FLOATING HOUSE, THE PHILIPPINES

Recommendations for Improvement of the Building Design

by Evaluating the Indoor Environmental Quality of the Pilot Floating House Project

in Macabebe, the Philippines

Reji Benoy

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by

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Abstract

This thesis aims to provide passive design recommendations to improve the design quality of low income houses in the Philippines, by evaluating the indoor environmental quality of the pilot floating house project. The pilot project is the result of researches carried out by Pieter Ham and Joran Van Schaik to find a solution for the housing backlog, poor living conditions and the seasonal natural disasters in the low lying areas of the Philippines. The thesis focuses on the indoor environmental quality, the thermal comfort of the pilot house.

Prior to the field visit, the significant parameters for the in situ measurement and the comfort standards for the region are chosen by literature studies. A systematic measurement plan is made in order to perform in situ measurements and field study. The measurements are done for a period of nine days. In addition to this, one of the objectives of the research is to develop an economical measuring and remotely accessible monitoring device for the thermal comfort parameters. It is achieved by programming Raspberry Pi and DHT22 temperature and humidity sensor.

Hypotheses are formulated after the field visit. Then the measured data is sorted systematically and analysed. This analysed data is further studied and the comfort performance of the house is compared with the comfort standards of the region. It is found that the performance is quite satisfactory for all the spaces in the house except the attic space, which has higher temperatures than the upper comfort level. Moreover the usability of the existing doors needs improvement in terms of controlling privacy and air velocity.

For the improvements, it is envisioned to have minimal interventions to the existing design and construction. For this two options are put forward. Both the options are compared with the existing design by making DesignBuilder models. The simulation results of the models are compared to find the better performing strategy.

Final design is made with the inference from the comparison of the simulation results, and visits to the local architecture. From the final design, the following design improvement recommendations are put forward for the housing type:

1. *"openings for ventilation at sleeping height in the attic floor"*
2. *"openings at top of the roof to enhance stack effect"*
3. *"collapsible doors with louvered shutters for providing users with more option in controlling air velocity and privacy"*

Acknowledgement

First and foremost, I would like to express my sincere gratitude towards my mentors Ir. Eric van den Ham and Ir. Pieter Ham whose constant guidance was a source of encouragement and inspiration in putting the best of my ability into the research. I am thankful for their support, sharing of information, motivation and giving a direction for my future endeavours. It was ***the compassionate approach*** in Pieter's research that motivated me to choose my research topic. I would also like to thank Dr. Willem van der Spoel, Ir. Joran Van Schaik, and Ar. Jurrian Knijijzer for their valuable time and suggestions during the process of research.

I am greatly indebted to Miss Bembong Balgan for her hospitality, supervision and support during the field visit in the Philippines. I also wish to express my gratitude to Mr. Angel Cruz, for his willingness to take time off his busy schedule showing around the places and local architecture. I would like to thank everybody in the Philippines who has helped and made me feel at home during the field visit, especially Rhestie and his family.

Wietse de Haan, has made the field visit fun and informative through participative support and encouragement. Though we had two separate research topics, we supported each other and worked together which helped a lot in my research, proving the old saying "unity makes strength". I owe a great deal to my friend Hamidreza Shahriari for giving me insight into DesignBuilder software and climate design. I also wish to thank my cousin Teena Thampi, for the time she devoted in checking and giving feedback on my python script. I want to thank all my friends for their support and encouragement.

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Contents

1. Introduction

1.1 Background and Problem Statement

Context : The Philippines

The Philippines is a country that comprises of over 7000 islands making it one of the largest archipelagos in the world, spanning over a 300,000 sq.km. The nation is categorised into three groups of islands: Luzon, Visayas and Mindanao[www.gov.ph, 2019]. The income and quality of life around the Philippines are of great extremes with around 26.5% of the population living below the poverty line [ph.undp.org, 2019]. In addition to that, the serious housing backlog results in a poor living condition [van Schaik, 2016]. The Philippines, in general has high temperature and humidity with a lot of rainfall [PAGASA, 2019].

Context: The Floating House, the Philippines

The pilot floating house in Macabebe, the Philippines is an outcome of the researches started by Pieter Ham and Joran van Schaik that aim to solve the housing backlog and improve the housing quality for low-income class in disaster-prone areas of the Philippines. The prime focuses have been towards sustainability, adaptability and affordability [van Schaik, 2016]. The result is a prefabricated typhoon resilient house with floating foundation. It has been designed considering the passive vernacular climate responsive strategies, as the low-income group cannot afford active design strategies in their house. For this, various parametric models were made and studied to develop design and construction guidelines [Ham, 2019]. The current housing scenario demands such better-quality affordable houses.

Context: IEQ and Thermal Comfort

Indoor Environment Quality (IEQ) involves several factors that create the indoor environment which affect the well-being of the occupants in the building. Some of the important factors include the thermal quality, air quality, light quality, and acoustic quality [Toyinbo,]. Thermal comfort is a very important factor to be considered for natually conditioned buildings, in order to provide a comfortable living space for the occupants [Nguyen et al., 2012]. The maintenance of the building environment consumes a large amout of energy [Brunsgaard et al., 2011]. It also adds to the emission of greenhouse gases [Gou and Siu-Yu Lau, 2013].

Figure 01: The floating house Macabebe, the Philippines [source: Ham, 2019]

Problem Statement

A good quality indoor environment is very important to make this housing type a success. So, it is now important to see how the floating house performs in real life. Therefore it is necessary to evaluate the indoor environment quality (comfort) of the pilot house in order to put foward the recommendations for the improvements by comparing necessary comfort models. It is needed to understand the indoor comfort with a bottom up holistic approach. The environmental parameters and the characteristics of the building have to be studied. Therefore it needs quantitative measurements and qualitative interviews with the residents [Brunsgaard et al., 2011]. Thus it gives a refined result to the studied problem. This thesis focuses on indoor environment quality, mainly thermal comfort. It also involves development of a cost-effective device to monitor the parameters of indoor environment quality for a longer period.

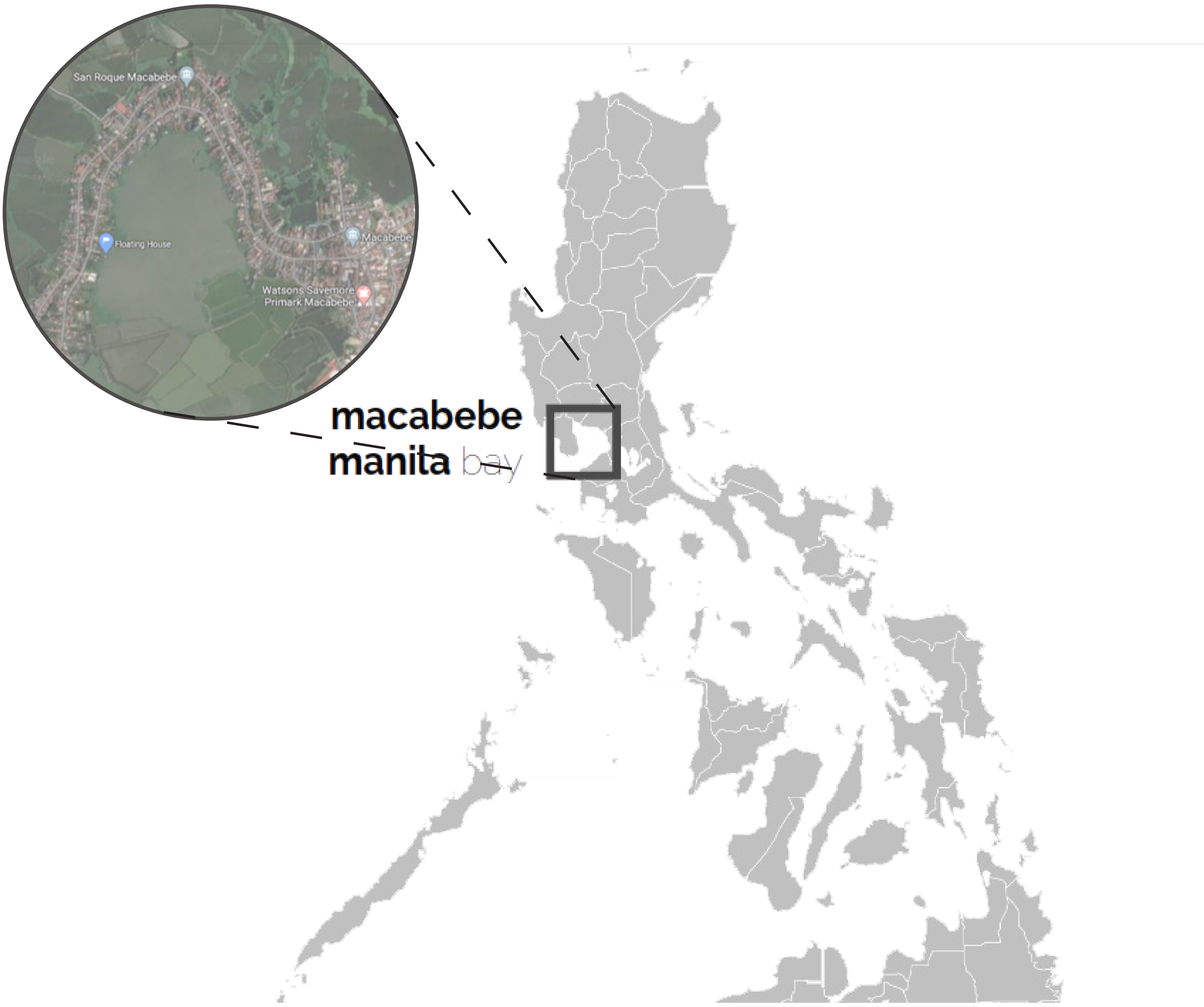


Figure 02: Site Location [source: Pieter Ham]

1.2 Objectives

From the problem statement described, the following objectives have been formulated:

Main Objective

To recommend improvement strategies for the design of the low-income houses with attic floor, in the Philippines, by evaluating the indoor environmental quality of the pilot floating house project.

Sub Objective

To develop a cost-effective measuring and remotely accessible monitoring device for the indoor comfort parameters in the pilot floating house.

1.3 Research Questions

From the objectives, the main research question is formulated and from the main question, sub questions are worked out:

Main Research Question

What vernacular design strategies can be advised for the design of the low-income houses with attic floor, in the Philippines, by evaluating the indoor environmental quality of the pilot floating house project?

Sub Questions:

1. **Design & Location:** How is the pilot floating house in the Philippines designed and constructed in terms of passive design?
2. **Indoor Comfort Parameters:** What are the comfort parameters that need to be measured, which influence the indoor environment quality of the housing type?
3. **Measuring & Monitoring System:** How to develop a measurement plan and monitoring system for indoor environmental quality of the pilot project?
4. **Indoor Comfort Performance of the Pilot House:** How does the pilot floating house perform in terms of the measured results?
5. **Improvement Strategies:** What are the improvement strategies needed to provide a better indoor environment for the housing type with respect to the analyzed data?
6. **Comfort Performance of the Improved Design:** How do the improved strategies perform when compared to the existing design?

By answering the sub questions, the main question can be answered.

1.4 Boundary Conditions

Inception

At first, a background study about the the pilot floating house is done in order to choose between evaluation of the indoor environmental quality and structural behaviour of the pilot floating house to understand the real-life performance within the given time limit. The research questions are then used to sculpt the overall process of the research. The conditions for the in situ measurements and comfort performance analysis are formulated with the inference of the literature study.

Field visit and Comfort Performance

The next stage involves the development of the systematic field visit and measurement plan which directed the activities performed during the field visit. The assessment of the results from the field visit is carried out with the adaptive comfort model for the Manila region.

Improvement Strategies and Comparison with the Existing Design

The inferences from the comfort performance of the house governed the improvements needed for the floating house. The software used for the simulation of the improved designs is DesignBuilder. The same comfort range used for the in situ measurements is used for the analysis of the simulation results.

Improved Design Recommendations

Two design principles are envisioned for the final design recommendations after studying the simulation results:

1. Minimal intervention to the existing architectural design and construction

The existing architectural design and construction are the result of extensive researches on the specific field.

2. Improvements should do justice to the local architecture of the region

British-Indian architect Laurie Baker said "we should be thinking and designing as Indian for Indians in India" in order for a building to adapt to the local context. The pilot project has borrowed passive design elements from traditional architecture of the Philippines to suit the local context.

1.5 Approach & Methodology

The steps taken to proceed with the research are based on the research sub questions in order to find answers to the respective questions.

Step 1: Answering sub questions 1 and 2

1. Pilot Project: It involves a study on the pilot project and its location information
2. Indoor Environment Quality: It involves a study on various aspects and parameters of indoor environment quality, selection of parameters to be measured, selection of comfort model for comfort requirements
3. Identifying requirements for the questionnaires

Step 2: Answering sub question 3

1. Measurement Plan (Quantitative Measurements & Qualitative Interviews): In situ measurements are neeeded to get reliable information to assess comfort performance
   - i. Selection of measuring devices and development of measurement methods and plan
   - ii. Development of questionnaires for daily review and interviews
2. Monitoring Device: Devices to remotely monitor the parameters for a longer period
   - i. Programming and development of cost-effective devices to measure and monitor the parameters
   - ii. Assembling of the components to make the devices
3. Field Visit
   - i. Installation of devices and measurements
   - ii. Interviews
   - iii. Other observations
4. Development of hypotheses

Step 3: Answering sub question 4

1. Documentation and analysis of the results
   - i. Effects of each parameter are checked
2. Comfort performance of the pilot house
   - i. Checking how the indoor spaces perform by inspecting the analysed data
3. Validation of the hypotheses

Step 4: Answering sub question 5

1. Design improvements

Step 5: Answering sub question 6

1. Comparison of the improved design using DesignBuilder Energy Plus software
   - i. Preparing the improved design model and analysis of the comfort performance

Step 6: Conclusion

At the end of the research unanswered queries are anticipated which will be addressed as and when they arrive. The conclusion of the thesis is to accomplish the objective which is the improved design recommendations for the housing type and development of economical weather monitoring system.

1.6 Relevance

Societal Relevance

The thesis is part of a bigger research plan to improve the housing quality in the Philippines. As specified in ASHRAE guidelines people are indoor most of the time. Various studies and researches have shown that comfort and health related issues are connected to the building characteristics [Arif et al., 2016]. By evaluating the indoor environmental quality of the pilot project, it would help to identify the problems within the existing house to improve the design and construction. Better environmental quality thus provides better quality of life for occupants. This helps in the success of the housing type and thus makes it possible to implement in a wider context.

Scientific Relevance

This thesis will be added to the ongoing researches to implement the concept in a larger scale. It thus helps the overall research in this field and can be a guideline for future projects. It also deals with evaluation of the adaptive thermal comfort for a naturally conditioned building; hence this thesis can be referred for analysis of similar buildings in similar contexts.

1.7 Research Framework

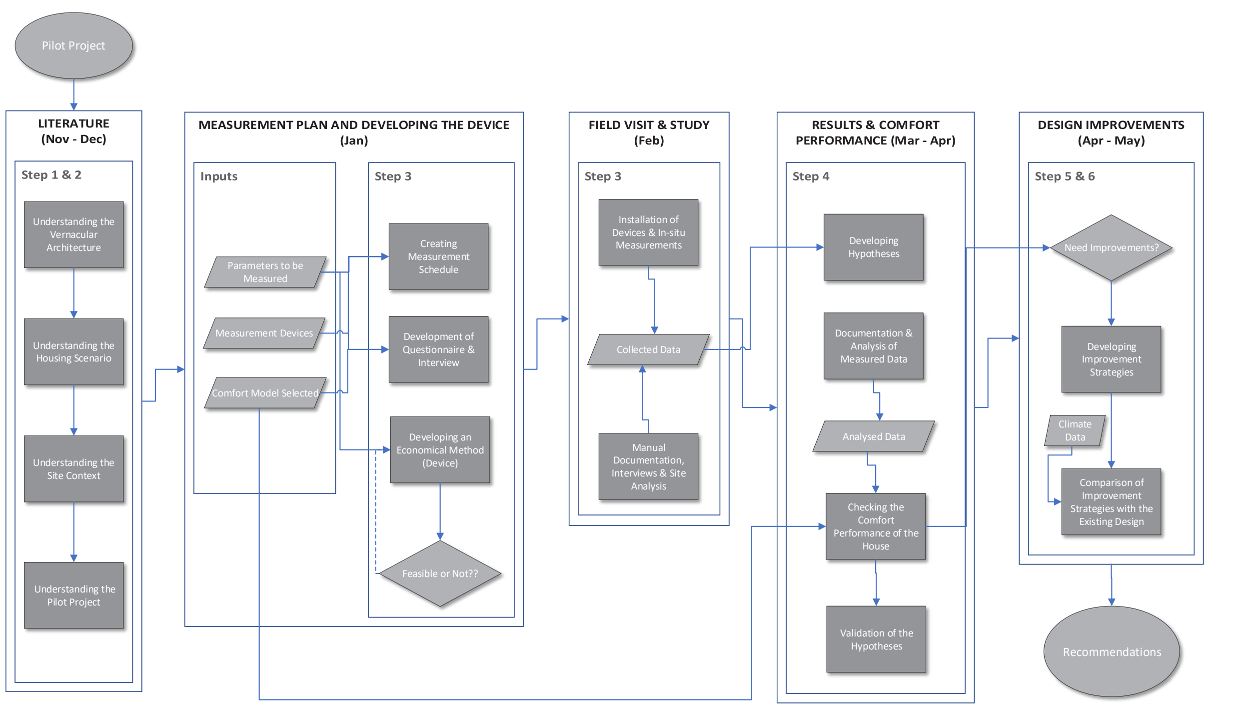


Figure 03: Research framework

2. Literature Study

2.1 Pilot Project

2.1.1 Design

The house is meant for a single family and has a space of 4.8m X 4.8m which is being divided into three zones: living zone, attic for sleeping and bathroom. The living zone has a TV area, dining area and a kitchen (Appendix A.1). It rests on a floating foundation to make the structure floating. The roof has a slope of 45^{o}. The eaves are 1.2 m long at 75^{o} angle from the wall [Ham, 2018]. As seen in the site plan the floating house is not exactly aligned to the cardinal directions, but for the ease of naming the facade and openings it is considered to be aligned. The foldable eaves and corridors protect the building from sun and rain. The surroundings do not have any obstacles except the buildings towards the North-west corner and South-west corner. It has an open ground towards the West side and open waterbody on all other sides. This is expected to help uninterrupted air movement, but on the other hand makes the house exposed to sun.

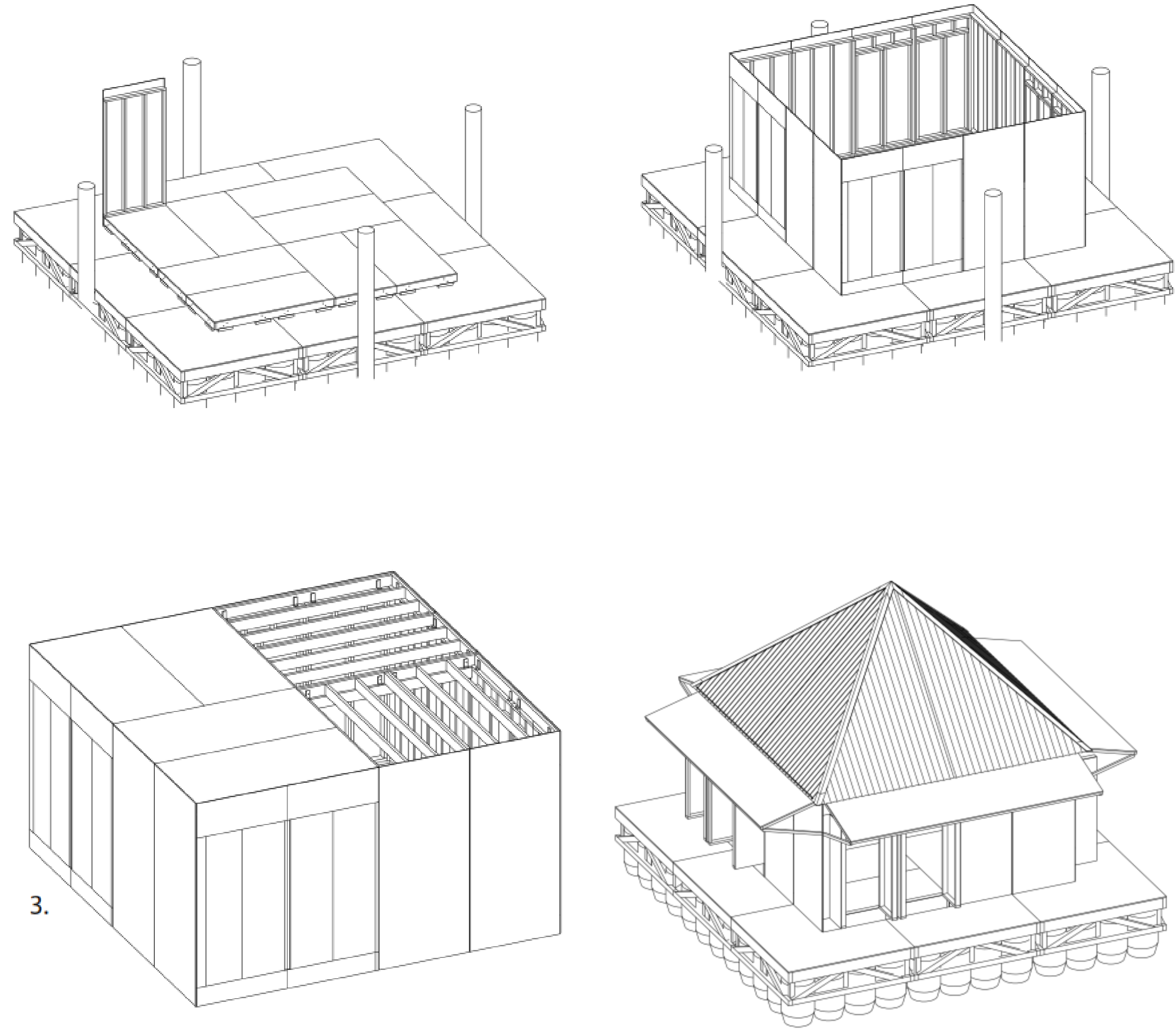


Figure 04: Design and construction of the Floating House [source: Ham, 2018]

Figure 05: Site Plan

2.1.2 Passive Vernacular Principles

The house also borrowed design principles and elements from the traditional Bahay Kubo (Figure 06) architecture which uses passive means for thermal comfort; such as sloped roof and overhangs for protection against sun and rain and large openings to facilitate cross ventilation [Ham, 2019]. Large door cum windows also provide daylighting to the indoor spaces.

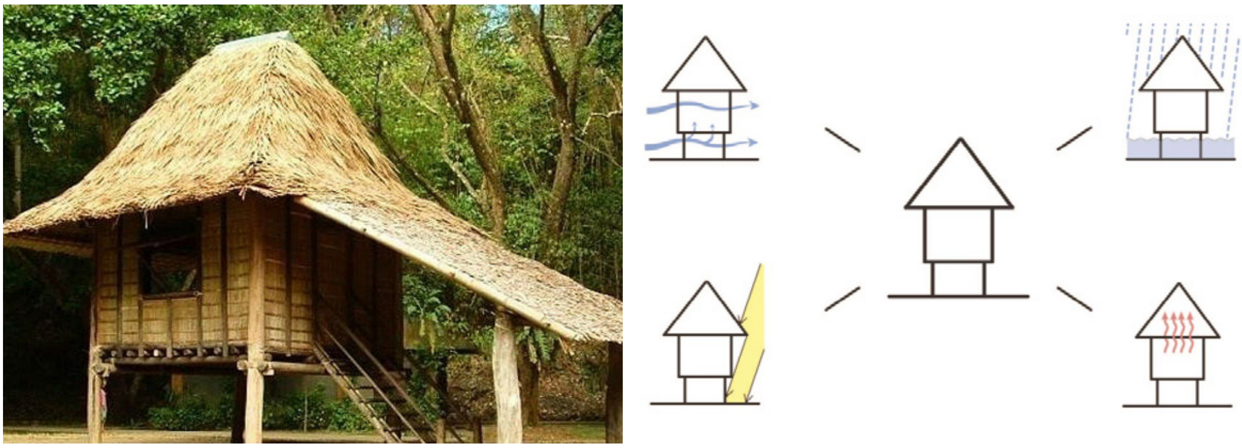


Figure 06: Bahay Kubo [source: www.balay.ph] (left), Principles borrowed from vernacular architecture [source: Ham, 2019](right)

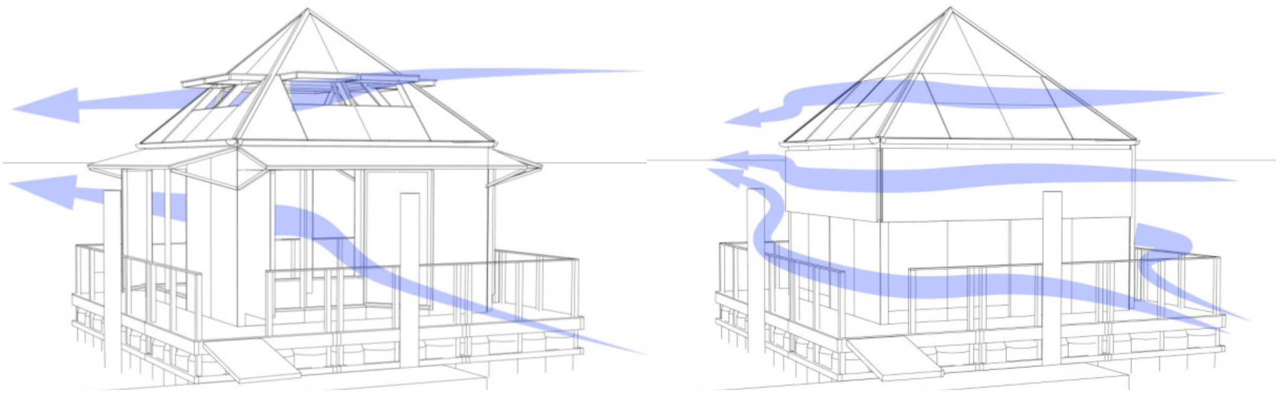


Figure 07: Natural Ventilation (left), Typhoon resilient (right) [source: Ham, 2019]

2.1.3 Materials

1. Foundation modules: Made of hardwood, which has recycled plastic drums that enable the structure to float
2. Floor panels: Timber beams are screwed together and 18 mm plywood is nailed and glued on top. There are eight such panels
3. Wall panels and door panels: Timber beams are screwed together and 18 mm fibre cement board is nailed and glued on the exterior side. There are eight such panels
4. Inner partition: 18 mm plywood
5. Roof panels: GI metal corrugated 4 mm sheet with 10 mm polyethylene foam insulation nailed and glued to 4 mm plywood
6. Foldable eaves: GI metal corrugated 4 mm sheet nailed and glued to 4 mm plywood

2.1.4 General Location Data

Macabebe, Pampanga is around 70 km from the Manila international airport.

Climate & Season: The Philippines can be considered to have tropical and maritime climate. The pilot project is located in the Pampanga Delta, Macabebe, the Philippines. The seasons are based on temperatures and rainfall. The Pampanga region falls in Type I category of the Climate Map of the Philippines. It is characterized by dry weather from November to April and wet during the rest of the year with highest rainfall between June and September [PAGASA, 2019] (Climate Map of the Philippines, 1951-2010).

Temperature: In general, the mean annual temperature experienced 26.6^{o}C, is the same throughout the country except that in the higher altitude region. The coolest month is January and warmest is May. The former has a mean temperature of 25.5^{o}C and the latter, 28.3^{o}C [PAGASA, 2019].

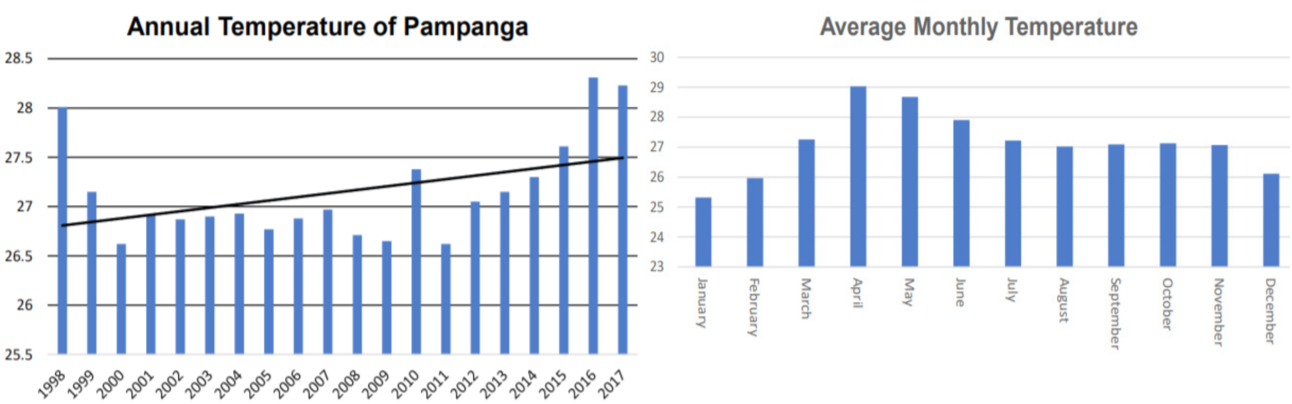


Figure 08: Temperature data Pampanga province from 1998 - 2017 [source: Lacap & Magat, 2019]

Temperature, Pampanga: Figure 08 shows the graphs of the annual temperature and average monthly temperature of the Pampanga province from 1998 - 2017. It shows that the temperature has been increasing since 2011 though there is a slight reduction in 2017. The year 2016 has the highest recorded annual temperature followed by the year 2017. April is the warmest and January the coldest for the Pampanga province [Lacap & Magat, 2019].

Humidity: The relative humidity is high in the Philippines due to high temperature and surrounding water bodies. The monthly average is between 71% in March and 85% in September. The high temperature and humidity results in uncomfortable environment especially from March to May [PAGASA, 2019].

Wind : The prevailing wind system can be divided into three [www.fao.org, 2019]:
North-East monsoon: from November to February
South-West monsoon: from July to September
Trade wind: rest of the year, generally from the east
Figure 09 shows the results of an analysis of wind speed and direction in Manila.

Tropical Cyclones: Due to the geographical location, the Philippines is vulnerable to cyclones that causes heavy rains, strong winds and flooding of the land. This may cause fatalities and destruction to properties. Cyclones mostly occur between May and November, but strong winds are there throughout the year. The average monthly tropical cyclone forecast of the Philippines is in Appendix A.3 [PAGASA, 2019].

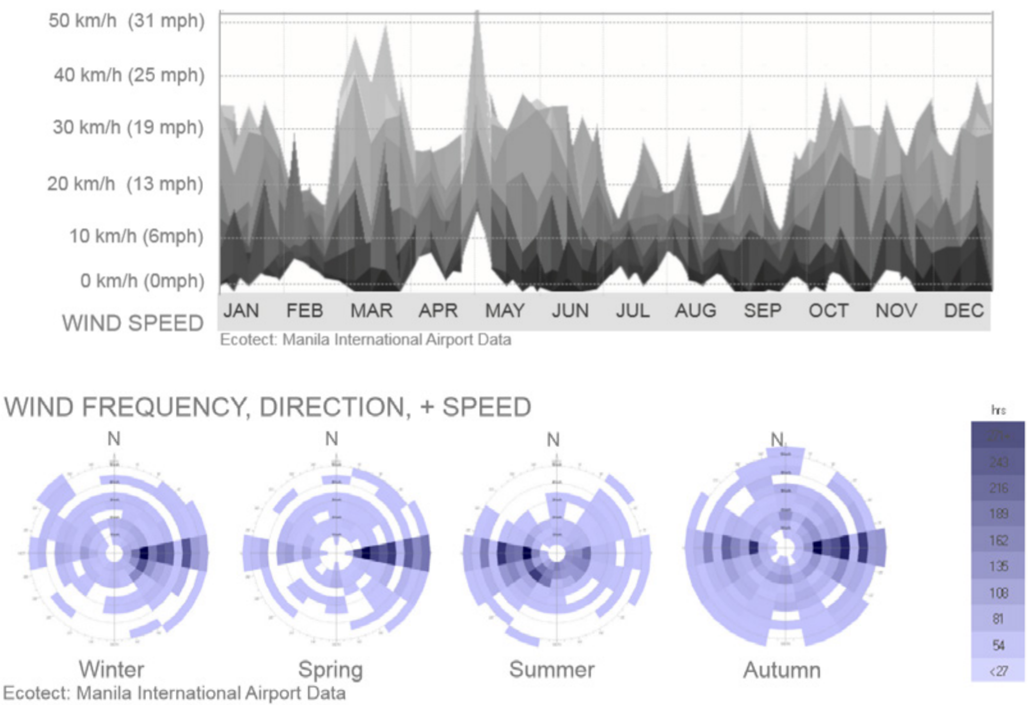


Figure 09: Wind velocity and directon Manila international airport[source: Callison: Manila Climate Analysis, 2012]

2.2 Indoor Environmental Quality

Indoor Environmental Quality (IEQ) includes various sub qualities that add up to create the indoor atmosphere. These influence the indoor comfort and well-being of the occupants [Toyinbo, 2019]. The Cambridge dictionary defines comfort as “the state of mind, when a person is relaxed and free from pain”. Some of the important factors or stimuli are indoor thermal comfort, indoor air quality, lighting quality, sound quality and spatial quality. These are the physical stressors that affect the well-being of the occupants, the other being psychosocial stressors [Bluyssen, 2013]. The unfavorable indoor conditions can hinder a person’s lifecycle and activities. Each individual receives, perceives and responds to the stressors differently [Bluyssen, 2013]. It is therefore important to understand the parameters that influence these factors in order to evaluate the indoor quality. This report focuses on the thermal comfort for the evaluation and design improvements of the pilot floating house while other factors are discussed in brief.

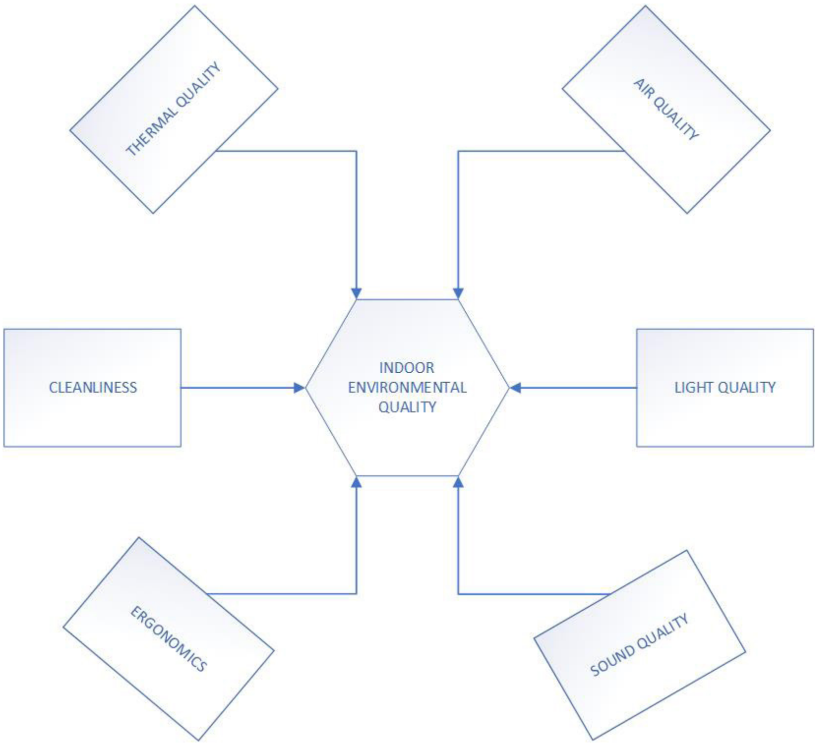


Figure 10: Factors affecting indoor environmental quality

2.2.1 Thermal Comfort

Thermal comfort is the state of mind with respect to thermal environment, which is affected by thermal sensations, psychological factors such as individual expectations and physiological factors which are the body’s responses to the thermal environment [Koenigsberger et al., 2010]. As the effect of undesirable heating and cooling of the body, thermal dissatisfaction can be caused. Usually, sensible and latent heat losses from body are conveyed in terms of environmental factors, skin temperature and skin conditions. Clothing also plays an important role in this [Kelvin et al., 2017]. The body continuously produces heat. It involves involuntary heat production which are continuous; such as tissue-building, energy conversion and voluntary heat production; such as that produced while carrying out any physical activity [Koenigsberger et al., 2010].

Body Heat Exchange

The body to be in thermal balance, the deep body temperature should be around 37^{o}C. If this is not maintained the body cools down or heats up causing discomfort. In order to maintain this all additional heat should be dissipated to the surroundings. The heat exchange occurs by the following mechanisms: [Koenigsberger et al., 2010]

1. **Thermal convection:** Heat transmission from the body to the air that is in contact with the skin or clothing. The convective heat loss rate is increased by faster air movement, low air temperature and high skin temperature.
2. **Thermal conduction:** Transmission of heat within bodies in contact having different temperatures. Heat flows till an equilibrium is reached. The body heat exchange by conduction is lesser compared to other mechanisms.
3. **Thermal radiation:** Transmission of heat in the form of electromagnetic waves. It does not need matter or a medium to travel. It depends on the surface temperature of the body, temperature of the opposing surface and emissivity factor.
4. **Evaporation heat loss:** Evaporation heat loss is determined by rate of evaporation that is dependent on the humidity; the drier the air, the faster the evaporation.

Thermal Balance of the Body

Thermal equilibrium between heat gain and heat loss is necessary for thermal comfort of the body.

Regulatory Mechanisms

1. Heat Gain
   - i. Metabolism
   - ii. Conduction
   - iii. Convection
   - iv. Radiation
2. Heat Loss
   - i. Conduction
   - ii. Convection
   - iii. Radiation
   - iv. Evaporation

Thermal Balance: (+) Heat Gain = (-) Heat Loss

2.2.2 Parameters for Thermal Comfort

There are four environmental parameters and two personal parameters that influence the thermal comfort of an individual. The environmental parameters are air temperature, air velocity, mean radiant temperature and relative humidity [Givoni, 1976]. Personal parameters include clothing and metabolic rates [Auliciems & Szokolay, 1997] [ASHRAE, 2010].

Temperature

1. Dry-bulb temperature: It is the real temperature of the air. The measuring thermometer bulb is dry and is measured by exposing it to the air but protected from radiation and moisture.
2. Operative temperature: It is more like the temperature that is experienced. Globe thermometer is used to measure this, which has a hollow black sphere with the temperature sensor inside it.
3. Mean radiant temperature: It is the average temperature of the surfaces enclosing the point of measurement that radiates heat in a steady condition. Human skin is sensitive to the radiant temperature. It can be derived from the operative temperature and dry-bulb temperature.

Air Velocity

It depends on the movement of air at a point with respect to time. The faster the air velocity, the faster the heat exchange process from the body to the air [Koenigsberger et al., 2010]. Air velocity is important for natural ventilation, especially for a warm and humid climate. The two natural types of ventilation are wind driven ventilation and buoyancy driven ventilation. The former is due to the pressure difference between the windward and leeward sides of the buildings and the latter due to difference in temperature. Hot-wire anemometer or an omnidirectional anemometer is used to measure the indoor air velocity[Spittka, 2019].

Relative Humidity and Absolute Humidity

For evaporation to take place, the air should be able to absorb the moisture. Relative humidity is the amount of moisture in the air with respect to the maximum amount of moisture it can hold (saturation-point humidity) and it depends on the air temperature. Absolute humidity is the amount of moisture present in unit volume of air [Koenigsberger et al, 2010].

Metabolic rates and clothing

As mentioned before, the human body produces heat continuously. The metabolic heat productions are of two types: Basal metabolism, which is a continuous and involuntary biological process and muscular metabolism which is the result of voluntary or controllable physical work except shivering [Auliciems & Szokolay, 1997]. The metabolic rates associated with each occupant's activities have to be considered. Clothing is an important factor that influences thermal comfort and heat exchange. A unit 'clo' is used for the purpose

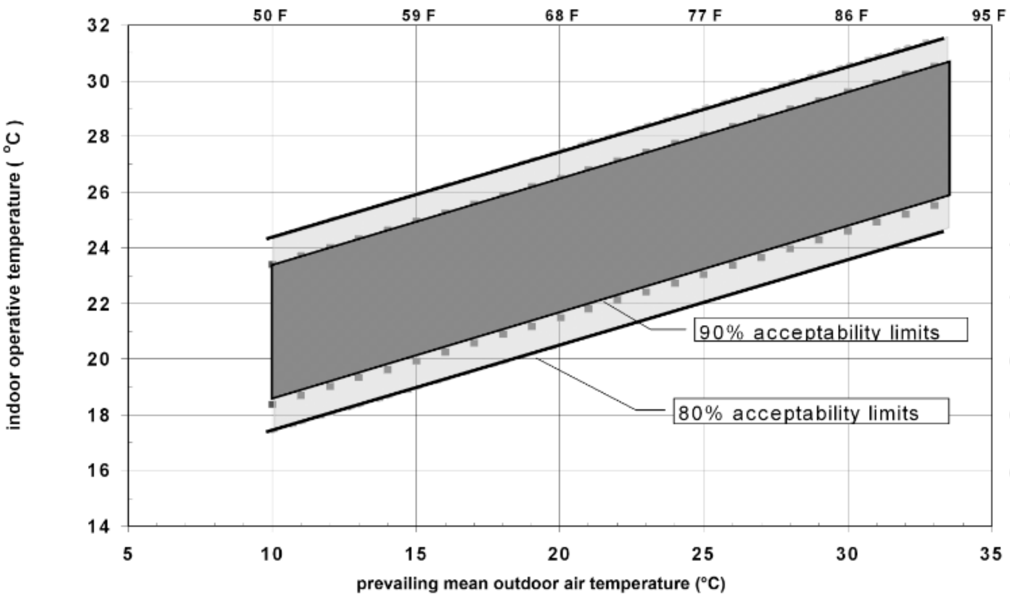


Figure 11: ASHRAE adaptive comfort graph [source: ASHRAE 55-2010]

of thermal comfort studies. Clothing insulation is generally evaluated using thermal manikin [ASHRAE, 2010]. The above factors for the location Manila , the Philippines are already considered for the adaptive comfort model in ASHRAE Standard 55-10 that is used for this report.

2.2.3 Thermal Comfort and Adaptive model

Researches have been done in developing various models to study the thermal comfort inside a building. It is necessary for architects and engineers to consider thermal comfort to ensure healthy life for occupants in the building. The present guidelines are primarily based on either thermal balance or adaptability [Toe & Kubota, 2013] . Fanger proposed steady state model with comfort indices, Predicted Mean Vote (PMV) model and Percentage of People Dissatisfied (PPD) in early 1970s which became the foundation for standards like ASHRAE 55 [Carlucci et al., 2018]. PMV uses a seven-point thermal sensation scale which is used to predict mean value among larger group of people [ASHRAE, 2010]. PPD when used as comfort appreciation differs for each person. It is considered that 5% of people in a group in a thermal environment feel dissatisfied at the neutral temperature as defined by the PMV model. This model failed especially in naturally conditioned buildings in hot climates, as adaptability of people is not taken into account. For example, people tend to respond to the climate change and accordingly the metabolic rate changes. This is not correct in PMV model [Spittka, 2019]. People have the ability to respond to the changes that caused discomfort in order to restore their comfort. Hence the thermal satisfaction could be achieved in a wider range of indoor temperatures than expected with just PMV/PPD model. The adaptive thermal comfort model counts on the analysis of various data collected during a field survey. This theory considers the adaptability and satisfaction of occupants thus reducing energy use [Carlucci et al., 2018]. This is different for each climate zone. Therefore this report focuses on adaptive comfort for the region, for the naturally ventilated housing type.

Adaptive Comfort Model for Hot-Humid Climate (Toe and Kubota, 2013)

Toe and Kubota have done research with ASHRAE RP-884 database to make an adaptable comfort equation for naturally ventilated buildings in hot and humid climate. They compared different climate groups and found hot-dry climate and hot-humid climate have similar regression coefficient, which is around 0.6 that is almost twice as that of the European and American standards. They used linear and probit regression analysis to develop the adaptable comfort equation. The former helped to understand the relation of indoor comfort temperatures with respect to outdoor temperatures. In probit regression analysis, they used thermal sensation and thermal preference votes for hot-humid climates, but not thermal acceptability vote. The temperature at the thermal neutrality for their study was taken from the thermal sensation vote that corresponds to zero. As per their inference the upper and lower comfort limits are decided on the basis of thermal sensation votes as the thermal preference votes have similar patterns.

As the inference for 80% acceptability limit, the upper comfort is not advised to be more than the predicted neutral operative temperature minus 0.7°C and the lower comfort limit is not observed. It is also mentioned that air velocity influences the upper comfort limit. Figure 13 shows the relation between the increase in comfort temperature with respect to increase in air velocity according to Nicol (2004). Moreover, Toe's and Kubota's study tells that the predicted neutral temperature is not influenced by humidity as it is always high

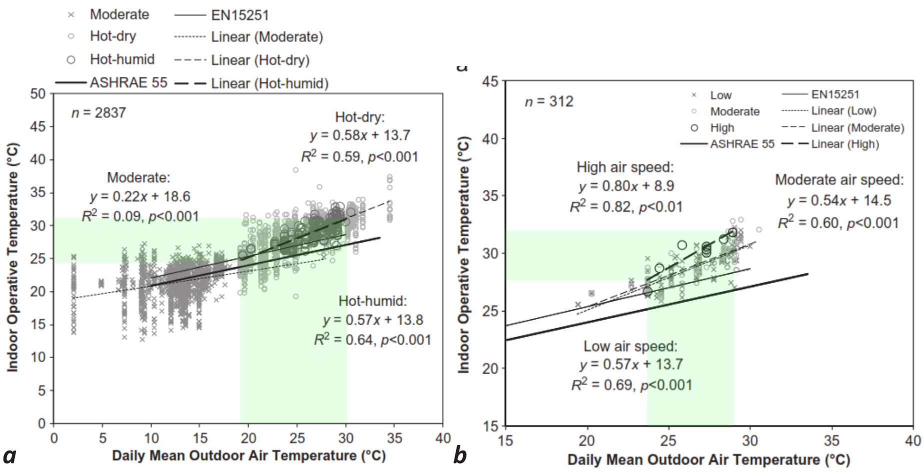


Figure 12: Results of Toe and Kubota, 2013

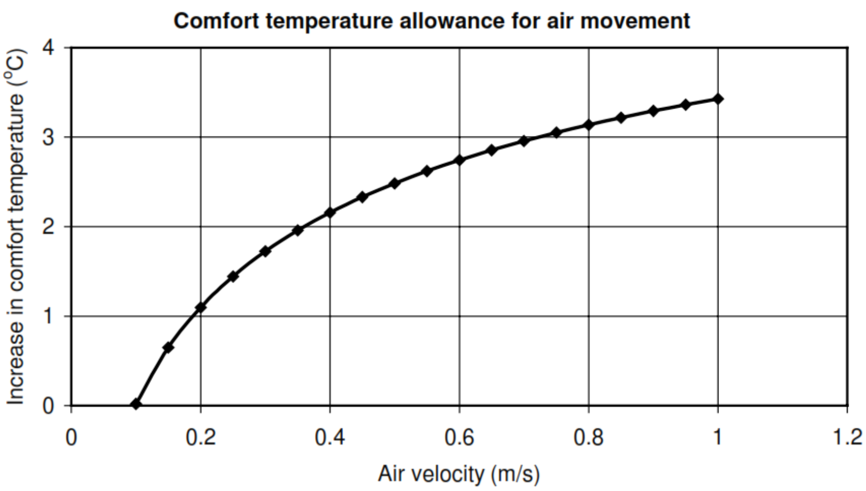


Figure 13: Increase in comfort temperature with air velocity [source: Nicol, 2004]

(above 60%) most of the time in hot-humid climate. Figure 12a shows a scattered diagram of observed indoor operative temperatures at neutral temperature against the daily mean outdoor temperatures for three climates. They have noticed each climate has a unique range of daily mean outdoor air temperatures. In case of hot humid climate, which is represented by thick dashed line in the graph, the daily mean outdoor air temperatures are higher than around 20°C and within around 31°C. Figure 12b, shows the air velocities being categorized into three groups: low (<0.3m/s), moderate (0.3 m/s to <0.65 m/s) and high 0.65 m/s or >0.65 m/s). According to ASHRAE, the increased air velocity can be considered to increase the upper comfort level when the indoor operative temperature crosses 25°C. The lower end of the regression line in Figure 12b, shows the indoor operative temperature above which air velocity can be considered.

Comfort Model Selected

As the pilot floating house falls under naturally ventilated and hot-humid climate group, the adaptive comfort study is chosen. The thermal sensation, thermal acceptance and thermal acceptability votes are not carried out during the field visit, as qualitative reviews did not take place. ANSI/ASHRAE Standard 55, is widely used as reference for comfort levels in National Building Code of the Philippines [Andamon, 2006]. Therefore, Adaptive Comfort Model in ASHRAE 55-2010 for Manila, the Philippines is used by referring the Climate Consultant 6.0.

As per this, the lower and upper comfort limits are 22.3°C and 30.5°C respectively for 80% acceptability limit and 23.3°C and 29.5°C respectively for 90% acceptability limit.

7-points thermal sensation vote used for the review based on ASHRAE, 2010

1. +3 = hot
2. +2 = slightly hot
3. +1 = warm
4. 0 = neutral
5. -1 = cool
6. -2 = slightly cold
7. -3 = cold

Other than this, 5-points thermal comfortable vote and thermal preference are also considered.

2. 3 Others

Rest of the parameters for the Indoor Enivornmental Qualities are discussed only in brief. The observations of which are personal, from my own assessment through general surveys, are discussed in the next chapter.

Air Quality

Indoor Air Quality (IAQ) depends on the pollutants present in the air inside a building and is an important factor for the indoor environment quality. Problems such as irritations on body, mental fatigue, head ache, nausea can be caused due to the presence of airborne contaminants [Wong & Huang, 2004]. It is therefore important to have pollutant free indoor atmosphere for comfortable living. There are two strategies commonly being used to deal with IAQ: (1) by increasing the ventilation and (2) by reducing pollution within and outside the building. In case of natural ventilation, the outdoor environment plays an important role. To investigate the overall air quality, biological, chemical and physical examinations are also needed [Arif et al., 2016]. Since the pilot floating house is a naturally ventilated house it is expected that the IAQ is very much related to the outdoor, as there are no filters installed. Cooking, smoking and other such factors can also cause changes in the IAQ.

Lighting Quality (Daylight)

Lighting is an important aspect for visual comfort. Inadequate lighting reduces the ability to see clearly and enhances the overall productivity. Thus it is important to ensure there that is enough light for the well-being of the occupants [Mujeebu, 2019].

Acoustic Quality

Indoor acoustic quality deals with controlling or reducing the unwanted sound inside a building. There are two types, room acoustics which deal with the sound transmission within the room and building acoustics that deal between rooms [Mujeebu, 2019]. Different sources both from outdoor and indoor can affect the acoustic quality.

Ergonomics/Spatial Quality

Ergonomics deals with the design quality of the objects, system and space around. It is important to consider the interrelationship between human body, mind and various aspects of architecture to provide a good indoor environment [Mujeebu, 2019].

3. Measuring & Monitoring

3.1 Methods

Both quantitative measurements and qualitative interviews with the occupants were considered to evaluate the indoor environmental quality of the pilot project. This combination helps to understand the indoor comfort with a bottom up holistic approach and answer the research question. This way it gives a refined result for the problem studied. The measurements may only explain 'how the situation is?' and in order to find out why, qualitative interviews and other observations may be needed [Brunsgaard et al., 2012]. Two types of measurements are planned to be made: Continuous and spot measurements. The former would be made throughout the period of measuring while spot measurements would be made during the visit to the building.

Quantitative Measurements: As the research primarily focuses on the thermal performance, on site measurements are carried out for dry-bulb temperature, globe temperature, relative humidity and air velocity. Details about the house is mentioned in Chapter 1. The details of the devices used for measuring is mentioned in section 3.2.

Qualitative Interviews: Questionnaires for interviews and daily thermal reviews are prepared but are not carried out as the occupants have not been living in the house during the period of measurement. Therefore, only general interviews are done. The prepared questionnaires can be found in Appendices B.2 and B.3.

3.2 Devices

For dry-bulb temperature, globe temperature and relative humidity

1. Hobo U12-012 with black globe attached to external sensor: 4 no.s indoor
2. Hobo U12-012 without external sensor: 1 no. outdoor

i. Range, Temperature:	-20°C to 70°C
ii. Range, Relative Humidity:	5% to 95%
iii. Accuracy:	± 0.35°C & ± 2.5%
iv. Height at which device is installed:	1.5 m from floor except attic
v. Interval of measurement:	5 mins (4 no.s indoor) & 10 mins (1 outdoor)
vi. Type:	Continuous measurement

For surface temperature

1. I-button Thermochron: 7 no.s

i. Range:	-15°C to 46°C
ii. Accuracy:	± 1°C
iii. Height at which device is installed:	1.5 m from floor on walls and centre of roof ceiling
iv. Interval of measurement:	10 mins
v. Type:	Continuous measurement

For air velocity

1. Extech SDL 350
   - i. Range: 0.2 m/s to 25 m/s
   - ii. Accuracy: ±5 %rdg
   - iii. Location: Multiple locations
   - iv. Interval: Multiple (10 mins, 5 mins, 2 mins)
   - v. Type: Spot measurments

3.3 IoT Humidity and Temperature Monitoring Device

In order to reach the subject objective 1, a cost-effective system is developed to monitor the indoor dry bulb temperature and humidity. As a result, four devices are made with DHT22 sensor that work on Raspberry pi. This enables the user to monitor the real-time measurements of the parameters anytime and anywhere in the world. For this https://ubidots.com/ IoT development platform is referred and used to store and monitor data online. The device is validated by comparing its results with that of Hobo U12-012. The devices are installed on 16 February.

3.3.1 Components for each device:

Raspberry Pi, DHT22 and resistor, Jumper cables, breadboard, Raspberry Pi USB adapter and a case

- i. Range, Temperature: -40°C to 80°C
- ii. Range, Humidity: 0% to 100%
- iii. Accuracy: ±0.5°C and ±1%
- iv. Storage: 16 GB (3 no.s) & 32 GB (1 no)
- v. Memory: 1 GB RAM
- vi. Interval: 3 mins

The cost spent for a device is less than 70 euros. The device is validated by comparing its results with that of Hobo U12-012. The final device is shown in Figure 16.

3.3.2 Programming and Hardware

The device is programmed using Python3 in a way that it reads data every three minutes and sends to the server. The device automatically detects the wireless network and starts sending the data. The program allows the device to store the data in the internal memory of the device. In case there is no network connectivity, the device would still store the data. The https://ubidots.com/ is a website where users can create free IoT platform for up to three devices. This enables to monitor the parameters through computers

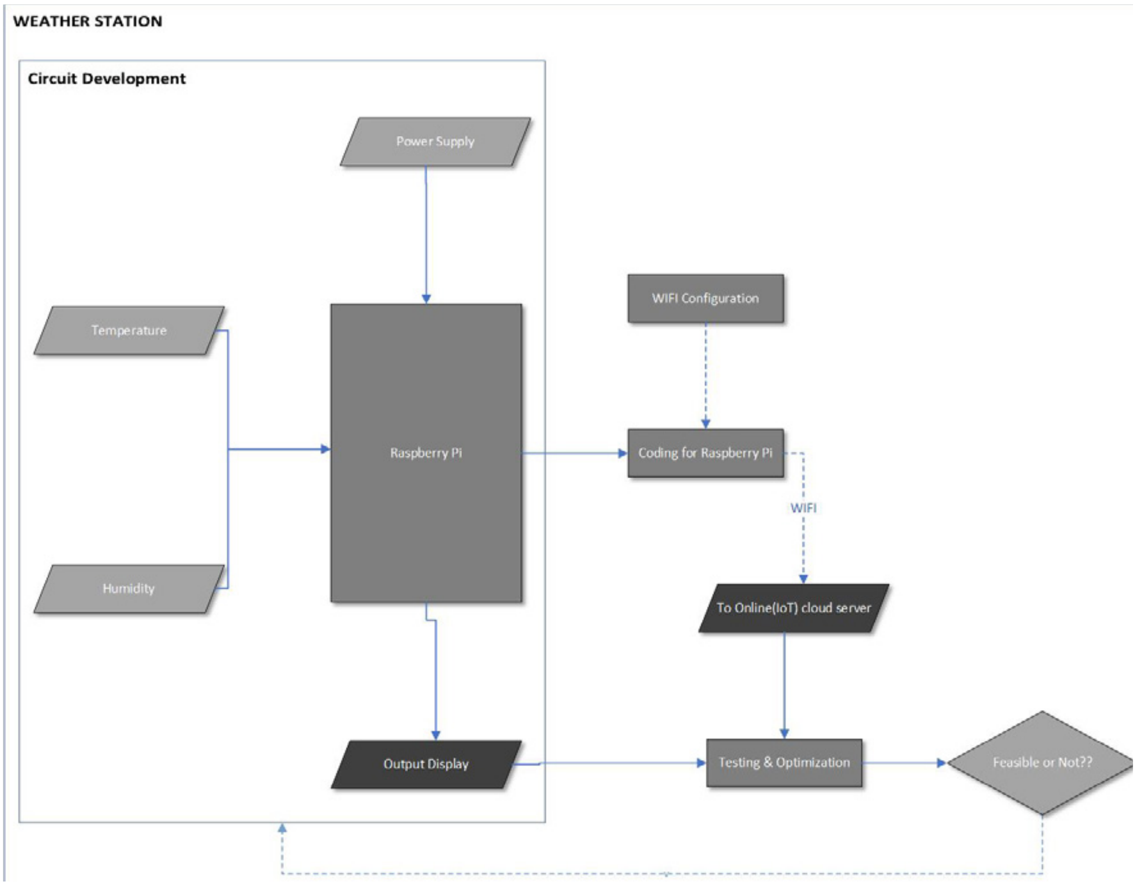


Figure 14: Work flow for developing the monitoring device

or mobile application from anywhere in the world. The entire script used for programming the device can be found in Appendix B.1.

Step 1.

The first step is testing of the DHT22 sensors. For this, a sensor is connected to the Raspberry Pi device as per the steps below using jumper cables and breadboard [PiMyLifeUp, 2019]. The circuit diagram is shown in Figure 15:

1. First provide the 10k resistor between Pin 1 and Pin 2 of the DHT22 sensor
2. Connect Pin 1 of the sensor to the physical Pin 1 (3v3) of the Pi

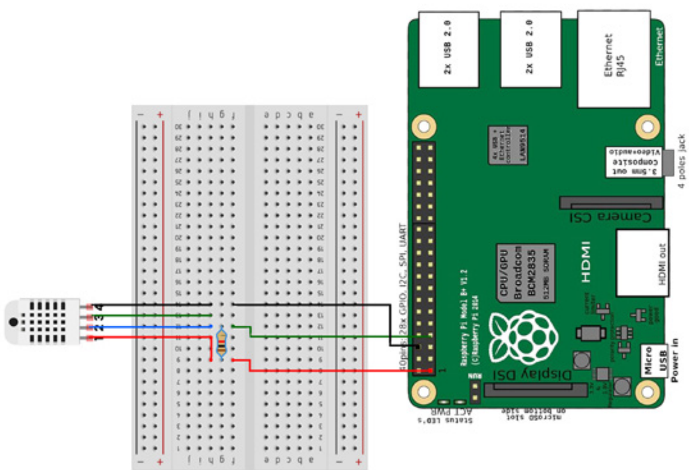


Figure 15: IoT device circuit diagram

3. Connect Pin 2 of the sensor to the physical Pin 7 (GPIO4) of the Pi
4. Connect Pin 4 of the sensor to the physical Pin 6 (GND) of the Pi

Step 2.

The sensors are programmed and tested in this step. The following are done (PiMyLifeUp, 2019).

1. It has to be made sure that the Raspberry Pi is up to date, python3-dev and python3-pip packages are installed. Also make sure latest versions of 'setuptool', 'wheel' and 'pip python' packages are installed.
2. The Adafruit DHT library is used to program the sensor. For this the library is installed in the system by running the following command:
   i. sudo pip3 install Adafruit_DHT
3. The initial program is done using python3 in order to make sure the sensor is working and reliable.
4. The results are then compared with the results of HOBO U12-012 in order to check the validity.

Step 3.

This step involves the programming of remote monitoring and data storing of the device. For this IoT platform by the website "https://ubidots.com/" is used. Free account can be created and a single account enables to monitor upto three devices. Two such accounts are created, as there are four devices, three are used inside the house and one outside the house. The data can also be exported and downloaded in the spreadsheet format with the respective time zone. The devices can also be monitored through the "Ubidots" cellphone application. The interface of Ubidots IoT platform is shown in Figures 17 and 18.

Step 4.

It is also programmed in such a way that the device also stores the data in its internal memory. Therefore, evn if there is any network issue the data is still saved. As soon as the network is available again, the device detects the network connectivity and starts sending the data online.

Step 5.

In case of power supply failure the device is configured to start automatically, when the power supply comes back. It is followed by assembling the components to make the hardware which is shown in Figure 16.

Figure 16: Final temperature and humidity monitoring device

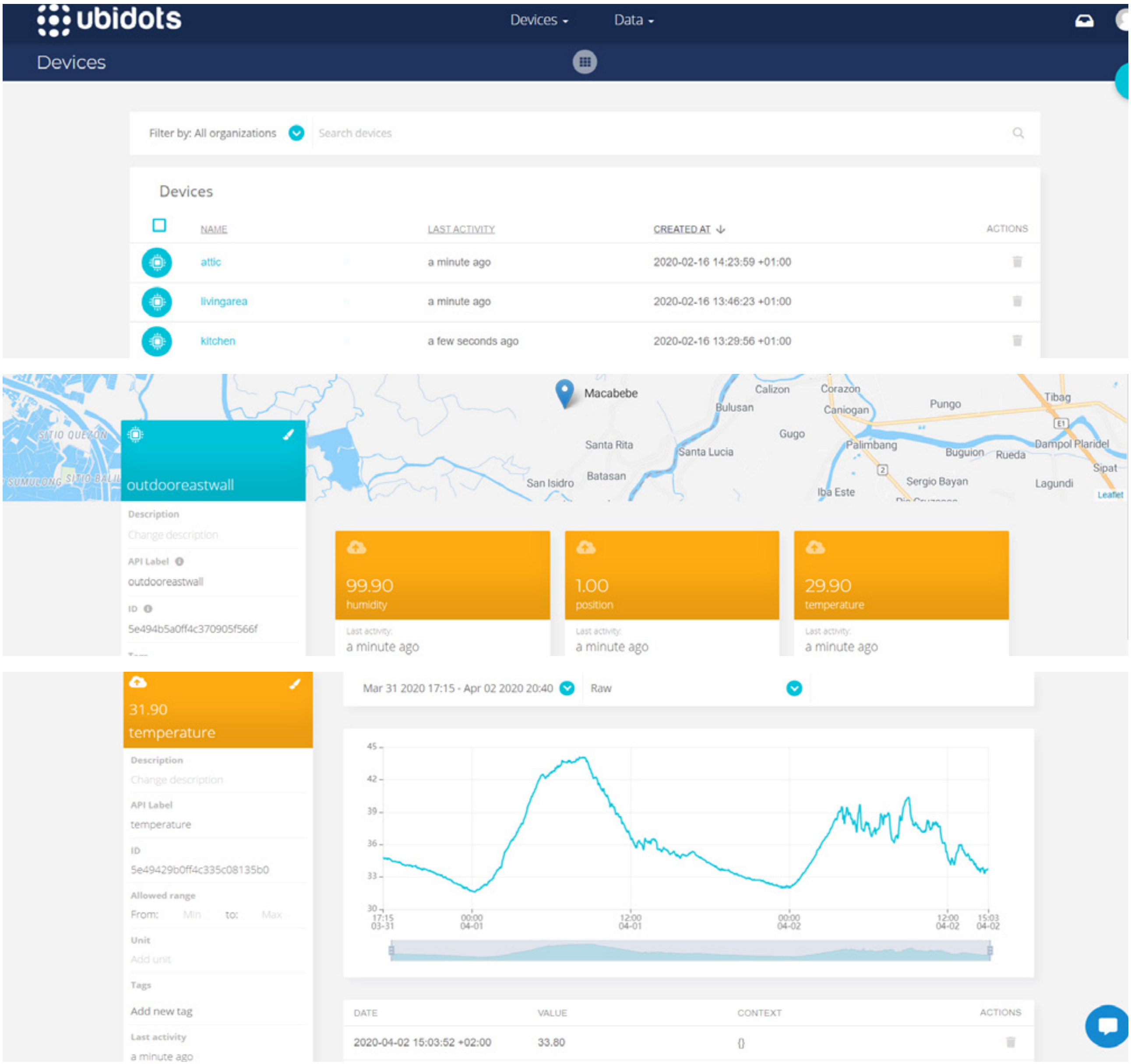


Figure 17: Ubidots website interface- live monitoring

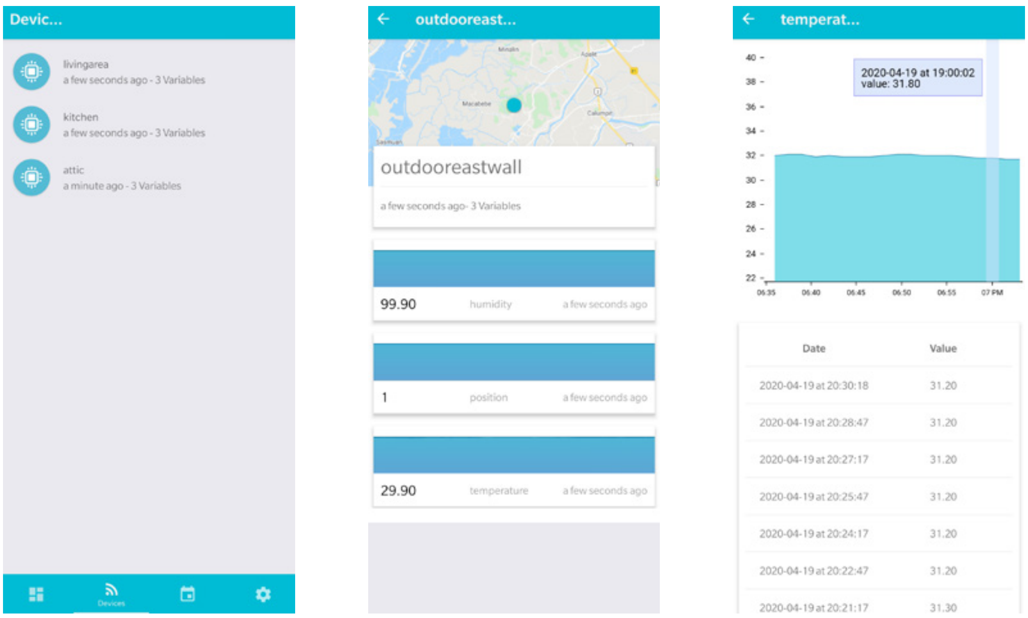


Figure 18: Ubidots cellphone application - live monitoring

3.4 Field Visit and Measurements

The measurement period for the house was planned for ten days from February 07, 2020 to February 17, 2020. Due to certain unexpected delays the measurement could be commenced only on February 08, 2020. Hence the period was reduced to nine days. The occupants were expected to be living in the house during the period of measurements, but they were not there due to their own personal reasons. The house was not being used during the period of measurement. Hence the qualitative interviews are not reliable and therefore the results of the interview are not discussed. Dry-bulb temperature, surface temperature, relative humidity and air velocity measurements are considered. The details of the house measured is mentioned in Chapter 1.


Figure 19: Field visit- Device installation (left), general interview with an earlier resident and the councellor of Macabebe(right)

3.4.1 Measurement Period

	Day	Time Spent
1.	February 08:	09:30 to 13:30 & 16:00 to 16:30
2.	February 09:	13:00 to 16:30
3.	February 10:	20:00 to 22:30
4.	February 11:	20:15 to 22:30
5.	February 12:	did not visit
6.	February 13:	18:15 to 21:00
7.	February 14:	10:00 to 13:00
8.	February 15:	08:00 to 09:00 & 10:30 to 12:00
9.	February 16:	07:45 to 13:00 & 19:15 to 22:30
10.	February 17:	09:00 to 13:00

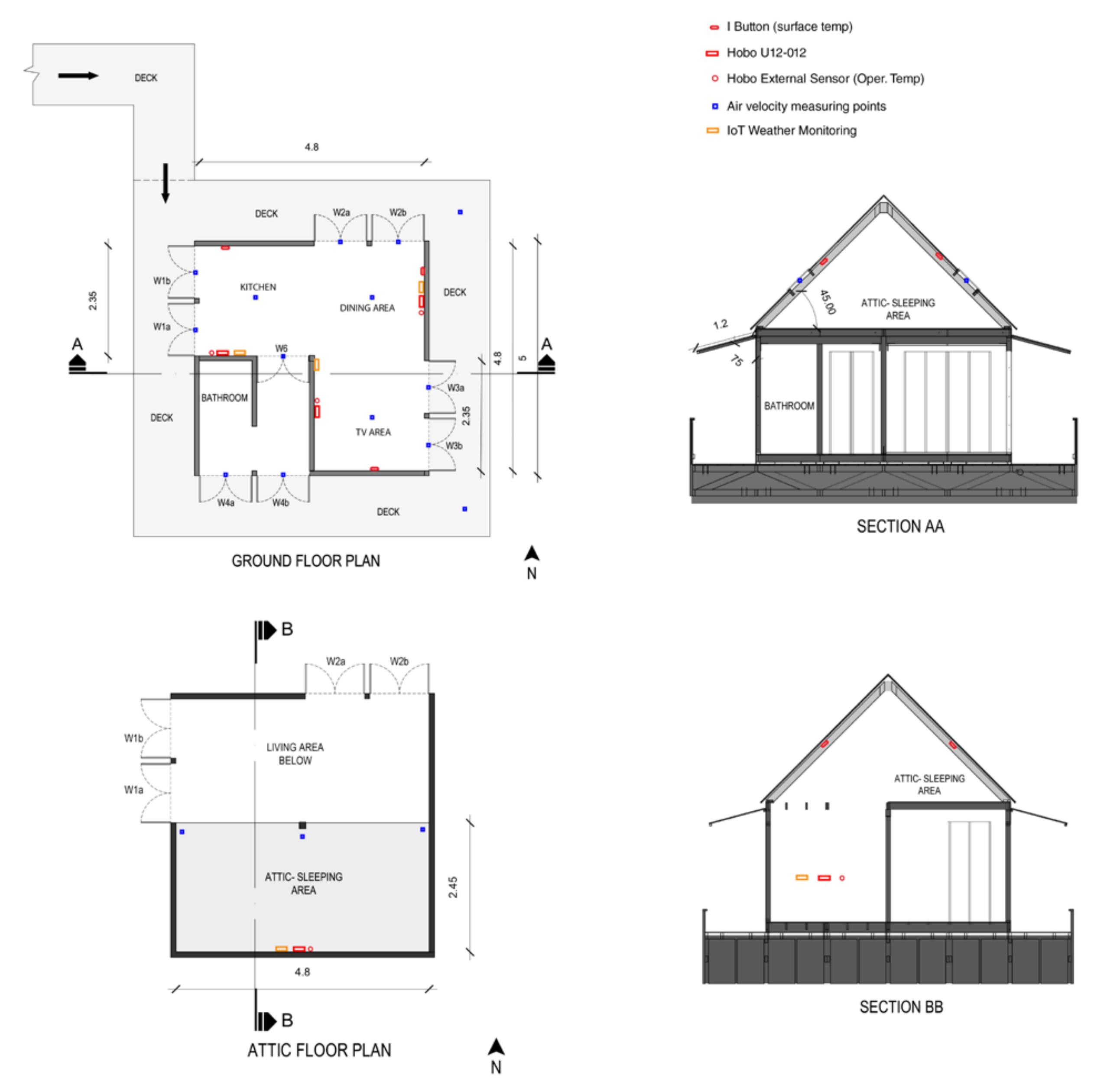


Figure 20: Measurement locations

3.4.2 Installation of the Devices and Measurement

The installation of the devices is carried out by two people.

Measurement of temperatures & humidity

The positions for the devices were finalized after checking the site conditions. Two devices were placed in the living area (TV area and dining area), one each in the kitchen and attic. The measurements started from February 08, 2020 morning to February 17, 2020 noon. Details of the devices are mentioned in section 2.2. In the attic the device is placed at the sleeping height. One device is placed in the exterior, a day each on each exterior wall except North side, which was measured for 2 hours. In this way it is expected to understand the location based influence. An external temperature sensor with black globe is used for each of the hobo device except the one used to measure the outdoor. The IoT air temperature and humidity monitoring devices are installed, one each in the living area, kitchen, attic, and outdoor east wall.

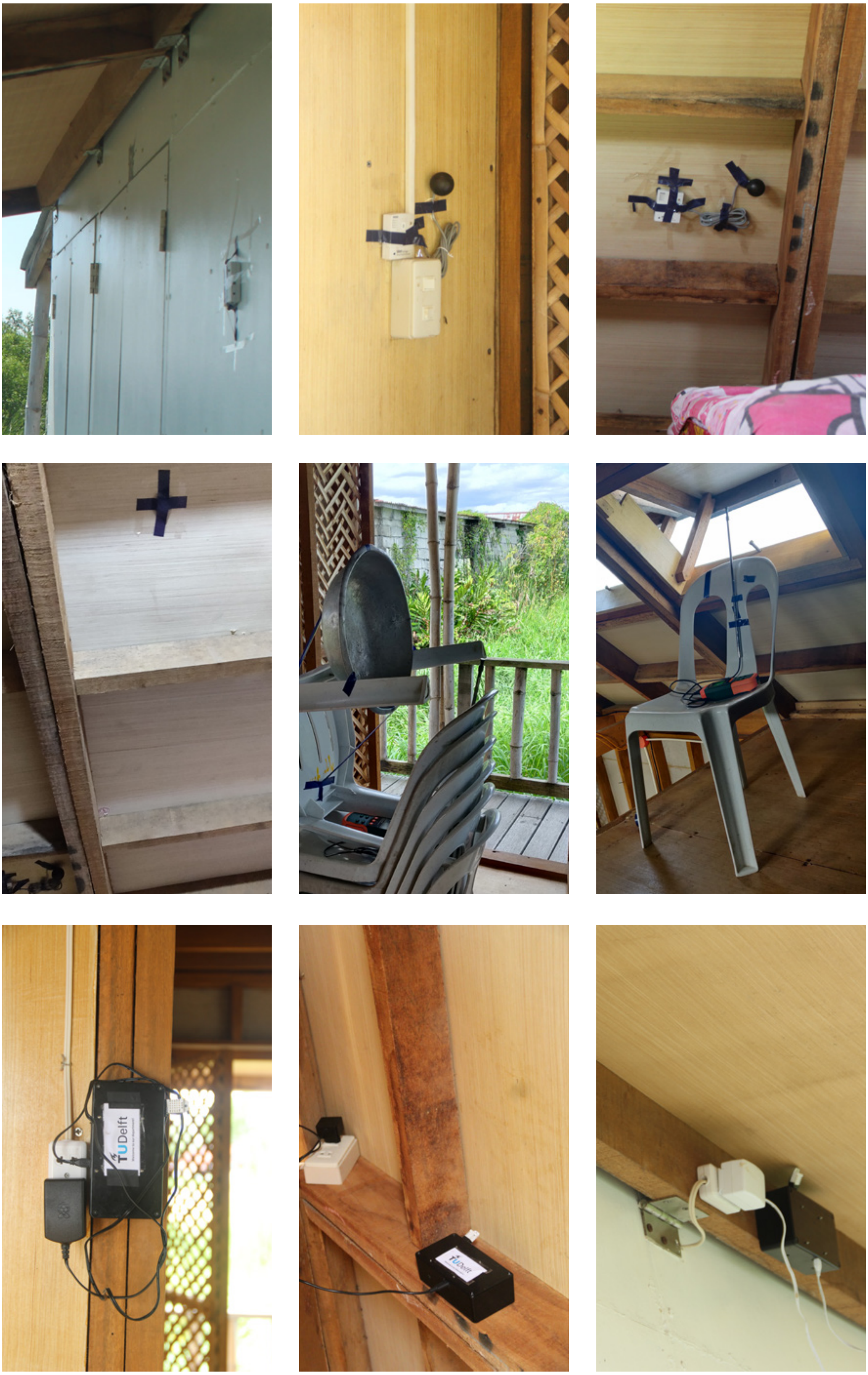


Figure 21: Hobo device- exterior east wall (top left), Hobo device and black globe external sensor- indoor living (top middle), Hobo device and black globe external sensor- indoor attic (top right), I button- south inner roof (center left), Measuring set up for air velocity (center middle and center right), Raspberry Pi IoT monitoring device- living zone, attic and exterior east wall (bottom))

Measurement of surface temperature

The I-buttons are placed against the surface of the interior walls and inner surface of the roof to measure the surface temperature. Location of the devices can be seen in Figure 21. For the roof, the devices are placed beneath each side of the hip roof, towards the centre of each side. This helps to understand the solar heat gain.

Measurement of air velocity

Air velocity at multiple locations are measured. The locations of measurements are shown in Figure 20. Since the instrument used is unidirectional, multiple directions are measured (i.e. from N, NE, E, SE, S, SW, W and NW). For each opening, measurements are made at the centre facing the wind direction. At first, for each opening, measurements are made for 10 minutes at 10 seconds interval and rest for 2 minutes at 2 seconds interval. For the rest of indoor locations measurements are made for 5 minutes at 10 seconds intervals for the first time and then 2 minutes at 2 seconds interval. Similarly, the outdoor wind measurements are also made. The average is taken for each location to find the velocity.

The following conditions are noticed in order to understand the effect of the openings during the period of measurement. The air velocity coming in from the South and West opening were negligible when compared to the other openings.

Conditions

On the first day, all the openings were open. Most of the time during the period of measurement, the south doors were closed, except the first day and second day. It is found that the air velocity is negligible at south opening and also it opens to the bathroom, which is not considered in this research. On 13th February only North and East doors were opened while spending time in the house during measurement. On 15th February only North and West doors were opened. In addition the following conditions were performed to see how it affects the parameters measured:

1. Feb 14
   i. Condition 1: Only East Opening Open: 10:15 to 11:30
   ii. Condition 2: Only North Opening Open: 11:30 to 12:30
   iii. Condition 3: Only Roof East Opening Open: 12:30 to 13:30
2. Feb 16
   i. Condition 4: Only Roof openings closed: 19:15 to 22:30
   ii. Condition 5: Only Roof opening open

Interviews with the occupants

As the occupants were not living in the house, the interviews and daily reviews are not expected to be reliable. Hence they will not be taken into consideration for this report. The interviews prepared and questionnaires made are in Appendix B.2 and B.4.

3.5 Hypotheses

After the preliminary study and site visit the following hypotheses are made. The hypotheses focus on the thermal comfort performance of the building and are used to analyze the results of the measurements. As per the light intensity measurements from the hobo device, the sunrise is at 06:10 and sunset at 18:10, hence this period is considered to be day and rest of the time to be night.

1. The building is a lightweight wooden structure and has large door cum window openings in the ground floor which is expected to be open during most of the day to provide better indoor comfort. Therefore, *"the building interior is expected to be responsive to the outdoor temperature".*
2. As the indoor space is protected from direct sun and there are enough openings to facilitate air movement the hot air inside can escape to the exterior, hence reducing the indoor dry-bulb temperature. During the night, the openings would be closed allowing the warm air to stay indoor. Therefore, *"the building interior is expected to have lower dry-bulb temperature than outdoor during the day and the other way during the night".*
3. The roof panels are expected to heat up the most due to solar radiation and this in turn heats up the space below the roof. As the attic is right below the roof, towards the south of the building and has only two windows on the east and west wall, *"the attic is expected to be the hottest space in the building during most of the day".*
4. The exterior walls in the ground floor are made of cement fibre board and the overhangs/eaves are expected to protect them from direct sunlight. Hence *"the interior surface temperature of the walls are expected to be lower compared to the interior surface temperature of the roof".*
5. Large openings are expected to provide enough air movement inside the house. The air velocity at the centre of the openings is expected to be close to that of the outdoor air velocity. During the period of measurement, the wind direction is from the NE & SE. Therefore, the air velocity at the N and E openings are expected to be the maximum, while at the S and W openings are minimum. *"The indoor spaces are expected to have good air movement".*

3.6 Other Parameters of Indoor Environmental Quality

During field obseravations, the air quality, daylighting and acoustic quality are found to be satisfactory. When talking to the earlier residents, they did not mention any issues with air quality or odour inside the house. As there are large openings, the indoor spaces are well lit during day. The location is generally in a less noisy place away from the crowd and traffic, therefore the acoustic problems cannot be observed. When it comes to the spatial quality, the house is good enough for a family of three or four members; preferably two adults and one or two minor(s). Periodic maintenance is also an important factor that adds to a good indoor quality.

3.7 Summary of Measuring and Monitoring

The measuring period is nine days. Parameters influencing the thermal comfort are measured for each space in the house except bathroom area. The measured parameters are dry-bulb temperature, black globe or operative temperature, surface temperatures, relative humidity and air velocity. Hobo U12-012 devices are used to measure dry-bulb temperature, operative temperature and humidity. The height at which the devices are installed is 1.5 m in ground floor and at the sleeping level in the attic. For surface temperature I-buttons are used. The interior surface temperature of the roofs and exterior walls at several locations are measured. Air velocity is measured at multiple points and different directions by hotwire anemometer. At the openings, air velocity is measured at the centre. Two IoT temperature and humidity monitoring devices are placed in the ground floor and one each in the attic and outdoor east wall.

4. Results & Comfort Performance

The results of the in situ measurements and observations are presented and discussed in this chapter to evaluate the indoor comfort performance which helps to decide the improvements needed. The collected data is first sorted and systemized with respect to each space for each parameter for each day.

4.1 Results and Discussions

The results are discussed in different sections, at first temperature followed by humidity, then air velocity and finally other field observations. It is observed that there is not much difference between the operative temperature (black globe temperature) and the dry-bulb temperature. Hence the dry-bulb temperatures are discussed in this chapter. The results of black globe temperature are in Appendix C. The light green shaded portion in all the graphs is the comfort range based on the 80% acceptability limit for the Manila region as per ASHRAE adaptive comfort obtained from the "Climate Consultant 6.0".

4.1.1 Temperatures

As mentioned in section 3.4.2 the data loggers are placed in all the exterior façades in order to understand the location-based influence. The data logger measured for only 2 hours in the North façade and therefore it is not considered. The results of these loggers are discussed first. Since the period of measurement is only nine days, the daily dry-bulb temperatures with 5 minutes interval are taken for analysis. Figure 22 shows the dry-bulb temperatures plotted against time. This helps to understand the uncomfortable times of the day. The abnormal outdoor temperature rise in the east and west can be explained by the location and the time as the solar radiation would have directly hit the device. Hot hours are generally from 13:30 to 15:30. For understanding the relation between the outdoor temperature and the indoor temperature of each space, the indoor temperatures are plotted against the measured outdoor temperatures (Figure 24).

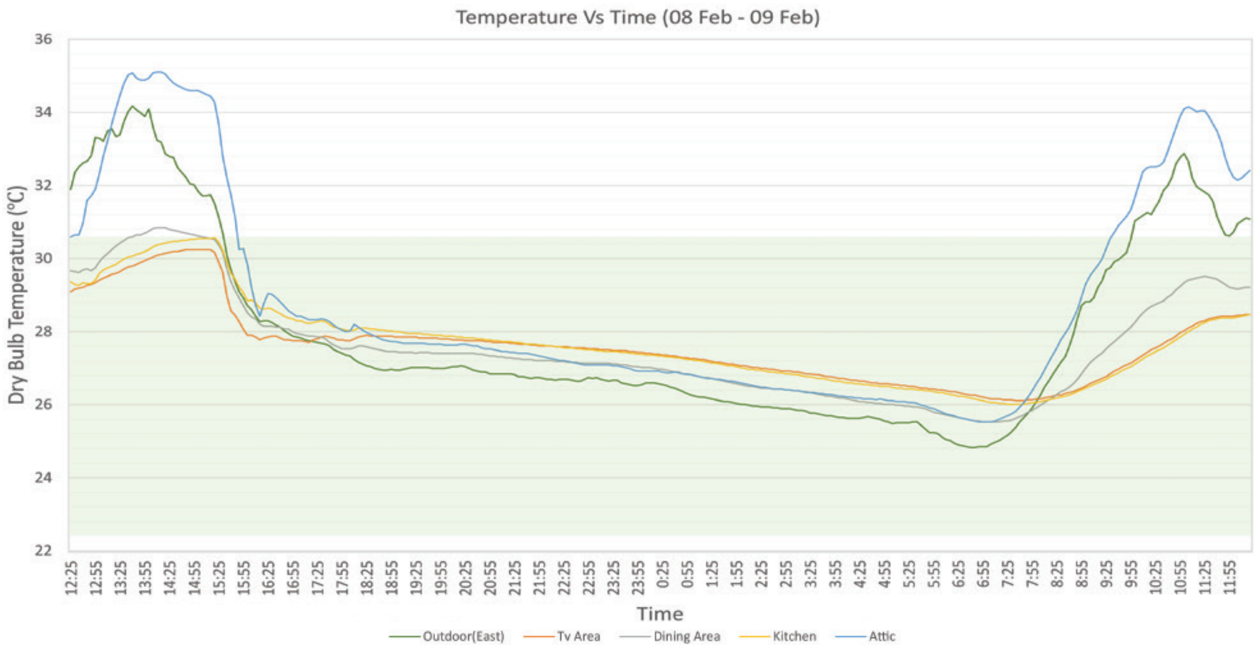


Figure 22: Temperature data

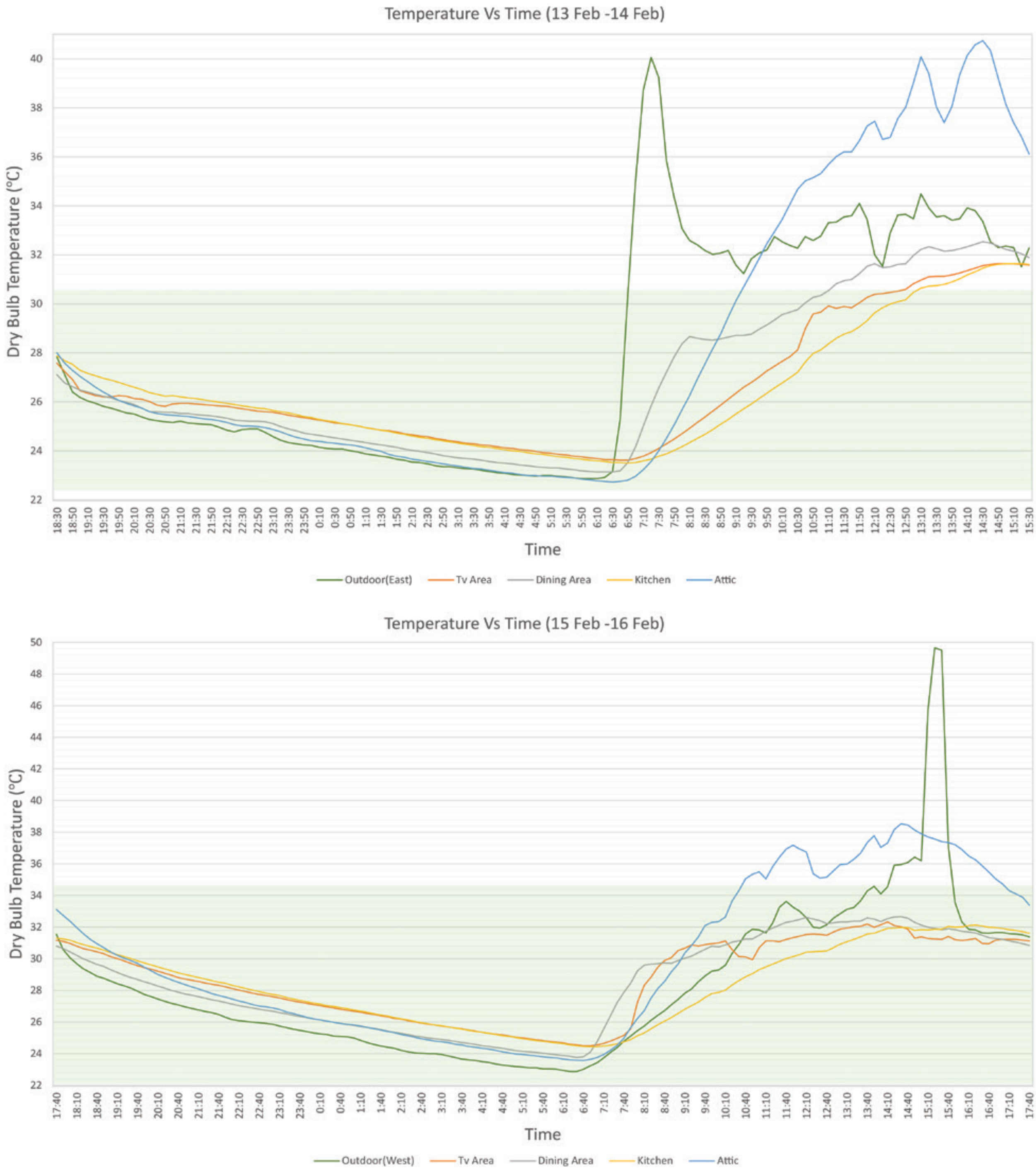


Figure 23: Temperature data

Is the interior of the building responsive to the outdoor temperature?

As expected, it can be seen from the graph that the indoor temperature is responsive to the outdoor. After around 5:00 pm it can be seen that all the temperature measurements are gradually going down with similar regression line. The temperature reaches the lowest just around 6:30 am and then it starts to rise. The temperature rise and drop during the day follows a steeper pattern. Figure 24 shows that all indoor spaces are following a similar trendline in the indoor temperature with respect to the outdoor, except the attic. The attic has a steeper slope, especially during the day.

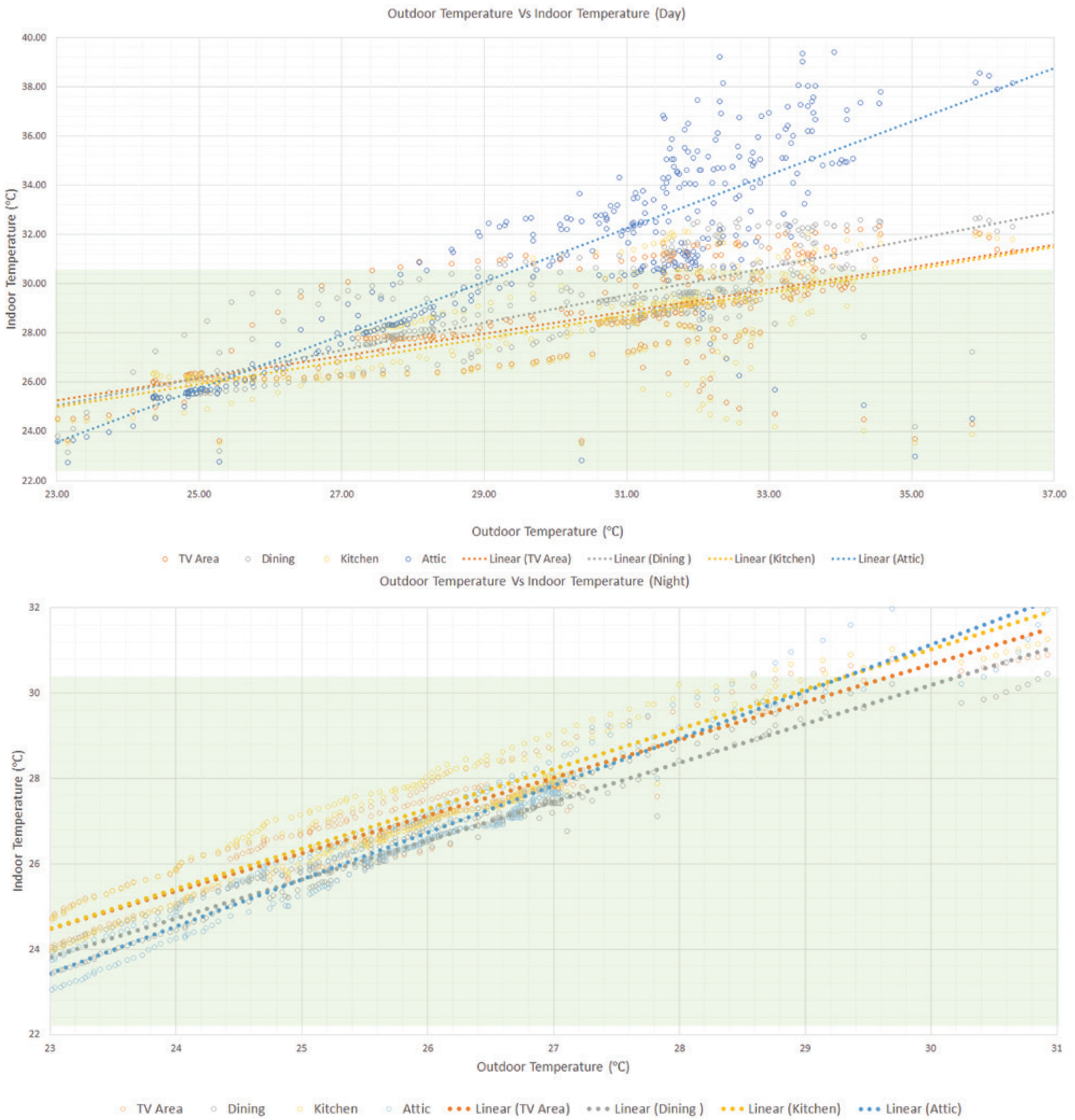


Figure 24: Indoor temperature Vs outdoor temperature- day (Top) & night (Bottom)

Which is the warmest and the coolest indoor space?

All the indoor dry bulb temperature measurements are plotted in the graph shown in Figure 25. As anticipated, during most of the day the exterior temperature is higher than the indoor temperature except that of the attic and at night the exterior temperature is the lowest. The higher temperature of the attic is due to the influence of the solar radiation which is discussed later. The attic is also the coolest space in the building as it goes down to around 1°C lower than the lower comfort level during the coldest night, which could be due to radiative cooling. The difference between the daily maximum and minimum temperatures of the attic varies from 10°C to 17°C while for the other spaces, it is between 6°C to 9°C. The horizontal lines, with respective colors of each space, on the graph in Figure 25 shows the increase in upper comfort level temperature with respect to the average air velocity of each space. The air velocity of each space is discussed in the section 4.1.3.

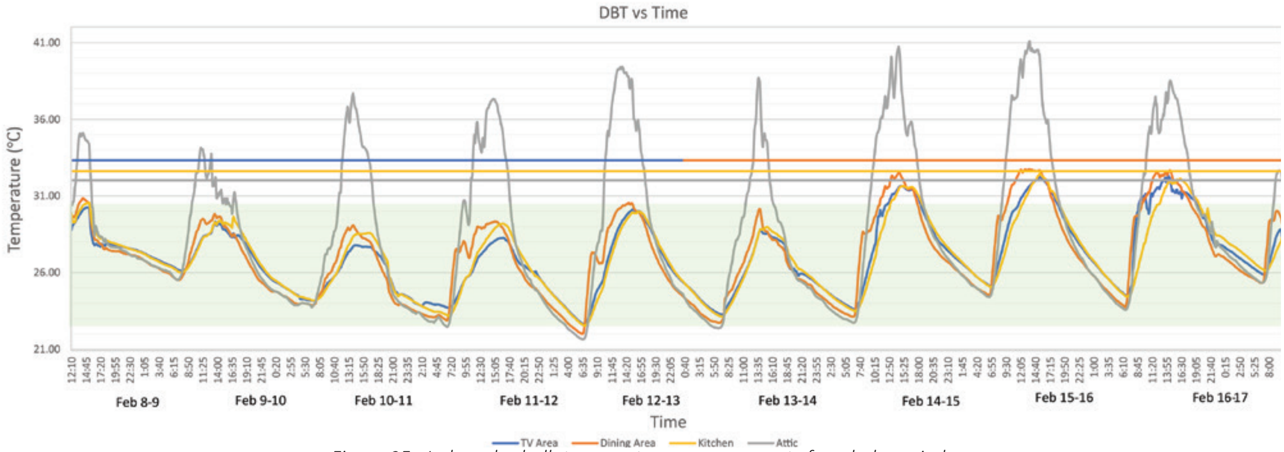


Figure 25: Indoor dry-bulb temperature measurements for whole period

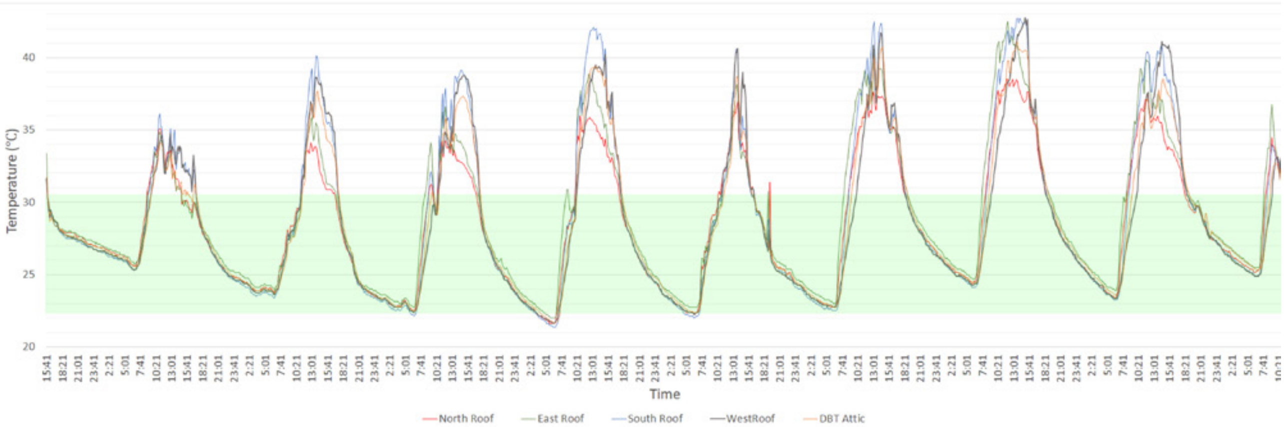


Figure 26: Roof inner surface temperature and attic dry-bulb temperature for the whole period

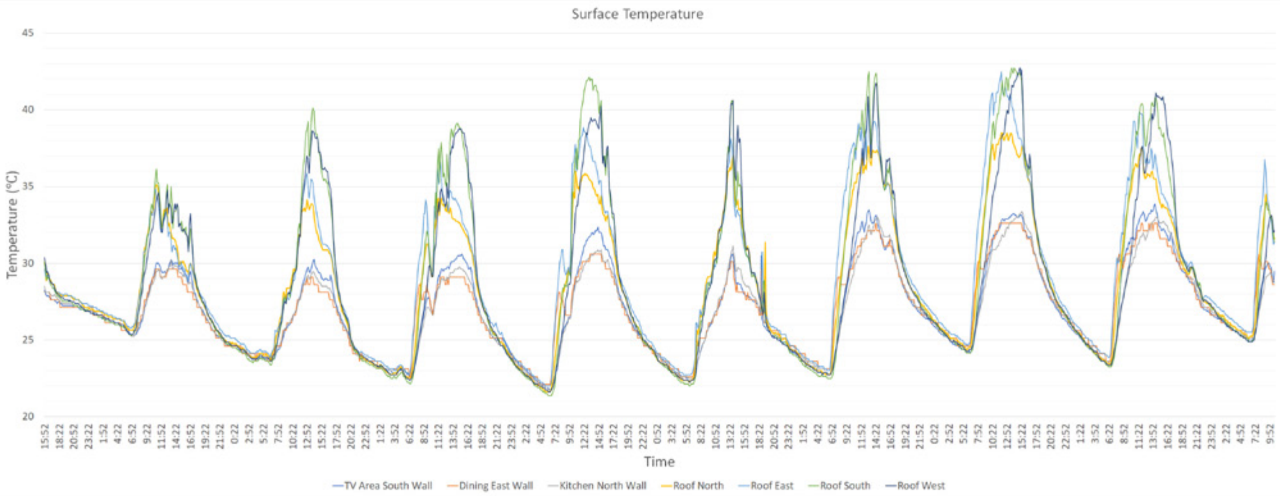


Figure 27: Roof inner surface temperature and walls inner temperature for the whole period

What is the effect of solar radiation in the building?

As expected, the temperature of the attic is well influenced by solar radiation. The roof is heated up during the day and this considerably contributes to the dry-bulb temperature of the attic, as it is right below the roof. From Figure 26 it can be seen that the south roof gets heated the most and the attic is towards the south of the building. The north roof gets heated the least almost 5°C to 6°C lower than the south. The inner surface temperature of the walls are lower when compared to that of the roof as the walls are protected by the eaves. The inner surface temperature results of the walls are shown in Figure 27.

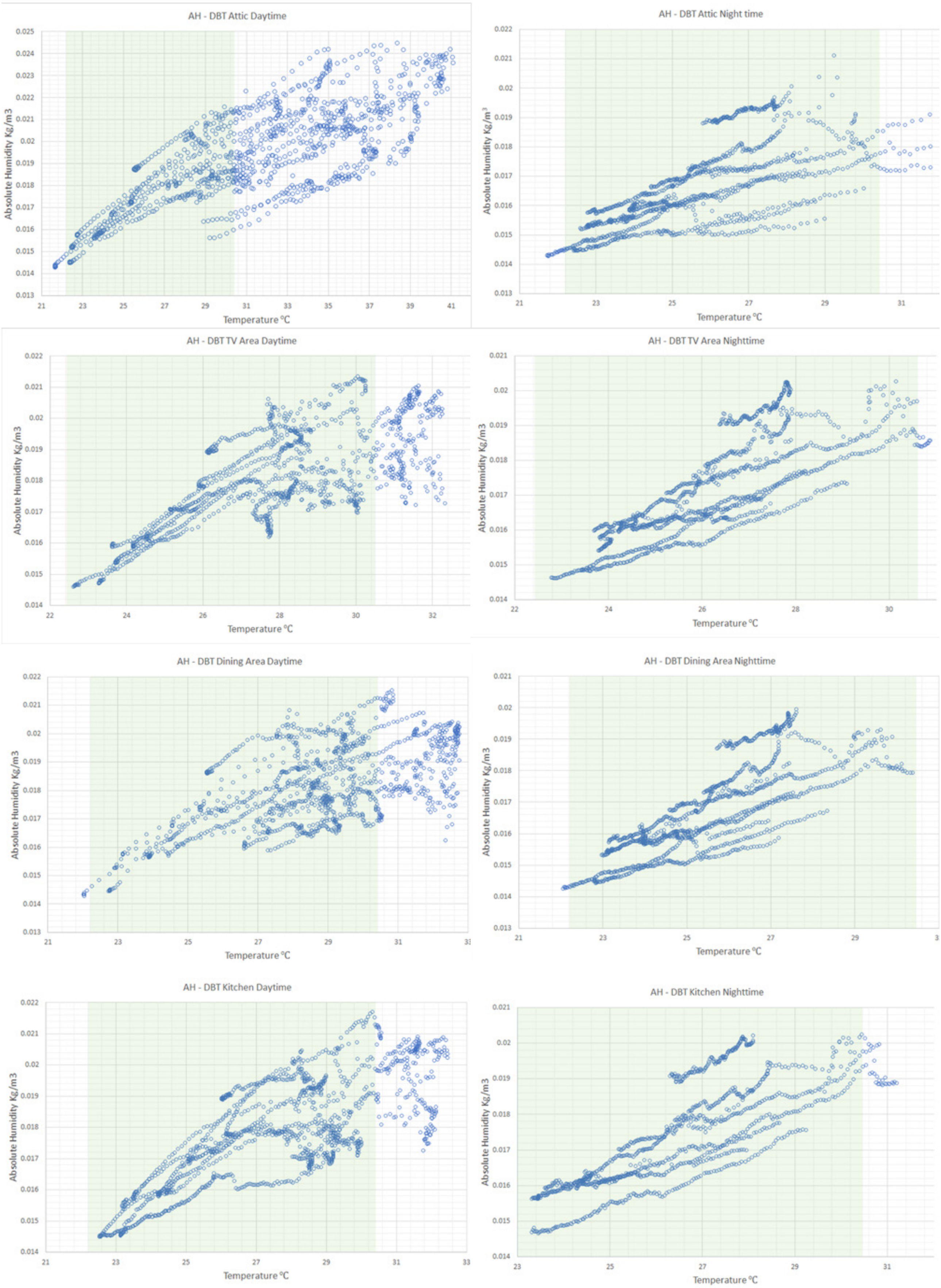


Figure 28: Absolute humidity vs dry-bulb temperature

4.1.2 Humidity

Being in a hot and humid climate, the humidity levels are expected to be high for most of the time. Figure 28 shows absolute humidity plotted against the indoor dry bulb temperature of each space during day and night. It can be noticed that the measured data form a pattern. During the day as the temperature rises, the moisture level is relatively low lagging behind the temperature and at night, the humidity is at a high level for the same temperature during day. This pattern could be the effects of cyclic changes in the humidity due to moisture sorption and the effect of the large surrounding water body. Further research in this is worth studying. According to Toe and Kubota(2013) as indoor humidity is high most of the time in hot-humid climate, it does not influence the neutral temperature. The other aspects due to humidity such as mold or fungal growth and odour are not considered in this research.

4.1.3 Air Velocity

Location		W 1 (West facing)	W 2 (North Facing)	W 3 (East Facing)	TV Area	Dining Area	Kitchen	Roof Opening East	Roof Opening West	Attic
Avg Air Velocity	m/s	0.47	0.87	1.01	0.63	0.62	0.40	0.94	0.64	0.31
Max Avg/measurement		0.63	2.55	1.54	1.01	0.87	0.60	1.34	0.96	0.50
Min Avg/measurement		0.31	0.34	0.58	0.30	0.39	0.21	0.54	0.46	0.14

Figure 29: Indoor air velocity

The air velocity data can be divided into three groups depending on the values: low (<0.3 m/s), moderate (0.3 m/s upto <0.65 m/s) and high (0.65 m/s and higher) [Toe & Kubota, 2013]. Air velocities are measured at different locations and multiple directions. Though multiple directions per location have been measured, the direction with the highest air velocity is taken for the location. Average velocity is found out for each measuring points. Average velocity for each space can be seen in Figure 29. It can be seen that most of the measurements fall in the moderate category and also experience high velocities. Though the attic just falls in the moderate category most of the time it has low velocity. The measurements are made at the sleeping height in the centre, but occupants use the space more towards the south with lesser air velocity. The increase of indoor comfort temperature for each with respect to the average air velocity for each space as per Figure 13 (Nicol, 2004) in Chapter 2 is mentioned below: According to Srivajana (2003), air velocity above 0.9 m/s is undesirable if the occupant is working under stressed conditions.

1. TV Area: Average air velocity is 0.63 m/s and the upper comfort temperature level increases by 2.8°C
2. Dining Area: Average air velocity is 0.62 m/s and the upper comfort temperature level increases by 2.8°C
3. Kitchen: Average air velocity is 0.4 m/s and the upper comfort temperature level increases by 2.1°C
4. Attic: Average air velocity is 0.31 m/s and the upper comfort temperature level increases by 1.5°C

4.1.4 Other Observations

The observations are mainly regarding user-friendliness:

1. As of now, the house in the ground floor has only doors cum windows. In case of ventilation and day

light, the occupants have to open all openings, this could affect privacy.

i. There is only limited option in controlling the openings.

ii. The extra fenestration is not being used.

2. In case of higher wind velocity, the shutters are being blown open and closed, also any light weight objects could be blown away inside the house.

3. At present there is no guard rail in the attic floor.

4.2 Discussion of the Results

The results are compared with the hypotheses in this part.

The building interior is responsive to the outdoor temperature: From the results it can be seen that the indoor dry-bulb temperatures are having a similar pattern as that of outdoor temperatures except a few fluctuations which are discussed before. As it is a light weight and naturally conditioned building the indoor spaces are quite fast to respond to the outdoor condition.

Indoor dry-bulb temperature vs outdoor dry-bulb temperature: As expected the indoor dry-bulb temperatures are lower than the outdoor during most of the day, except that of the attic space and are higher than the outdoor during the night for the measured period.

Effects of solar radiation: Much of the exterior walls in the ground floor are protected from solar radiation by the overhangs. It can be seen that the attic is much hotter than the rest of the spaces as it is right below the roof and is towards the south.

Openings and air velocity: As the openings are large, the air velocity at the openings are similar to that of the outdoor. It can be seen that most of the spaces have moderate to high air velocity which is beneficial for the thermal comfort. The attic being the hottest space has comparatively low air velocity.

Conditions performed: The conditions mentioned in section 3.4.2 do not actually show any impact on the results. This could be because of the short duration for the measurement of the conditions.

4.3 Comfort Performance

For this study purpose the comfort range of the temperature is taken from the "Climate Consultant 6.0" based on the adaptive comfort model for the Manila region, the Philippines. Manila is around 70 kms from the building location. The green shaded region in the graph shows the comfort zone with 80 % acceptability limits with the lower comfort level being 22.3°C and higher comfort level being 30.5°C. The results show that the comfort performance of the building is quite satisfactory for most of the measurement period, except that in the attic. During the hottest day it can be seen that the attic gets hotter than the upper comfort level by over 11°C, while the other spaces are hotter by around 3°C to 4°C. During the time of measurement, the roof openings were closed most of the time. This could also affect the increase in attic temperature. Temperature goes around 2°C below lower comfort level during the coldest night.

The attic is the most uncomfortable space during most of the day, which is influenced by solar radiation. It is therefore important to reduce the heat gain by the roof and improve the ventilation in the attic. Besides the climate aspect of comfort performance, from the observations made, the user-friendliness of the doors can also be improved.

4.4 Conclusion of the Comfort Performance

From the analysis it is seen that the attic is the hottest space. It can be seen that the dry bulb temperature goes over 11 °C with respect to the upper comfort limit on certain days.

1. The reasons are due to the solar heat gain as the roof is getting heated, the heat transfer from the inner roof surface to the attic through convection, location of the attic (towards the south), less air velocity or air movement. It is also assumed to have less heat dissipation as there are only two openings above the attic. It is therefore important to:
   i. reduce the solar heat gain
   ii. increase the air velocity (ventilation) in the attic (especially at sleeping height)
   iii. provide means to dissipate heat to the exterior (stack effect opening at roof preferably topmost part)
2. User-friendliness of the door shutters in terms of:
   i. controlling the air velocity
   ii. controlling the privacy
3. Provide smarter and easier way to open and close the door or window shutter.

4.5 Results of IoT Monitoring Devices

The dry-bulb temperature data obtained from the IoT monitoring devices is discussed in this section. This helps to find out if the device can be used for long term monitoring or whether the devices need any improvements. Daily review with a current occupant is done for four days, which is discussed in Appendix B.3. It has been done for understanding the relation between the temperature and occupant preference, the results have not been applied in this research.

4.5.1 Comparison with the Hobo Devices

First the results are compared with that of the Hobo U12-012 measurements of the respective spaces. The comparison of results are shown in Figures 30 and 31. It can be seen that the Raspberry Pi devices are showing higher temperatures compared to that of the Hobo devices in the respective location. Lack of calibration of the sensors, overheating of the devices and location of the devices are expected to affect the results of the IoT monitoring devices.

	Hobo TV Area	Raspberry Pi	Difference
	°C	°C	°C
02/17/20 12:00:00 AM	27.70	29.50	1.80
02/17/20 01:00:00 AM	27.43	29.40	1.97
02/17/20 02:00:00 AM	27.19	29.10	1.91
02/17/20 03:00:00 AM	26.89	28.80	1.91
02/17/20 04:00:00 AM	26.65	28.50	1.85
02/17/20 05:00:00 AM	26.35	28.20	1.85
02/17/20 06:00:00 AM	26.11	27.90	1.79
		Average	1.87

	Hobo Dining Area	Raspberry Pi	Difference
	°C	°C	°C
02/17/20 12:00:00 AM	27.01	29.50	2.49
02/17/20 01:00:00 AM	26.72	29.40	2.68
02/17/20 02:00:00 AM	26.40	29.10	2.70
02/17/20 03:00:00 AM	26.11	28.80	2.69
02/17/20 04:00:00 AM	25.87	28.50	2.63
02/17/20 05:00:00 AM	25.67	28.20	2.53
02/17/20 06:00:00 AM	25.45	27.90	2.45
		Average	2.59

Figure 30: Comparison of temperature measurements of Hobo device and IoT device: Living area

	Hobo Kitchen	Raspberry Pi	Difference
	°C	°C	°C
02/17/20 12:00:00 AM	28.221	29.30	1.08
02/17/20 01:00:00 AM	27.875	29.00	1.13
02/17/20 02:00:00 AM	27.677	28.70	1.02
02/17/20 03:00:00 AM	27.382	28.50	1.12
02/17/20 04:00:00 AM	27.087	28.20	1.11
02/17/20 05:00:00 AM	26.769	28.20	1.43
02/17/20 06:00:00 AM	26.451	27.90	1.45
02/17/20 07:00:00 AM	26.207	27.70	1.49
		Average	1.23

	Hobo Attic	Raspberry Pi	Difference
	°C	°C	°C
02/17/20 12:00:00 AM	27.481	29.40	1.92
02/17/20 01:00:00 AM	27.063	29.00	1.94
02/17/20 02:00:00 AM	26.818	28.70	1.88
02/17/20 03:00:00 AM	26.402	28.30	1.90
02/17/20 04:00:00 AM	26.085	28.00	1.92
02/17/20 05:00:00 AM	25.768	27.70	1.93
02/17/20 06:00:00 AM	25.501	27.40	1.90
02/17/20 07:00:00 AM	25.355	27.30	1.94
		Average	1.92

Figure 31: Comparison of temperature measurements of Hobo device and IoT device: Kitchen (left) & Attic (right)

4.5.2 Temperature

For further investigation, the hourly indoor dry-bulb temperatures from the IoT devices are plotted against the respective outdoor temperature for March, April and May (Figures 32 and 33). This is done to understand the temperature distribution and reliability of the IoT devices. April is the hottest month, followed by May for the Pampanga region (Figure 08). From the graph, the relation between the indoor temperature and outdoor temperature seems to be similar when compared to that of Figure 24, but the temperature

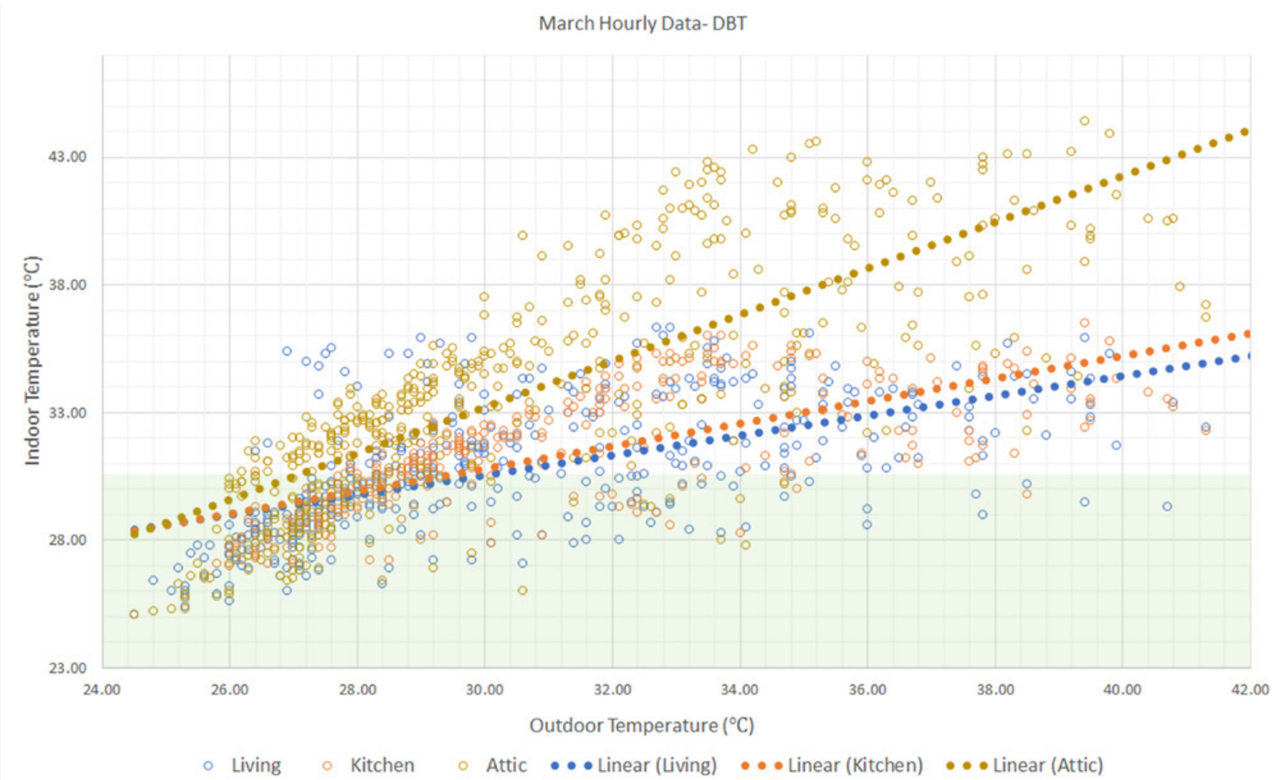
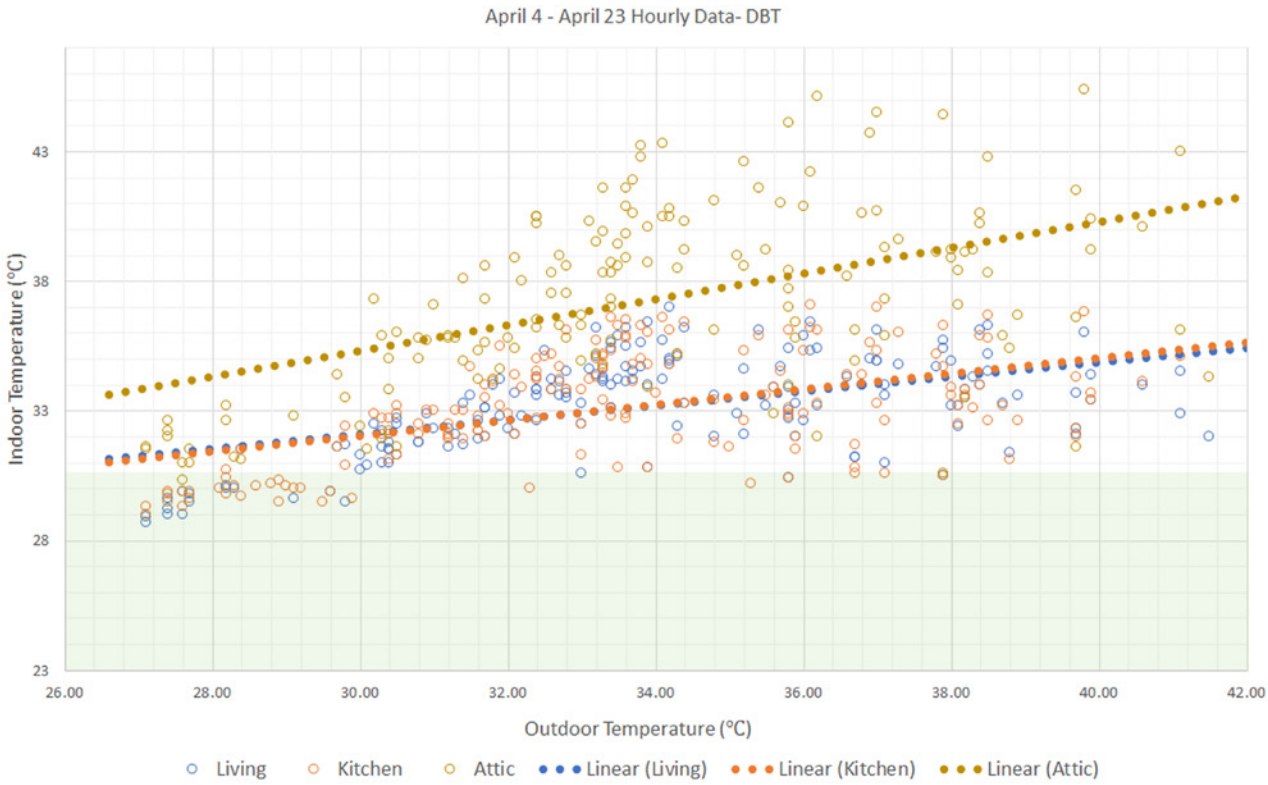


Figure 32: Hourly indoor temperature vs hourly outdoor temperature - March



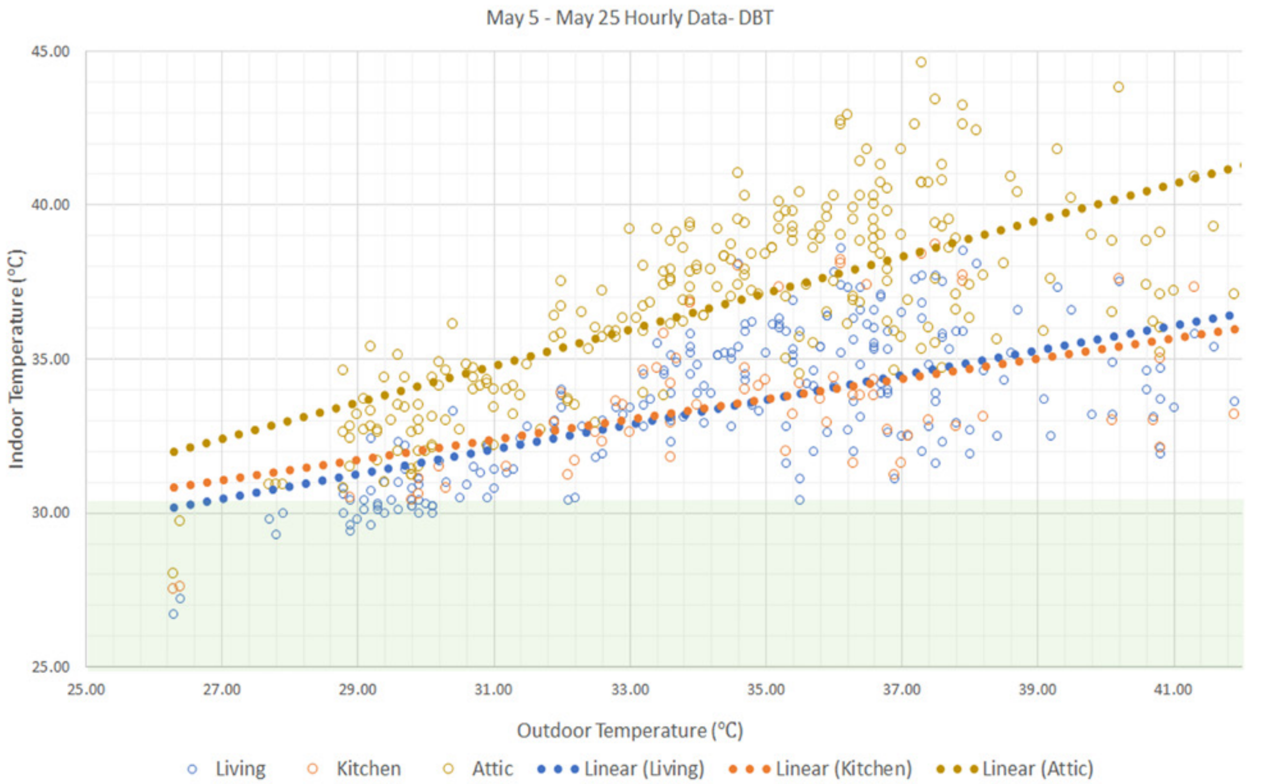
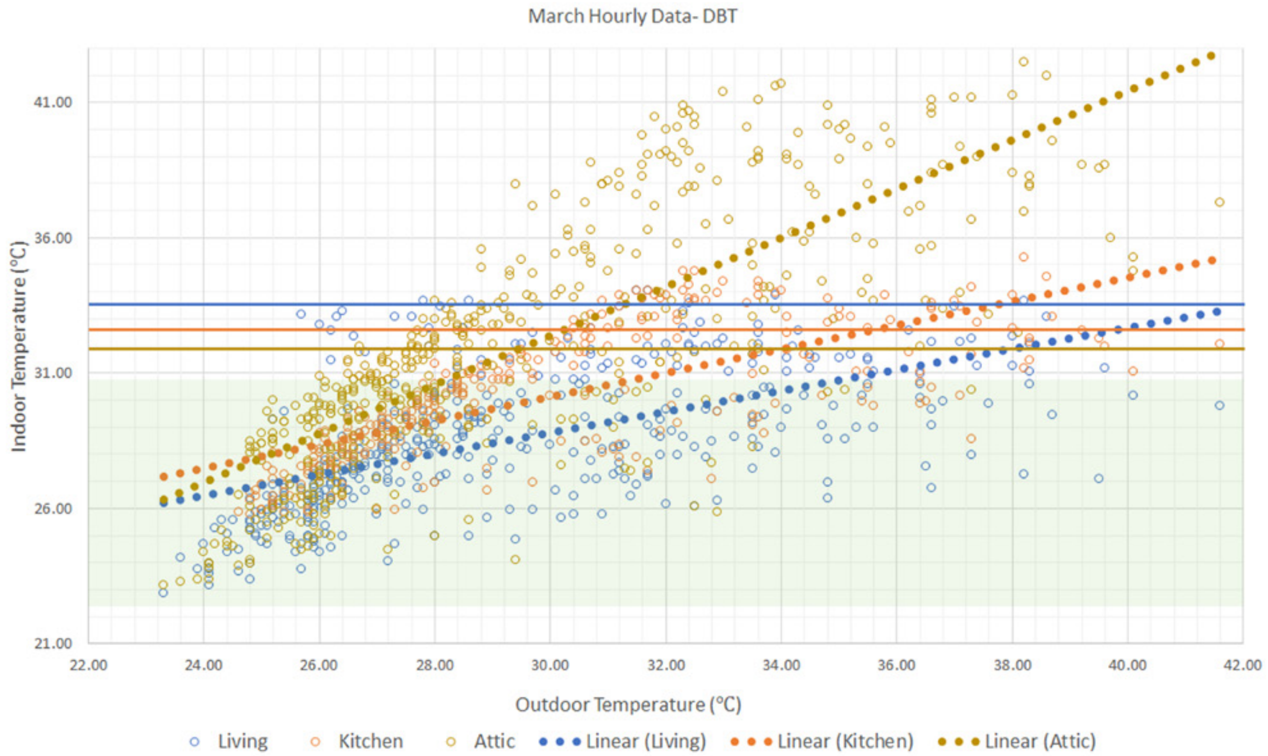


Figure 33: Hourly indoor temperature vs hourly outdoor temperature - April (top) & May (bottom)

values are higher when compared to that of the Hobo devices and mostly out of the comfort range. It can be seen that the attic is the hottest space. For March, the regression line for the attic has a steeper slope compared to that of the other spaces. It is noticed that the devices turn off after continuously running for four or five days. In addition, while sorting the data it is found that the current occupants might be turning off the indoor devices in the night after around 7:00 pm till the morning around 8:00 am on certain days. Hence measurements during these periods are not available. In addition one graph each is plotted for March and



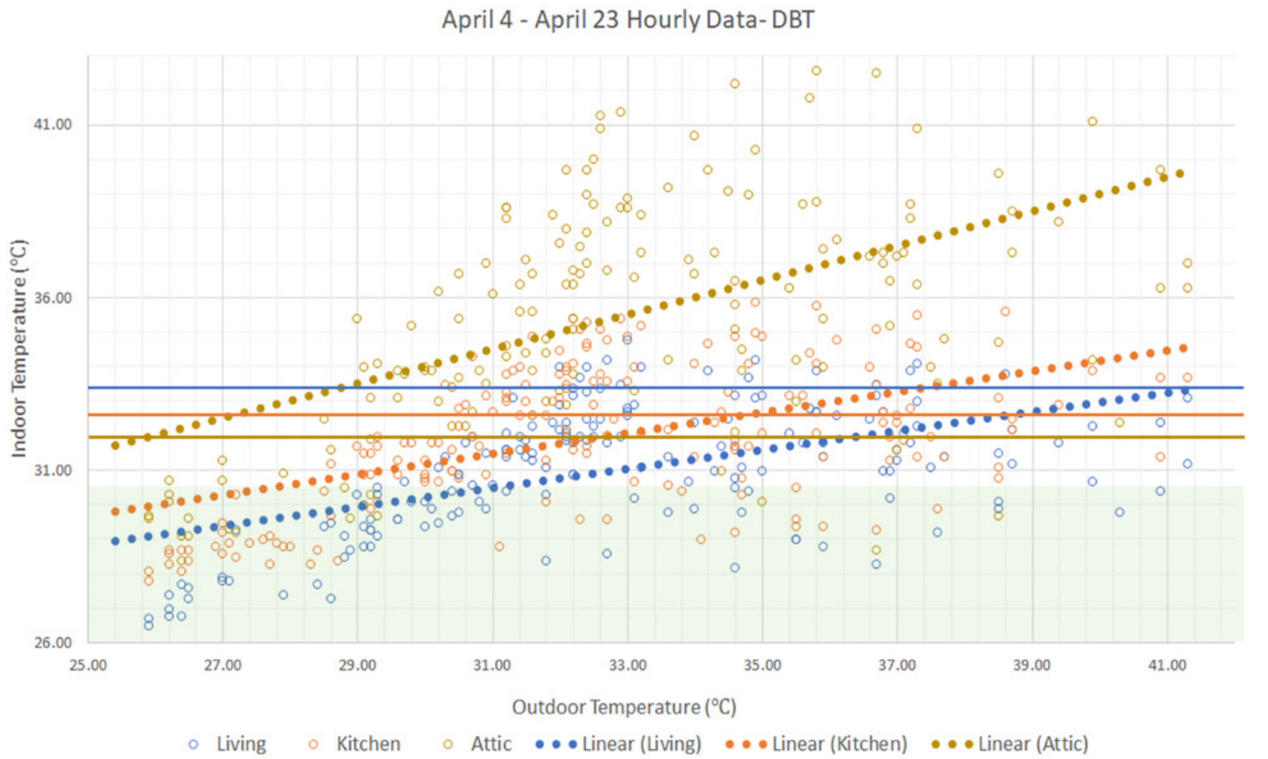


Figure 34: Hourly indoor temperature vs hourly outdoor temperature considering average difference- March (top) & April (bottom)

April considering the average difference with respect to the measurements of the respective spaces using the hobo device. The results are now found to be more reliable. The increase in upper comfort temperature for each space with respect to the measured average measured air velocity, are denoted by the horizontal lines with respective colours of the spaces. Being two of the hottest months, with in situ measured average air velocity, the temperature of living area is quite satisfactory, while kitchen is slightly higher. The attic as expected is very high, around 10 °C to 12 °C above the upper comfort level.

4.5.3 Conclusion

The results of the IoT devices are relatable to the results of the hobo devices and can be used for further studies. However, the following conclusions are made and can be investigated:

1. The IoT devices have to be programmed considering the calibration of each sensor to obtain precise measurements.
2. In order to obtain uninterrupted measurements, it is important to see that the device works continuously. The shutting down of the devices could be due to over heating of the devices. Therefore the devices can be turned off for a short time, once in three or four days.
   i. If there is overheating this could be affecting the temperature reading of the devices. This could be a reason for the high temperature measurements by the IoT devices [www.kandrsmith.org, 2020]. Further investigation could be done to clarify this.

From the aforementioned points, it can be said that the Raspberry Pi IoT monitoring devices need improvements.

5. Improvement Strategies

The analysis of measured data and comfort performance in the previous chapter has helped to understand the problems of the pilot house with respect to its indoor comfort. The strategies for improvements are discussed in this chapter. Since more discomfort has been found in the attic, the strategies are focused on the improvements of roof and attic space.

5.1 Improvement Strategies for roof and attic

The roof which is exposed to the direct sun can influence thermal discomfort in the naturally conditioned building due to the trapped hot air below the roof and lack of ventilation. Hence it is important to make sure the roof and space below it are well designed [Roslan et al., 2015].

According to Givoni (1994) roof with dark colours tend to have higher indoor temperature than that of outdoor, when compared to the lighter colours as light colours are able to reflect heat radiation from its surface [Roslan et al., 2015]. The use of reflective material combined with optimum roof pitch helps to reduce the heat transfer from roof to the space below. Higher pitch also facilitates better air movement and roof ventilation influences the interior roof surface temperature [Roslan et al., 2015]. Figure 34 explains the stack effect. Hot air will be trapped on top of the roof, if openings are not provided. Figure 35 explains the effectiveness of the combination of stack and wind pressure effect and thus it helps dissipating hot air from the attic. In addition to this, air gap in the roof structure helps significantly in reducing the heat gain [Roslan et al., 2015]. It is therefore important to consider these apects to improve thermal comfort in the attic.

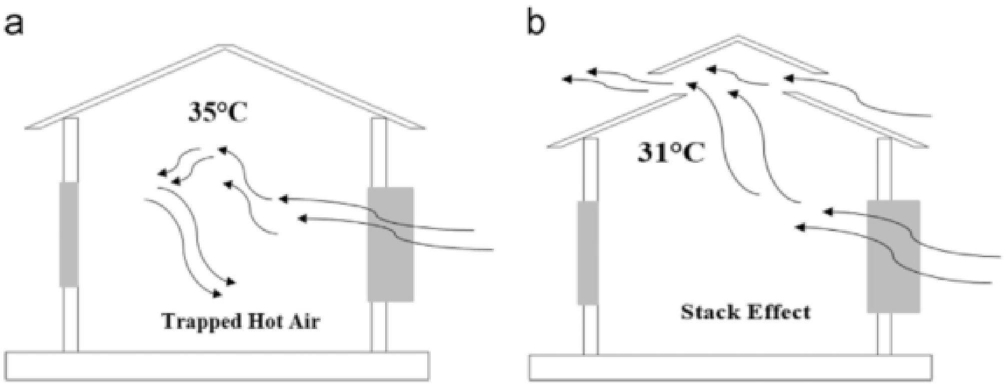


Figure 35: Effect of roof opening (source: Roslan et al., 2015))

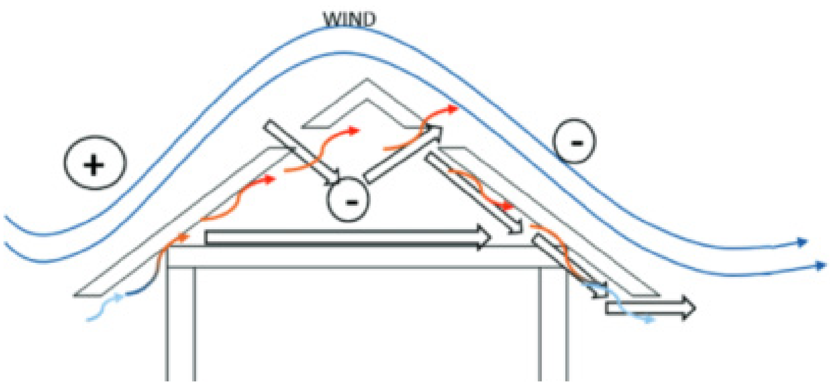


Figure 36: Effect of attic ventilation (Source: Roslan et al., 2015))

5.1.1 Roof and Attic: Pilot House

Figure 36 shows the conceptual section of the floating house explaining the existing scenario. There are only two openings above the attic level, almost at the centre of the roof. As mentioned in Chapter 1, the attic is mostly used for sleeping, and it can be seen that the openings do not help the air movement at the sleeping level. It is verified with the in situ measurements. Moreover, the hot air is expected to be trapped as there are no openings at the top level to facilitate stack effect.

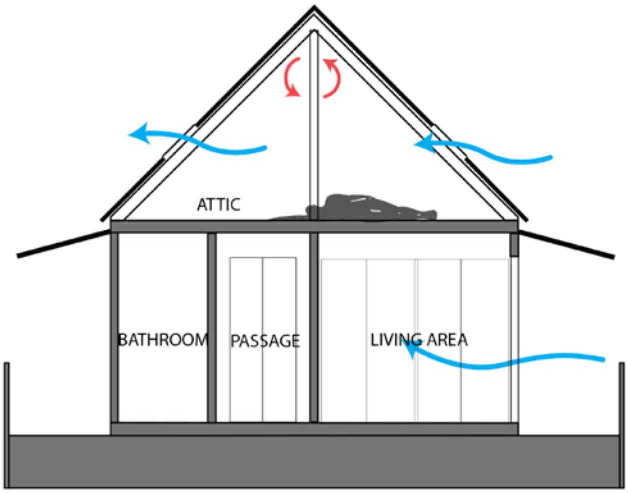


Figure 37: Existing scenario

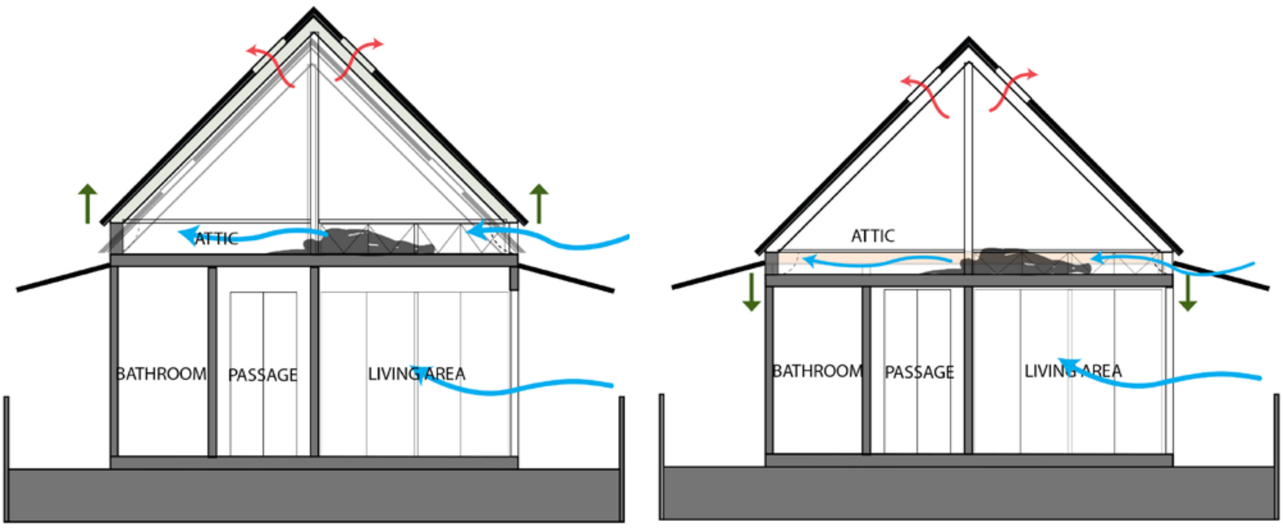


Figure 38: Improvement strategy: Option 1 - Raised roof (left) & Option 2 - Attic lowered (right)

The recommended improvements are made with minimum intervention to the existing architectural and structural design. Figure 37 explains the recommended improvements. For Option 1, the roof structure is lifted and window openings are provided at the sleeping level to facilitate air movement. In order to extract the rising hot air, openings are provided at the top of the roof, this facilitates combination of stack and wind pressure. Similar strategy is used for Option 2, but in this case the attic is lowered to the height of ground floor openings while the height of the entire building remains the same. The openings are provided at the attic level above the openings in the ground floor. The construction and user-friendliness of openings are expected to be easy on a vertical surface rather than on the slope of the roof. Hence the openings are provided vertically. The height of the openings for the simulation is considered using the formula; '$O_h[m] = 0.85 \times F_h[m]$', where F_h is the height of the facade wall [Spittka, 2018]. Based on Spittka's study the opening height could be related to the facade height. As the attic is raised by 50 cm, an opening of height 42.5 cm is provided for simulation and for attic lowered option an opening of height 29.5 cm is provided. Detailed size and positions are not discussed in this report and they can be further studied and optimised.

5.1.2 Attic and Roof Openings

The current openings are hard to operate as it is heavy and towards the centre of the slopping roof. In order to facilitate better air movement, it is decided to provide openings at the sleeping height in the attic floor. Similar to the openings in the ground floor, louvered plantation shutters can also be provided in the attic, which is discussed in the next section. A combination of moveable louvers and Dutch roof or double hip roof can be implemented. Final design is discussed in Chapter 7. The existing roof has 10 mm polyethylene foam insulation below the roofing sheet. In order to find the effect of the design strategies, existing insulation and materials are retained. Materials and insulation for roof is not studied in this report as it is out of the scope.

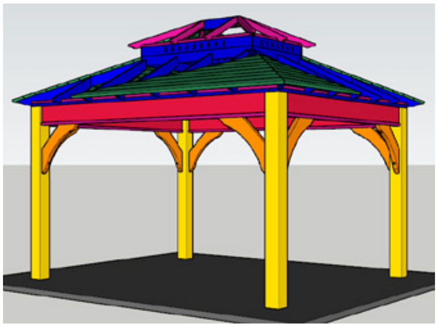



Figure 39: Roof opening in a local building (left) and Double hip roof with opening [source: www.nor-weh.com](right)

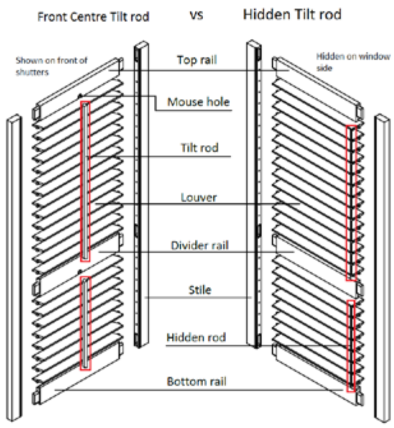



Figure 40: Plantation shutter in a traditional house, Palawan (left), Plantation shutter details [source: www.diyplantationshutters.com] (center), Dutch door [source: www.miniatures.com] (right)

5.2 Controlling Air Velocity and Privacy

As of now, in the house the user does not have the options between fully opened and closed openings, as they are all doors cum windows. This affects the user-friendliness in terms of controlling air velocity and privacy. While doing case studies on local architecture, it is noticed that many buildings including houses use plantation shutters with moveable louvers to manually control the air velocity and privacy. This can be implemented along with Dutch style doors for the openings (Figure 39). Final design is discussed in Chapter 7.

5.3 Conclusion of Improvement Strategies

Based on the studies, the following improvements are considered in order to improve the design:

Attic space: Option 1 - The roof structure is raised in order to provide openings for ventilation at the sleeping level in the attic floor. Option 2 - The attic floor is lowered to the top of the ground floor openings in order to provide openings for ventilation at the sleeping level.

The locations of the openings are similar to that in the ground floor, opening height is considered using the formula

Oh[m] = 0.85 x Fh[m]

Roof openings: Openings with operable louvers are provided at top level of the roof to facilitate stack effect, hence it helps to dissipate the hot air trapped in the roof.

Shutter of openings: A combination of Dutch door with plantation shutters are provided. This helps the user to control the air velocity and privacy.

The final design is discussed in Chapter 7.

6. Performance of the Improved Strategies

In this chapter the thermal comfort performance of the improved designs are compared. For this three models are made:

1. the existing house
2. option with roof raised
3. option with attic lowered

The simulation results of these models are compared and discussed. Only the operative temperature results of the attic are considered for comparison in this chapter. The occupancy and operational schedules are made only for the purpose of simulation. The height of the existing window opening is considered to be the height of the triangular roof opening, they are not optimised. The existing roof openings are not discussed in the improved design models.

6.1 DesignBuilder Simulations

DesignBuilder is a tool used to assess building designs by providing various informations and thus helps engineers and architects. It uses EnergyPlus engine. In DesignBuilder two methods can be used to model infiltration and natural ventilation: Scheduled natural ventilation and Calculated natural ventilation. Calculated natural ventilation method is chosen for the simulation, especially because the building is naturally conditioned [DesignBuilder].

Weather data: For the purpose of simulation, hourly weather data of Manila is used, as the building location is around 70 km from the Manila International airport. Same settings are used for all the three models.

Building activity and occupancy: The 'TM59_1-BedLivingKitchen' template is modified for the simulation and for the occupancy three people are considered. Schedules are mentioned in Appendix D.2.

Building materials: Building materials are edited as mentioned in Chapter 2.1.2. The materials properties for the simulation are similar as that of the existing project. Solar absorption value provided is 0.6.

Building openings: Doors are modelled as windows with minimum total solar and light transmission of 0.01 and maximum u-value of 7 W/m^{2}K to make it opaque. Roof openings are modelled to be always 33 % open, as louvers are considered. Schedules of the openings are mentioned in Appendix D.2.

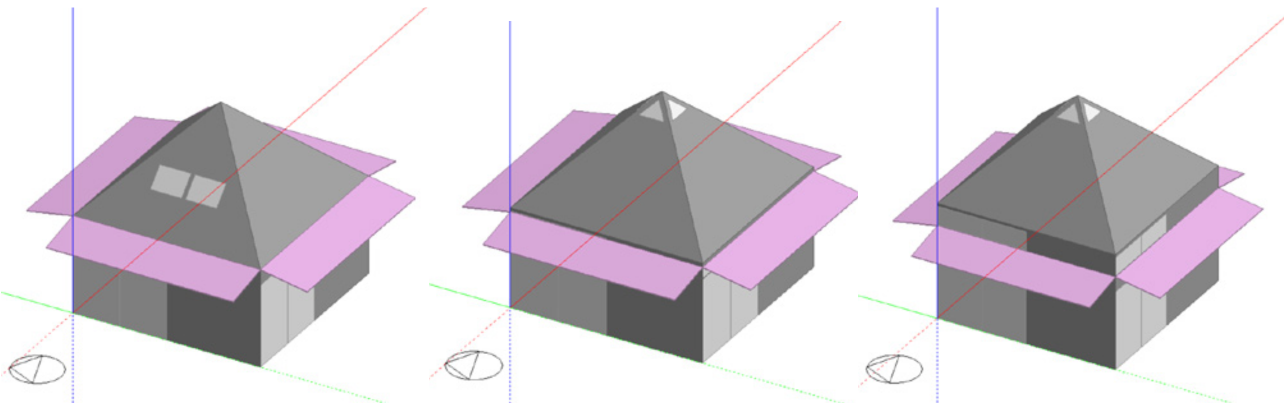


Figure 41: Existing house (left), Attic lowered (center), Roof raised (right)

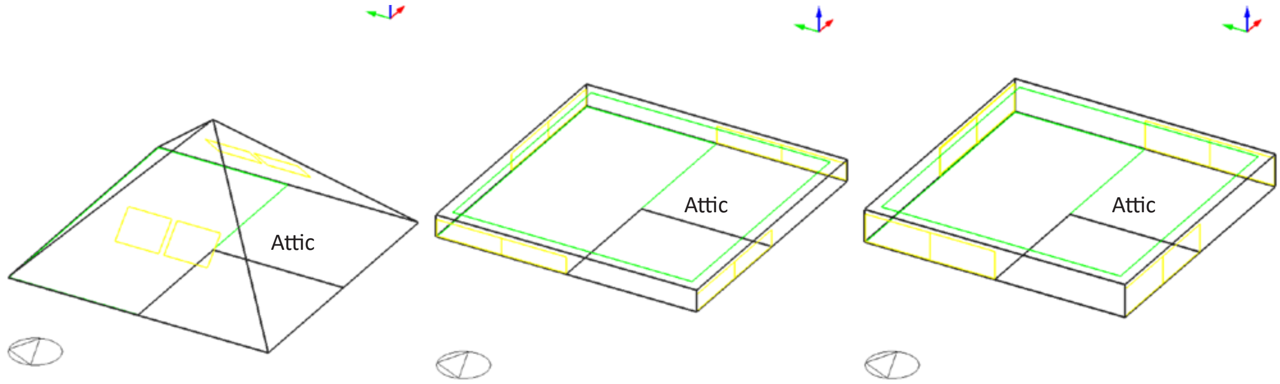


Figure 42: DesignBuilder Attic zone- Existing house (left), Attic lowered (center), Roof raised (right)

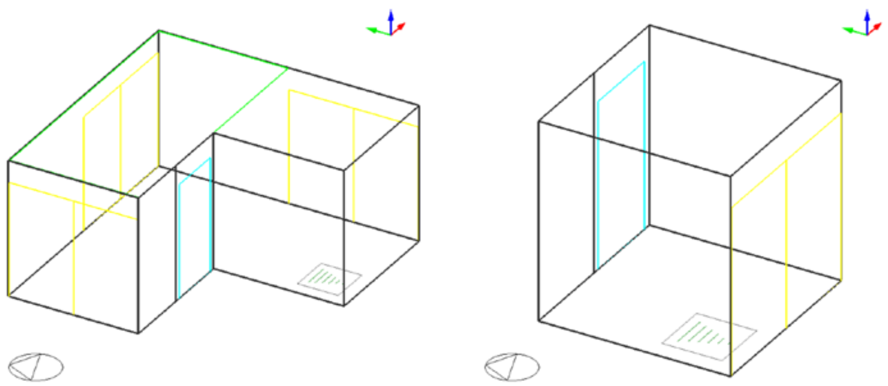


Figure 43: DesingBuilder Groundfloor zone- Living (left), Bathroom(right)

Ventilation setpoint temperature: 28°C

Building Lighting: TM59_Default_Light

Openings: No changes in the ground floor with respect to the existing design.

Attic floor: For attic lowered option, the opening height is given 0.28 m and for the roof raised option the opening is 0.48 m. The width remains the same as that of the openings in the ground floor.

Simulation: All the models are first simulated for one month period (February) in order to compare the results. Hourly results are compared. Then the model that performs better is simulated for a year and daily average operative temperature result is plotted.

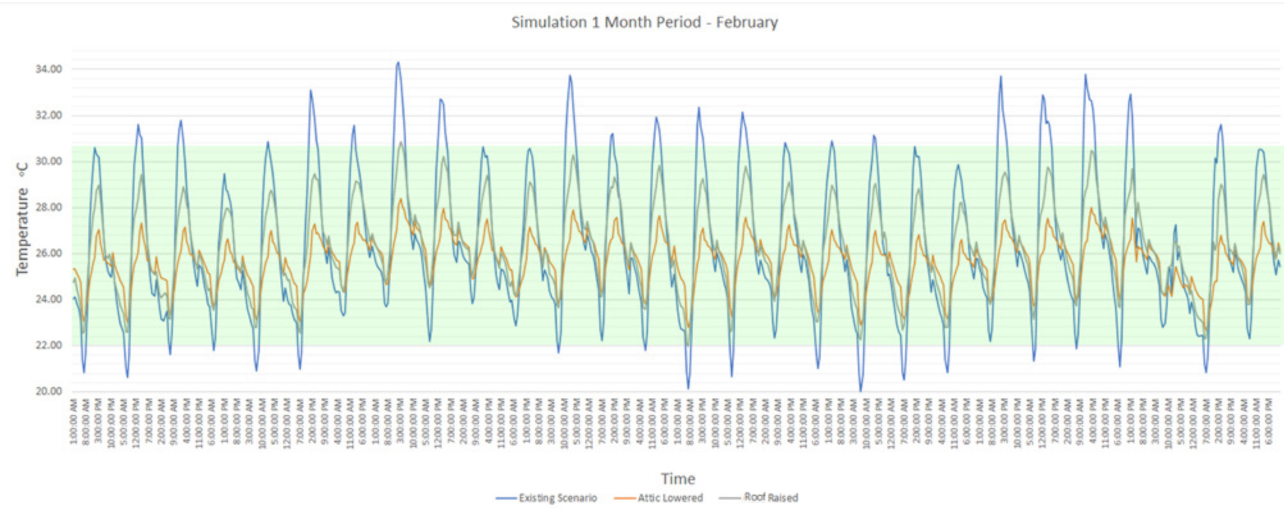


Figure 44: Simulation Result - Operative Temperature at attic zone plotted against time for each model

6.2 Results

The results of the simulation are discussed in this section. As the model is not calibrated and validated with the in situ measurement, there is some inaccuracy in the result. The results are considered only for comparison and hence it is more accurate to look at the difference between the results of simulation models. Figure 43 shows the graph with hourly zonal operative temperatures of the attic floor plotted against time for each simulated model. The green shaded portion is the same comfort range used for the analysis of in situ measurements. From the simulation results it is clear that improved strategies give a better thermal comfort performance in the attic. The hourly operative temperature for the month of February falls within the comfort range for both the improved models. It can be seen that the attic lowered model performs the best. Since the attic is lowered, the exterior walls are protected from the sun by the foldable overhangs. This can help the attic from overheating. As per the simulation results, there is a significant reduction of operative temperature in the attic zone which is between 4°C and 6°C. The improved designs also perform

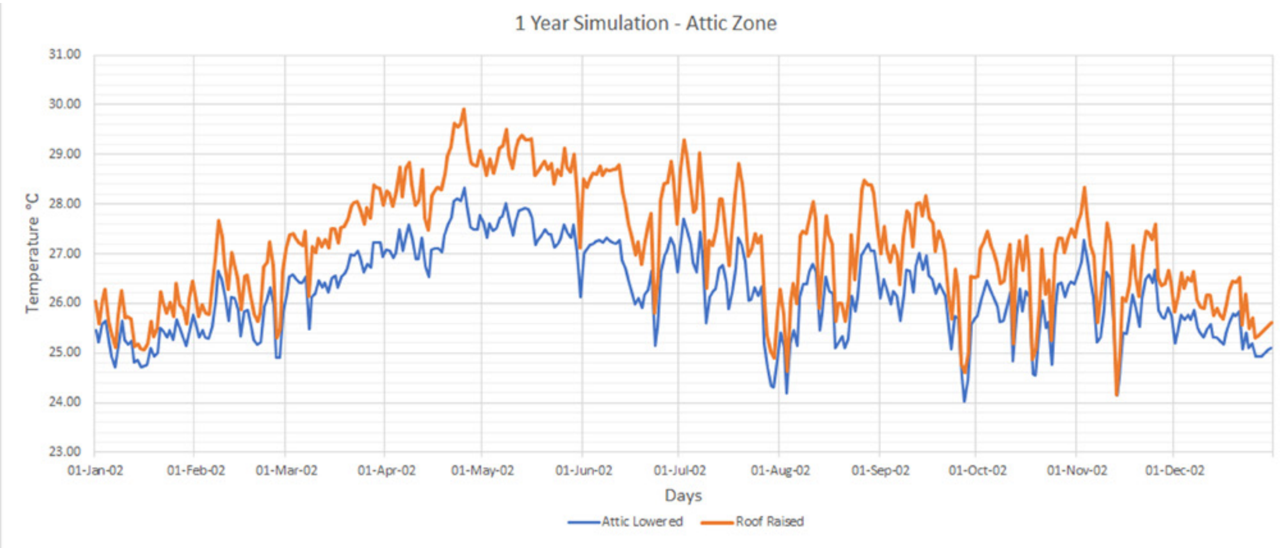


Figure 45: Simulation Result - Daily average operative Temperature at attic zone plotted against time for each model

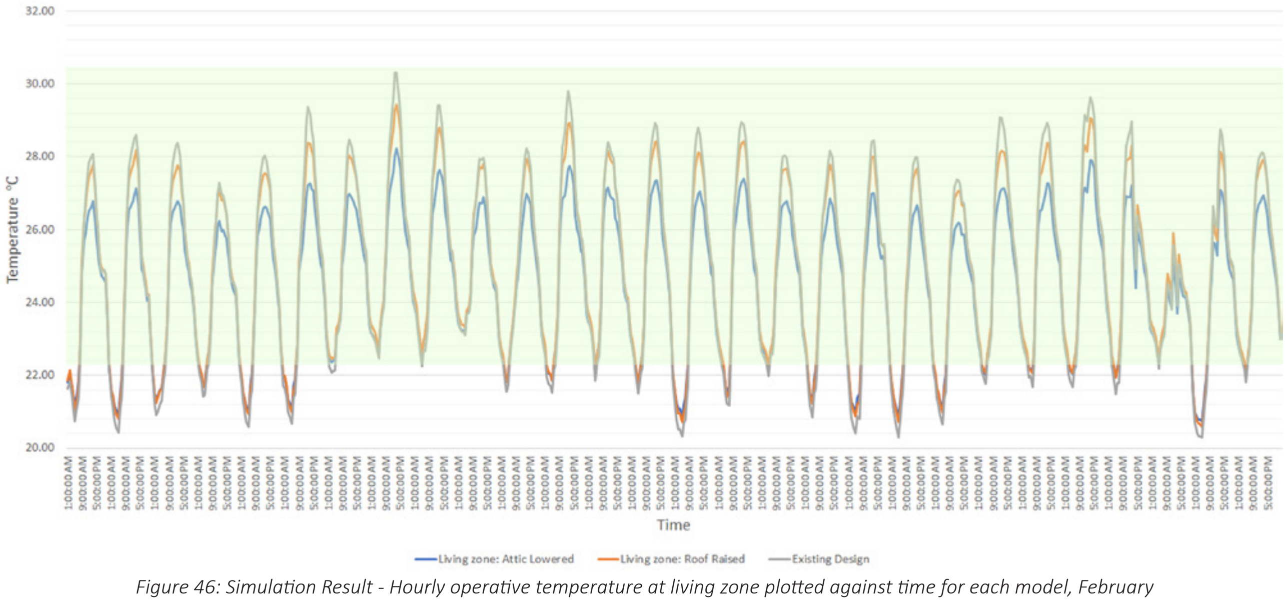


Figure 46: Simulation Result - Hourly operative temperature at living zone plotted against time for each model, February

better when comparing the lower operative temperatures with that of the existing design. During certain days the operative temperature of the existing design falls upto 2°C to 3°C below the lower comfort level, which is due to the radiative cooling in the night time as the radiant temperature is lower than the outdoor air temperature. At the lower operative temperatures both the improved designs perform almost similar and better than the existing design as they have openings on top of the roof. The DesignBuilder graph of the same is in Appendix D.3. Figure 44 is the graph showing daily average of operative temperature in the attic zone for one year. It can be seen that the option with the attic lowered is performing better. Figure 45 shows the comparison between the simulated operative temperature of living zone of the improved designs and existing design for a period of one month (February).

6.3 Conclusion from the Results

The following conclusions can be made from the simulation results in terms of thermal comfort:

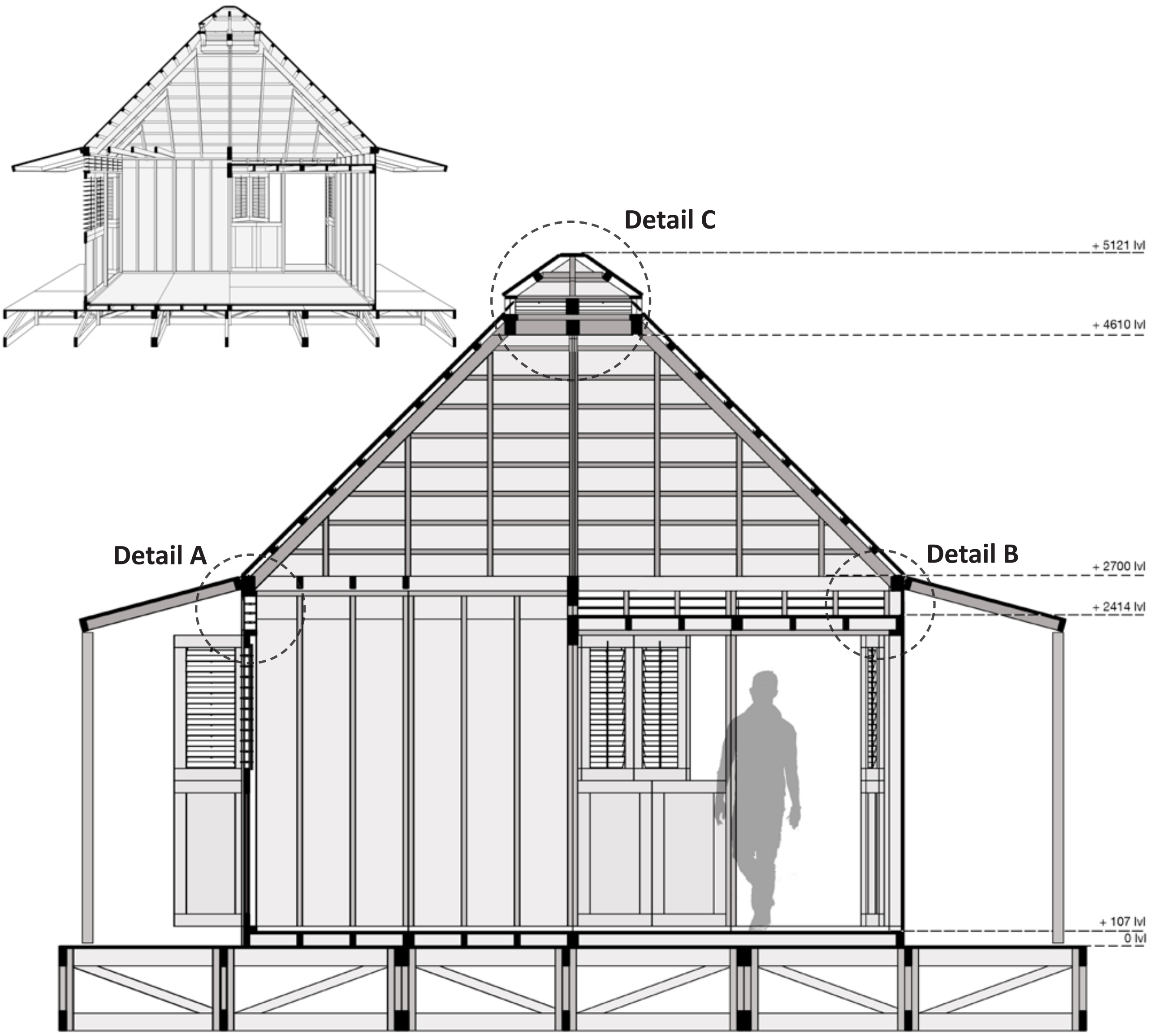
1. It is clear that the improved models are performing better than the existing pilot floating house. Both the options are within the comfort range.
2. For the attic lowered option, hottest temperatures in the attic zone are around 4°C to 6°C less than that of the existing design and around 2°C to 3°C less than that of the design with the roof raised.
3. When compared to the lower temperatures both the improved designs perform similar with around 2°C more than that of the existing design.
4. Among the improved options, the attic lowered to the height of the ground floor opening is the best performing design. The external walls of the attic in this option are protected by the foldable eaves.
5. In the case of the living zone, all the designs perform similar with respect to lower comfort level, while the option with the attic lowered, performs better with respect to the upper comfort level.
6. Effect of radiative cooling can be further studied.

7. Final Design Improvements

Having discussed the improvement strategies and compared their performance with the existing design, this chapter looks into incorporating the strategies to the design and construction of the housing type. It is done considering minimal intervention to existing architectural design and construction, as they are the result of extensive researches. The suggested improvements can be further optimized or studied, not in this report as it is beyond the scope of this research. Drawings and illustrations are discussed here.

7.1 Drawings

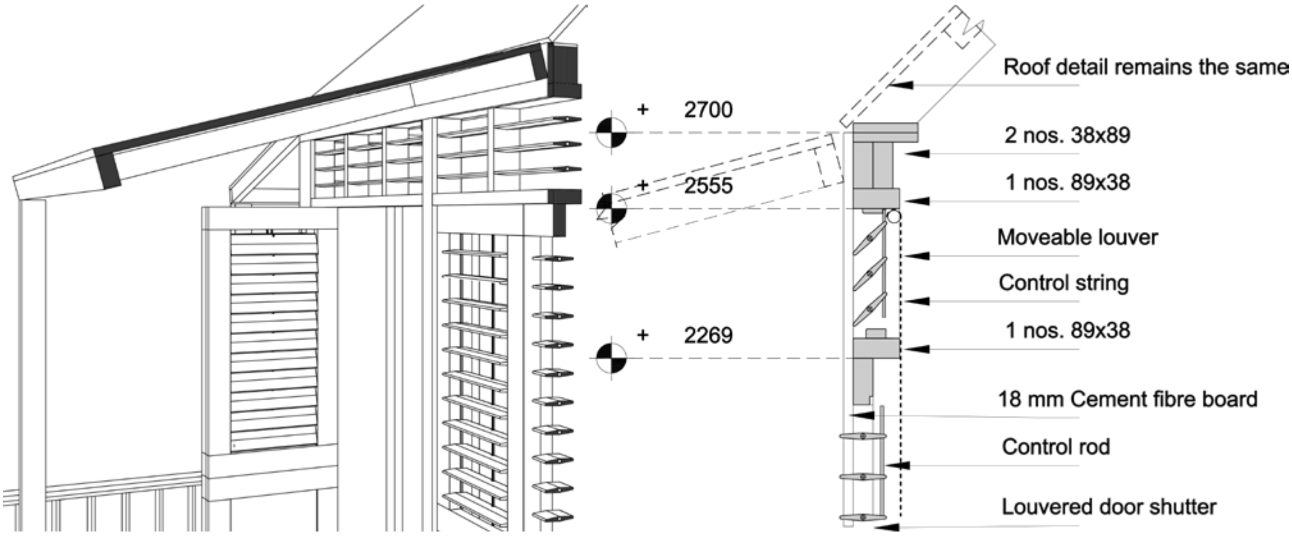
Building Section: The dimensions and specifications of the planks, connections and other materials are as per the Pilot Project Briefing (2018), the details of which are provided in the Appendix A.1.
The attic level is lowered by 286 mm with respect to that of the existing design. Hence openings of height 178 mm are provided at the attic and openings of height 248 mm above the North and West side doors, with operable louvers. The bottom of the attic floor modules is at the top level of ground floor openings.



All dimensions in mm

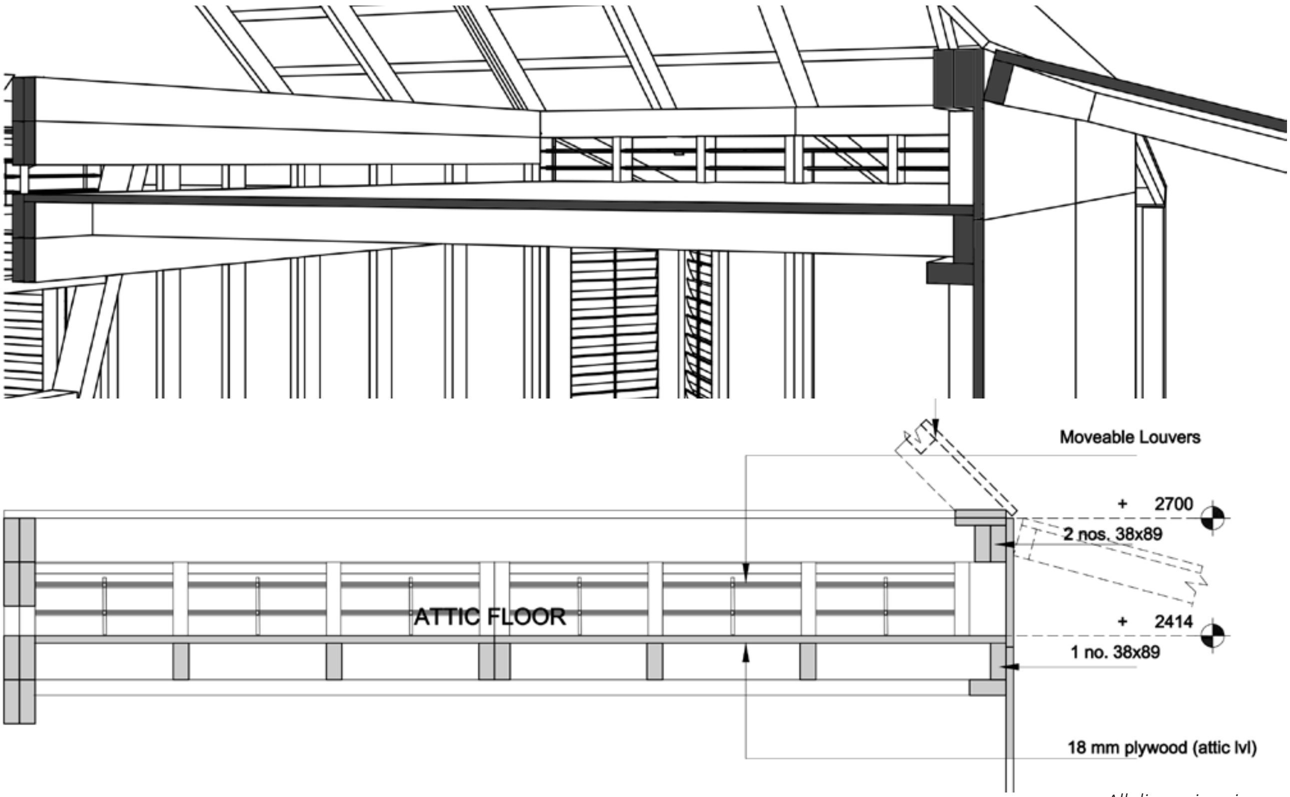
Figure 47: Section of the improved design

The attic floor is further protected by the existing foldable eaves. In case of a heavy wind the eaves can be closed, hence the attic openings are protected. It is shown in detail B, Figure 49. Roof opening at the top level is provided by means of double hip roof as shown in detail C, Figure 51, which facilitates the extraction of hot air. The roof is only raised slighty and is expected not to affect the structural aspect significantly. The roof opening is 127 mm, which is based on the size of available planks (89 mm + 38 mm). According to Agarwal (2007), the roof pitch should be at least 22° and hip roofs are found to be performing good during cyclone.



All dimensions in mm

Figure 48: Detail A



All dimensions in mm

Figure 49: Detail B

The slope of the top roof is given 35° in order to achieve similar height of the existing design, aesthetics and considering the typhoon resiliency. No overhangs are provided to avoid building up of force under them. In addition, roof members and roof sheeting have to be well secured.

Door Openings: The design of existing doors can be seen in the Appendices A.1 and B.4. The existing opening shutters are redesigned in such a way that the user gets more options in terms of usability. To achieve this, collapsible doors with moveable louvers are provided. The shutters are divided into two halves along the height. This helps the user to open the top part alone and use it as windows or if needed the whole door can be opened. By providing the collapsible door, the shutters could be opened to either sides of the opening leaving the centre free, thus providing more space as shown in Figure 49. This, along with the moveable louvers also help the user to control the privacy and air velocity. It therefore does not need the extra shutters with fenestration as provided in the existing design.

Roof Openings: In case of the openings on top of the roof for the stack effect, they can be opened or closed by means of control strings as shown in Figure 50. By providing openings on all sides, the wind could escape and does not build up force under the roof. During severe conditions the roof openings can be closed.

Various local buildings have been visited and the improvements for design have been done by considering the elements of the architecture of this region. Some of the buildings visited are mentioned in Appendix B.5.

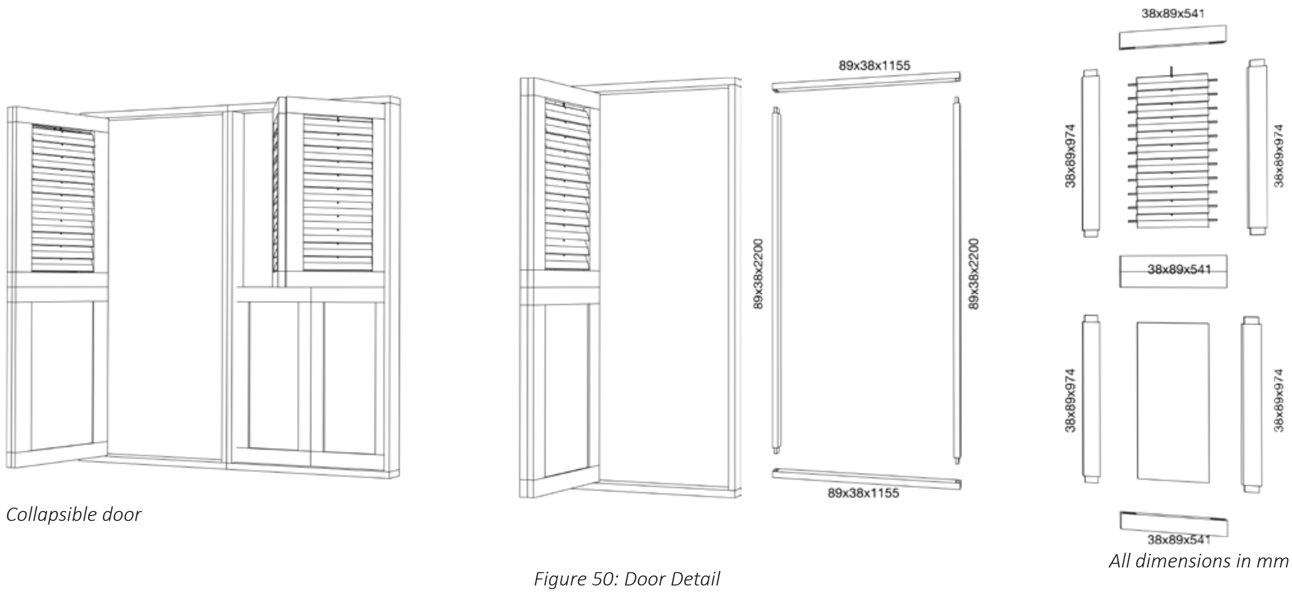


Figure 50: Door Detail

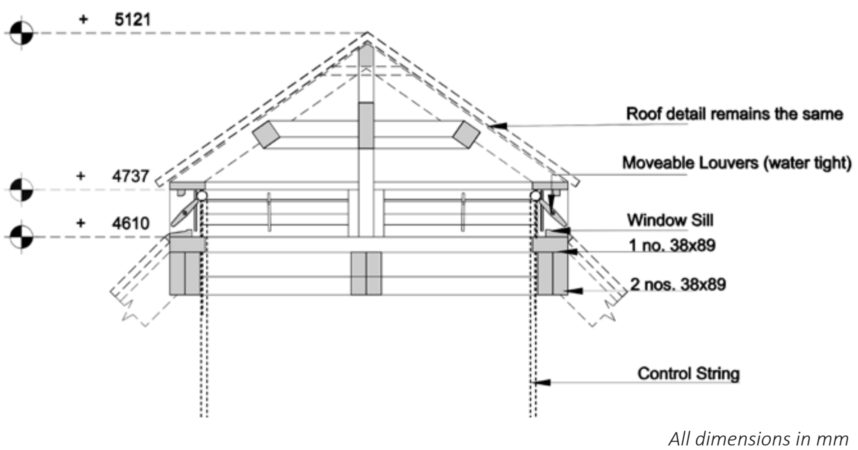


Figure 51: Detail C

7.2 Views

Figure 52: Exterior view

Figure 53: Interior view from kitchen

Figure 54: Interior view from the north opening

Figure 55: Interior view from the attic

7.3 Simulation Result of the Final Design

The final design is simulated in DesignBuilder using the same settings mentioned in Chapter 6. The results are compared to that of the attic lowered option chosen in Chapter 6. Figure 56 shows the comparison. It can be seen that the final design performs similar to that of the simulation results of attic lowered strategy. Figure 57 shows the result of simulation with 2019 weather data of the region in order to compare with the

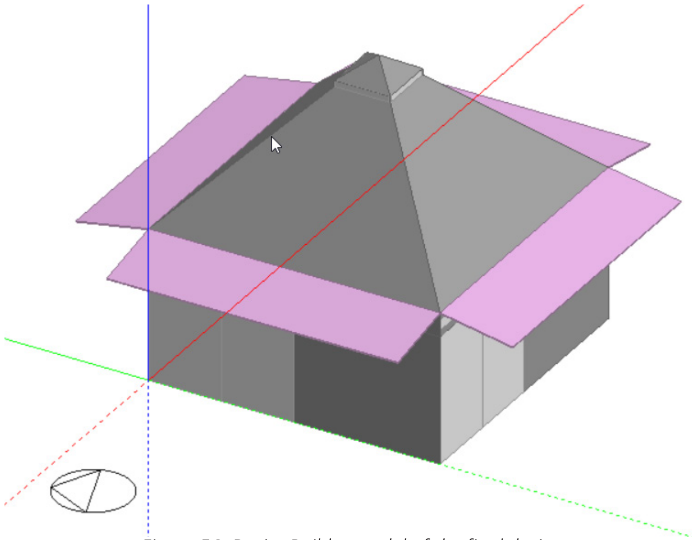


Figure 56: DesignBuilder model of the final design

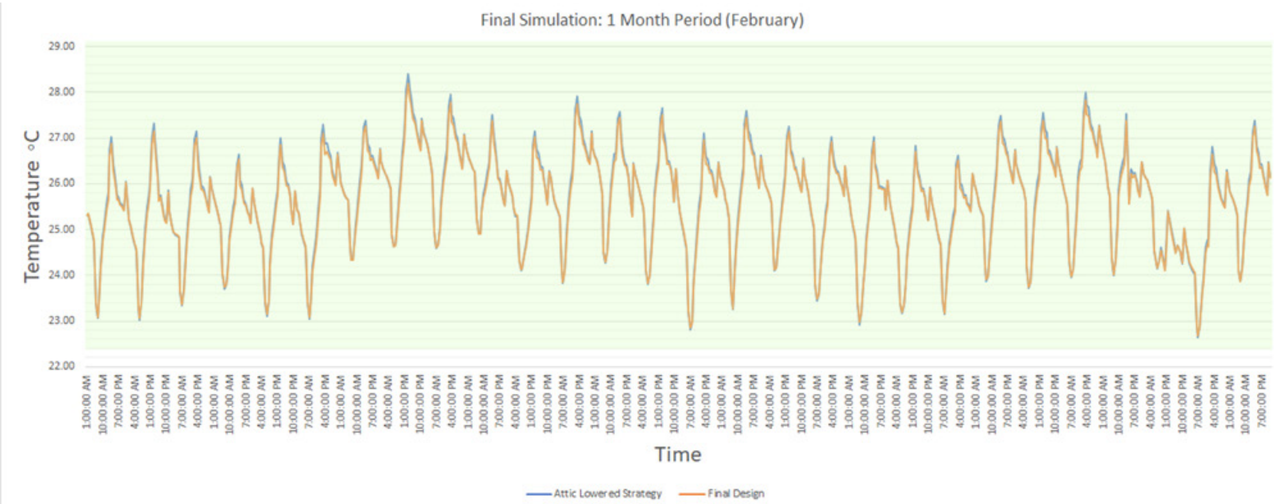


Figure 57: Comparison with DesignBuilder simulation result of attic lowered strategy (attic zone)

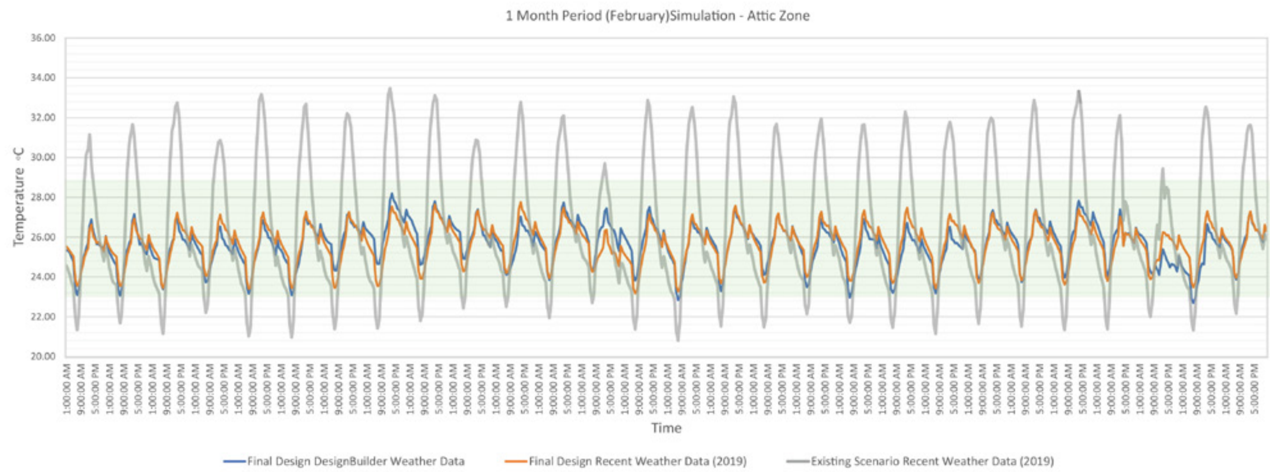


Figure 58: DesignBuilder simulation of final design with recent weather data and comparison with the existing design (attic zone)

DesignBuilder weather data. The existing design is simulated with 2019 weather data and it can be seen that the final improved design performs better. Figure 58 shows one year simulation result of both final design and existing design and the final improved design is performing better.

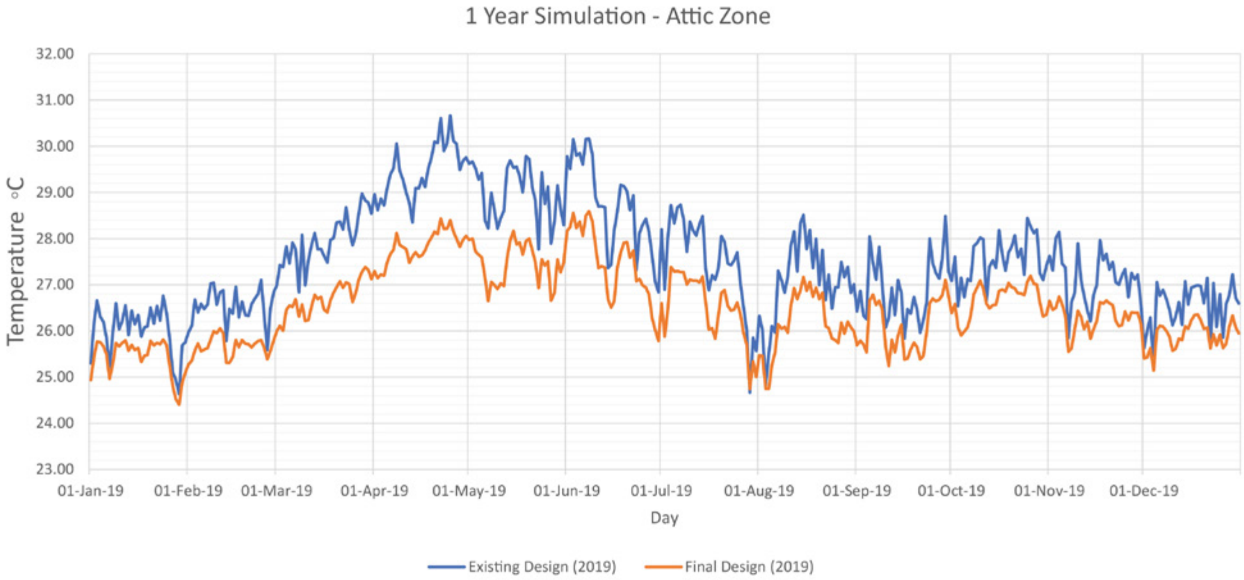


Figure 59: DesignBuilder 1 year simulation of final design and comparison with the existing design (attic zone)

8. Conclusion and Discussion

The answers to each research question are discussed in this chapter in order to reach the research objectives. For this, the sub questions are first discussed individually and then the main research question. This leads to the final conclusion which decides whether the main objectives and sub objectives are reached.

8.1 Literature Study

1. How is the pilot floating house in the Philippines designed and constructed in terms of passive design?

The region has an annual average temperature of 26.5°C and relatively high humidity throughout the year. The pilot floating house is designed by borrowing design elements from the Bahay Kubo, a vernacular architecture of the region. The main elements are the following:

1. Large openings to facilitate ventilation and day lighting
2. Sloped roof with overhangs to protect from the sun and rain
3. Roof openings to dissipate hot air to the exterior
4. Stilts to stay above the flooding water: in this case, a floating foundation

In addition to this, the house is a light structure with prefabricated components, where exterior walls are made of cement fibreboard and has a hip roof of 45° slope with metal sheeting nailed on to plywood with insulation in between. It is designed to be typhoon resilient as well. The building is relatively open on the sides and is surrounded by water.

2. What are the comfort parameters that need to be measured which influence the indoor environmental quality of the housing type?

The main parameters for indoor environmental quality are thermal quality (comfort), air quality, sound quality, lighting quality, ergonomics and cleanliness. As the house is a naturally conditioned building, thermal comfort is given priority in this study. The parameters chosen for the measurement are:

1. Dry-bulb temperature
2. Operative temperature
3. Surface temperature
4. Relative humidity
5. Air velocity

In addition, interviews and daily thermal questionnaires are also prepared. Field observations are made for other parameters.

8.2 Measuring and Monitoring

3. How to develop a measurement plan and monitoring system for indoor environmental quality of the pilot project?

A systematic plan is developed for nine days of measuring. The devices used are:

1. HOBO U12-012 data logger for measuring dry-bulb temperature, operative temperature and relative humidity
2. Thermochron I-button for measuring surface temperature
3. Extech SDL350 hotwire anemometer for measuring air velocity

IoT Monitoring Devices

Development of the economical remotely accessible monitoring system for the paremeters is one of the sub objectives. This is made possible by programming four Raspberry Pi devices to measure dry-bulb temperature and humidity. Three are placed indoor and one outdoor. The devices send data to the online cloud every 3 minutes. Ubidots online IoT platform is used for this. It is later noticed that the devices when continuously running, shut down after four or five days.

The devices show higher temperature readings when compared to that of the hobo measurements. The devices thus need calibration. Overheating of the devices due to continuous usage could also be a reason for higher temperature reading. Hence it can be said that the devices need further improvements. However, considering the average difference with respect to the measurements of the respective spaces using the hobo device, the results are more reliable for further studies.

8.3 Results and Comfort Performance

4. How does the pilot floating house perform? (by investigating the in situ measurements and observations)

ASHRAE adaptive comfort model for the Manila region, the Philippines is selected from the Climate Consultant 6.0 software for analysing the comfort performance of the pilot floating house. The performance is analysed considering the 80% acceptability limit. The measured results show that the comfort performance of the building is satisfactory most of the time except that in the attic floor. During the hottest days the attic floor gets hotter than the upper comfort level by around 11°C. From the in situ measurements it can also be seen that the air velocity is relatively low in the attic compared to that of the other spaces in the house. In addition to this it is also observed that the door shutters can be improved in terms of controlling air velocity, privacy and user-friendliness.

8.4 Improvement Strategies

5. What are the improvements needed to provide better indoor environment for the housing type with respect to the analyzed data?

From the inferences of results and comfort performance of the pilot house it is clear that the comfort performance of the attic space needs to be improved, thus the overall performance. For this two options are put forward based on which the following improvements are needed as per the analysis:

1. To reduce the solar heat gain: By lowering the attic to the height of the ground floor door frame and hence the attic is protected by the foldable eaves.
2. To increase the air velocity: By providing opening at the sleeping height which is based on the location of the openings in the ground floor. For the second option, the roof is raised to achieve the space for openings.
3. To dissipate heat by stack effect: By providing openings at the top of the roof to dissipate hot air to the exterior by means of double roof.
4. To control air velocity and privacy: By providing operable louvers incorporating principles of Dutch door and collapsible doors.

8.5 Comfort Performance of the Improved Strategies

6. How does the improved strategies perform when compared to the existing design?

Using the DesignBuilder software which is based on EnergyPlus software, the models of improved and the existing design models are made. These models are provided with the same setting for the purpose of running simulation. Manila weather data for a year is provided. From the results, which is only for comparison, it is found that the attic lowered option performs better with the daily maximum temperatures around 4°C to 6°C lower than that of the existing design during the month of February. The attic in the existing design has lower operative temperature in the early morning during certain days than that of the outdoor temperature due to radiative cooling. For the improved designs the lower temperatures are within the lower comfort level as the result of roof top openings.

8.6 Final Design Recommendations

The final improved design is achieved by considering minimal interventions to the existing design and construction, also by borrowing elements from the local architecture of the region.

1. Lowering the attic floor: The attic floor is lowered by 286 mm to the top of the door openings. This gives an opening height of 178 mm at the attic, while it gives 246 mm opening height on top of north and west side door openings. This also makes the attic space come under the foldable eaves thus reducing the solar gain. In short, *"openings for ventilation at sleeping height in the attic floor".*
2. Roof openings: Roof openings are provided by creating a double hip roof. The second roof comes at + 4610 mm level from the outdoor deck level. The slope of the roof is 35°. Operable louvres are provided with control strings, thus enabling the user to open or close the opening from the lower levels. The structure and dimensions of the openings need further optimization. In short *"openings at top of the roof to enhance stack effect".*
3. Collapsible louvered doors: The shutters are divided into two, along the height, allowing the user to open it completely or use it as windows. In addition to that the operable louvers help in controlling air

velocity and privacy. Apart from this, the doors are collapsible and hence they can be opened to either sides leaving the centre free. This way the user gets more control options. In short, *"collapsible doors with louvered shutters for providing users with more option in controlling air velocity and privacy".*

8.7 Objectives and Further Studies

The main objective of this research is *"to recommend improvement strategies for the design of the low-income houses with attic floor, in the Philippines, by evaluating the indoor environmental quality of the pilot floating house project".* Thermal comfort performance of the building is focused in the research . In order to achieve this, the research is formulated in the following chapters:

1. Literature Study: Literature study has helped to understand about the floating house and its context. It also gave information to proceed with the research.
2. Measuring and Monitoring: In situ measurements and observations are very significant in this research as they gave more relevant location based information of the house which helped to analyse the performance of the existing design. By developing the Raspberry Pi based devices, an economical system to monitor the temperature and humidity is achieved, but it needs improvement.
3. Results and Comfort Performance: The performance of the existing house in terms of thermal comfort and user-friendliness is found, based on which improvements are made.
4. Improvement Strategies: Improvement strategies are put foward in this stage which helped in making the final design recommendations.
5. Performance of the Improved Strategies: The DesignBuilder simulation results are compared to find the better performing design strategy.
6. Final design: Final design recommendations considering the improvement strategies are proposed in this stage.

To conclude, it can be said that the main objective is reached by following the aforementioned chapters.

Further Studies: However, certain aspects need further optimizations such as the opening size, materials and roof structure. It is also worth studying the effect of nearby water body and radiative cooling on the indoor climate. From the results of IoT devices, it can be seen the IoT device needs further improvements.

Limitations: As the building was unoccupied, there was no operation or occupancy schedule and hence factors with respect to occupancy are not considered in this research. Calibration of the DesignBuilder model with in situ measurements are not done as the time was limited.

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List of Figures

List of Abbreviations

ANSI: American National Standards Institute

ASHRAE: the American Society of Heating, Refrigerating and Air-Conditioning Engineers

GI Sheet: Galvanized Iron Sheet

IAQ: Indoor Air Quality

IEQ: Indoor Environmental Quality

IoT: Internet of Things

PAGASA: The Philippine Atmospheric, Geophysical and Astronomical Services Administration

PMV: Predicted Mean Vote

PPD: Predicted Percentage of Dissati

Appendices

Appendix A

A.1 Floating House Philippines

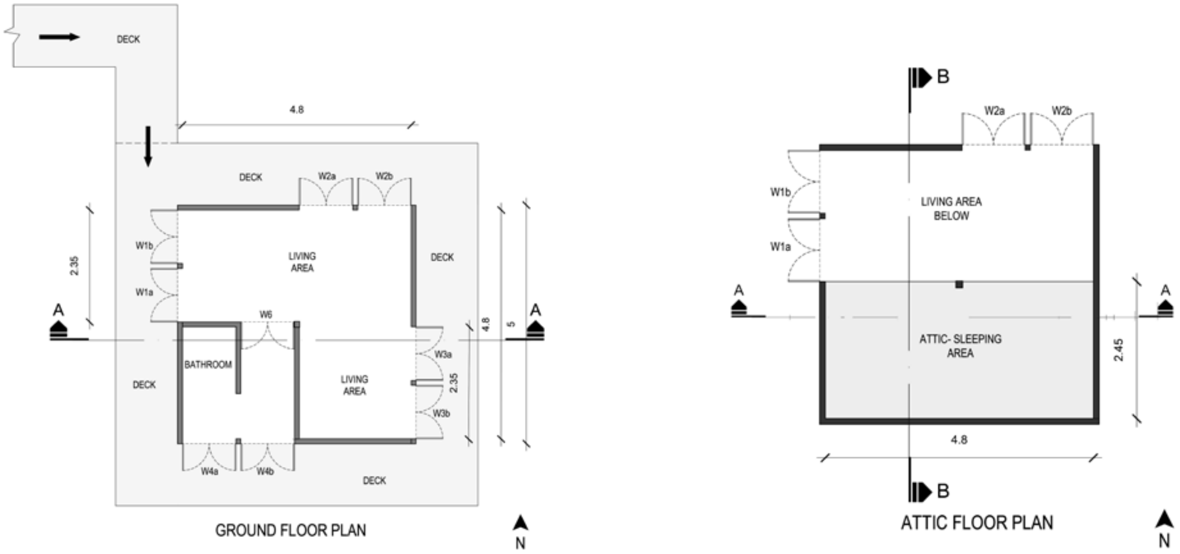

Figure 01: Floor plans

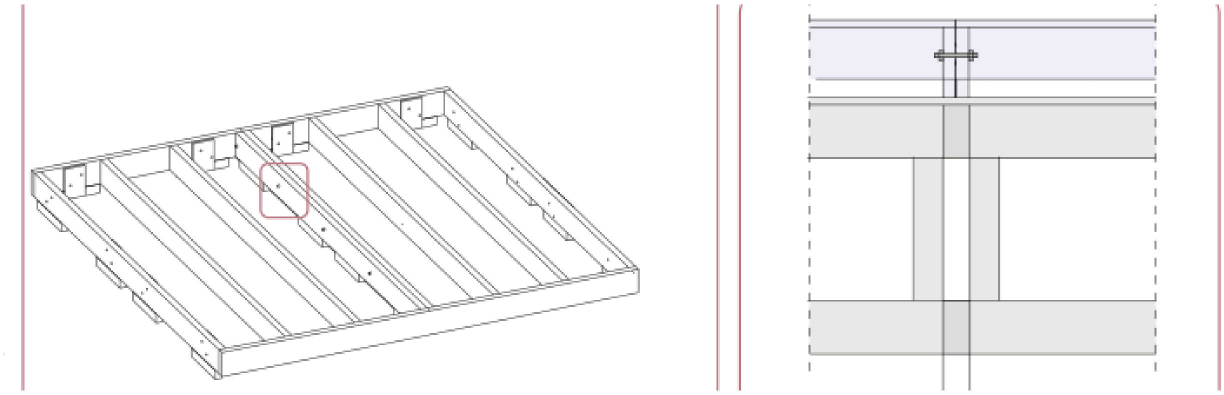

Figure 02: Connection floor modules [source: Pilot Project Briefing - Briefing, 2018]

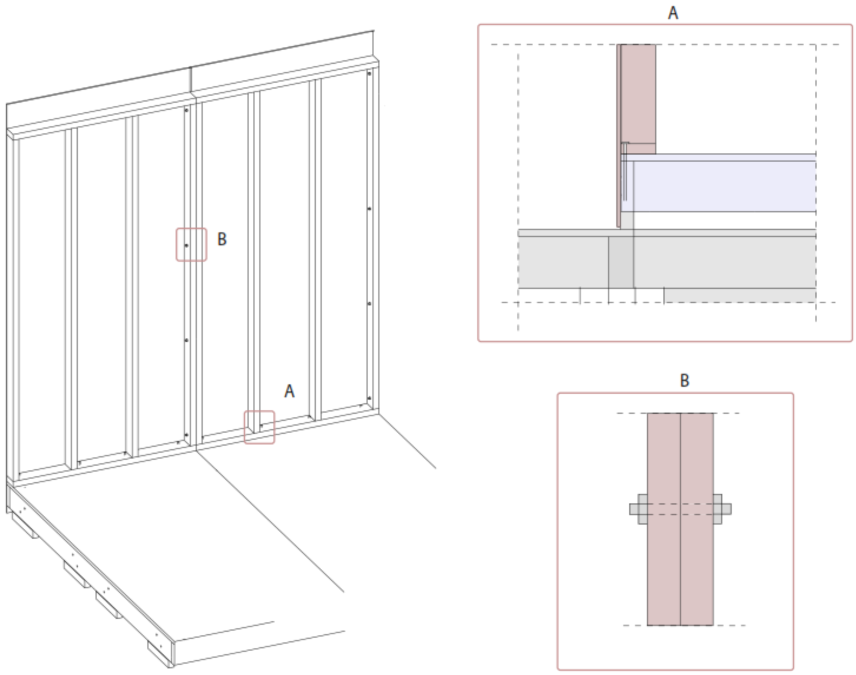

Figure 03: Connection wall modules [source: Pilot Project Briefing - Briefing, 2018]

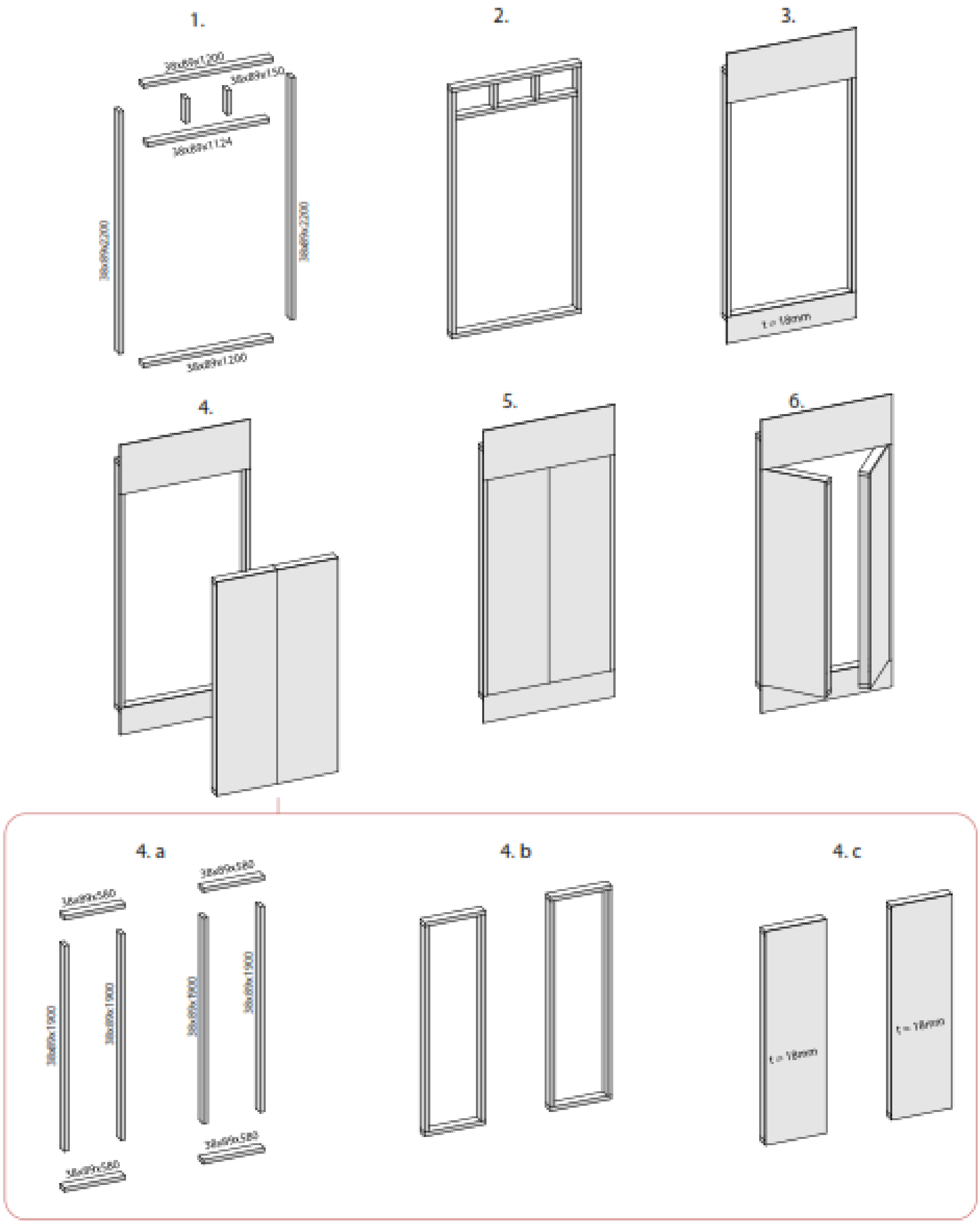

Figure 04: Panels with doors [source: Pilot Project Briefing - Briefing, 2018]

A.2 Climate Map

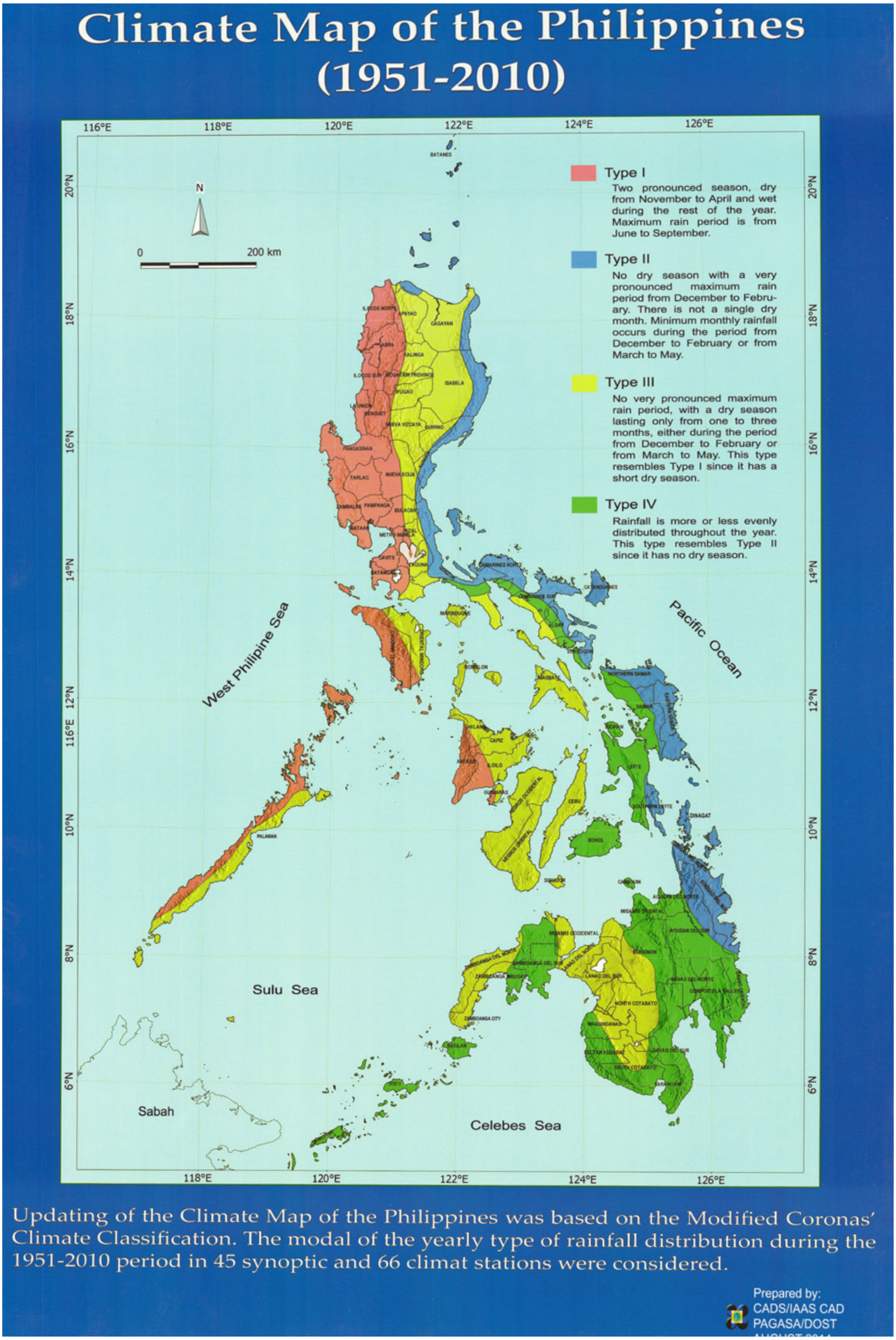

Figure 05: The Philippines: climate map [source: PAGASA, 2019]

A.3 Tropical Cyclone Forecast

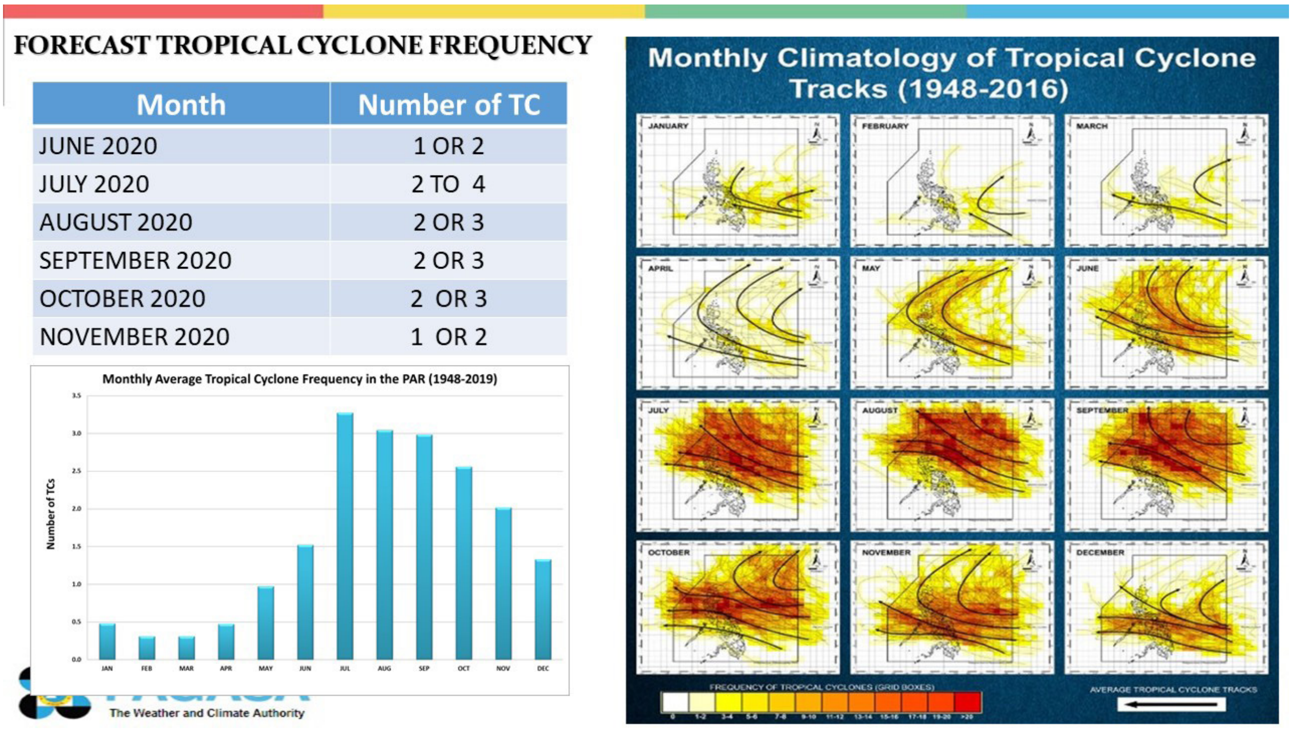

Figure 06: The Philippines: monthly tropical cyclone forecast [source: PAGASA, 2019]

Appendix B

B.1 Script for IoT Temperature and Humidity Monitoring Device

[Ubidots,2020][PiUpMyLife,2020]

```
import Adafruit_DHT
from datetime import datetime
import sys
import time
import requests
import math
import random

TOKEN = "BBFF-CQlpeUGr20CPsIaWVO2wdnMeqCR9HT"  # Put the Ubidot TOKEN here
DEVICE_LABEL = "machine"  # Put the device label here
VARIABLE_LABEL_1 = "humidity"  # first variable label
VARIABLE_LABEL_2 = "temperature"  # second variable label
VARIABLE_LABEL_3 = "position"  # third variable label
record_file ='/home/pi/IoTWeatherLogger.csv'
no_of_attempts = 2 # keep this less than 3
wait_time = 90  # frequency of log in seconds

def log_payload(payload,log_file):
   lat,long = payload[VARIABLE_LABEL_3]["context"].values()
   print(lat,long)
   timestr = datetime.now().strftime('%Y-%m-%d-%H:%M:%S')
   with open(log_file, 'a') as f:
    f.write('{},{},{},{},{}\n'.format(timestr, payload[VARIABLE_LABEL_1], payload[VARIABLE_LABEL_2],lat,long))

def build_payload(variable_1, variable_2, variable_3):
   # Creates two random values for sending data
   sensor = Adafruit_DHT.DHT22
   pin = 4

   humidity, temperature = Adafruit_DHT.read_retry(sensor, pin)
   value_1 = humidity #10
```

```
    value_2 = temperature #20
     # Creates a random gps coordinates
    lat = random.randrange(34, 36, 1) + \
        random.randrange(1, 1000, 1) / 1000.0
    lng = random.randrange(-83, -87, -1) + \
        random.randrange(1, 1000, 1) / 1000.0
    payload = {variable_1: value_1,
               variable_2: value_2,
               variable_3: {"value": 1, "context": {"lat": lat, "lng": lng}}}

    return payload


def post_request(payload):
    # Creates the headers for the HTTP requests
    url = "http://industrial.api.ubidots.com"
    url = "{}/api/v1.6/devices/{}".format(url, DEVICE_LABEL)
    headers = {"X-Auth-Token": TOKEN, "Content-Type": "application/json"}

    # Makes the HTTP requests
    status = 400
    attempts = 0
    while status >= 400 and attempts <= no_of_attempts:
        try:
            req = requests.post(url=url, headers=headers, json=payload)
            status = req.status_code
        except requests.exceptions.RequestException as e:
            pass

        if status >= 400:
            attempts += 1
            time.sleep(5)

    # Processes results
    if status >= 400:
        print("[ERROR] Could not send data after %d attempts, please check your token credentials and internet
connection"%(no_of_attempts,))
        return False
```

```
    print("[INFO] request made properly, your device is updated")
    return True


def main():
    payload = build_payload(
        VARIABLE_LABEL_1, VARIABLE_LABEL_2, VARIABLE_LABEL_3)
    log_payload(payload,record_file)
    print("[INFO] Attemping to send data")
    post_request(payload)
    print("[INFO] finished")


if __name__ == '__main__':
    while (True):
        t1=time.time()
        main()
        t2=time.time()
        time.sleep((wait_time-int(t2-t1)))
```

B.2 Prepared Daily Review Questionnaire

Daily review to assess the indoor comfort performance of the
Pilot Floating House, Macababe, the Philippines

Name: .... Age: .... Gender: .... Date: ....

01. Morning: **.............................. am (after you wake up)**

Which part of the room are you at the moment?

☐ Sleeping Area ☐ Living Area ☐ Kitchen Area

A. What do you think of the temperature at the moment?

☐ Hot ☐ Slightly hot ☐ Warm ☐ Neutral ☐ Cool ☐ Slightly cold ☐ Cold

B. How do you feel at the moment?

☐ Very uncomfortable ☐ Uncomfortable ☐ Just uncomfortable ☐ Just comfortable ☐ Comfortable ☐ Very comfortable

C. What do you prefer the temperature to be at the moment?

☐ Colder ☐ Neutral ☐ Warmer

Please explain your answers: ....

02. Before-noon: **between 10:30 am & 11:30 am**

Which part of the room are you at the moment?

☐ Sleeping Area ☐ Living Area ☐ Kitchen Area

A. What do you think of the temperature at the moment?

☐ Hot ☐ Slightly hot ☐ Warm ☐ Neutral ☐ Cool ☐ Slightly cold ☐ Cold

B. How do you feel at the moment?

☐ Very uncomfortable ☐ Uncomfortable ☐ Just uncomfortable ☐ Just comfortable ☐ Comfortable ☐ Very comfortable

C. What do you prefer the temperature to be at the moment?

☐ Colder ☐ Neutral ☐ Warmer

Please explain your answers: ....

03. After-noon: **between 14:30 pm & 15:30 pm**

Which part of the room are you at the moment?

☐ Sleeping Area ☐ Living Area ☐ Kitchen Area

A. What do you think of the temperature at the moment?

☐ Hot ☐ Slightly hot ☐ Warm ☐ Neutral ☐ Cool ☐ Slightly cold ☐ Cold

B. How do you feel at the moment?

☐ Very uncomfortable ☐ Uncomfortable ☐ Just uncomfortable ☐ Just comfortable ☐ Comfortable ☐ Very comfortable

C. What do you prefer the temperature to be at the moment?

☐ Colder ☐ Neutral ☐ Warmer

Please explain your answers: ....

04. Night: **.............................. pm (before you sleep)**

Which part of the room are you at the moment?

☐ Sleeping Area ☐ Living Area ☐ Kitchen Area

A. What do you think of the temperature at the moment?

☐ Hot ☐ Slightly hot ☐ Warm ☐ Neutral ☐ Cool ☐ Slightly cold ☐ Cold

B. How do you feel at the moment?

☐ Very uncomfortable ☐ Uncomfortable ☐ Just uncomfortable ☐ Just comfortable ☐ Comfortable ☐ Very comfortable

C. What do you prefer the temperature to be at the moment?

☐ Colder ☐ Neutral ☐ Warmer

Please explain your answers: ....

B.3 Daily Review Results

		24-Mar-20	27-Mar-20	01-Apr-20	03-Apr-20
Morning (7:00)	Temperature℃	27.37	26.47	26.97	28.07
	Sensation Vote	Slightly Cold	Slightly Cold	Neutral	Neutral
	Comfort Vote	Comfortable	Comfortable	Comfortable	Comfortable
	Preference	Neutral	Neutral	Warmer	Warmer
	Explanation	Well ventilated, wind makes it feel cold	Well ventilated, wind makes it feel cold		
Before Noon (11:00)	Temperature℃	30.07	30.47	**32.87**	29.57
	Sensation Vote	Slightly Hot	Slightly Hot	Neutral	Neutral
	Comfort Vote	Comfortable	Comfortable	Comfortable	Comfortable
	Preference	Colder	Colder	Warmer	Neutral
	Explanation	Sun is hot	Sun is hot	Sun is not yet hot	Sun is not yet hot
After Noon (15:00)	Temperature℃	30.97	32.67	32.17	31.77
	Sensation Vote	Slightly Hot	Slightly Hot	Hot	Hot
	Comfort Vote	Comfortable	Comfortable	Just Comfortable	Just Comfortable
	Preference	Colder	Colder	Colder	Colder
	Explanation			Did not open the openings	Did not open the openings
Before Sleep (19:00-19:30)	Temperature℃	27.77	27.97	30.97	29.47
	Sensation Vote	Cool	Cool	Cool	Cool
	Comfort Vote	Comfortable	Comfortable	Comfortable	Comfortable
	Preference	Warmer	Warmer	Neutral	Neutral
	Explanation	The wind makes it feel cold	The wind makes it feel cold	The wind makes it feel cold	The wind makes it feel cold

Figure 07: Result of daily review

Figure 07 shows the result of the daily review for four days by the current occupant of the pilot floating house. As the device was turned off on March 24 afternoon and April 3, March 25 and April 2 temperature measurements are considered for the respective dates. It can be seen that till around 32°C, the resident was comfortable . It can also be noticed that even if the temperature is around 30°C the wind makes him feel cool during night. On April 1, at around 11:00 the temperature is found to be 32.87°C and surprisingly, the occupant found it to be having neutral sensation. In terms of the daily comfort review, a larger number of samples can be used to understand the response of people, it can be even done for the people living in nearby houses and this data can be further used.

B.4 Prepared Interview Questionnaire

Questionnaire for Indoor Environmental Quality

Name: ______________________________________ **Age:** ___ **Gender:** ___ **Date:** ________**Time:** _______

How often you clean the house? ☐ Daily, ☐ Alternate days, ☐ Once a week, ☐ Once a month, ☐ Never

GENERAL

1. How do you feel now? Do you have any health problem?

a) ☐ Healthy.

b) ☐ Not so good/ not so bad.

c) ☐ Sick.

d) Other (please specify): ____

2. How often do you visit this house?

a) ☐ I live here.

b) ☐ Very often.

c) ☐ Once a while.

d) ☐ Very rarely.

e) Other (please specify): ____

3. What kind of clothing do you wear inside the house?

____

4. What kind of activities do you do in the house?

a) ☐ Working

b) ☐ Get-together with friends

c) ☐ Household works

c) ☐ Family time

d) Other (please specify): ____

5. Which part of the house do you use the most?

a) ☐ Drawing area

b) ☐ Dining area

c) ☐ Kitchen area

d) ☐ Sleeping area

5. When do you spend your time in the house? You can choose one or more.

a) ☐ Morning; Time duration: from _______ to _______

b) ☐ Afternoon: Time duration: from _______ to _______

c) ☐ Evening: Time duration: from _______ to _______

d) ☐ Night: Time duration: from _______ to _______

e) ☐ To sleep: Time duration: from _______ to _______

Thermal Comfort

7. Do you open the windows and doors?

a) ☐ Very often

b) ☐ Often

c) ☐ Rare

d) ☐ Very rare

8. Do you open the roof openings?

a) ☐ Very often

b) ☐ Often

c) ☐ Rare

d) ☐ Very rare

9. When do you usually open doors or windows? You can choose one or more.

a) ☐ Morning; Time duration: from _______ to _______

b) ☐ Afternoon: Time duration: from _______ to _______

c) ☐ Evening: Time duration: from _______ to _______

d) ☐ Night: Time duration: from _______ to _______

e) ☐ While sleeping: Time duration: from _______ to _______

10. When do you usually open the roof openings? You can choose one or more.

a) ☐ Morning; Time duration: from _______ to _______

b) ☐ Afternoon: Time duration: from _______ to _______

c) ☐ Evening: Time duration: from _______ to _______

d) ☐ Night: Time duration: from _______ to _______

e) ☐ While sleeping: Time duration: from _______ to _______

11. Do you use a fan?

a) ☐ Yes, how often? ____

b) ☐ No

Indoor Air Quality/ Hygiene

12. Do you smoke inside the house?

a) ☐ Yes

b) ☐ No

c) If Yes, how often? ____

13. What do you use for cooking?

a) ☐ Gas stove

b) ☐ Electric stove

c) Other (please specify) ____

14. When do you cook?

a) ☐ Morning; Time duration: from _______ to _______

b) ☐ Afternoon: Time duration: from _______ to _______

c) ☐ Night: Time duration: from _______ to _______

15. Have you experienced any problems mentioned below after spending time inside the house?

a) ☐ Eye Irritation

b) ☐ Skin Irritation

c) ☐ Breathing trouble

d) ☐ Headache

c) Other (please specify) ____

16. Have you felt any odour inside the house?

a) ☐ Yes

b) ☐ No

c) If Yes, please specify ____

Others

17. How do you rate the acoustic quality inside the house?

a) ☐ Very good

b) ☐ Good

c) ☐ Neutral

d) ☐ Poor

e) ☐ Very poor

Comments: ____

18. How do you rate the day light quality inside the house?

a) ☐ Very good

b) ☐ Good

c) ☐ Neutral

d) ☐ Poor

e) ☐ Very poor

19. How do you rate the spatial quality inside the house?

a) ☐ Very good

b) ☐ Good

c) ☐ Neutral

d) ☐ Poor

e) ☐ Very poor

Comments: ____

20. What is your overall opinion about the indoor quality of the house?

a) ☐ Very good

b) ☐ Good

c) ☐ Neutral

d) ☐ Poor

e) ☐ Very poor

B.4 Field Visit: Floating House

Figure 08: Tilted drums

Figure 09: Leakage in the pipe to septic tank

Figure 10: Floating house with newly made entrance gate and replaced poles supporting the eaves

Figure 11:Moisture in rafters and battens due to water from the roof opening

Figure 12: Roof insulation

Figure 13: The shutters of pilot project

Figure 14: Houses raised on stilts, Macabebe

B.5 Additional Field Work

In addition to the measurements, the following activites are done with the help of the local carpenter in the site:

1. Repairs are carried out to fix the poles supporting the eaves
2. Gaps in the eaves are fixed
3. Solignum is applied to the exterior exposed timber members
4. New entrance gate to the house is made
5. Leakage of pipe to the septic tank is fixed
6. Extra electrical plug points are made
7. Visited local material suppliers
8. Instructed a person from the municipality of Macabebe how to repair the IoT devices, if necessary.

B.6 Field Visit: Local Architecture

Figure 15: Roof made of reed with opening for stack effect, Palawan

Figure 16: Louvered opening in roof, Palawan

Figure 17: Naturally conditioned house, Palawan

Figure 18: Open Hall with double roof, Hagonoy

Figure 19: Renovated Bahay Kubo, Hagonoy

Figure 20: Model of Bahay Kubo, Hagonoy

Figure 21: Ventilation below ceiling level, Hagonoy

Figure 22: Ventilation below ceiling level, Hagonoy

Figure 23: Operable glass louver in a residence, Hagonoy (left), operable wooden louver in a residence, Palawan (center) and roof ventilation in a residence, Macabebe (right)

Figure 24: Louvers used for the opening in a school building built in 1940s, Macabebe

Figure 25: A traditional hut built for travellers, Palawan

Appendix C

C.1 Dry-bulb Temperature & Operative Temperature

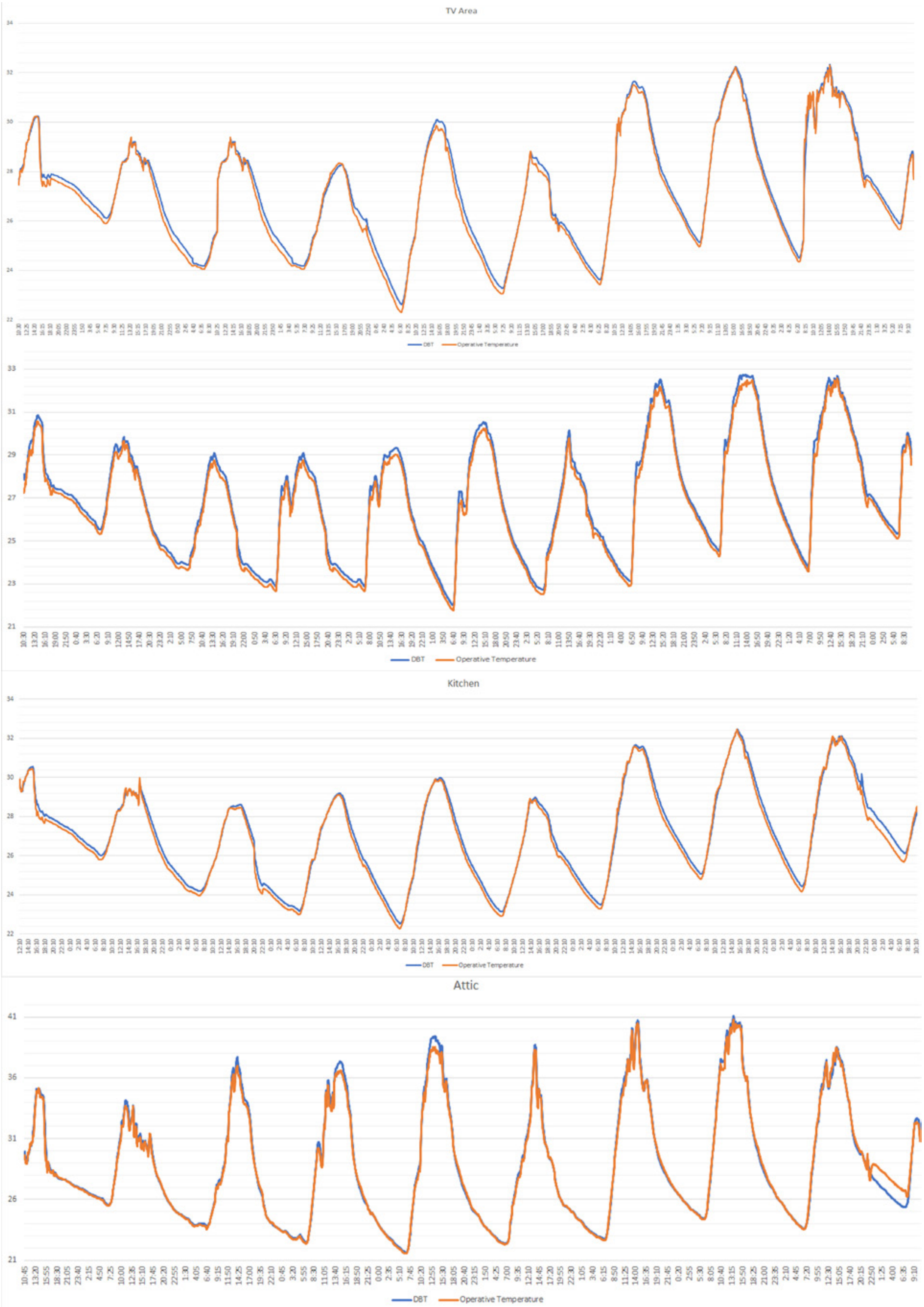

Figure 26: Dry-bulb temperature and Operative temperature of each location

C.2 Absolute Humidity

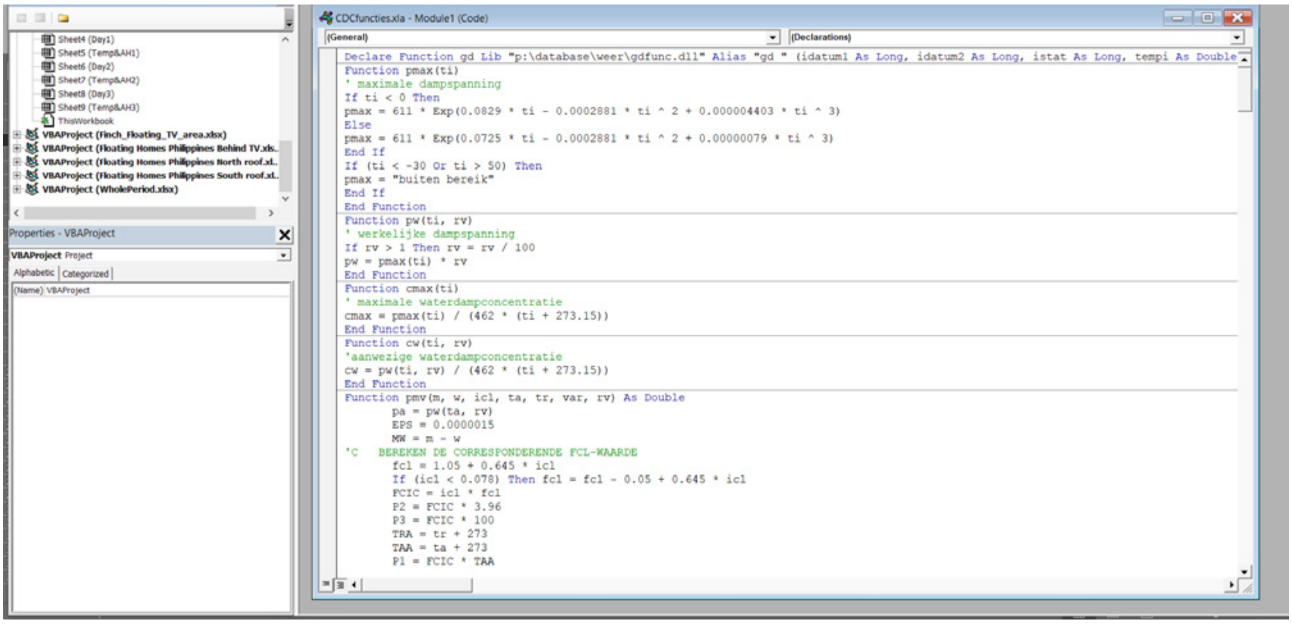

Figure 27: Formula used to find absolute humidity [source: Eric van den Ham]

C.3 Adaptive Comfort Range

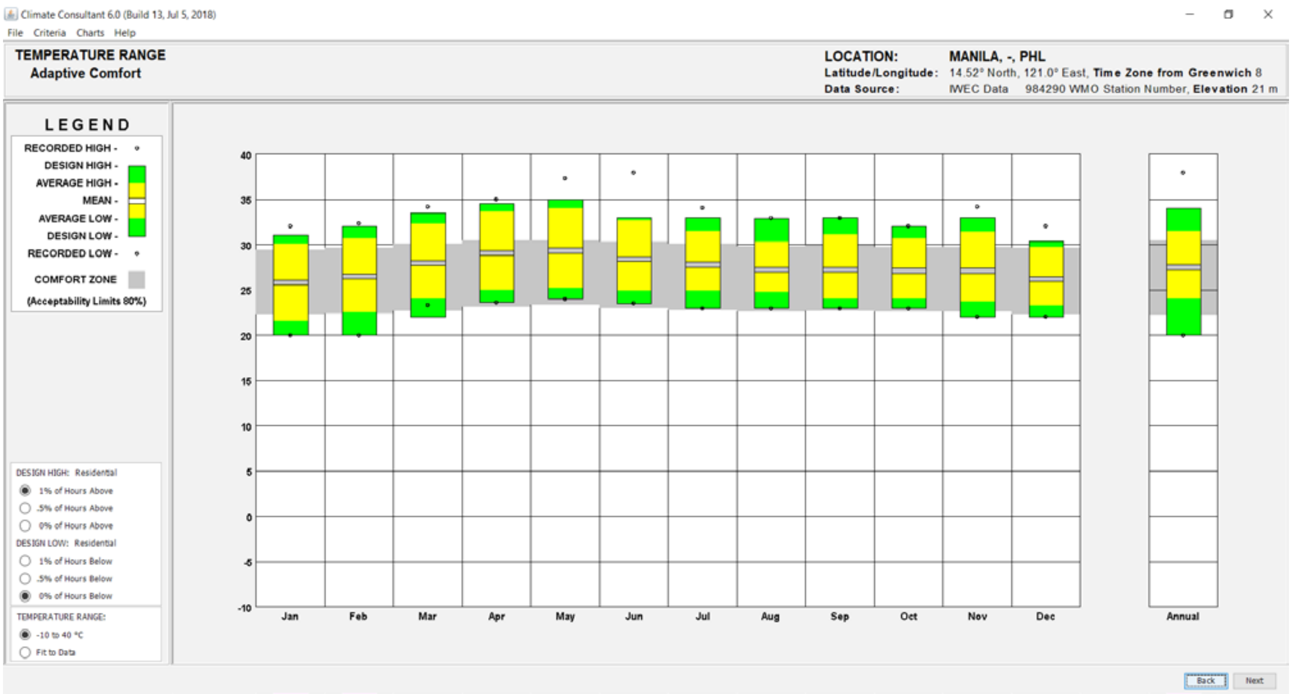

Figure 28: Adaptive comfort range, Manila from Climate Consultant

Appendix D

D.1 Further DesignBuilder Settings

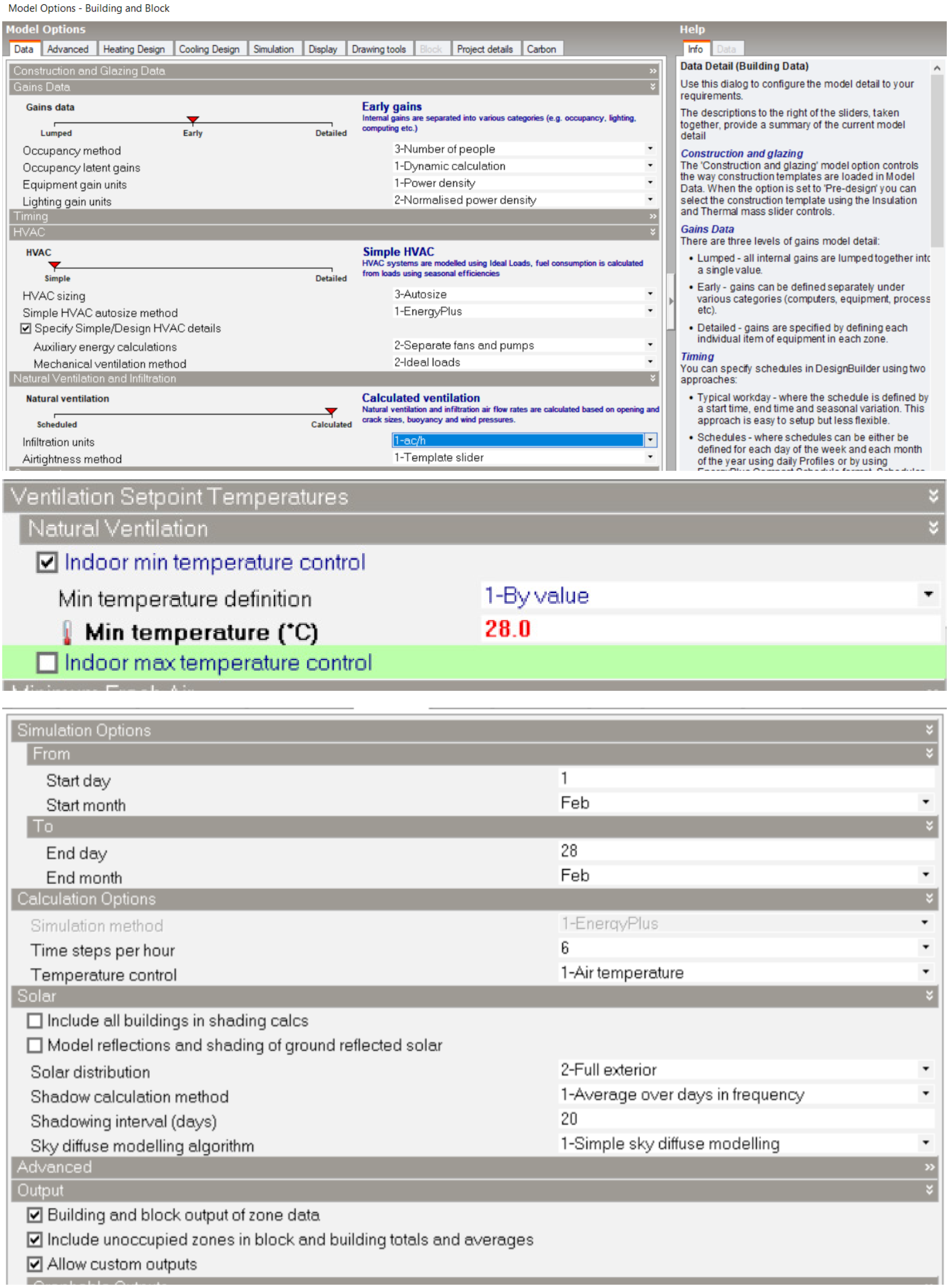

Figure 29: DesignBuilder settings

D.2 Schedule of Operations

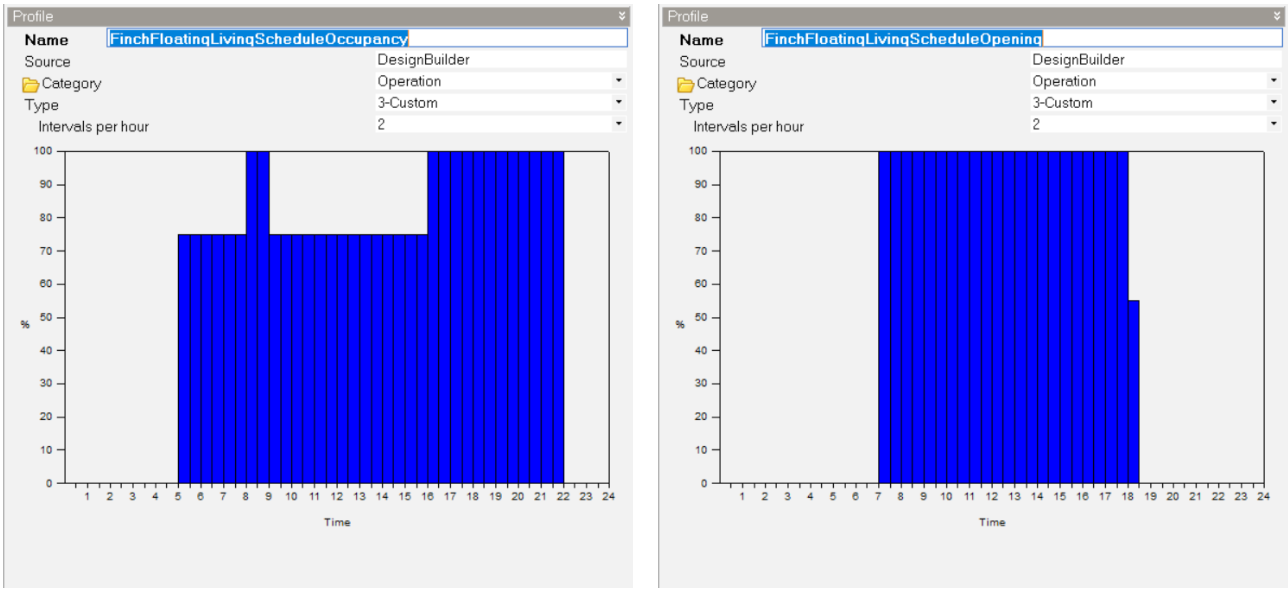

Figure 30: Living zone occupancy schedule (left) and living zone opening's schedule (right)

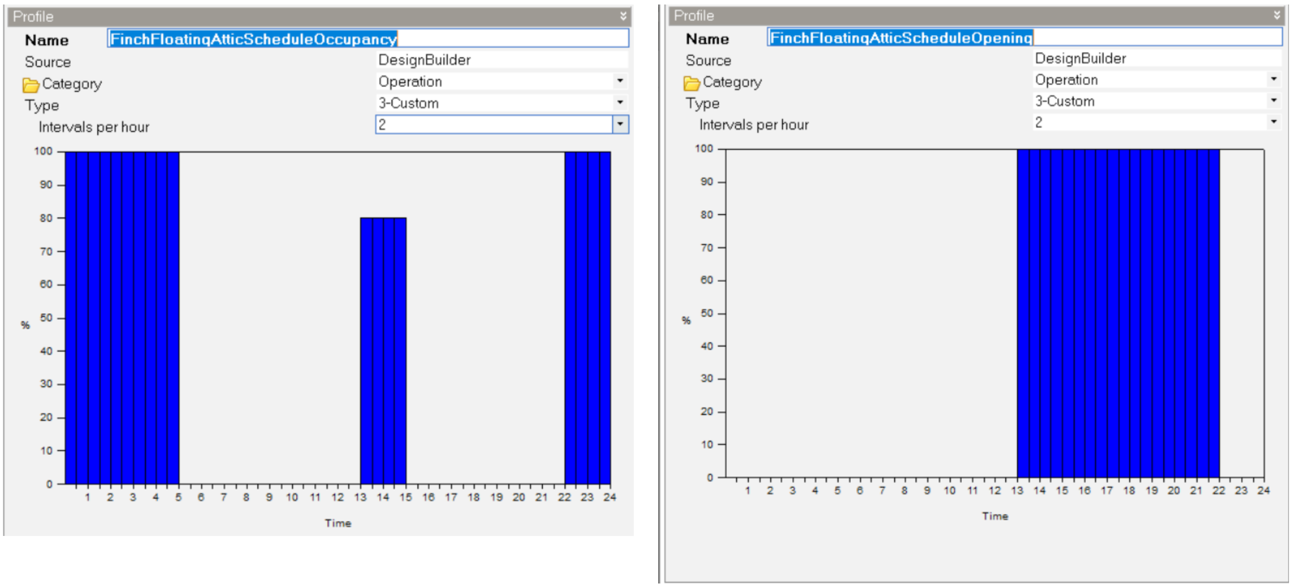

Figure 31: Attic zone occupancy schedule (left) and attic zone opening's schedule (right)

D.3 DesignBuilder Results

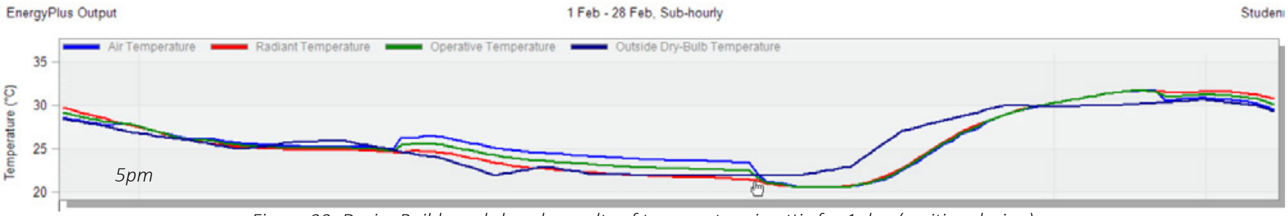

Figure 32: DesignBuilder sub-hourly results of temperature in attic for 1 day (exsiting design)

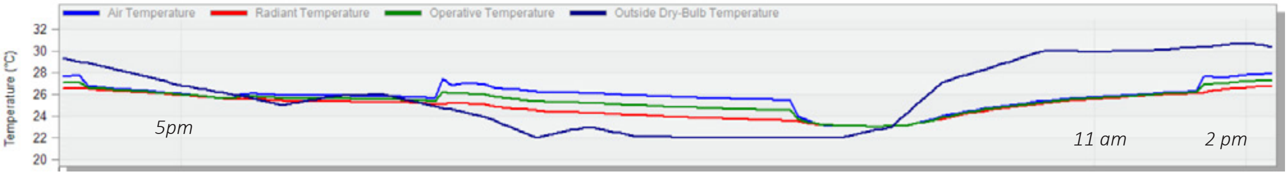

Figure 33: DesignBuilder sub-hourly results of temperature in attic for 1 day (attic lowered)

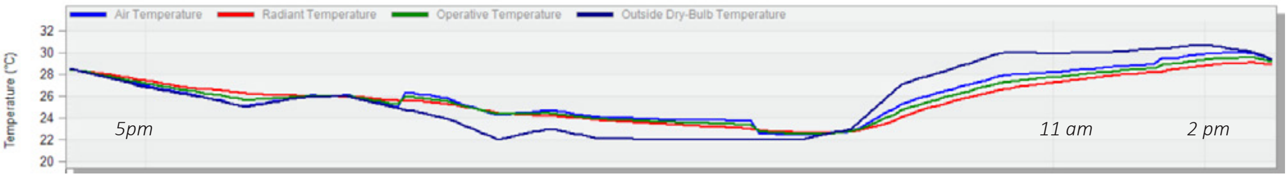

Figure 34: DesignBuilder sub-hourly results of temperature in attic for 1 day (attic raised)

Appendix E

Figure 35: Roof raised option

The visualization of the roof raised option is shown in Figure 35. The walls of the attic in this design is exposed to the sun. Further the reflected heat from the foldable eaves could enter into the attic space through the openings. This is evident in the DesignBuilder simulation.