoor temperature of the 1st floor with a green façade (July 27th - August 3rd) and an unshaded façade (August 9th – 15th)

Scenario 3: Shading device & bare façade (16th – 24th August)

This part discusses the benefit of a shading device on the performance of the rooms. During the period from 16th - 24th August, the first floor was shaded by the aluminium shading device while the upper floor was unshaded. Measured data of indoor and outdoor temperatures were shown in Fig. 17. There are differences in indoor temperatures between the two rooms. The second floor (bare façade) was warmer during the day and cooler at nights and highest difference was 1°C at noon. However, since the performance of the two rooms is different even when the façades are the same, such a comparison might not accurately reflect the difference in performance of the two façade types. Therefore, indoor and outdoor temperatures of the 1st floor during the two different periods were plotted in Fig. 18. The first period is 9th - 15th August where the room was unshaded, the second period is 16th - 24th August where the room is shaded by the aluminium shading device. In both periods, the second-floor room was unshaded. Generally, the shading device helped to reduce the indoor temperature of the room. The differences peaked at around 1°C when the outdoor temperature is not high (27 - 29°C). At higher outdoor temperature (higher than 35°C), the average temperature difference is not more than 0.5°C. The larger effect at a lower outdoor air temperature range can be explained by the difference in outdoor conditions of the two periods. During the shaded period (16th - 24th August), the maximum air temperature was lower than 32°C, see Fig. 18. & Fig. 17.

As discussed above, both shading devices and greenery improve the performance of the tube house façade by lowering the indoor temperature in warm weather conditions. Considering the above results, the green façade is believed to have a slightly better cooling effect when compared to the shading device.

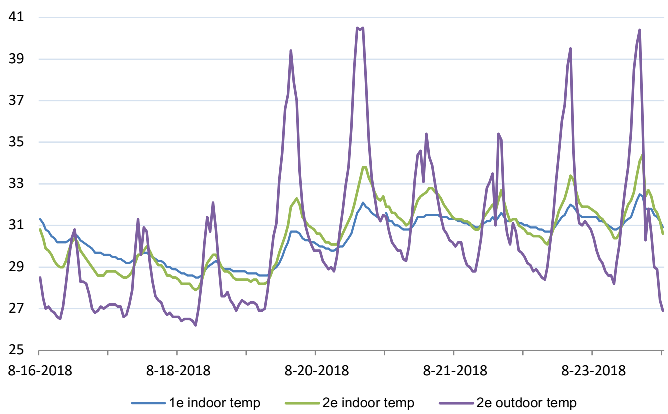

FIG. 17 Indoor and outdoor temperature of 1st & 2nd floor during the period from 16th - 24th August (°C)

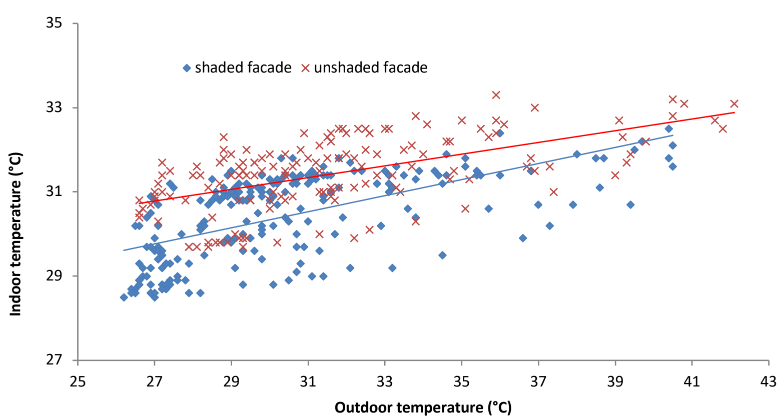

FIG. 18 Indoor and outdoor temperature of the 1st floor when unshaded (9th – 15th August) & shaded (16th – 24th August)

4.3 ENERGY PERFORMANCE

There were 2 periods in which air-conditioners were being used and monitored for assessing the energy performance of the different façade types. The first period was 15th - 24th July, with the green façade on the first floor and a shading device on the second floor. Air-conditioners were used on 15th, 16th, 17th, 23rd and 24th July. The air-conditioner was used for a total of 25 hours. The cooling set-point was 27°C, based on a study of adaptive thermal comfort by Nguyen (Nguyen et al., 2012)effective temperature, standard effective temperature . There was not much difference in the consumption during the first three days when the outdoor temperature was not high (Fig 19). Moreover, in the first three days, 5 hours of air-conditioning were divided in two sub-periods of 2 hours and 3 hours, from 12:00 until 14:00 and from 16:00 until 19:00. Because it takes some time to cool the space to the desired temperature level, a short air-conditioned period can lead to a minimum difference in performance of the two rooms. On 23rd and 24th of July, the outdoor temperature was higher and the air-conditioned period was 5 consecutive hours and a different consumption was recorded. In total, the first-floor unit consumed 12.39 kWh while the upper room's consumption was 14.75 kWh. The difference was 12.5% in total cooling energy.

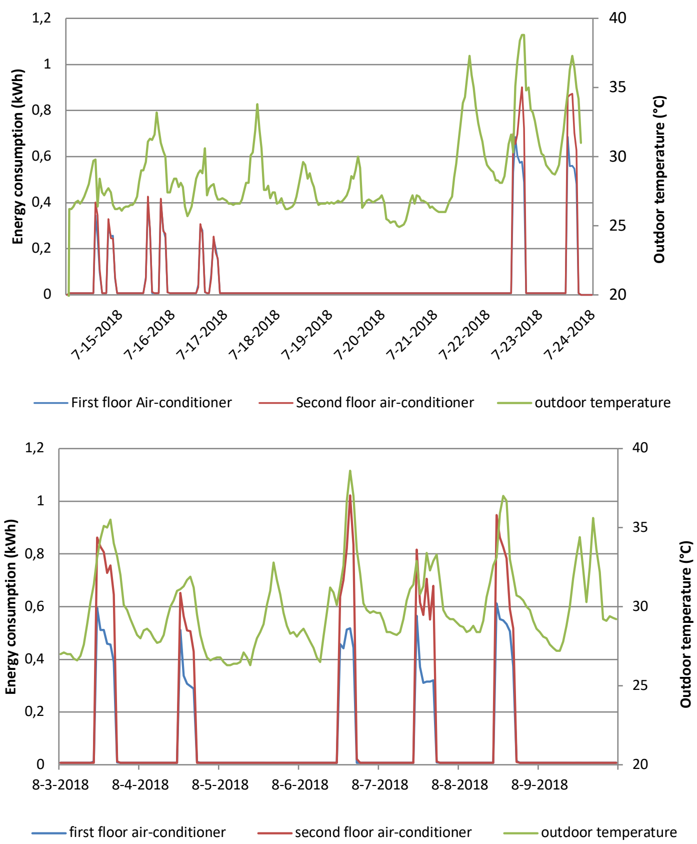

FIG. 19 Air-conditioner electricity consumption of the two rooms (kWh) and outdoor temperature (°C)[a] 15th July – 24th July [b] 3rd August – 9th August

The second air-conditioned period was from 3rd - 8th of August, with an exception made on 5th August. There was a green façade on the first floor and an unshaded façade on the second floor. The cooling set-point was 27°C and the heating hours were 5 consecutive hours during the day, from 12.00 until 17.00. The difference in the consumption was clearly seen in Fig. 19. The first floor required much less energy to be cooled down compared to the second floor. Energy consumption was 13.44 kWh and 20.87 kWh for the first floor and second floor respectively, which resulted in an energy saving of 35%.

5 DISCUSSION & CONCLUSION

The two rooms were configured exactly the same way in two floors and they were tested for difference in performance. The higher room is warmer when the outdoor temperature is higher. The maximum difference was in the afternoon when the outdoor temperature was at its peak. When outdoor conditions were cooler (at night or cooler days), the higher room had a lower temperature. This difference in thermal performance alerts the follow-up tests to take this effect into account as a boundary condition.

During the 2 months of experimental period, the outdoor environment was not stable. There were some hot days where the temperature exceeded 40°C and there were cooler days with lots of rain. This had some effects on the results of the paper. Similar research in the future is recommended to consider this boundary condition before conducting an experiment to enhance the quality of the results. The indoor temperature of the green façade room and the bare façade room were compared. The first test compared two different rooms (first floor and second floor) in the same period and the other test compared the same first floor room in two different periods. Both showed that there is a potential reduction of up to 1°C in indoor temperature by applying a green façade.

A room with an aluminium shading device was also tested. The shading device was equally effective as the green façade, for example, 1°C lower in indoor temperature compared to the bare façade, when the outdoor temperature is not too high (lower than 30°C). However, when the outdoor temperature rises beyond 30°C, the aluminium shading device became less effective and the peak difference was only 0.5°C.

Despite little improvement compared to the shading device, the green façade is still recommended in this specific case because of the following reasons. Firstly, measurements of temperatures just behind the green façade show that the green façade can help to reduce the outdoor temperature and improve the thermal performance of outdoor spaces. A lot of houses with green façades can contribute to a greater improvement in the urban scale. Secondly, plants and trees in general have many other benefits such as purifying the air, noise cancellation, creating a relaxing atmosphere for the occupant, etc. Finally, in terms of thermal performance, the leaves of this climbing plant will naturally fall off during winter season which allows direct solar gain and hence reduces heating costs.

In terms of energy consumption, the green façade in this case could save up to 35% of the cooling demand during the days, if the air-conditioners were used for 5 consecutive hours. Such a difference might be due to the 1°C temperature difference provided by the green façade, as discussed in section 4.2.3. During the cooler days, the energy consumption for cooling is less, hence the energy saving of the green façade is also lower, or the air-conditioning is even not necessary. A significant energy saving was seen when the peak outdoor temperature was higher than 33°C.

Energy savings on winter days for heating need further investigation to gain a better assessment of the benefits of a green façade.

The current construction of the building is lightweight masonry, single glazed windows, no thermal insulation, and high infiltration rate. Such practice is very popular in Vietnam as it is believed to enhance passive cooling, removing heat from the building. However, as the outdoor conditions are becoming hotter, especially in the urban area, using an air-conditioner is often inevitable. In that case, it is recommended that residential buildings need a higher performance envelope. It can prevent heat gain from the external hot air temperature and save further cooling energy. It is also suggested that, for the same total duration of air-conditioning period, air-conditioners should be used in an uninterrupted period, rather than in multiple, separated shorter periods, for better energy saving.

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