AurovilleConsulting

KALPANA THERMAL COMFORT ANALYSIS

A comparison between occupant satisfaction and environmental comfort conditions

DECEMBER, 2020

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EXECUTIVE SUMMARY

- Data from Kalpana building complex was collected from January till July. Surveys and environmental data were collected for 42 days.
- 3 methods to evaluate thermal comfort were used: Post-Occupancy Evaluation Surveys, Predicted Mean Vote (PMV) and Adaptive Comfort model.
- Results of measured indoor data from both methods (PMV and Adaptive model) showed similar results for most of the cases.
- Results when compared to occupant's thermal sensation also showed similar results in Winter and Summer seasons, except for afternoon in Pre-summer season.
- During Winter time (January) temperature was within acceptable ranges most of the time, for both PMV and Adaptive Comfort method.
- According to the Post-Occupancy Evaluation survey, 'unacceptable' conditions during 'Pre-summer' were only found in 9% of the votes.
- During Pre-summer (March), according to the PMV calculations, 'unacceptable' conditions were found 28% of the time. According to the Adaptive Comfort model this number was found to be 55% of the time.
- According to Post-Occupancy Evaluation survey, during Summer season, 'unacceptable' conditions were found in 47% of the votes.
- During Summer seasons (May, June and July), conditions were found to be considered 'unacceptable' 88.2% of the time according to the PMV method and 80.1% according to the Adaptive Comfort model.
- Active cooling strategies are required during Summer months, especially during office hours, as external environmental conditions are too severe.

CONTENTS

1. INTRODUCTION

1.1. Justification and Background

According to ASHRAE 55 (2017), thermal comfort is "the condition of mind that express satisfaction with the thermal environment and it is assessed by subjective evaluation". Several aspects can influence thermal comfort, such as physiological aspects (height, weight, age), physical variables (air temperature, wind speed, humidity), as well as socio-psychological (state of mind) (Saint-Gobain, 2020). Among the physical aspects, there are: Air temperature (or dry bulb temperature), wind/air speed, humidity, radiant temperature, clothing insulation and metabolic rate. These parameters are combined into physical equations that predict indoor thermal conditions for building occupants.

Evaluating thermal comfort is not an easy task – since it is a psychological state of mind rather a physiological state, where physical aspects can also influence - there is no 'magic-recipe' to evaluate thermal comfort in a simplistic way, and many models have been developed so far. The most important methods, which are also described in ASHRAE 55 and ISO 7730 are the PMV/PPD[1] model developed by Fanger (1970) and the Adaptive Comfort model introduced in ASHRAE 55 in 2004. More recently, in 2010, ASHRAE introduced the Post-Occupancy Evaluation (POE) practices.

Thermal comfort can significantly impact not only health and well-being of occupants, but also disrupt work, causing heat stress and decreasing productivity of workers. Among the effects of heat stress, we can mention: the inability to concentrate, muscle cramps, sever thirst, heat exhaustion and heat stroke (Health and Safety Executive, 2013).

Thermal comfort has been gaining more attention nowadays especially due to climate change, where climate conditions become harder to predict, excessive energy demands and changes in the global economy, where understanding comfort conditions are crucial in the design of more resilient buildings (Nicol & Roaf, 2017).

[1] PMV stands for Predicted Mean Vote and PPD for Predicted Percentual of Dissatisfaction

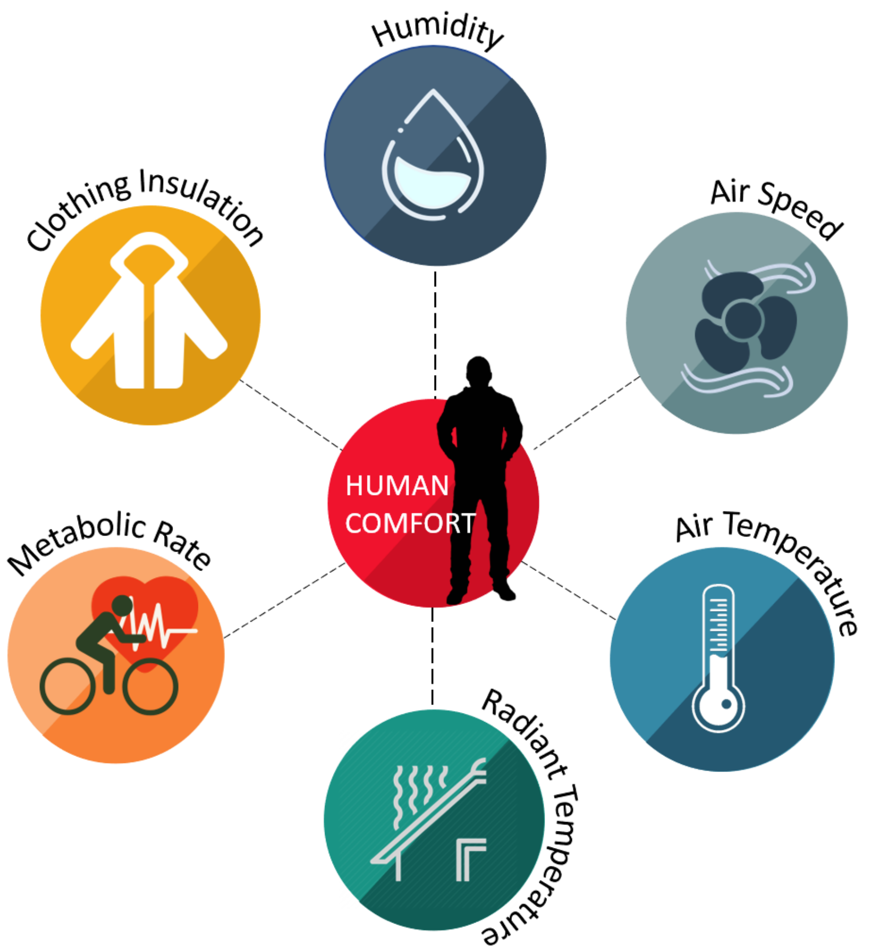
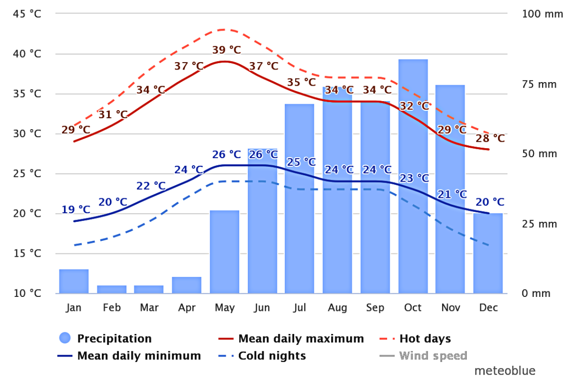


Figure 1: Physical variables that influence thermal comfort (Source: https://www.linkedin.com/pulse/role-cfd-evaluating-occupant-thermal-comfort-sandip-jadhav/)

1.2. Site Description and Climate conditions

The analyzed building is an office located in Auroville, Tamil Nadu, India. In terms of climate, Auroville has a Tropical Humid Climate. Temperature ranges from 28-29 °C in December and January, up 39 °C in May, with peaks around 43 °C, in May, the hottest month. Rainfall is scarce, with a year average of 1,250 mm per year. Most of the rainfall is concentrated in the months October through December, with occasional showers in May, June, July. Since Auroville is located near the coast, humidity is also considered high, with yearly average of 75%. However, it can get as low as 30% on hot and dry Summer days. Wind direction is predominantly southwest, but also from north-northeast.



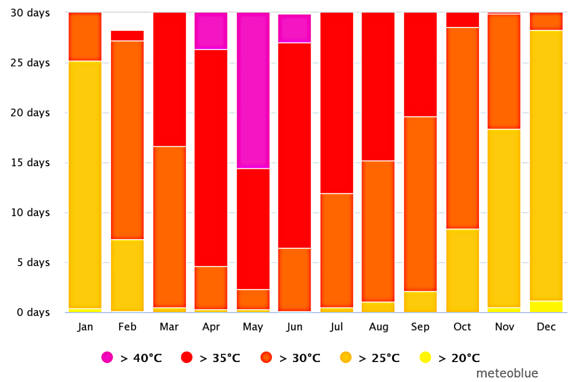


Figure 2: Temperature and hot days in Auroville (Source: meteoblue.org)

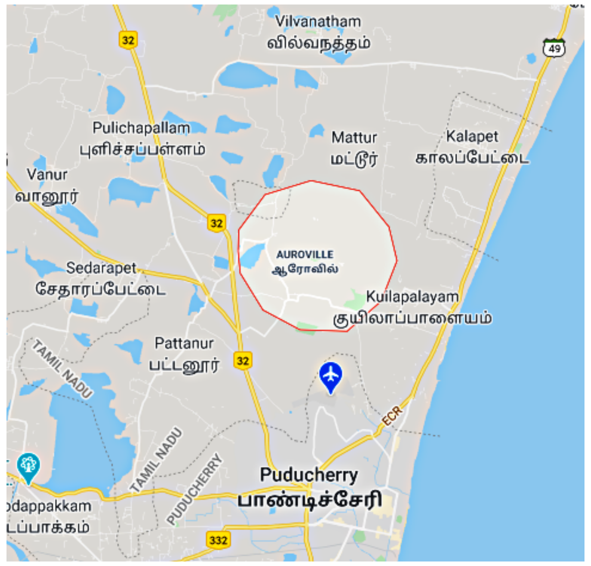


Figure 3: Auroville location and Kalpana aerial shot

The office building analyzed for this study is situated in the Kalpana apartment complex, a mixed-mode building, completed in 2019. The building is predominantly oriented northwest and the office space is situated on the west façade, 1st floor. The building has a no air-conditioner (non-AC) policy in order to minimize energy consumption and CO2 emissions. Bio-climatic design strategies were implemented to control heat gains, including AAC (Autoclave Aerated Concrete) blocks and reflective tiling on the roof. The building is also designed for natural cross-ventilation and is oriented northwest-southeast to minimize heat gains and maximize capture of predominant breeze. The building is equipped with high efficient appliances, to minimize energy consumption, including fans, over which occupants have control.

The office has a total of 30 occupants, but due to the recent COVID-19 pandemic, the occupancy number was highly variable, as people were also working from home.

2. METHODOLOGY

2.1. Data Collection

To analyze thermal comfort conditions, a twin-approach has been taken: (i) thermal comfort surveys (POE surveys) shared with occupants and (ii) daily measurement of indoor climatic conditions. These daily measurements were recorded for all days that the POEs were circulated.

43 surveys were conducted over a 5-month period from January to July 2020, covering both the hottest months of the year and some of the cooler months. For the purpose of this study, seasons were divided as follows: Winter – January and February; Pre-summer – March; and Summer – May, June, July. Figure 4 reflects the days that the surveys were taken against external temperature. A total of 1,304 answers were collected over the analysis period of 5 months.

Office occupants were asked to fill the surveys for 4 time slots of the working day – early morning (between 8-10am), late morning (10-12am), Afternoon (1-3pm) and Evening (3-5pm). For each of these time slots, occupants were required to rate their subjective thermal comfort from 1 to 7 (or -3 to +3 in the 7-point scale). Other questions in the survey were[2]:

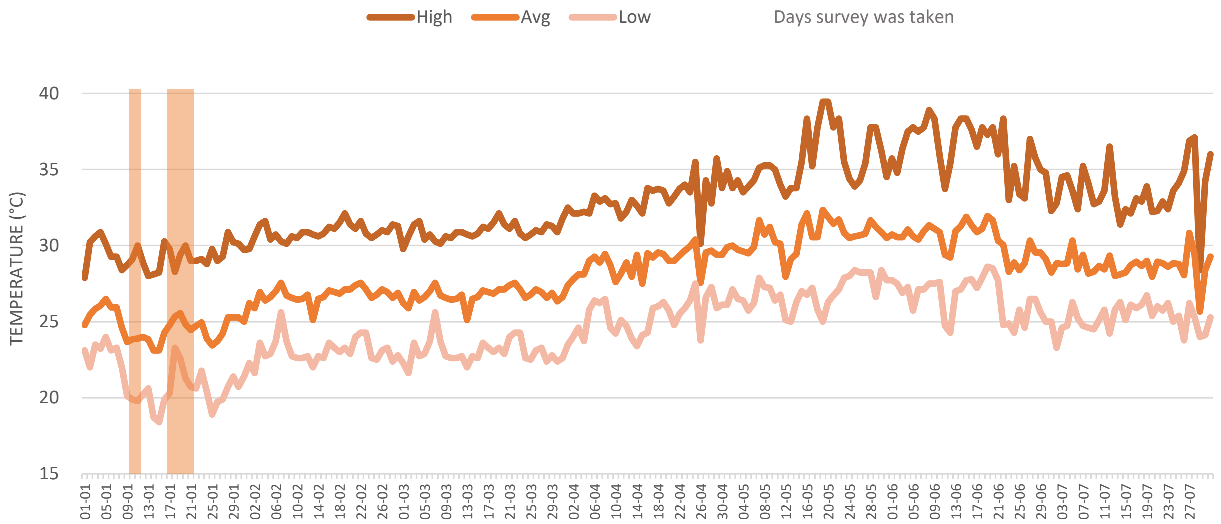


Figure 4: Days survey was taken vs Outdoor temperature

[2] Please refer to Appendix A for more details on the surveys sent to building occupants.

- Age, height and weight
- Clothing[3] (bottom and top)
- 'When do you think there is most often a problem?'
- 'What is (are) the main reason(s) for your dissatisfaction? How would you describe them?'
- 'Which of the following do you adjust when feeling uncomfortable? (multiple answers acceptable)'

In order to record environmental conditions, 3 devices were used: (i) a WBGT (wet-bulb globe thermometer), capable of reading dry-bulb, temperature, wet-bulb temperature, relative humidity and globe temperature; (ii) a hand-held anemometer for wind-speed measurements; (iii) a weather station on top of Kalpana A block to measure outdoor environmental conditions. Figure 5 shows the equipment used and the office environment where data was measured and collected.

Readings from the WBGT were taken minute by minute during working hours (9am-5pm). Measurements for wind speed were also held simultaneously as the WBGT was collecting data. Data from the weather station was collected hourly during the measurement days. Information regarding building location, environmental control devices and data collected is summarized below according to Table 1. Table 2 depicts the summary of information regarding data points and collection.

Figure 5: (a) Measurement equipment and (b) Survey environment

[3] A small catalogue of the most common garments used in office were catalogued and associated with their respective clothing insulation.

City/State	Location	Building	Environmental control device	Year	Month	No of survey day
Auroville, Tamil Nadu	12.002 N; 79.813 E	Kalpana Complex	Operable windows, Blinds, Fans, Window and door vents	2020	Jan	13
					Mar	5
					May	7
					Jun	15
					Jul	6

Table 1: Summary of survey and site information

Month	Season	Surveys collected	Measurement data points collected
January	Winter	256	4,627
March	Pre-summer	208	2,200
May	Summer	116	2,464
June	Summer	596	6,340
July	Summer	128	1,815
Total		**1304**	**19,089**

Table 2: Data collection summary

2.2. Data Analysis

The data provided in the surveys is further analyzed. The first information to be described is the proportion between male/female occupants, as this can impact significantly the analysis, since men and women have different perceptions on thermal comfort (Szokolay, 2008, p. 19). Male-female ratio are very similar, although there is slightly higher number of male occupants when compared to female. Refer to Table 3.

Gender	Total number of samples	%
Male	191	59
Female	135	41
Total	**326**	**100**

Table 3: Total samples by gender

Details on age, weight and height are provided below on Table 4. It is important to notice that perception of thermal comfort can differ based on weight and age. Refer to Table 4.

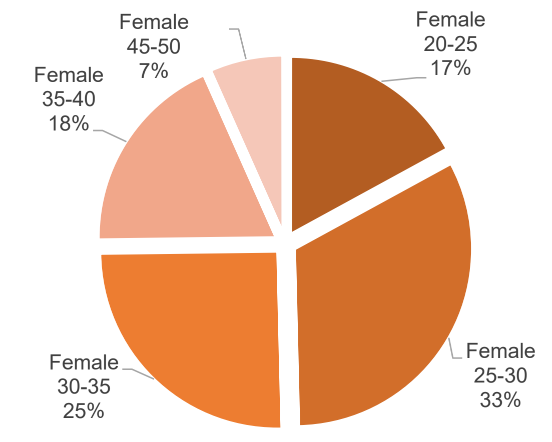
	Age	Weight (kg)	Height (cm)
Max	52.0	95.0	185.0
Mean	34.8	71.0	167.6
Min	19.0	53.0	149.0

Table 4: Population details according to the surveys

Age distribution is described below through Figure 6. Male and female are divided to show age representation in each group. Majority of both populations are around 25-30 years old, however more predominantly in male population, with 52% of data samples, while for women this numbers is at 33%, followed by 30-35 at around 25%, making women population in terms of sample slightly older.

The analyzed samples show a good uniformity regarding age distribution, gender and weight. Majority of samples have an age between 20-30 years old and around 70 kg, with no significantly overweight individuals. The distribution between male and female employees is also highly proportional.

Another significant fact while analyzing thermal comfort is clothing insulation. In general, the men who participated in this study tended to wear lighter clothes compared to women who participated in this study according to the data provided by the respondents. Values for both male and female samples are shown in Table 5.



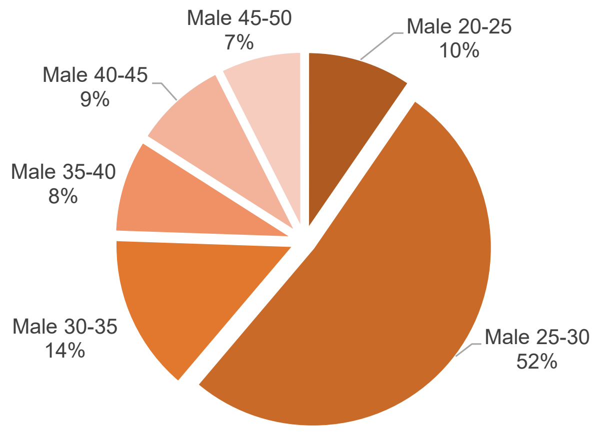


Figure 6: Male and Female population by age group

I_{cl} [4]	Male	Female	Average
Max	0.37	0.50	-
Mean	0.18	0.34	0.24
Min	0.12	0.12	-

Table 5: Clothing insulation by gender

Table 6 shows the most common garments for men and women, as their clothing insulation value. These values were further used to analyze the thermal comfort situation for male and female occupants.

Gender	Top	Bottom	Total I_{cl}	% of respective population
Male	Short Sleeve T-shirt	Shorts	0.15	77%
Female	Kurti	Salwar	0.40	24%

Table 6: Most common garments per gender

Environmental data was collected as aforementioned. The main variables, as calculated based on collected data (operative temperature and prevailing mean outdoor temperature), both from indoor and outdoor, are shown in Table 7 below.

[4] I_{cl} stands for clothing insulation. It is measured in clo and 1 clo is equal to 0.155 m2K/W, where 0 clo correspond to a naked person and 1 clo is the necessary insulation to keep a person comfortable at 21 °C, 0.1 m/s wind speed and 50% relative humidity.

Variable	Max	Mean	Min
Dry-bulb indoor temperature (T_{dbind})	36.50	31.24	25.20
Indoor relative humidity (RH_{ind})	79.70	61.06	36.60
Indoor wind speed (Ws_{ind})	1.66	0.65	-
Mean radiant temperature (T_r)	36.92	31.49	25.30
Operative temperature (T_{op})	36.73	31.40	25.27
Outdoor temperature (T_{out})	38.89	27.83	18.39
Outdoor relative humidity (RH_{out})	98.00	78.47	36.00
Outdoor wind speed (Ws_{out})	4.11	1.02	-
Prevailing mean outdoor temperature (PM_vT)	31.18	28.16	24.03

Table 7: Environmental variables

Calculation for the Predicted Mean Vote (PMV) and adaptive comfort method were done using pythermalcomfort, a python package made available by Center for Built Environment (CBE), Berkeley, University of California. All occupants were assumed as desk-based respondents,seated, typing, with a metabolic rate of 1.1 met[5].

Figure 7 shows the external temperature and humidity conditions by season. Working hours (9:00 am-5:00 pm) are highlighted in the same graph in red color. It is important to notice that most extreme weather conditions are usually experienced during working hours, where external temperatures reach their highest, especially around 11am-2pm.

[5] 1 met = 58.2 W/m2. It is equal to the energy produced per unit of surface of a seated person at rest.

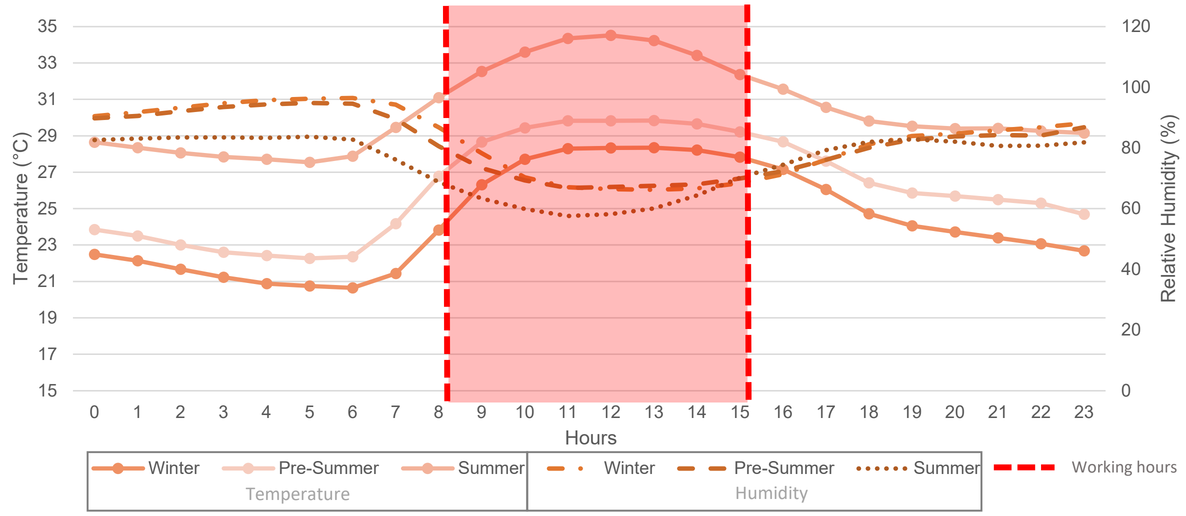


Figure 7: External temperature and relative humidity versus working hours

3. RESULTS

3.1. Occupants Thermal Perception

Occupants' responses to the survey are summarized in Table 8 through 10. According to the occupants, usually afternoon periods are more uncomfortable, regardless of the season. However, during the Summer time, this proportion of votes changes, concentrating more on the afternoon period compared to the others, while during Winter this proportion is more equally distributed.

When do you think there is most often a problem?	Winter		Pre-summer		Summer	
Period of the day	**Total**	**%**	**Total**	**%**	**Total**	**%**
Morning (8-10am)	8	15%	-	-	1	1%
Late Morning (10-12pm)	7	13%	7	17%	24	13%
Afternoon (13-15pm)	29	56%	34	81%	159	86%
Evening (15-17pm)	8	15%	1	2%	-	-

Table 8: Summary of most problematic period of the day

Hot temperatures are the major concern among occupants. Hot temperatures were listed 40.6% of the time as the main cause of discomfort. High humidity and low air movement are following next with 14.4% and 15.5% respectively. Incoming sun was also listed by building occupants, but not as significantly as it was expected. This can be explained by existing shading and overhangs in the building.

List	Winter	Pre-summer	Summer	Total	%
Temperature too hot	25	27	162	214	40.6%
Humidity too high (damp)	13	10	53	76	14.4%
Air movement too low	8	15	48	71	13.5%
Heat from equipment	4	10	42	56	10.6%
Incoming sun	8	11	36	55	10.4%
Draughts from the window	4	10	23	37	7.0%
Humidity too low (dry)	0	4	14	18	3.4%

Table 9: Summary for reasons for discomfort

In order to overcome discomfort, occupants have voted in their mean adaptation measures. Ceiling fan (26%) is the most usual adaptation measure, as it can bring instant cooling due to high wind speeds. The fact that occupants have control over equipment is a positive factor that contributes to higher thermal comfort. Closing windows and blinds (22%) contributes to keep the environment cooler and avoid heat exchange with the outdoor, at the expense of lower air circulation. Drinking water is another important measure listed (20%) and it helps cooling the body down, positively influenced by the ease of access to drinking water points in the building.

Adaptation Measure	Total	%
Ceiling Fan	179	26%
Window blinds, shades	151	22%
Drinking water	137	20%
Doors	95	14%
Windows operation (open/close)	89	13%
Adjustable air vent	40	6%

Table 10: Summary of most common adaptation measure

3.2. Thermal Sensation Vote (TSV)

Building occupants rated their thermal sensation 4 times a day. Results are summarized below in terms of Mean Thermal Sensation Vote[6] (mTSV). It is important to notice that results during Summer are much higher when compared to the data collected during other seasons. Refer to Table 11.

Season	Average of mTSV (-3 to 3)
Pre-summer	0.44
Summer	1.33
Winter	-0.01

Table 11: mTSV per Season

Table 12 breaks down the mTSV by periods of the day. Majority of higher votes (>1) are concentrated in late morning and afternoon periods. In Summer, evenings also show a high mTSV.

Period of the day	Winter	Pre-summer	Summer
Morning	-0.56	-0.19	0.51
Late Morning	0.30	0.62	1.41
Afternoon	0.45	1.06	2.09
Evening	-0.22	0.29	1.32

Table 12: mTSV by period of the day and season

[6] For the purpose of this report, mTSV was defined as the average vote of a sample in a given day in order to facilitate representation of the data collected.

Figure 8 displays the frequency of voting by seasons, according to the 7-point thermal sensation scale (-3 to +3). Notice that the 'Hot' and 'Very Hot' only occur during Summer season. During Winter, votes tend towards 'Slightly Cold', 'Neutral' and 'Slightly Hot'. The same occurs for the 'Pre-summer' season. During Summer, votes are concentrated in between 'Neutral' and 'Very Hot'.

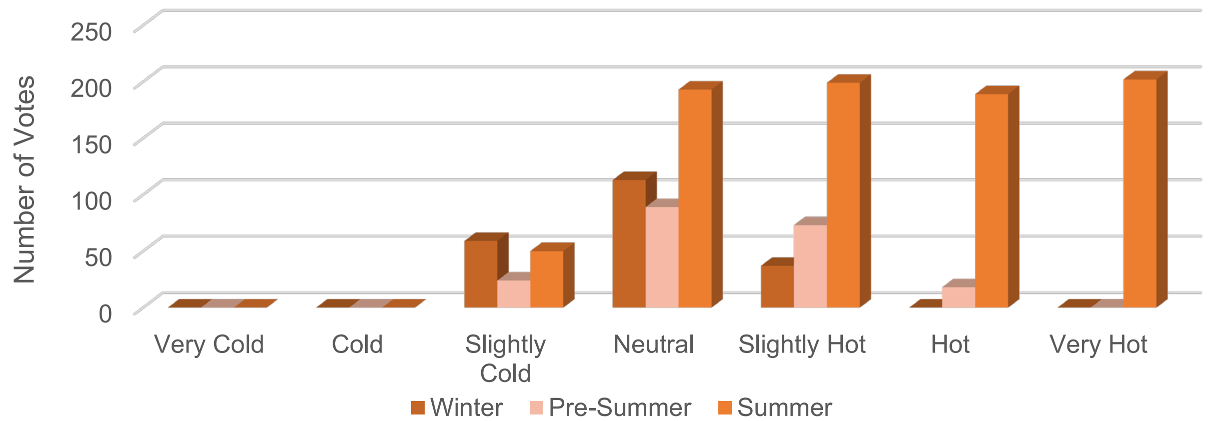


Figure 8: Frequency of votes per season

In order to assess thermal acceptability, the following criteria was set: ranges between -1 and +1 are defined as 'acceptable', while other ranges (-3, -2 and +2, +3) are defined as unacceptable. This is widely used as parameter to assess acceptability limits for thermal environments, first described by P.O. Fanger in 1970 and subsequently adopted by ASHRAE/ANSI. Applying this concept, it is found that during Winter season, thermal comfort is within acceptable range 100% of the time, while during Pre-summer, the 'unacceptable' range goes up to 8%. During the Summer months, the data depicts a significant increase in the 'unacceptable' range, going up to 43% of voting frequency, as can be seen by Figure 9 below.

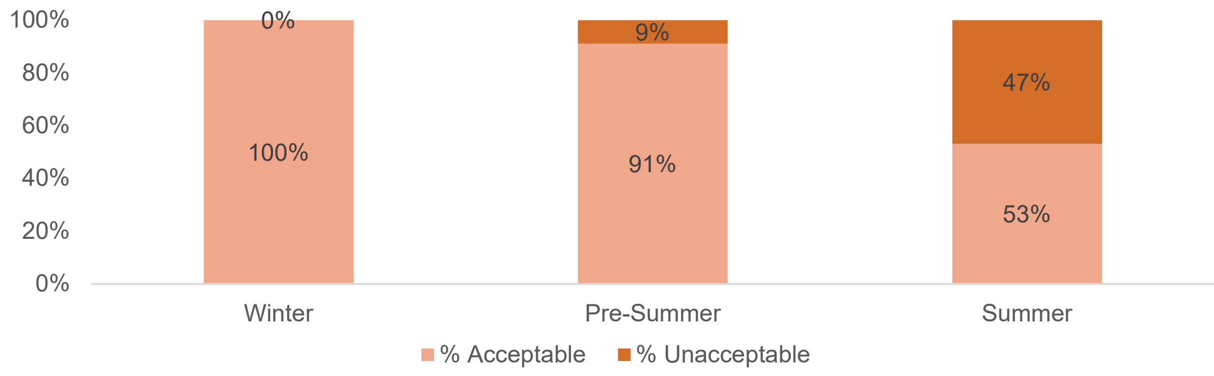


Figure 9 :Acceptability as a percentage of time based on surveys responses

3.3. PMV and PPD

To assess thermal comfort based on measured environmental data, the three classes of thermal environment as described by ASHRAE 55 were used[7], where thermal conditions can be evaluated based on either the PMV (Predicted Mean Vote) or the PPD (Predicted Percentage Dissatisfied). Refer to Table 13.

Category	PPD (%)	PMV
A	< 6	-0.2 < PMV < 0.2
B	< 10	-0.5 < PMV < 0.5
C	< 15	-0.7 < PMV < 0.7

Table 13: Thermal comfort categories based on ASHRAE-55

The calculated PMV and PPD for each season were grouped according to the period of the day when the survey was taken in order to compare both sets of data. The results found for PMV and PPD based on environmental measured data are found in Table 14.

[7] ISO 7730:2005 also makes use of a very similar conditions.

	PMV	PPD (%)
Pre-summer		
Early Morning	0.13	7.85
Late Morning	0.35	11.16
Afternoon	0.32	12.22
Evening	0.38	11.91
Summer		
Early Morning	0.69	19.26
Late Morning	1.06	33.78
Afternoon	1.61	56.33
Evening	1.35	44.39
Winter		
Early Morning	0.24	9.06
Late Morning	0.18	8.77
Afternoon	0.06	8.14
Evening	0.18	9.73

Table 14: Calculated PMV and PPD based on periods of the day

As described, the data collected with the occupants' survey and the environmental measured data is then compared. Nevertheless, a good correlation of data can be found among the measurements taken and the survey data. Refer to Figure 10.

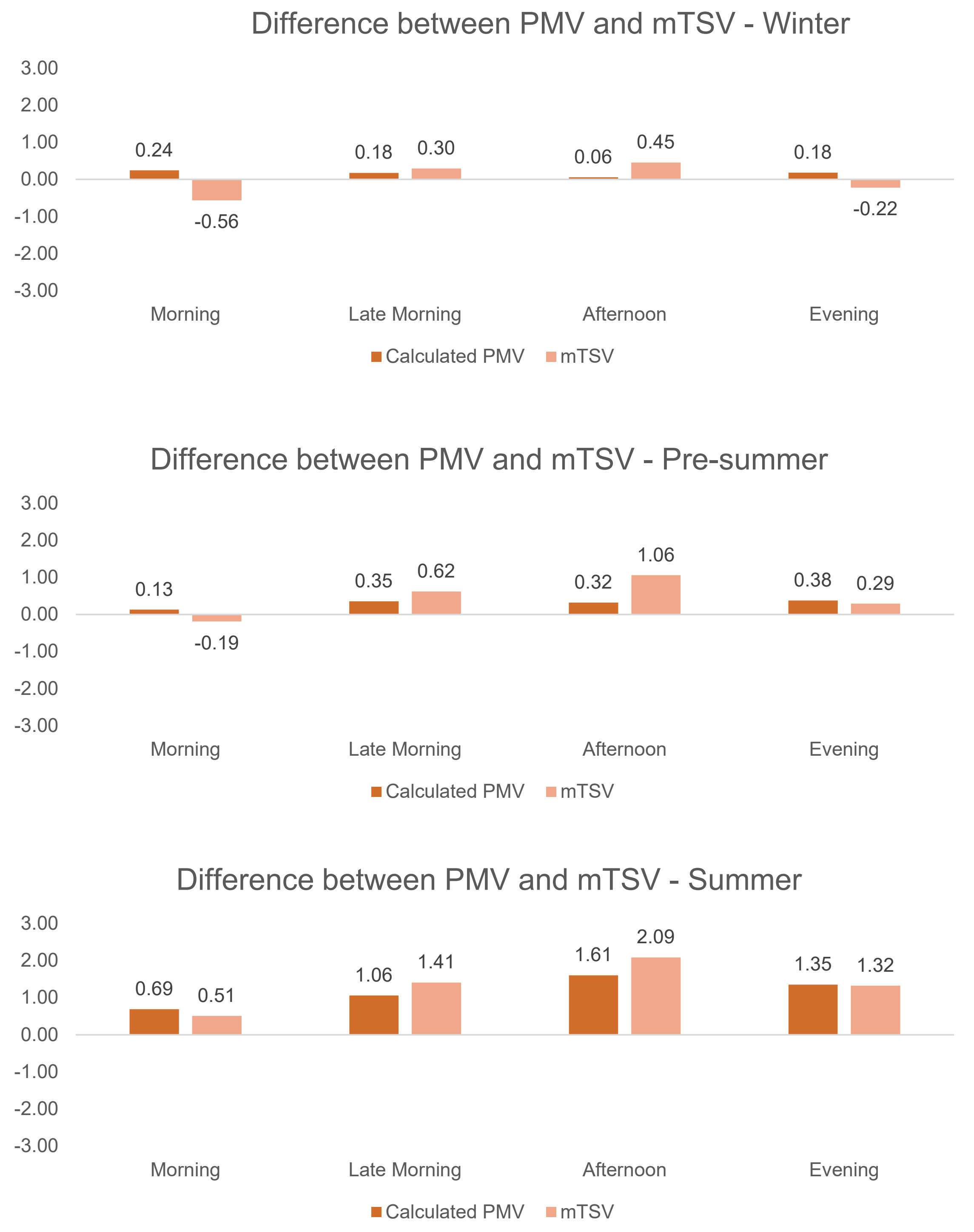


Figure 10: Comparison between PMV and mTSV

To assess the quality of thermal environment, the PMV and PPD data is plotted using the ASHRAE Thermal comfort categories displayed in Table 13. According to this analysis, the data of the Winter season has good levels of thermal comfort. No 'unacceptable' ranges can be found during this season, meaning that the PPD is always below 15%. However, since the PPD ranges from 8.14% and 9.73%, only B and C categories can be found. During Pre-summer season, the data indicate that during 28% of the office hours the thermal environment is considered 'unacceptable', while during 43.9% and 28.2% of hours it considered within categories B and C respectively. For Summer season, the data points to the thermal environment being considered 'unacceptable' during 88.2% of office hours.

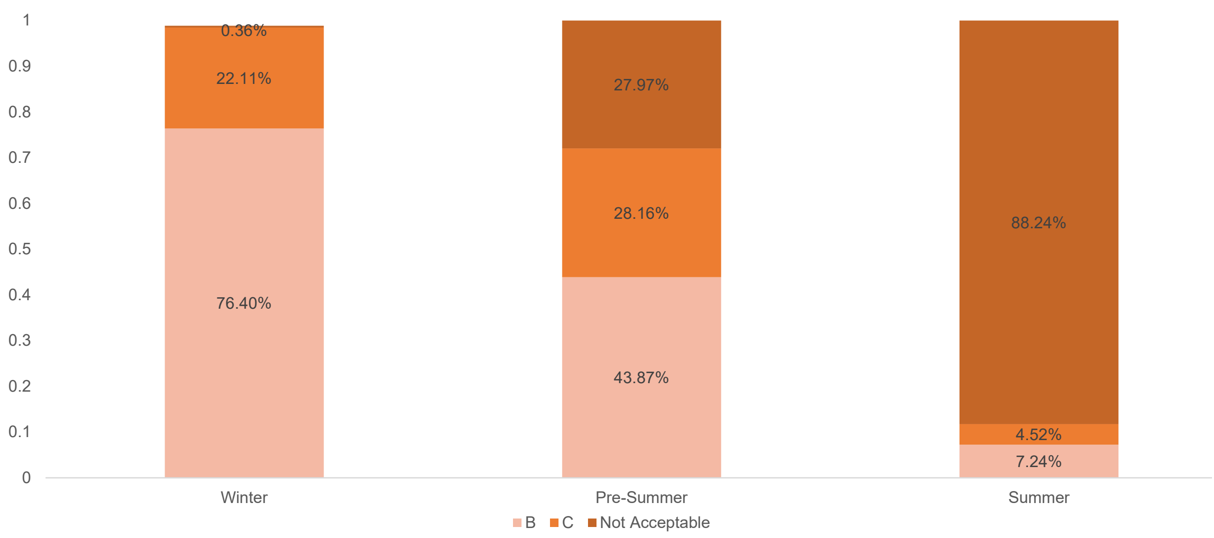


Figure 11: Thermal comfort categories based on PMV and PPD

3.4 Adaptive Comfort Acceptability Limits

Another way to assess thermal comfort is through Adaptive Comfort model, also described in ASHRAE 55. This model relates the capability of the human body to adapt to the external environment. It is mostly used for naturally ventilated buildings, as it takes into consideration the outdoor temperature, and also operative temperature and wind speed, defining zones of 80% and 90% of satisfaction. Table 15 describes the average comfort temperature based on the running mean temperature, as the 80% upper limit of indoor temperature.

Hours	Operative Temperature	Average of Tcmf[8]	Upper 80% Limit
9	32.20	27.29	32.59
10	32.75	27.26	32.75
11	33.52	27.26	32.74
12	34.02	27.24	32.72
13	34.14	27.24	31.24
14	34.02	27.24	31.24
15	33.74	27.24	32.08
16	33.21	27.24	31.25
17	32.81	27.26	32.22

Table 15: Hourly average of 80% acceptability limits for Summer season

To exemplify how measured conditions relate to the adaptive thermal comfort model, the data obtained on 1st June was plotted for 11:16 am. The operative temperature was 34.1 °C while the calculated prevailing mean outdoor temperature was 30.9 °C. Wind speed was set to 1.2 m/s. It can be noticed that under the given conditions, the thermal comfort requirements for the adaptive model are also not satisfied, where the plotted points fall outside the 80% and 90% limits of the graph. Refer to Figure 12.

A similar analysis in terms of acceptability for the adaptive model was developed and compared to the PMV/PPD model. For this analysis, operative temperatures that were higher than the 80% upper limit for the given environmental conditions are considered 'unacceptable'.

It was found that during Winter, operative temperature was considered 'unacceptable' 18.9% of the time. During Pre-summer season, temperature was considered 'unacceptable' 55% of the time. For the Summer season, operative temperature was considered 'unacceptable' 80.1% of the time. Refer to figure 13.

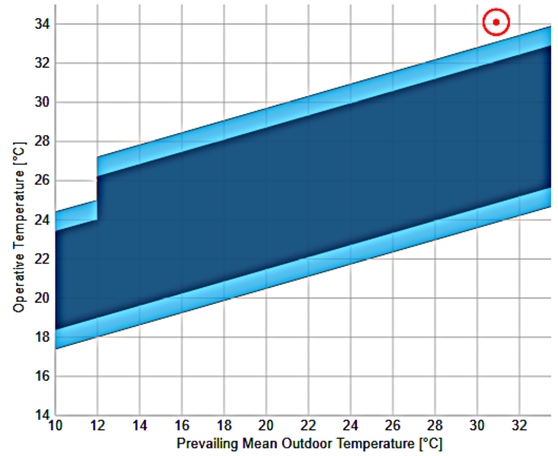


Figure 12: Adaptive comfort model example for 1st June 11:16am (Source: https://comfort.cbe.berkeley.edu/)

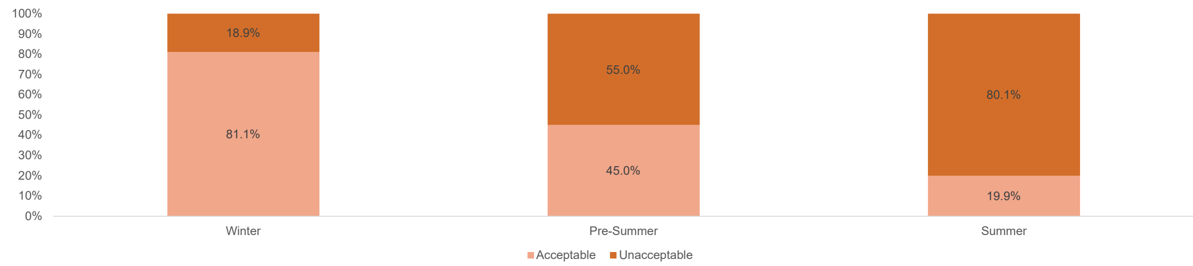


Figure 13: Acceptability limits based on percentage of time

3.5. Passive and Active Strategies

The majority of design strategies applied in the Kalpana building complex relies on passive strategies. These are design strategies that rely on local environmental conditions - natural ventilation, and shading devices – orientation, efficient materials, for example, aiming to reduce heat gains in the building. Under severe weather conditions, as can be observed during Summer season, these strategies may not be enough to control heat gain within the building and will consequently compromise thermal comfort. Active strategies, on the other hand, are design strategies that rely on mechanical or electrical inputs, where some energy conversion is required. Air-Conditioners are a good example of active strategies, as they convert electrical energy into mechanical (cooling) energy.

Figure 14 displays the psychrometric chart of the building weather conditions and suggested design strategies according to Climate Consultant Software. This chart was plotted for Summer season during office hours. The green points are the local weather conditions at a given hour of the day. Majority of the points are located under the area 15, meaning that active cooling is needed under these conditions. These points correspond to 94.1% of the hours. The need for active cooling is also highlighted since office hours are also the hours where most exposure to extreme heat is experienced, and thus lower levels of thermal comfort. Comfort through natural ventilation can be obtained 5.8% of the time, which also should not be neglected, but it can only be achieved during a small portion of the time.

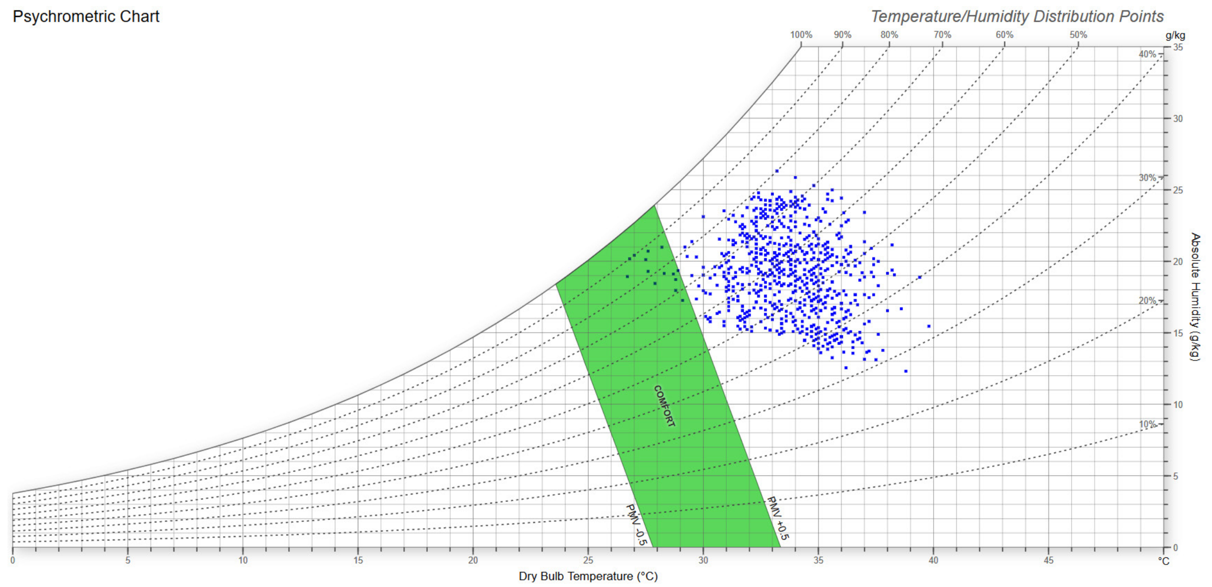


Figure 14: Psychrometric Chart of Design Strategies (Source: Climate Consultant)

4. CONCLUSIONS

This study presents an assessment of thermal comfort conditions in Kalpana, a building complex located in Auroville, Tamil Nadu, from January through July. Indoor measurements and surveys were distributed among building occupants for 42 days. The building has no air-conditioning systems, relying only on natural ventilation and cooling appliances such as ceiling fans, where occupants have full control of the devices. Based on the data collected and the survey answers, thermal comfort of occupants was evaluated using ASHRAE 55, a widely accepted international standard reference for thermal comfort, used also in sustainable buildings. Two different methods of evaluating thermal comfort were compared, including a comparison between measured data and occupant's responses.
In this work, the aim was to assess thermal comfort during Summer conditions. It is important to note that evaluating thermal conditions for the entire year is beyond the scope of this report and would require further studies. With this in mind, the main findings can be listed below:

- Both PMV and Adaptive Comfort method showed to be a good way to assess thermal comfort for the data collected. However, the Adaptive Method is more recommended for naturally ventilated buildings.
- PMV method is found to underestimate effects of the hot environments.
- The building shows 'acceptable' comfort criteria during Winter months (January), however only as 'B' and 'C' category.
- According to occupant's thermal sensation survey, 'unacceptable' conditions during 'Pre-summer' were only found in 9% of the votes. This number contrasts with the PMV and Adaptive Comfort method, showing that occupants have a high tolerance to hot environments.
- During Summer season (May, June and July), conditions were found to be 'unacceptable' 88.2% of the time according to the PMV method and 80.1% according to the Adaptive Comfort model. Voting frequency for unacceptability was also very high (47%), showing that the building is very uncomfortable during Summer season (May, June, July). Late morning and Afternoon (10am-3pm) were found to be the most critical periods of the day during Summer season, either by occupants voting and based on measured indoor conditions.

4.1. Recommendations

During Summer season the need for active cooling is essential in order to provide thermal comfort to building occupants, as showed in the Thermal Comfort Surveys and Environmental data collected. The use of active cooling technologies does not mean, however, that such practices shall be considered 'unsustainable'. Exposing occupants to extreme heat can bring health issues in the short and long term, as excessive stress, dehydration, heat stroke, etc., especially in older and overweight people. This should be avoided at any costs.

The use of low energy and efficient cooling technologies are becoming increasingly common and accessible to the general public. A few low energy and efficient cooling technologies are listed below and could be integrated in the building design to improve occupants' thermal comfort:

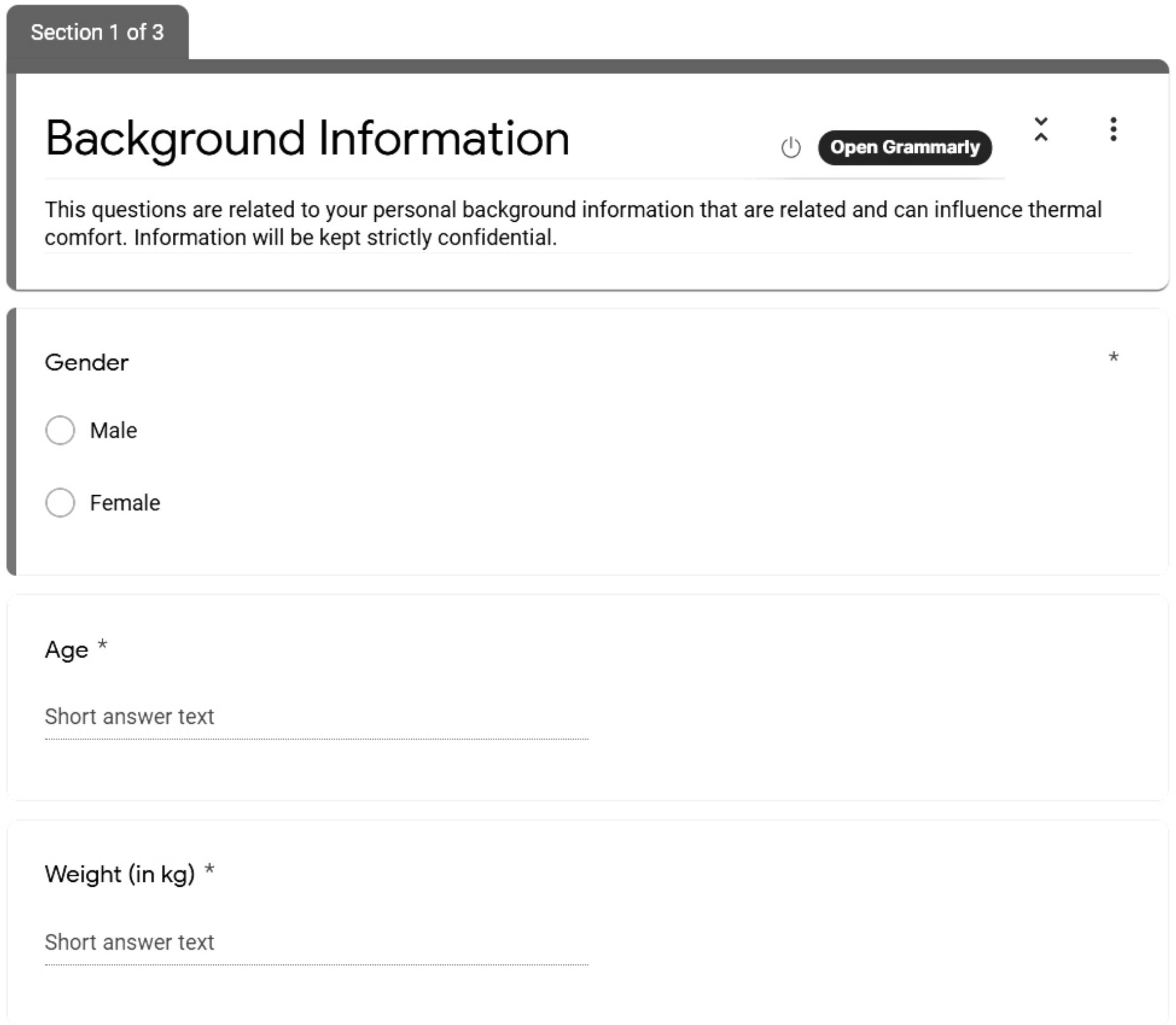
I. Multi-split systems and Variable Refrigerant Fluid Systems (VRF) operated by solar PV
II. Individual Evaporative Cooling systems during dry hot days

The listed technologies are only a few examples of possible alternatives to thermal comfort issue during the Summer months showed in this report. Description and application of such technologies in the analyzed building can be detailed further in another study and would enhance and complement the results presented in this report.

5. REFERENCES

- ANSI/ASHRAE . (2017). *Standard 55 - Thermal Environmental Conditions for Human Occupancy.* ASHRAE.
- Health and Safety Executive. (2013, June). *Heat Stress in the Work Place*. Retrieved from A brief summary: www.hse.gov.uk/pubns/indg451.htm
- Meteoblue. (2020). *Climate (modelled)*. Retrieved September 04, 2020, from Climate Auroville: https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/auroville_india_6620455
- Nicol, J. F., & Roaf, S. (2017). Rethinking thermal comfort. *Building Research & Information*, 711-716.
- Saint-Gobain. (2020). *Thermal Comfort*. Retrieved September 12, 2020, from Multi-Comfort: https://multicomfort.saint-gobain.com/comforts-and-solutions/thermal-comfort
- Szokolay, S. V. (2008). *Introduction to Architectural Science - The Basis of Sustainable Design.* (2. Edition, Ed.) Oxford: Elsevier.
- Tartini, F., & Schiavon, S. (2020). pythermalcomfort: A Python package for thermal comfort research. *SoftwareX 12*, 100578. https://doi.org/10.1016/j.softx.2020.100578

6. APPENDIX A


Section 1 of 3

Background Information

This questions are related to your personal background information that are related and can influence thermal comfort. Information will be kept strictly confidential.

Gender *

- Male
- Female

Age *

Short answer text

Weight (in kg) *

Short answer text

Height (in cm)

Short answer text

Clothing - Top *

- Short Sleeve T-shirt
- Long Sleeve T-shirt
- Sleeveless T-shirt
- Long sleeve shirt
- Long sleeve sweater
- Long sleeve sweatshirt
- Kurta
- Sari
- Dress
- Other...

Clothing-Bottom *

- Shorts
- Sweatpants
- Trousers
- Jeans
- Ankle-lenght skirt
- Knee-lenght skirt
- Salwar
- Sari
- Other...

Where is your seat located?

- Accounts Room
- Main office (1st floor)
- Conference Room (Ground Floor)
- Other...

After section 1 Continue to next section

Section 2 of 3

Thermal Comfort and Satisfaction

From a scale of 1 to 7, being 1 too cold, 7 too hot and 4 is neutral, what is your current thermal comfort (select one for each timing)

Morning 8-10am *

	1	2	3	4	5	6	7	
Too Cold	○	○	○	○	○	○	○	Too hot

Later Morning 10-12pm *

	1	2	3	4	5	6	7	
Too Cold	○	○	○	○	○	○	○	Too hot

Afternoon 13-15pm *

	1	2	3	4	5	6	7	
Too Cold	○	○	○	○	○	○	○	Too hot

Evening 15-17pm *

	1	2	3	4	5	6	7	
Too Cold	○	○	○	○	○	○	○	Too hot

After section 2 Continue to next section

Section 3 of 3

Dissatisfaction Reasons

If you have answered Unsatisfied (1,2 or 3) in any of the questions above, please answer the following questions

When do you think there is most often a problem?

- ○ Morning 8-10am
- ○ Late Morning 10-12pm
- ○ Afternoon (13-15pm)
- ○ Evening (15-17pm)

What is (are) the main reason(s) for your dissatisfaction? How would you describe them?

- ☐ Temperture too hot
- ☐ Air movement too high
- ☐ Heat from equipment
- ☐ Temperature too cold
- ☐ Air movement too low
- ☐ Draughts from the window
- ☐ Humidity too high (damp)
- ☐ Humidity too low (dry)
- ☐ Hot/Cold Surfaces (doors, wall, ceilings)
- ☐ Incoming sun
- ☐ Other...

Which of the following do you adjust when feeling uncomfortable? (multiple answers acceptable)

- ☐ Window blinds, shades
- ☐ Doors
- ☐ Windows operation (open/close)
- ☐ Ceiling Fan

- [ ] Adjustable air vent
- [ ] Drinking water
- [ ] Other...

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