Design Solutions to Improve Comfort in CEAT Lounge

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Abstract

The CEAT Lounge is the main social space at the College of Engineering and Agro-Industrial Technology (CEAT), University of the Philippines Los Baños. It serves as a meeting place, study, and dining area for the students. The CEAT Lounge is a semi open space, a concrete structure with a metal sheet roof and no walls. The current design does little to protect its users - the students, from the hot, humid, and rainy climate of the Philippines. The metal sheet roof increases the temperature inside, while the large openings allow direct solar radiation to hit the space, which makes the space uncomfortable. In addition, during the monsoon season the space is exposed to both rain and wind, rendering it unusable. The project's objective is to improve the students' comfort inside the lounge. Solar radiation study was performed to investigate how direct solar radiation heats up the space. Different roof build-ups were explored to reduce longwave infrared radiation. Hourly transient thermal simulations were done to assess users' comfort inside the space for the entire year. Low-tech solutions such as putting parapets, and opaque screen at the top of the open walls are recommended to block direct sunlight. The roof, being exposed to the sun all day long was improved by increasing the solar reflectance and adding insulation with low-e coating. Transparent operable wind and rain protection was installed in the wall openings to shield it from rain and wind. Fans were added to enhance thermal comfort by providing elevated air speed when the operable shade is in use. The next step is to coordinate with the college administration, students, and alumni to implement the proposed design solutions at the actual site of the CEAT Lounge.

1. Introduction

Figure 1. CEAT Lounge full of students

Table benches serving as dining, study, and hangout areas fill the CEAT Lounge, the main social space at the College of Engineering and Agro-Industrial Technology (CEAT), University of the Philippines Los Baños. It is the designated spot for academic student organizations and where the only canteen in the college is located, hence the space is always occupied with students as well as faculty and staff as seen in **Figure 1**.

The CEAT Lounge is a 10 x 30 m semi open space, a structure with metal roof, no walls, and concrete floor and columns. The roof is made up of a single sheet metal with a rusty, faded green paint outside. This build-up does little in making its users comfortable against the hot, humid, and rainy climate of the Philippines. This discomfort is more pronounced at the lounge's location, which belongs to a climatic type with distinct wet and dry seasons from May to October and from November to April, respectively (Ella, 2006). The metal sheet roof increases the temperature inside, while the large wall openings allow direct solar radiation to enter the space, which makes the users feel uncomfortable. In addition, during the monsoon season, the space is exposed to both rain and wind rendering it unusable.

Hence, this project aims to provide a more comfortable space for the students. Also, this project hopes to promote awareness and start a campaign across the whole university about climate responsive design.

2. Methodology

2.1 Thermal simulation

Thermal comfort of users with the existing build-up of the CEAT Lounge was assessed by performing annual hourly transient thermal simulations using TRNSYS 18 with the Grasshopper plug-in TRNLizard.

The lounge having no walls means it is naturally ventilated which is equivalent to an outdoor environment. Hence, standard effective temperature (SET) which is suited in evaluating outdoor spaces (Kinouchi, 2011 as cited by Honjo, 2009) was used as the metric for thermal comfort. It accounts in relative humidity, mean radiant temperature, air velocity, as well as activity rate and clothing levels (ANSI/ASHRAE Standard 55-2010).

SET of 17.5 – 30 °C was selected as an extended comfort range (slightly cold to slightly warm) as shown in **Table 1**. This range was considered comfortable because in naturally ventilated buildings, thermal perceptions and tolerance are likely to make the occupants accept a wider range of temperatures because of thermal adaptation which can be mainly attributed to behavioral adjustments and psychological adaptation (Brager, G.S., de Dear, R.J. as cited by Gou, Z, et al., 2018).

Table 1. SET comfort range

SET (° C)	Sensation	Physiology
37.5 - 44	Very hot, great discomfort	increased disruption of evaporative regulation
34.5 - 37.5	Hot, very unacceptable	profuse sweating
30 - 34.5	Warm, uncomfortable, unacceptable	sweating
25.6 - 30	Slightly warm, slightly unacceptable	slight sweat, vasolidation
22.2 - 25.6	comfortable, acceptable	physiological thermal neutrality
17.5 - 22.2	slightly cool, slightly unacceptable	initial vasocontriction
14.5 - 17.5	cool, unacceptable	slow body cooling
10 - 14.5	cold very unacceptable	beginning of shivering

Table from *Predicting outdoor thermal comfort in urban environments: A 3D numerical model for standard effective temperature by Nazarian, Fan, et. al. (2017)*

Operation time for the thermal simulation was from 07:00 to 18:00 and number of students varies throughout the day. Weather data used was from Ninoy Aquino International Airport (NAIA) in Manila due to the unavailability of hourly data from Los Baños, Laguna.

2.2 Hot roof protection

Several roof variants were explored to improve the roof as depicted in **Figure 3.** These variants are divided into three groups:

A) Single sheet metal roof without insulation
B) Single sheet metal roof with insulation
C) single sheet metal roof with insulation and air gap in between

Solar reflectance of the outside roof surface (SR_{out}) was increased to 0.60 which corresponds to the color white from the existing faded green finish with SR_{out} of 0.34 (Dean Steel Buildings, 2015). This was applied to all variants to decrease the absorbed solar radiation. Variants of the inside roof surface with low-emissivity coating were also done within groups A, B, and C.

Thermal conductivity (λ) and thickness (d) of single sheet metal used are λ = 79.5 W/mK and d = 0.0004 m. For the bubble wrap, λ = 0.032 W/mK and d = 0.004 m were used.

The performance of these variants at steady-state was assessed by calculating the outside surface temperature (T_{out}), inside roof surface temperature (T_{in}), and perceived temperature (T_{feel}) using Engineering Equation Solver (EES). Boundary conditions assumed for solar radiation (Q_{sol}), sky temperature (T_{sky}), ambient temperature (T_{amb}), inside space temperature (T_{space}) and soil temperature (T_{ground}) used were:

$Q_{sol} = 450$ W/m²
$T_{sky} = 12$ °C
$T_{amb} = 28$ °C
$T_{space} = 28$ °C
$T_{ground} = 27.5$ °C

Q_{sol} of 450 W/m² was used since most of the hourly solar radiation values from the weather data lie below this value as shown in **Figure 2**. Convective heat transfer coefficients were assumed to be 10 W/m²K on the outside roof surface (α_{out}) and 3 W/m²K on the inside roof surface (α_{in}).

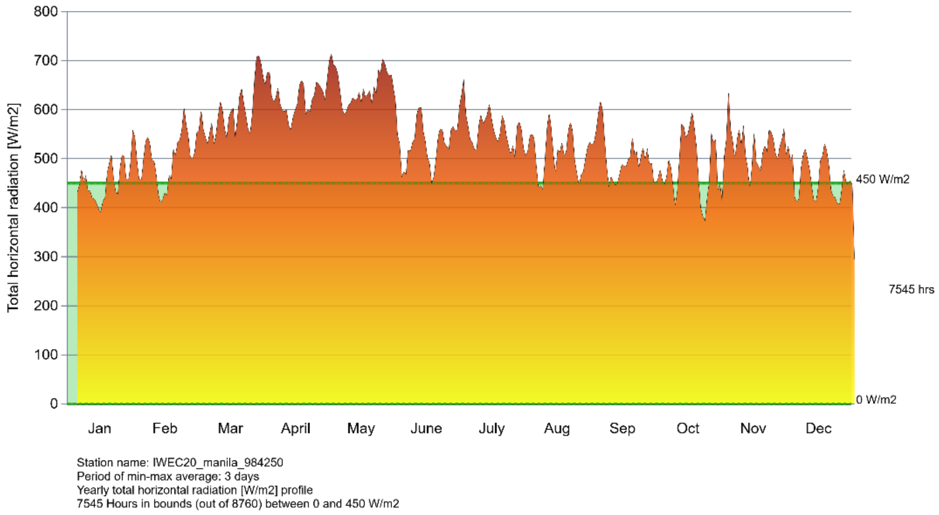

Figure 2 . Total horizontal radiaton

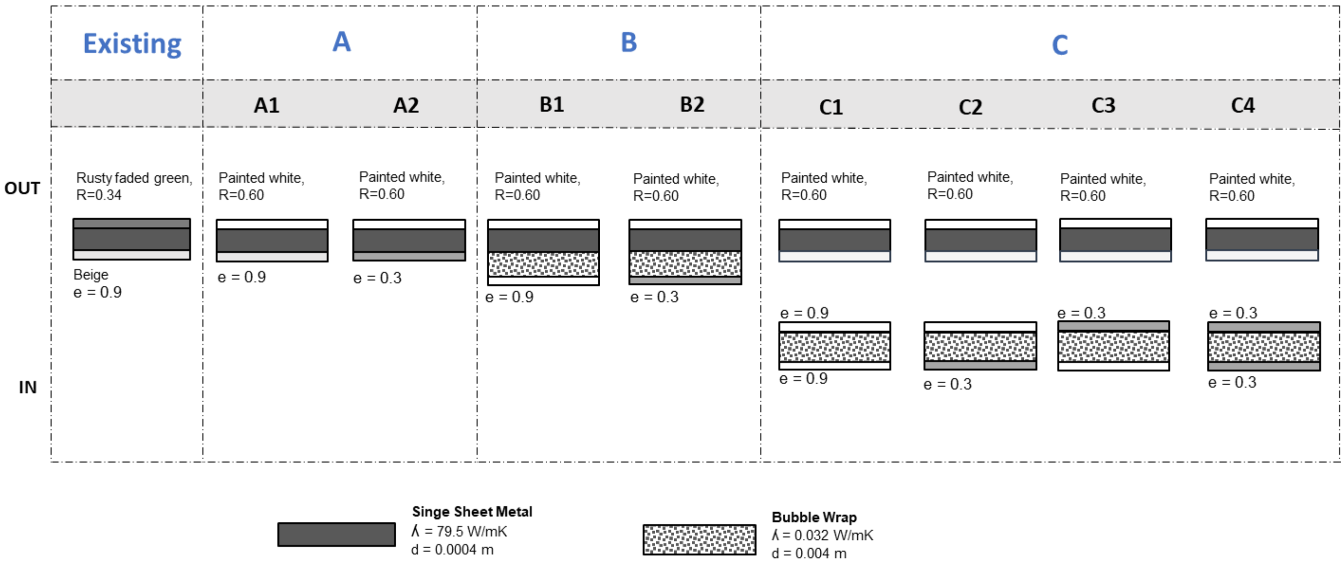

Figure 3. Summary of roof variant

2.3 Blocking direct solar radiation

Solar radiation study on the floor considering the surrounding buildings was performed using Radiance with parameters -ab 3 -ad 1024 -as 512 -ar 300 -aa 0.1.

Several design solutions of blocking the direct sun from striking the floor were explored such as extending the roof overhang and partially closing the walls while still maintaining views to the outside. See **Figure 6**. These include installing opaque screens on the upper half of the walls and putting parapets at the bottom of the wall.

2.4 Rain protection

In the current design (**Figure 4**), water enters the inside space due to the lack of walls, especially when rain is accompanied by strong winds. Therefore, rain protection was included among the design solutions. This protection was assumed to be transparent to maintain views to the outside and to allow daylight inside the space. This should be operable, to be only used when it is raining, but for simplicity in setting up the thermal model, the rain protection was assumed to be in use all the time. Thermal properties of a single-glazed glass with λ = 5.42 W/mK, and solar heat gain coefficient (SHGC) = 0.70 were used.

Figure 4. Damaged sheets

3. Results

3.1 Hot roof protection

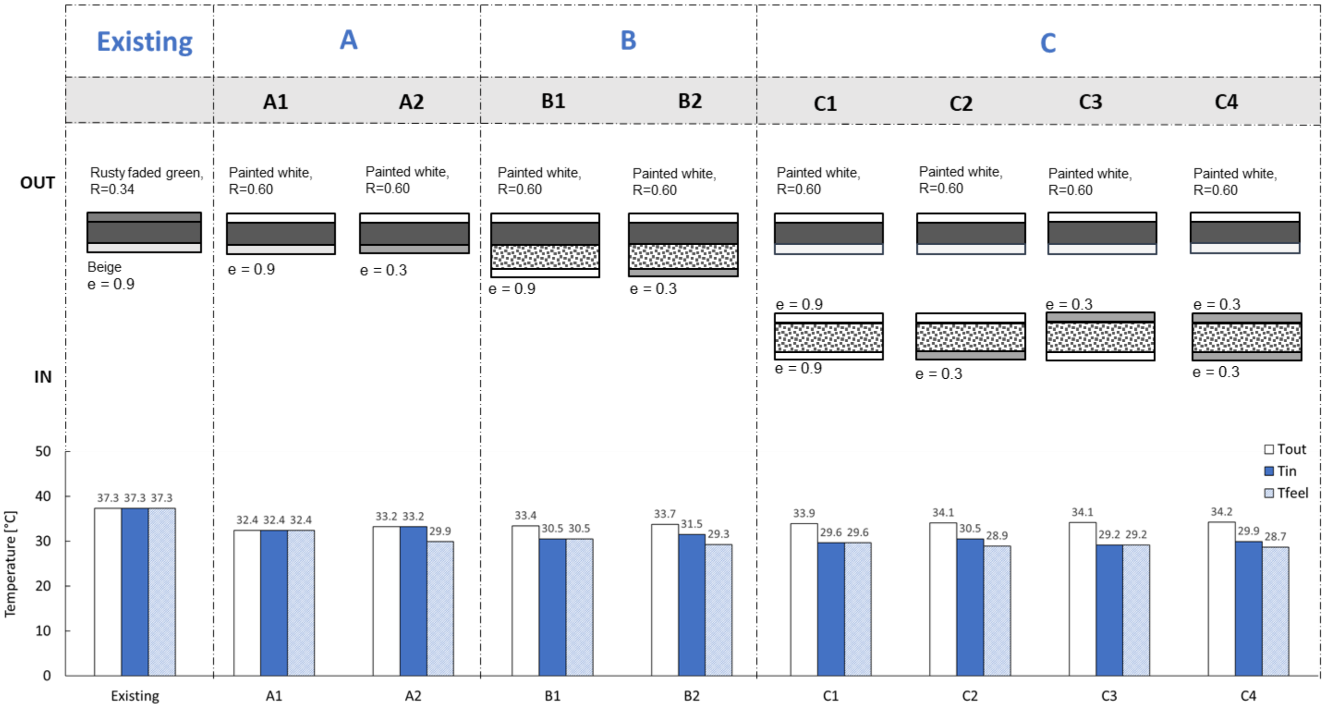

Figure 5. Performance of the roof variants

Outside surface temperature (T_{out}), inside roof surface temperature (T_{in}) and perceived temperature (T_{feel}) at steady-state were calculated for the eight roof variants as shown in **Figure 5**.

With the existing roof, T_{out} and T_{in} are 37.3 °C which is also equal to T_{feel}.

Comparing the existing roof and A1, it can be observed that **increasing the solar reflectance of the outside surface**, from 0.34 to 0.60, decreases the temperatures to 32.4 °C, since there is less energy absorbed by the roof.

Comparing A1 and A2, it can be observed that by **applying low-emissivity coating to the inside roof surface**, T_{feel} is decreased to 29.9 °C, since the heat being emitted is decreased.

Comparing A2 and B2, it can be observed that **installing insulation** lowers the amount of heat which passes through the whole roof build-up, thus reducing T_{in} from 33.2 °C to 31.5 °C and T_{feel} from 29.9 to 29.3 °C.

Comparing B1 and C1, it can be observed that **having an air gap between the sheet metal and insulation**, T_{in} and T_{feel} are reduced from 30.5 °C to 29.6 °C.

Set C explores the different placement of the low-e coating, either at the surface of the insulation facing the cavity or at the surface facing the inside space or both. Comparing the four variants in Set C, it can be observed that the lowest T_{feel} is from putting low-e coating on both surfaces of the insulation (C4).

Among all the variants, C4 has the lowest T_{feel}, 28.7 °C, which is comparable to the perceived temperature of C2 (28.9 °C). Considering that C4 requires twice the amount of low-e coating, C2 can be considered the best roof configuration among the eight variants.

3.2 Blocking direct solar radiation

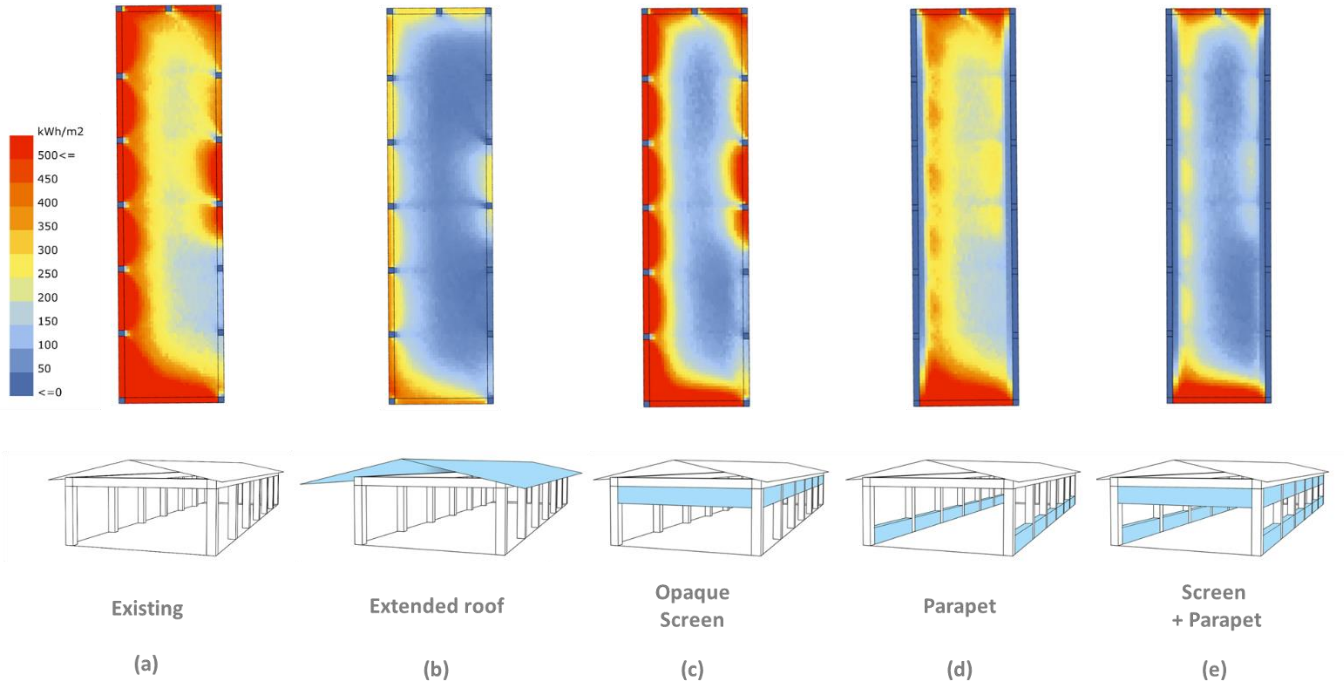

Figure 6. Annual solar radiation study on the floor using different architectural elements

(a) With the existing design, high levels of solar radiation (>500 kwh/m^2) in the perimeter is being received. Total annual radiation for the whole floor is 107.6 kWh.

(b) Extending the roof by 2 m decreased the radiation from both the high and low-angle sun. Total annual radiation is 37.66 kWh which corresponds to a **65%** reduction compared to the current design.

(c) Installing 1 m high opaque screen reduced the radiation at the center of the space, which comes from the low-angle sun. Total annual radiation is 80.92 kWh which accounts to a **24.8%** reduction from the current design. Only 1 m screen was used to maintain visual connection to the outside.

(d) Putting 1 m parapet decreased the radiation in the perimeter, which comes from the high-angle sun. Total annual radiation is to 66.6 kWh which is a **38.1%** reduction compared to the current build-up.

(e) The combined effect of using the opaque screen and parapet resulted to a total annual radiation of 39.6 kWh which is a **63.2%** decrease compared to the existing design. This is comparable to the reduction using the extended roof, but this option is preferred as large extended roof overhangs are susceptible to damage by strong winds.

3.3 Thermal comfort

After performing solar radiation study and exploring different roof build-ups, thermal comfort in the new design was assessed by performing annual hourly transient thermal simulations to see the effect of changing the various architectural elements. Standard effective temperature (SET) of 17.5 - 30 °C was considered comfortable.

Figures 7 to 12 show the SET and operative temperature (T_{op}) plotted against corresponding outside air temperature within the 07:00 – 18:00 operation time. The two horizontal lines represent the comfort band.

Figure 7 shows the SET and T_{op} with the current build-up. It can be noted that there are very low SET values (6 to 15°C) which occur in the morning and can be explained due to high wind at those times. The space is perceived comfortable **74.8 %** of the time.

Figure 8 shows the temperatures using the improved roof (C2). The maximum SET is 35°C compared to the existing design of 40 °C. However, not all hours fall within the comfort range and are perceived comfortable for only **79.6 %** of the time.

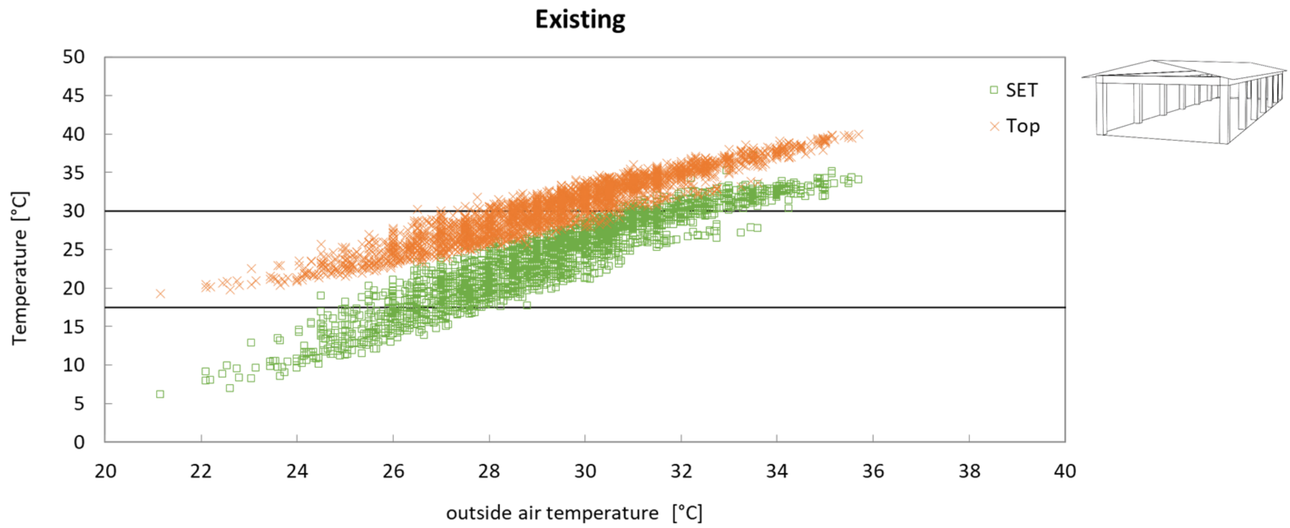

Figure 7. Existing build-up thermal comfort

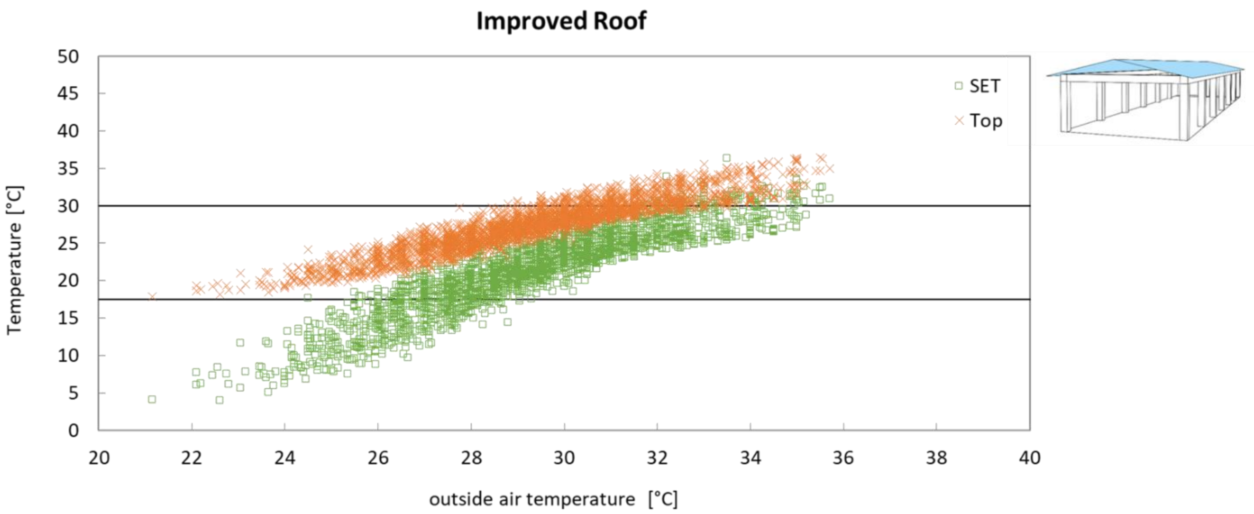

Figure 8. Improved roof thermal comfort

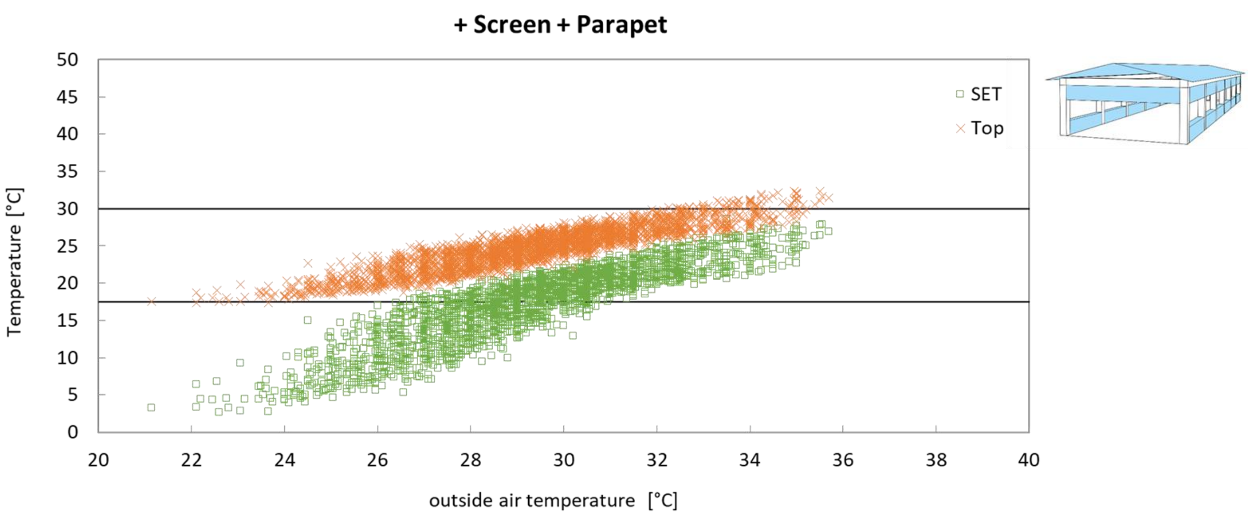

Figure 9. Thermal comfort with the addition of screen and parapet

Figure 9 shows the temperatures using the improved roof (C2) with parapet and opaque screen (e). The maximum SET is 32 °C and space is perceived comfortable **60.0 %** of the time. Hours within comfort band are lesser than previous variants due to more SET values falling below 17. 5 °C.

Figure 10 shows the temperatures when the rain protection is in use. **30.8 %** of the temperatures fall within the absolute comfortable range of 22.5 to 25.6 °C, but using the extended comfort range of 17.5 to 30 °C, **95.1 %** of the time is perceived comfortable. Low SETs from **Figure 9** are now within the comfort range.

However, there are still hours when inside space is perceived unacceptably warm. For these hours, fans can be used to supply some air movement which increases comfort as shown in **Figure 11.**

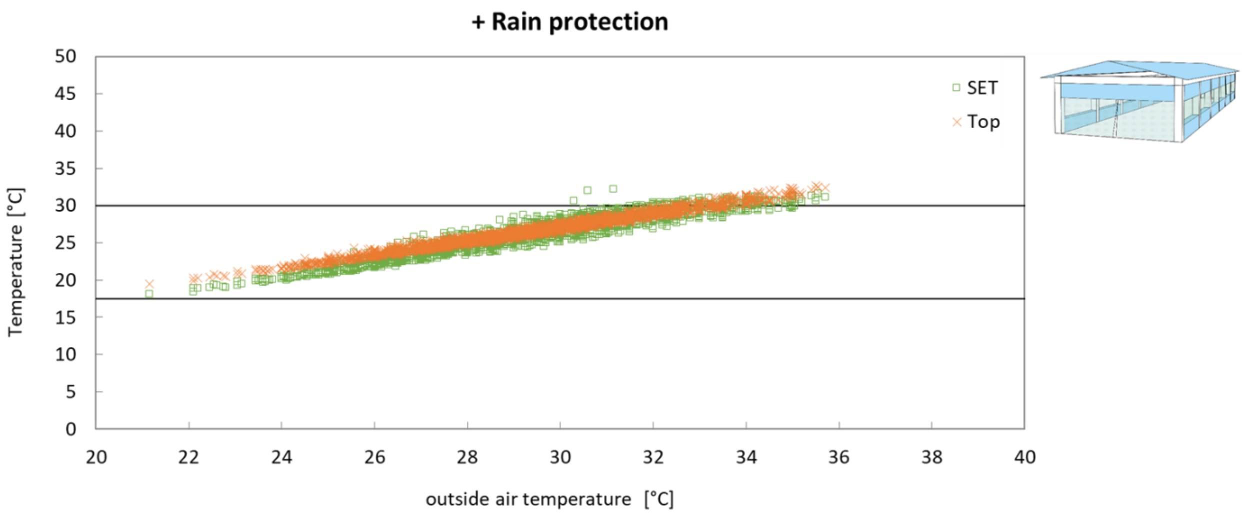

Figure 10. Thermal comfort with the addition of rain protection sheets

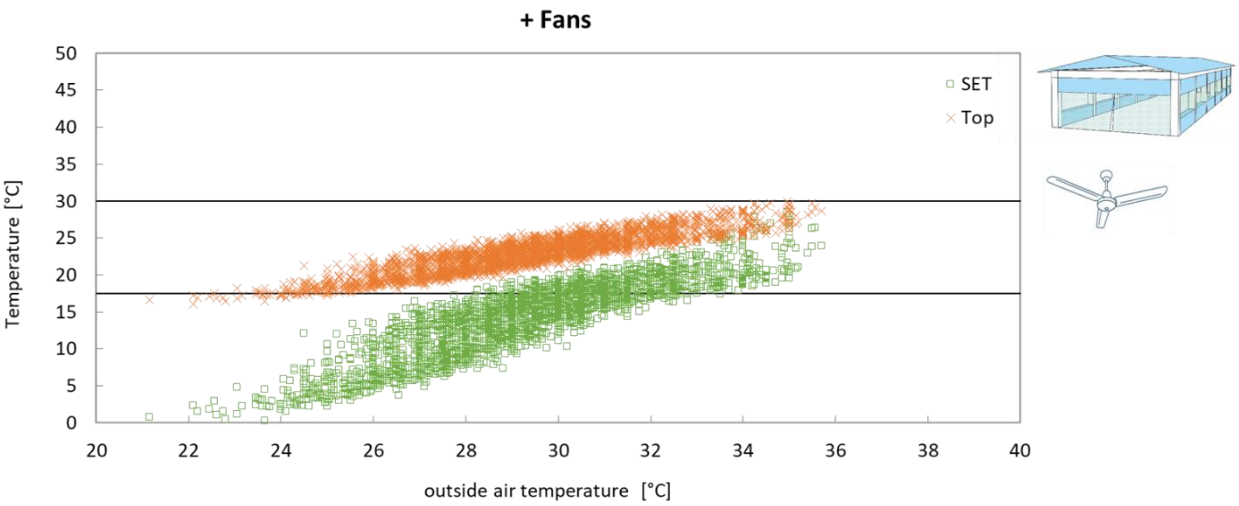

Figure 11. Thermal comfort with the addition of fans

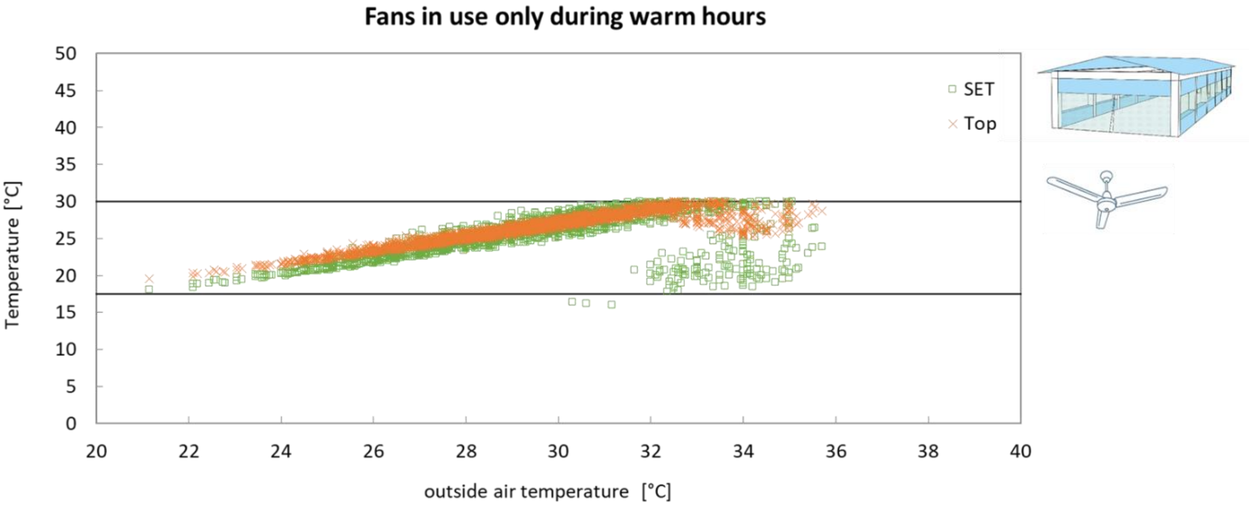

Figure 12. Thermal comfort when fans are only used during warm hours

Figure 12 shows the temperatures when the rain protection is in use and fans are turned on just when it gets too warm (> 30 °C). This shows that behavioral adjustments such as adjustments to the surrounding (turning fans, opening a window, etc.) can maintain thermal comfort. Thermal adaptation may also include adjustments made to one self, such as clothing, activity, eating or drinking (Fountain, M. et al., 1996 as cited by Gou, Z. et al., 2018).

Summary and Conclusion

The current design of the CEAT Lounge does little in making its users comfortable against the hot, humid, and rainy climate of the Philippines. Hence, this study was undertaken to develop design solutions to improve the students' comfort inside the space. In addition, it is hoped that carrying out this project will create awareness about climate-responsive design and start a campaign for low-tech sustainable design in the university

Low-tech, inexpensive solutions can be implemented in the CEAT Lounge to improve comfort inside the space. 1 m opaque screen at the top and 1 m parapet at the bottom of the open walls can block 63% of direct solar radiation from both the high and low-angle sun, while still maintaining views to the outside. The roof being exposed to the sun all day long, can be improved by increasing the solar reflectance of the outside surface by painting the roof white. This reduces perceived temperature (T_{feel}) by 7.4 K. Adding insulation with an air gap from the roof can decrease T_{feel} by an additional 2.8 K. Low-emissivity coating at roof surface facing the inside space can decrease the longwave infrared radiation, thus reducing T_{feel} further by 0.7 K. Transparent, operable sheets can protect the users from wind and rain during rainy season. Fans can further enhance thermal comfort by providing elevated air speed when the operable sheets are in use.

Outlook

For the next step, coordination with the college administration, students, and alumni associations will be carried out to implement the proposed design solutions at the actual site of the CEAT Lounge.

Recommendations

For future studies, it is recommended to assess light comfort which is important for students when studying.

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