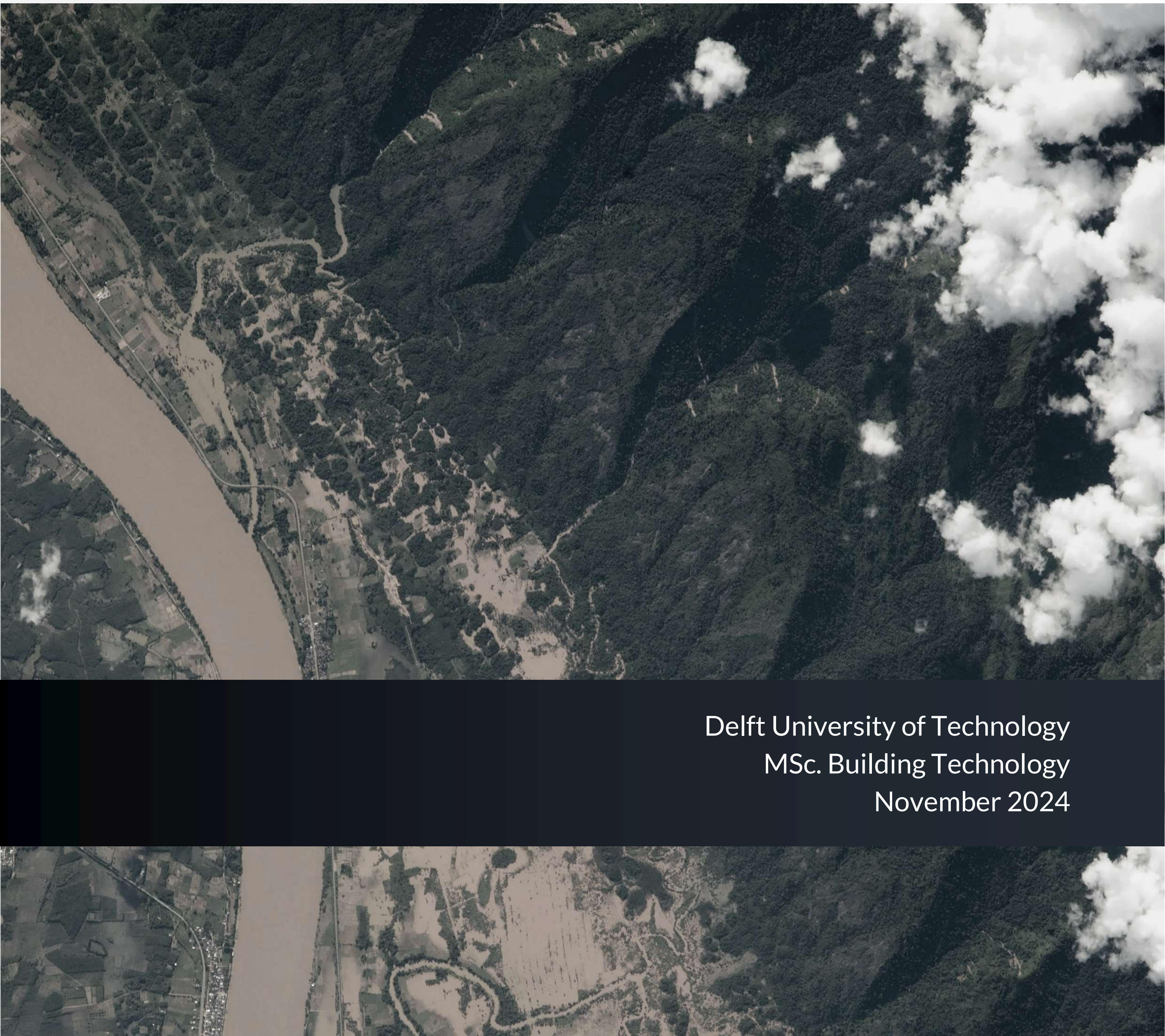
Low-Tech flood-resistant housing through amphibious structures & passive cooling methods for tropical climates

Kim My On



Delft University of Technology
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“ Low-Tech Flood-Resistant
Amphibious Housing
for Tropical Climates that lower
the Energy Demand with
Passive Cooling methods and
build resilience against
extreme weather circumstances
with Amphibious structures”

Building Technology Graduation Project

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Cover Image: The Mekong River on the border between Thailand and Laos. NASA (2015).

Abstract

Global warming is causing more extreme weathers leading to floods, inundation, high temperatures and increasing of cooling demands. More resilient homes and mitigation of CO2 emissions are needed. This thesis aims to investigate the integration of passive cooling to adaptive flood-resistant homes. The popular stilts houses located in the Mekong Delta are being analyzed: a vernacular home developed by the inhabitants that aims to cope with the local climate and floods. Multiple researchers concluded that improvements need to be made to cope with overheating in homes and for more dangerous floods in the future. According to literature review designs that incorporate insulation, natural ventilation, (moveable) shading and operable windows are the best methods for passive cooling of buildings in humid climates. Amphibious structures enable buildings to adapt to the changing water levels but staying fixed to one place. Simulations demonstrate that transforming a traditional stilt house into a flood-resistant amphibious home can reduce the operative temperature by a maximum of 1 degree Celsius. Integrating insulation in the walls and roof, along with an insulated tropical roof and floor vents, can lead to a maximum temperature reduction of 4 degrees Celsius. As a result; lower indoor temperature, adaptive flood-resistance and reduced energy demand for cooling. Further research and attention is needed to make designing for homes related to flood circumstances more accurate and find more of an approach that lives with water instead of fleeing from it.

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1 Introduction

This master's thesis is part of the Graduation Project Studio in the Building Technology master track at the Faculty of Architecture and the Built Environment, TU Delft.

The aim of this thesis is to provide new knowledge and explore innovative solutions for designing housing that incorporates passive cooling strategies while protecting residents from increasingly frequent floods in the future. Although numerous studies have been conducted on strategies for mitigating the negative effects of sea-level rise and reducing high indoor temperatures, limited research has been done on integrating both concerns in housing design.

The Mekong Delta provides an ideal case study of a vulnerable region, given its low elevation, high temperatures, and heavy rainfall. One of the region's most popular housing typologies '**stilts housing**' will be analysed for its adaptation to local climate and flood conditions. These houses have traditionally been built by local communities to address these challenges.

According to sources, the current (vernacular) housing typologies are not well suited to future climate change impacts. Issues such as overheating and the increasing threat of floods are causing many residents to relocate to already densely populated urban areas in Vietnam.

This thesis reviews existing literature on flood-resistant housing methods and passive cooling strategies relevant to similar tropical climates. The goal is to identify future-proof solutions for low-cost, resilient housing. The research addresses the following sub-questions:

1. How does the current stilts typology respond to high temperatures and floods?

2. What low-cost passive cooling strategies are most effective in tropical climates?

3. How can the flood-resistance of stilts housing be improved without significantly increasing construction and material costs?

The thesis concludes with a final design proposal, answers the research questions, recommendations for further research, and a reflection on the research process and outcome.

I would like to thank my family, friends and mentors Dr.Ir. Thaleia Konstantinou and Dr.Ir. Martin Tenpierik for their help and support during my research journey.

2 Research Framework

2.1 Background

2.1.1 The Building Industry and Global Emissions

The building industry is facing the need to adapt to the impacts of climate change, requiring a shift towards constructing more resilient housing solutions and designing more sustainable buildings as almost 40 % of the total global emissions is derived from the building industry. This stems mainly from the embodied carbon emissions of buildings; the design, production and deployment of often used materials as cement and steel. Solutions therefore should avoid unnecessary extraction and production of materials, striving to be more regenerative and improving the decarbonization of conventional materials (UNEP.org, 2023).

2.1.2 Climate Change and Adaption

Climate change is inevitable and the effects are noticeable; more extreme weather events are causing people to relocate as the safety of their homes and themselves is being questioned and nature is urging us to adapt to new circumstances, leading to different needs.

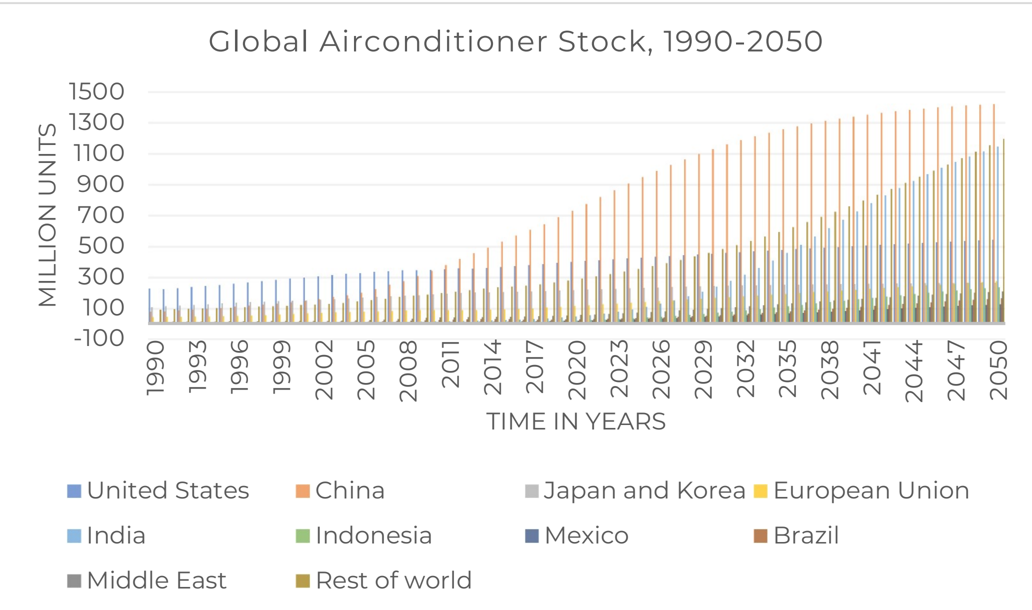


Fig. 2.1: Global Airconditioner Stock, 1990-2050. (IEA, 2018). [The Future of Cooling – Analysis - IEA]

2.1.2.1 Increased Cooling Demands

The increase in the global average temperature shows that more and more places are warming up rather than cooling down (Climate.gov, 2024). According to NOAA's [2023 Annual Climate Report] the combined land and ocean temperature has increased at an average rate of 0.06° Celsius per decade since 1850. Since 1982 this rate has become more than three times as fast: 0.20° C per decade.

According to Scoccimaro et al. the energy use in the building sector for cooling is the fastest increasing energy demand as this number was twice as big in the last twenty years in IEA countries. It should be noted that some tropical countries that potentially would require high cooling demands are not yet equipped with air conditioners, which could imply for a large increase of energy use in the future. IEA expects the air conditioner supply to triple by 2050, see Fig. 2.1 (IEA, 2019).

2.1.2.2 Floods force relocation

The National Oceanic and Atmospheric Administration reported that the global mean water level in the ocean rose by 3.6 millimeters per year from 2006–2015, which was 2.5 times the average rate of 1.4 millimeters per year throughout most of the twentieth century. By the end of the century, global mean sea level is likely to rise at least 30cm above 2000 levels, even if greenhouse gas emissions follow a relatively low pathway in coming decades (NOAA, 2022). The proportion of population exposed to large floods has increased 20% from 2000-2015, which is significantly higher than the previously reported 2.6% in a study examining sea-level-rise-events from 1970-2010 (Tellman et al., 2020).

The potential increase in flood intensity and probability is among the most severe impacts that climate change poses to delta cities (Hunt & Watkiss; Wong et al., 2014). This is most relevant for the tropics, where the combined effects of sea level rise and of a fast-growing population and economy pose a challenge to the livability of densely inhabited cities of low-lying delta’s (McGranahan et al., 2007). The vulnerability is enhanced due to the effects of warming on the monsoon systems (IPCC, 2013).

2.1.3 Mekong Delta

2.1.3.1 Geographical Context

The Mekong Delta is located in South-East Asia and covers up an area of about 39,000 km^2 with multiple rivers. The Mekong River is the main river, originating in the Tibetan Plateau and flowing through Vietnam, China, Myanmar, Laos, Thailand and Cambodia. All rivers of the Mekong Delta eventually end up flowing into the South China Sea.

During the reclamation of the Mekong River Delta, the environment was very severe, characterized by wild animals, numerous ponds and swamps, which were filled with heavy miasma. A safe home to shelter from the animals and climate circumstances was one of the first priorities back then (cantho.gov.vn, 2020).

The topography of the Mekong Delta at that time and even now has been the lowlands with an average height of fewer than 2 meters above the sea level (Bolay et al., 2019). From September to November each year, floods from the Mekong River make the southwestern nearly submerged in the sea of water. Therefore, to build houses, huts, camps, the first thing is to build the foundation somewhere high and relatively flat. Those places are commonly found along rivers and canals and are convenient for transportation and communication.

2.1.3.2 History and Socio-economic context

The Mekong Delta's history dates back to ancient civilizations like Funan and Chenla, with Khmer influence prevalent until the Vietnamese expansion in the 17th century. During the colonial era, the region came under French control as part of Indochina. It served as a strategic battleground during the Vietnam War, witnessing intense military operations. Post-war, the delta faced challenges of reconstruction and environmental degradation. However, modern development initiatives have led to rapid economic growth and urbanization. Today, the Mekong Delta remains a vital agricultural and economic hub for Vietnam, attracting visitors with its unique cultural heritage and vibrant landscapes.

Around 20% of the total Vietnamese population lives in the Mekong Delta, this is approx. 20 million people (Vriend, 2009). According to GDL the average household size of a family in the Mekong Delta is 3.39 (2021). The International Wealth Index is 79.1 and people in the Mekong Delta make around 3-5 million VND per year, which is around 109 – 182 euros (Chanh, 2022; GDL, 2021). It is typical that families build their own houses or inherit them from their ancestors. Building a house costs around 1,800.00 euros (Nguyen, 2023).

One of the various local cultural traits in the story of how to build a house in the Mekong Delta in the past and many villages is "taking turns". This means that the whole neighborhood helps one family to build a house without fees in one turn, and then another family in another turn. Therefore, the story of how each family has built their house sometimes includes a deep feeling of gratitude to all of their neighbors (Truong, 2020).

2.1.3.3 Climate Effects

Global warming presents significant challenges for the Mekong Delta, including rising sea levels leading to saltwater intrusion, threatening freshwater resources, agriculture, coastal erosion and inundation. More frequent and intense extreme weather events, such as storms and floods, can cause widespread damage to infrastructure and communities (Smajgl et al., 2015). Changes in precipitation patterns may result in droughts followed by heavy rainfall, impacting water availability and irrigation systems. Biodiversity loss is a concern due to habitat degradation and loss of eco-systems like mangrove forests (Halsema & Seijger, 2023).

These impacts collectively threaten agricultural productivity, food security, and livelihoods in the region, necessitating urgent action to mitigate and adapt to the effects of global warming. According to the MRC research, a wide range of potential changes are projected to occur over the next 20 to 50 years. Temperatures are projected to increase across the basin and across seasons (mrcmekong.org, 2024). It is expected that in 2100 the Mekong Delta will be largely below annual flood level (see fig. 2.2).

The 2050 year flood risk map shows that 91.1% of the total Vietnamese Mekong Delta is found under very high, high and medium-risk condition. Mainly on the Northern side of the VMD, and located adjacent to the two rivers. The risk map was calculated as a product of hazard (i.e. depth of inundation), and vulnerability (i.e. exposure of people or assets to flood, their susceptibility and their resilience).

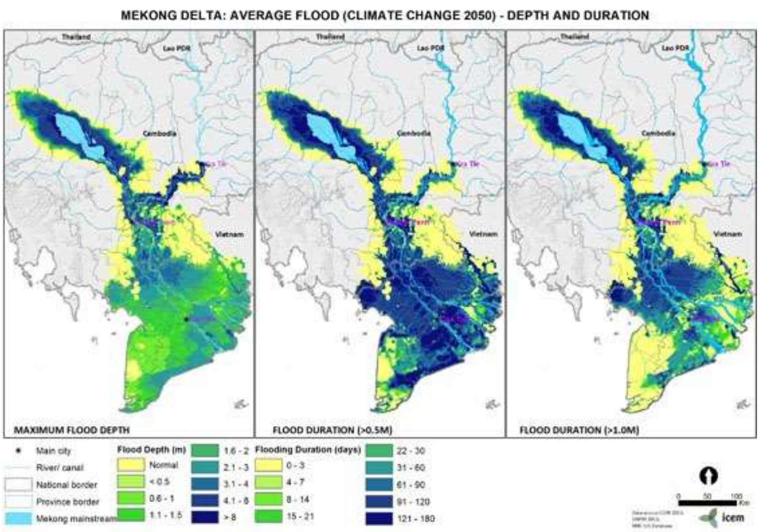


Figure 2.2 Mekong Delta: Average Flood (Climate Change 2050) - Depth and duration.

Source:https://icem.com.au/portfolio-items/mekong-delta-average-flood-climate-change-2050-depth-and-duration/#

According to Nguyen et al. (2021) the Mekong Delta is coping with Fluvial and Pluvial floods. These floods be characterized by slow rising and receding of river water for 2-6 months, and rapidly between July and November (Chinh et al., 2016). Far inland the tides can be influenced by an amplitude between 3.5 - 4.0m from the East Sea, and 0.8 - 1.2m from the Gulf of Thailand (Tri, 2012; Tuan et al., 2007).

The main climate characteristics of Vietnam are a high annual temperature and high solar radiation. Therefore, overheating becomes the biggest problem in houses that passive design needs to deal with (Nguyen et. al., 2017). Especially during the peak temperatures, the attic floor with low air velocity can exceed the upper comfort level with relatively high numbers (Ham, 2022).

2.1.3.4 Stilts Housing

The local housing (see fig. 2.3), which were inherited from their ancestors, are adaptive to the natural environment. Cham housing located along the river in the An Giang province has lost its Cham authenticity because they change their culture to adapt to the surrounding environment; the annual floods caused by global warming.

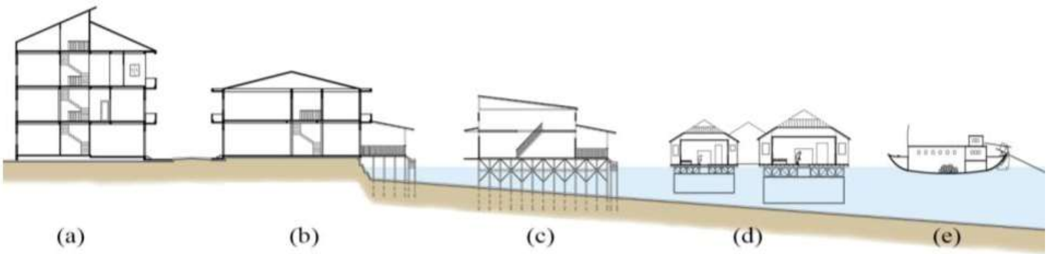


Fig. 2.3: Housing Typologies in Mekong Delta according to the ground floor structures. a= houses on the ground, b= half ground and half stilts houses, c= stilt houses, d= floating houses, e= houseboat. *(Vu & Duong, 2016).*

The Cham's accommodation (fig. 2.3c) is a wooden house on high stilts, which has a ladder in the front and a bridge connected to the higher leveled road. The ground floor is often empty and used for avoiding floods. Unlike the other ethnic housing in VMD, the Cham stilt house is designed very delicately in a large and airy space with the environment. Currently, a large number of Cham stilts housing has remained in An Giang and have become an unique housing typology in the VMD.

The design of a sample flood adaption housing takes into consideration the characteristics of ethnic group housing in the Vietnamese Mekong Delta. Flood-resilient amphibious housing strategies should be considered to cope with greater and more regular floods.

2.1.4 Amphibious Flood-resistant Housing

A number of researchers and designers have been attracted and seek to improve the livability of areas, vulnerable to flooding. Among them, flood-resistant amphibious housing have been introduced to low-lying countries as the Netherlands, India, Indonesia and Vietnam.

A solution for sea-level-rise has led to the design of amphibious structures. An Amphibious House is a type of house that stands on land but floats on water (Climate-ADAPT, 2023). It is designed to rest on fixed foundations for the most part. However, during an extreme flood it rises between guideposts and the buoyancy bodies lift the house, and the house comes ashore dry (Barker & Coutts, 2016; Tiwari et al, 2023).

As Ahmed (2023) said in his article for Adapting the Built Environment for Climate Change; "one of the main advantages of amphibious living is that it gives the residents the opportunity to cope with flood, instead of evacuating or being devastated" (p. 349). However Amphibious housing has not been applied much yet, because it still seems to be novel and expensive, further research is needed.

There is also much research into passive cooling method, but mostly about the concept and integration of itself. A study about 'Adapting towards resilience', stated that future studies should provide a more in-depth focus on the application of passive strategies for reducing the energy demand for cooling, thus improving the energy performance of these Amphibious typologies (Rosso et al., 2020).

Another flood-resistant method is dry-proofing which excludes any water entering a building via waterproof materials and construction. A flood-"resilient" method allows water into the building to avoid structural damage but is constructed so that the impact of flooding is minimized (wet-proofing). A more structural impacting method is elevating the floor levels above the predicted flood level by using structural columns or posts, resulting in pile dwellings.

For housing on fluctuating water levels, floating dwellings could be a solution. The house rests on a buoyant base or foundation which can rise and fall with the level of the water. However these dwellings are not fixed to one place. So the amphibious method includes the strategy of floating houses however it is supported by guidance posts which fixate the house to one place. This is ideal for the extreme climate of the Mekong Delta, varying from drought to periods of wetlands.

2.2 Problem Statement

The Mekong Delta has become more vulnerable to extreme and more regular floods and temperatures, it's current typology needs to be improved. Many current flood-resistant methods are still expensive and more integrative designs with passive cooling are needed since many housing, including the stilts housing are still coping with overheating. Implying the increase of air conditioners and energy demand for cooling in the future The other problem of flooding is that residents have to move away from coastal areas to already very dense cities. All leading to more CO_2 emissions.

The potential increase in flood intensity and probability is among the most severe impacts that climate change poses to delta cities (Hunt & Watkiss; Wong et al., 2014). This is most relevant for the tropics, where the combined effects of sea level rise and of a fast-growing population and economy pose a challenge to the livability of densely inhabited cities of low-lying delta's (McGranahan et al., 2007). The vulnerability is enhanced due to the effects of warming on the monsoon systems (IPCC, 2013).

So much has already been devised to counter flooding and high temperatures, usually expensive interventions. In order to increase the accessibility of the target group, more attention should be paid to affordable interventions. Certainly for the people in the Mekong Delta who live in a vulnerable environment and have little to spend. This could be feasible by using local materials and easy construction techniques. Which has also been done by them over the years and a lot of experience has been gained and much to be learned from.

2.3 Research Question

How can low-tech amphibious housing lead to passive cooling to lower Energy Demands and create Flood-resistant housing? (Mekong Delta)

Design Question:

How can we design low-tech flood-resistant amphibious housing with a passive cooling system and which are accessible to low-income people and can effectively be implemented across the tropical climate region?

2.4 Objective

The aim is to find "how" or "in which conditions" the relationship between passive cooling and flood-resistant amphibious housing structures work, leading to new insights for building construction companies, designers etc. to make use of the concept and show the potential of Amphibious housing in new areas and different climates.

Final products of the thesis are design proposals, a final design which incorporates both flood-resistance and passive cooling, that uses as much as natural and local materials as possible to keep the expenses low and eco-friendly. And further recommendations.

The thesis is also referring to the UN sustainability goals 9 and 11 (unstats.un.org, 2024):

> *9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.*
>
> *11: Make cities and human settlements inclusive, safe, resilient and sustainable.*

2.5 Scope

The problem statement highlights that there is a need for affordable, flood-resistant amphibious housing designs that use passive cooling methods to ensure a comfortable indoor climate without relying heavily on active systems.

The study will be focused in the Mekong Delta, specifically the An Giang Province of where the flood-resistant vernacular housing typology is attempted to be improved for future and more extreme climate events.

The targeted population for this study will be the residents of the Mekong Delta, or more generally communities located in vulnerable flooded areas and tropical climates.

2.6 Relevance

Societal Relevance

The topic is relevant to the society because it tackles the housing challenges caused by changing climate events resulted of global warming. As more and more areas are affected by the extreme weather circumstances and human living conditions are being threatened. It also introduces the concept of amphibious housing and low-energy performed designs, attempting to create sustainable flood-resistant housing solutions. Solutions to which could be relevant to (low-income) households in tropical climates. The topic forces designers to think of all target groups and be guided by old and traditional but working methods and techniques of creating Thermal Comfort.

Scientific Relevance

Examining if the Building Modelling Tools (Rhinocerus) and Calculative Building Modelling Tools(Ladybug, Design Builder) that nowadays exist can assess the weather circumstances of floods and high temperatures. Recommendations for further research and developments in these programs as the urgency for these kinds of housing is increasing and the lack of, is threatening the livability of many homes.

2.7 Methodology

The thesis is based on the following phases:

Phase 1: Literature Review

Phase 2: Context Assessment

Phase 3: Site Analysis

Phase 4: Research Through Design

Phase 5: Testing and Evaluating

Phase 6: Concluding

Phase 1 is finding the right sources and literature to use for the literature review and reviewing them. This consist of books, research studies, (review) papers, state-of-the-art projects etc.

Phase 2 is finding more information about the area, the housing typology, climate and local materials.

Phase 3 consists of assessing the site, climatological context of the typology in the Mekong Delta. This will be done through existing drawings and climate calculation tools. This will be the basis for the next (Design/Proposal) phase.

In Phase 4 the first design drafts will be proposed and tested based on the literature review.

Phase 5 evaluates the improved designs, based on how well the design performs for cooling, natural ventilation/air flow etc. This will be done through simulations in DesignBuilder. Leading to a final design.

Phase 6, end the chapter with a cost-analysis, conclusions and further recommendations.

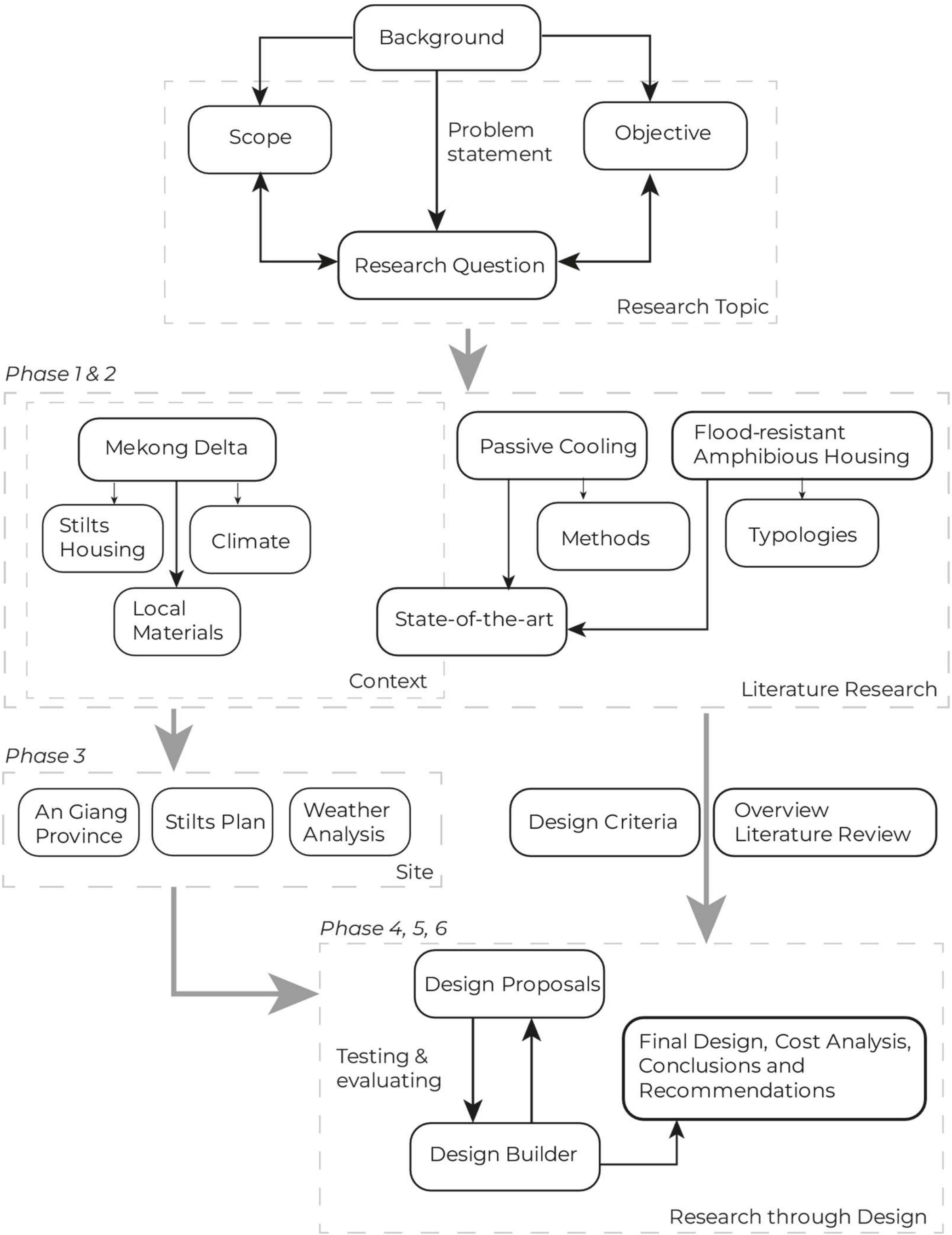


Fig. 2.3: Methodology Flow-Chart made by author.

3 Literature Review

3.1 Introduction and method

Based on the sub questions, specific groups of keywords and synonyms have been used to find relevant articles, papers and books.

Literature Research is done by using World Cat Discovery and Google Scholar. Most of the relevant literature were found by the following key-words:

Amphibious	**Housing**	**Flooding**	**Mekong Delta**
Flood-resistant	*Homes*	*Inundation*	*Tropical Climate*
Flood-resilient	*Living*	*Floods*	*Humid Climate*
	Residences	*Heavy rains*	*Hot and warm climate*
	Concepts	*Precipitation*	*South-Vietnam*
	Structures		*Delta*

Passive Cooling	**Methods**	**Tropical Climate**
Natural Cooling	*Methodologies*	*Humid Climate*
Vernacular cooling	*Concepts*	*Hot and warm climate*
	Case studies	
	State-of-the-art	

Table 3: Keywords for finding Literature Materials, made by author.

For chapter 2 the State-Of-The-Art articles were scoped for only "Amphibious" housing structures. The focus was set on Housing Typologies in the Mekong Delta. " *Vernacular Housing in the Mekong Delta* ", " *Housing Typologies in the Mekong Delta* " and " *Housing Situation in the Mekong Delta* ".

The part about flooding in the Mekong Delta is written based on literature which are about the flooding situation of Vietnam in general and more specified of the area. " Flooding in the Mekong Delta " and " Floods/Flooding/Sea-level rise in Vietnam ".

3.2 Mekong Delta’s Flood-Resistant Cham Stilts Housing

3.2.1 Introduction

In this chapter the following sub-questions will be answered: what are the vernacular characteristics of Stilts housing in the Mekong Delta, how does the typology deal with the floodings and what materials are the houses made from.
Before answering these sub questions with several research studies, an general overview of the housing typology will be given. How is the house being used and what functions are there. In the end there will be a conclusion and a summary of the most important findings for the Design Proposal; what passive cooling concepts have been applied already and what aspects of the typology enable the current flood-resistance.

3.2.2 Overview Typology

The Mekong Delta has been a place of many ethnic groups for years. The main ethnic groups are Kinh, Khmer and Cham. Each of these ethnic groups have their own work and living areas in the Mekong Delta. Each group has their own housing typology with their characteristics.

Housing on stilts is often created either by an extended family or group of families who have the same businesses that are attached to water or are near the floating markets or villages (Vu & Duong, 2018). The economic activity of the Cham people is various, which is combination of agricultural production with fishing, craft weaving and trading (see fig. 3.1.1)

Fig. 3.1.1: Riverside houses on stilts. Mekong Delta, Vietnam. Captured by Q.T. Luong, 2013.

Source: terragalleria.com

If the stilts houses face both front and back side to water the house needs to be connected to the ground/land by building a bridge made out of bamboo or wood.

Function wise, the part with the front to the road is more likely accessible for guests and the waterfront for kitchen and family activities. As well as the upper floors where the bedrooms are. If the house has also
a business then the ground floor is used for this: welcoming guests, unloading goods etc. First floor, and the floor level was always higher than the peak annual flood (see fig. 3.1.2).

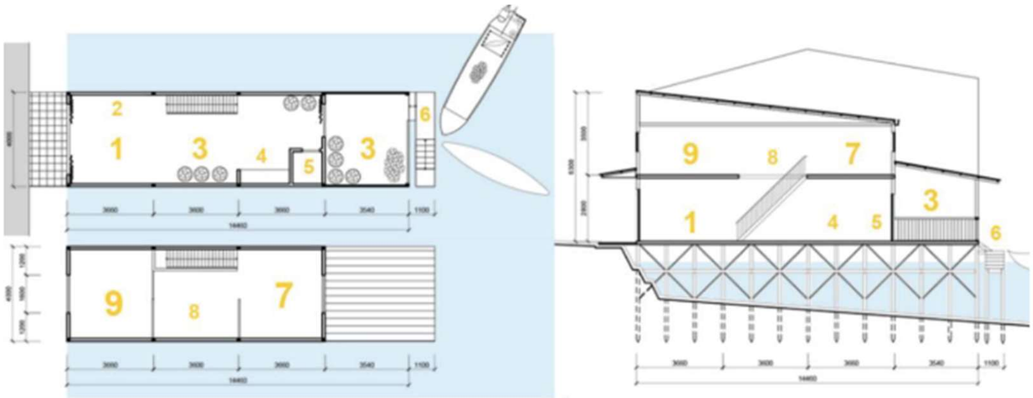


Fig. 3.1.2: Spatial organization of house on stilts in Mekong Delta. 1= living space, 2= worship table, 3= storage, 4= kitchen, 5= toilet, 6= back veranda, 7= bedroom, 8= toilet, 9= bedroom. Source: *Vu & Duong (2016).*

3.2.3 Vernacular Housing Characteristics

From a Survey and Field Measurement by Pham et al. (2023) in the Cham Villages from Tra Vinh and An Giang it was concluded that to keep housing cool during hot days, Cham ethnic people use the natural ventilation system. 1) opening the large window and door to deliver fresh air into the housing by cross-ventilation. It helps encourage to maintain indoor temperatures close to outdoor temperatures. 2) using a light-colored material to help roof reflect heat. 3) creating a high pitched roof to reduce heat transfer to space below. 4) stilts housing with an empty ground floor to help enhance natural ventilation, see figure 3.1.3 below.

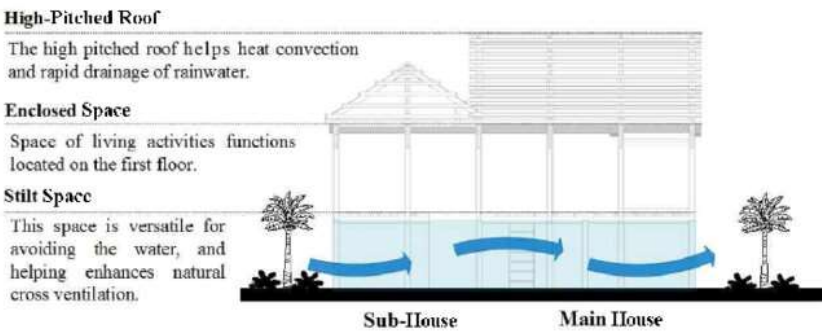


Fig. 3.1.3: Model of Cham Stilt Housing. Source: *Pham (2021).*

The stilts themselves are made of timber or concrete and the structure of the house out of steel, timber or concrete. For the walls and spatial dividers, light-weight materials as tole, timber walls or accurate sheet metal, leaves or brick is used. And for the roof, tole. Thus allowing easy and simple maintenance.

3.2.4 Flood Safety Characteristics

People in Mekong Delta have traditionally highly adapted to climatic conditions for a long time, such as seasonal floods (from upstream of Mekong River), salinity, drought, fresh water shortage, and so on. They adjust their houses from the ground/water levels (floating or on stilts), they flexibly combine working,
living and trading spaces; their routines have been also adjustable seasonally and annually (Hạnh & Duong, 2018).

A qualitative study on the Flood Safety Characteristics on the Cham Ethnic Stilt housing concluded that the Cham Stilts housing is creatively adapted to the local natural environment, especially flood. All spatial functions were effectively designed on the first floor, and the floor level was always higher than the peak annual flood (see fig. 3.1.4).

Due to rising seawater levels, the design of housing to adapt to climate change is a great concern these days in VNMD. It is known that dwellings in the Mekong Delta are becoming more vulnerable to induced natural events (e.g., flood, invasion, or draught). There exists a need to study housing typology to adapt to these conditions (Pham, 2022).

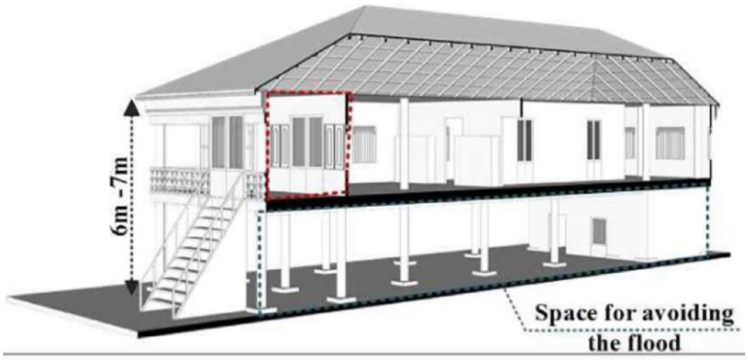


Fig. 3.1.4: Section Model of Cham Stilt Housing. Source: *Pham (2021).*

3.2.5 On-site materials and construction methods

As most people earn their relatively small earning through agriculture, fishery or handwork, affordable materials often are the only option. At first, unlimited wood for house construction was often wild trees available in the forest such as Cajuput, Avicennia, mangrove apple, Nauclea, crape myrtle, Jamblon (to make columns, trusses); thatch, Cyperus Iria, Nipa leaves (for roofing), Nipa palm strips, corn buds (buds which have not become the leaves of nipa trees) for tying.

Nowadays often houses are built with timber or bamboo frames and the connections are easily made through mortise, tenon, and stud joints see fig. 3.1.5

and 3.1.6(Pham et al., 2024). The tools for building houses are very simple: hammers, knives, machetes, slabs (cut, chop, clean the floor), hoes, shovels (dig or cover), saws, plane, chisel etc.

Another benefit by using locally sourced materials is reducing the emissions for transportation associated with choosing materials that are located or produced far away. Instead, for example using reclaimed materials like stones, bricks, wood and metal; those that have been salvaged from old buildings or structures and repurposed for new construction (theluxbuild, 2022).

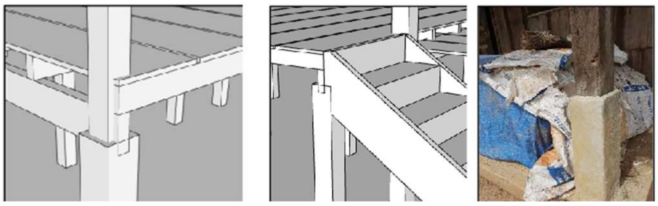


Fig. 3.1.5: Details of the Floor and Post Joists: (left) Timber Post, Bearer and floor joist with mortise and tenon joint; (mid) Timber post and stair with stud joint. (right) cement is clad to protect the posts. Source: *Pham (2024).*

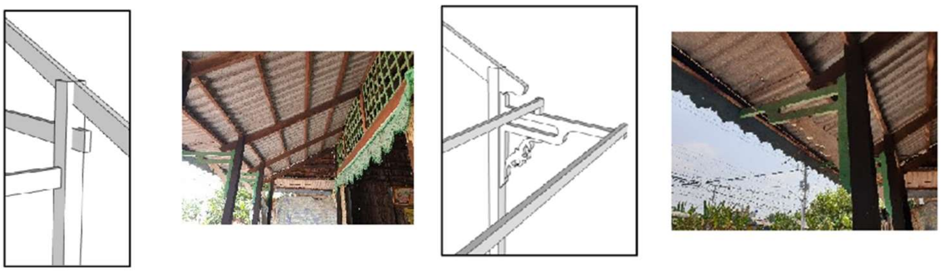


Fig. 3.1.6: Details of roof trusses: (left) transverse beam and post with mortise and tenon joint; (right) Rafter and post with mortise and tenon joint. Source: *Pham (2024).*

When about to build a house, people put pillars and rafters in the right position and tried assembling to check their accuracy. When the time to build it came, they installed joints and removed the seals. Using bamboo to make purlins and rafters, included submerging them in mud or “fed oil” for about six months to harden them for termite prevention (Truong, 2020).

3.2.6 Conclusion

To conclude on the sub questions: what are the vernacular characteristics of this typology and how does the typology deal with the floodings.

To keep housing cool during hot days, Cham ethnic people use the natural ventilation system: 1) opening the large window and door to deliver fresh air into the housing by cross-ventilation 2) using light-colored roofs to reflect heat 3) creating a high pitched roof to reduce heat transfer to space below 4) extra airy space on the ground floor created by the stilts helps creating airflow.

The Cham Ethnic Stilt is creatively adapted to the local natural environment, especially flood. All spatial functions were effectively designed on the first floor, and the floor level was always higher than the peak annual flood. However the rising seawater levels are becoming more extreme, thus the design of housing to adapt to these extreme climate conditions is needed.

Noticeable is the usage of local materials in their buildings to reduce construction costs and energy consumption; no need of heavy equipment or technologies. Incorporating local or reclaimed materials offers environmental sustainability, cost-effectiveness and reduced carbon footprint. Also it supports the local economies and builds a strong connection to the surrounding social and natural environment.

3.3 Passive Cooling Methodologies in Hot & Humid Climates

3.3.1 Introduction

In this chapter the following sub question will be answered: what affordable passive cooling strategy are there for hot and humid climates on the basis of Literature about passive cooling concepts and a review of important findings of case studies in tropical climates.

3.3.2 Background

Passive cooling techniques and systems are significant due to their ability to save energy for cooling buildings and replace the intensive mechanical cooling systems. These techniques, which have been neglected for a period, are getting more and more attention by researchers and designers in the context of sustainable design for energy conservation and reduction of greenhouse gas emissions (Du, 2019; Samuel et al., 2013).

There are two distinct groups within passive cooling concepts, based on the use of auxiliary equipment: passive design strategies and passive cooling systems. The first strategy 'Heat protection' to cope with overheated climates is by avoiding gains due to solar radiation (by shading and reflective barriers) and 'heat rejection', which avoids heat transfer through the envelope (by insulation and infiltration sealing).

Beyond these defensive strategies, passive cooling requires the evacuation of heat from the building to the atmosphere, the sky and the earth, which is called 'Heat dissipation' and relates to active measures and energy generation using active mechanic equipment or passive measures like natural ventilation, night sky radiation, etc. Electricity generation or the design for daylight, can contribute to reducing this energy consumption (Konstantinou & Prieto Hoces, 2018; Ulrich et al., 2018).

Choosing a suitable passive cooling strategy for a particular project is important in order to save energy and provide a comfortable environment. The suitable strategy is decided by the climate condition, urban environment, building type and style, material use and operation of the building. Ultimately, the energy use in the building is related to the users' wishes and behavior (Konstantinou & Prieto Hoces, 2018; Du, 2019; Prieto Hoces et al., 2018, Samuel et al., 2013).

Additionally, the application of passive cooling strategies is strongly related to architectural design especially in the early design stages. As the spatial design of urban morphology, building form and component can strongly influence the application. Solar control and natural ventilation are the main passive cooling techniques used in the building spatial design. (Du, 2019).

3.3.3 Vietnamese Context

In Vietnam, popular passive design strategies include solar control, natural ventilation and evaporative cooling. Direct evaporative cooling often requires sophisticated equipment and may raise the air humidity
and mold growth on walls and clothes. Natural ventilation is low-cost, easy to apply and provides good indoor air quality, but it strongly relies on natural wind and building configuration as well as building location. Since Vietnam has hot and humid climate, natural ventilation in most cases would be the better choice for passive cooling because the increase of air humidity due to direct evaporative cooling is not expected for humid climate (Nguyen et al, 2017; A. T. Nguyen & Reiter, 2014; Samuel et al., 2013).

3.3.4 Case Studies

Case Study 1	Research Method	Passive Cooling methods	Results
(Chen et al., 2020) "The effect of improving thermal insulation, natural ventilation and solar shading on reducing cooling load, lowering the indoor temperature and attaining a good daylight environment in an office in Tangerang, Indonesia."	Measurement tools and simulation	-Improving thermal insulation by adding 50mm Glass wool between the existing steel plates and gypsum boards. And the windows' glass was changed to Low-E single-pane glass. -Natural ventilation by vertical operable vents between the windows at each North and West façade. -Solar shading by operable louvres, whose angle can be adjusted were	Based on measurement results: -In terms of daylight environment, the shading effect of *operable louvers* can effectively reduce the excessive daylight caused by direct light, regardless of whether the louvers are open or closed. -In terms of thermal environment, the indoor temperature can be reduced by both *shading and natural ventilation*.

		installed outside the windows.	-insulation improvement reduced the annual cooling load Based on simulation results: -the effect of shading by operable louvers and natural ventilation by vertical operable vents on reducing annual cooling load is small when the building airtightness is low.

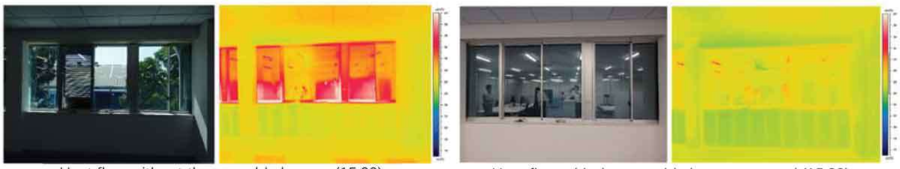


Fig. 3.2.1: Heat Flow before/after the operable louvers were used

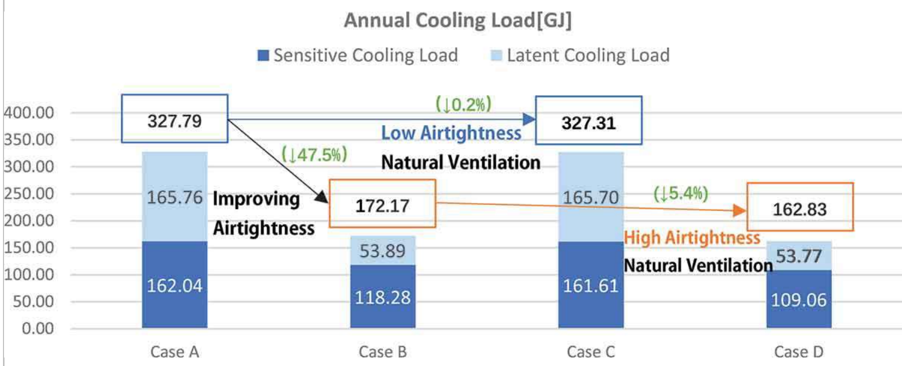
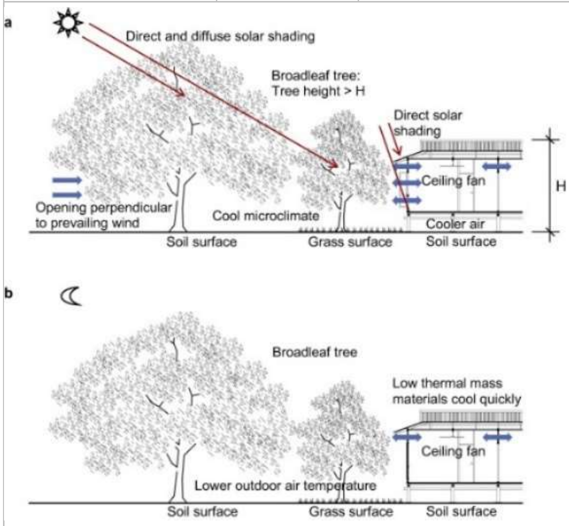


Fig. 3.2.2: Annual cooling load of each case (airtightness test)

Case Study 2	Research Method	Passive Cooling methods	Results
Toe, D. H. C., Kubota, T. (2015). "Comparative assessment of vernacular passive cooling techniques for improving indoor thermal comfort of modern terraced houses in hot–humid climate of Malaysia."	Field measurement	-Night ventilation/ Nocturnal structural cooling maintaining relatively low indoor air temperature through heat modulation by high thermal mass structures. -Roof or ceiling insulation: Reduce solar heat gain through the roof. -Window and wall shading: Shading from direct and diffuse solar radiation to reduce solar	-night ventilation can be more efficient in areas with a large diurnal air temperature range or in areas with high night-time wind speed that can increase the ventilation rate -applying a small internal courtyard to the building as seen in the traditional Chinese shophouses, reduces the nocturnal indoor air temperature to the outdoor level though major modification be required -Alternative methods of enhancing night ventilation are

		heat gain through external windows into indoor spaces, reduce radiant heat of external walls so that the building structures are less heated. -Small courtyard concept(Traditional Chinese house): Enhance night ventilation by ventilative and radiative cooling at night, prevent vertical air exchange and minimize cross ventilation with hot outdoor air during daytime to maintain relatively low indoor air temperature. -Microclimate modification and/or urban heat island mitigation: Reduce outdoor air temperature by cross-ventilation (Traditional Malay house) or urban heat island intensity especially during night-time to supply relatively cool air for night ventilation	the use of exhaust fan in the target room or at a higher place such as the atrium above the staircase to increase ventilation rates in the whole house during night-time, and the use of jack roof or ventilation opening near the ceiling to allow hot air to be released above. -Consideration should be given to issues of security, mosquitoes, rain, noise pollution and air pollution when implementing night ventilation systems -studies have shown that high indoor humidity conditions may cause condensation and damp ness on or within building structures and stimulate microorganism (i.e. mold, bacteria and fungi) growth, affecting occupant respiratory health in addition to building degradation (Fisk et al., 2007; Hens, 2009). Humidity control techniques should be dealt with in-depth in future studies



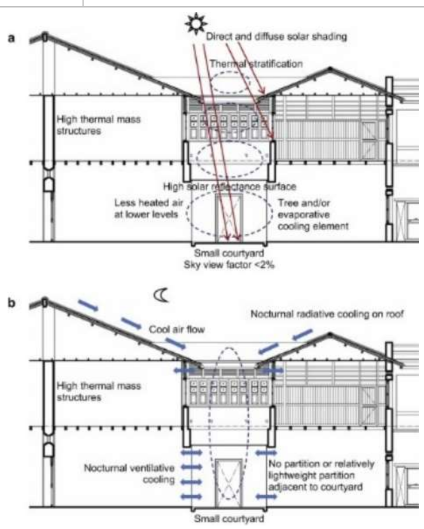


Fig. 3.2.3: (left) Conceptual illustrations of passive cooling techniques used in the traditional Malay houses. (a) Daytime; (b) night.)

Fig. 3.2.4: (right) Conceptual illustrations of passive cooling techniques used in the traditional Chinese shophouses. (a) Daytime; (b) night. *Note:* Sectional drawing with permission of TTCLC, National University of Singapore.

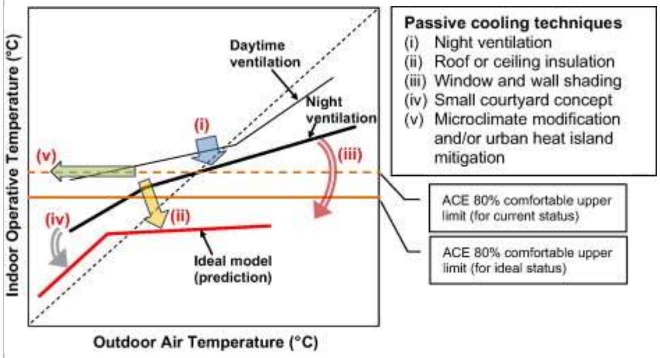


Fig. 3.2.5: Prediction of cooling effects of the proposed passive cooling techniques for existing terraced houses in Malaysia.

Case Study 3	Research Method	Passive Cooling methods	Results
(Chungloo & Limmeechokchai, 2007) "The case study of solar chimney and wetted roof in Thailand"	Experimental Test cell with measurements	-Natural ventilation by a solar chimney -Evaporative cooling: Wetted roof	-From the experimental result of utilizing the solar chimney during the period of high solar radiation and high ambient temperature, the difference between temperature at the inflow into the solar chimney and temperature at the outflow from the solar chimney tends to decrease. -Water spraying on the metal ceiling does not only decrease temperature in the room but also increases the temperature difference and increases the related air flow rate from room to the solar chimney too. -The spraying of water on the roof and the combination of solar chimney with the spraying water on roof is recommended during the high temperature of ambient air.

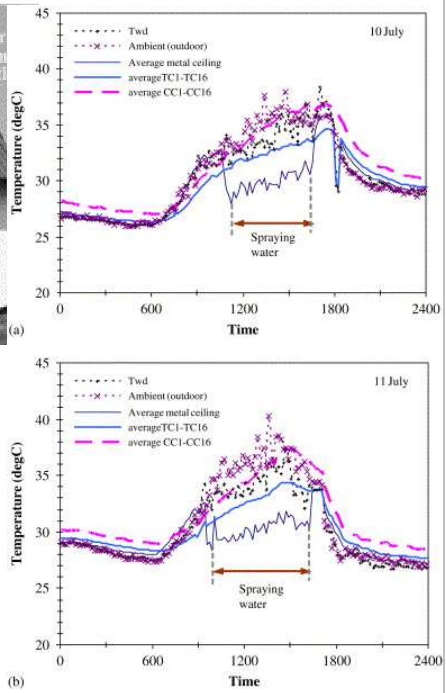


Fig. 3.2.6: (left) (a) Wall and roof facing north direction of the test cell; (b) the roof solar chimney on the south roof of the controlled cell.

Fig. 3.2.7: (right)The experimental results during application of solar chimney and spraying water on test cell's north roof: comparison of average temperatures in the rooms on July 10 (a) and July 11 (b).

3.3.5 Conclusion

Based on the case study findings, potential passive cooling techniques for tropical climates would be: (1) improving thermal insulation in the wall, roof or ceiling, (2) increasing natural ventilation by vertical operable vents or a solar chimney which airflow increase during different periods of the year, (3) reducing solar heat gain by solar shading through (operable) louvres in the window or wall, (4) maintaining a low indoor temperature by night ventilation/nocturnal structural cooling through high thermal mass structures, (5) a small courtyard, and (6) microclimate modification and/or urban heat island (UHI) mitigation by cross-ventilation or (7) applying a wetted roof during high temperature of ambient air.

For the stilts typology techniques 1, 2, 3 and 4 would have the most impact on reducing the cooling demand and require less of an intervention in the home structure.

3.4 Flood-resistant Amphibious Housing

3.4.1 Introduction

In this chapter the following sub questions will be answered: how can the flood-resistance of the Cham's Stilt housing be improved? And can this be done with local materials? To answer the sub questions the concept of the flood-resistant amphibious housing technique is being examined and state-of-the- projects will be analyzed per buoyancy structure, materials, context and production costs.

3.4.2 Concept and Principles

Flood-resistant housing can be seen as a method to cope with flooding. Or as Nilessen & Singelenberg(2011); Barker & Croutts (2016) speak of " flood-proofing " a building. According to the Merriam Webster (2024, January 24) the term " amphibious " means to be able to live on land and in water.

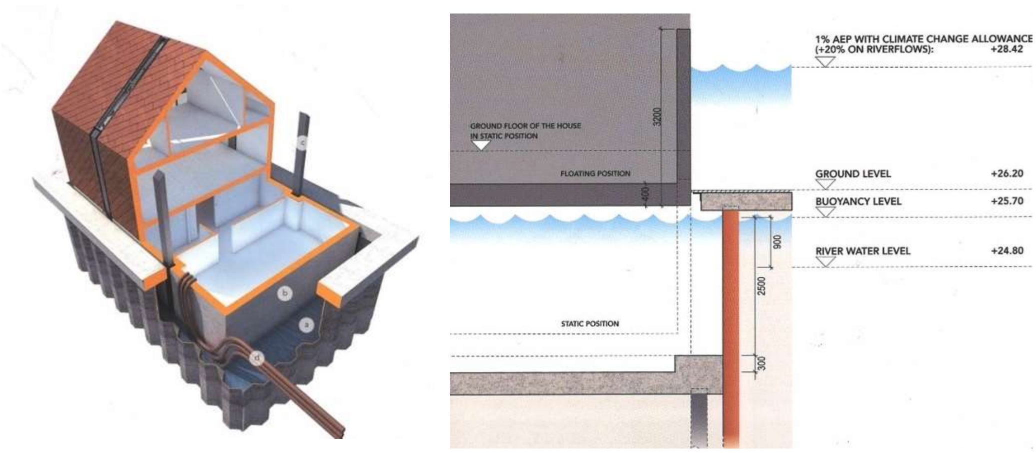
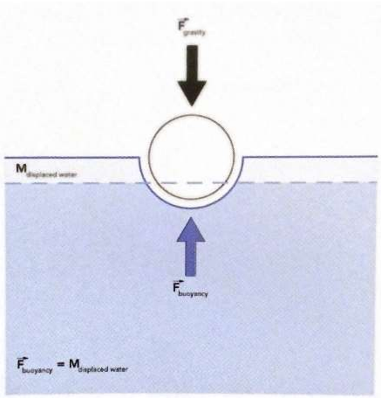


Fig. 3.3.1 & 3.3.2: Amphibious House 3D cutaway model and a section through the base and wet dock during floods. a = Wet dock and debris control, b = Can-float base and dwelling, c = Guide posts and running gear, d= Flexible utility connections (Barker & Coutts, 2016).

An Amphibious House is a type of house that stands on land but floats on water (Climate-ADAPT, 2023). It is designed to rest on fixed foundations for the most part. However, during an extreme flood it rises between guideposts and the buoyancy bodies lift the house, and the house comes ashore dry (Barker & Coutts, 2016 and Tiwari et al, 2023).



The flotation is designed based on the Archimedes' principle, illustrated in figure 5. This states that any object immersed in fluid is buoyed up by a force equal to the weight of the fluid displaced by the object.

For example if a house weighs about 220 tons, approximately 225m3 of water is displaced when it becomes buoyant. Another principle is the Pontoon's principle which states that the mass or volume of the house should be less than the density of water.

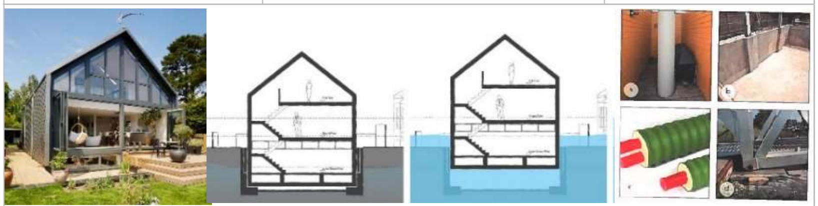
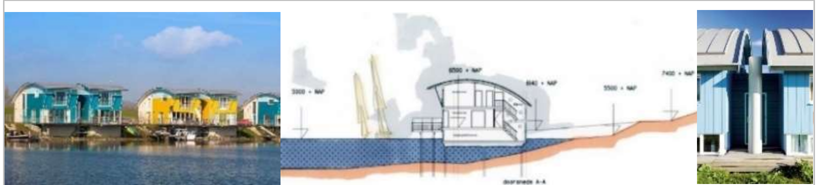
Fig. 3.3.3: Archimedes principle.

The slab(mounting platform) of an amphibious house should be designed considering the following factors: 1) normal loading in dry weather, 2) water loading, and 3) structure weight during the floating time in the wet season. The max. weight that the buoyancy force can lift is equal to the water volume displaced by the submerged portion of the house. And in order to increase buoyant force, the volume of water displaced by the submerged portion must be increased. Volume increases can be accomplished by increasing the submerged portion's length, width, and height. A larger surface area displaces more water, resulting in a greater buoyancy force (Tiwari et al, 2023).

3.4.3 State-of-the-art

The following overview will show flood-resistant amphibious housing projects. There are categorized based on the type of structure: floating pontoon or box and no vertical guidance posts(A), floating pontoon or box and vertical guidance posts(B) and vertical guidance posts with recycled jugs or tanks (C).

Type	*Project*	*Concept*	*Costs in Euros*
A. Structure with floating pontoons/box and no guidance posts	"Thailand Ban San Village" By the National Housing Authority Thailand	- steel pontoons filled with Styrofoam that create buoyancy. - solar panels on the roof - prefabricated	Approx. €50.400 Euros (390,05 €/m^2) (Raksakul, 2015).
	 Fig. 3.3.4 – 3.3.6: Thailand Ban San Village, NHA prototype and from afar. Source: (Raksakul, 2015)		

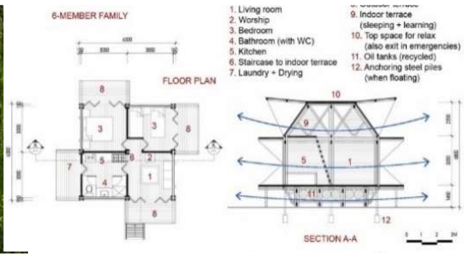
B. Structure with floating pontoons/box and guidance posts	“1st Amphibious home in the UK” By BACA Architects	- Terraces set at different levels are designed to flood incrementally and alert the occupants well before the flood water becomes threatening (hydroscapes). - utilities via elephant cabling/flexible service pipes are designed to extend up to 3m, allowing all of the services to remain clean and operational during any flood event. -lightweight timber frame house, supported by concrete piles and ground slabs, with waterproof concrete hull	€750.000 Euros (3658,54 €/m^2) (Coutts, 2018).
	 Fig. 3.3.7 - 3.3.9: Amphibious house, section and .8a guides posts and running gear, .8b impermeable ‘can-float’ hull, .8c flexible insulated connections, .8d flexible access. Source: baca.uk.com and (Barker & Coutts, 2016).		
	“Maasbommel NL” By Factor Architecten bv/ Dura Vermeer	- flexible mooring posts, concrete box and light-timber frame - concrete foundation - waterproof aggregate and extra water-repellent joint tape - flexible pipes - prefabricated	Unknown
	 Fig. 3.3.10 - 3.3.12: Maasbommel view from across the river, section and post. Source: Factor Architecten bv and Dura Vermeer.		

<table>
<tr><td></td><td>“The LIFT House India”

By Prithula Prosun and the BFP</td><td>- static “service spine” and “amphibious” units
- static structure is made out of brick and concrete
- the buoyant foundations are a hollow concrete ferrocement structure and a bamboo frame filled with empty plastic bottles.
- rainwater harvesting, toilet composting
- solar energy, natural ventilation
- prefabricated</td><td>€2592,90 Euros/ unit (Prosun, 2011)</td></tr>
<tr><td></td><td colspan="3">  
Fig. 3.3.13 - 3.3.16:The Lift House, vertical guidance posts, plans and construction of the concrete ferrocement structure. Source: Prithula Prosun and buoyantfoundation.org</td></tr>
<tr><td>Type</td><td>Project</td><td>Concept</td><td>Costs in Euros</td></tr>
<tr><td>C.
Vertical guidance posts and tanks/jugs</td><td>“Amphibious Retrofitting in An Giang VN”

By Buoyant Foundation Project</td><td>- vertical guidance posts and recycled jugs for buoyancy
-retrofitting the houses on stilts to cope with more extreme future weather circumstances.
- These retrofits are effective, pre-emptive solutions to the dangers posed by annual flooding events to impoverished and flood prone communities in the region. They also serve as proof-of-concept, as experiments and sources of data, which might provide the basis for the improvement of this foundation system and for the propagation of this strategy throughout Southeast Asia.</td><td>Unknown</td></tr>
</table>

	 Fig. 3.3.17 - 3.3.20: During the 2018 seasonal monsoon flooding, Nao's house in An Giang Province before retrofitting, after and exploded view of the structure. Source: amphibiousbuoyantfoundation.org		
	"Amphibious Retrofitting in Long An VN" By Buoyant Foundation Project	- vertical guidance posts and recycled jugs for buoyancy	Unknown
	 Fig. 3.3.21 - 3.3.24: Nang's House located in Long An Province, prior to retrofit, after, during 2018 monsoon flooding and exploded view of the structure. Source: amphibiousbuoyantfoundation.org		
	"Blooming Bamboo House VN" By H&P Architects	-anchoring steel piles and recycled oil tanks - Situated in the Middle of Vietnam -A solution to a typical building that meets basic residential needs and can be replicated in the near future is the objective of the project. -Simple assembly (bolting, ting, hanging, supporting…), - bamboo module units (9 cm – 10 cm [3.5 in – 4 in], length of 3.3m & 6.6m [10.8ft – 21.6ft]). - The structure (with anchoring, tying, solid connection) will be strong enough to float in floods. -The structure's space will be for flexible uses (residential, educational, healthcare, community) and will allow for extension (add-on space) as needs arise. -Using local materials	€1385,57 – 1847,43 Euros/Unit

		(bamboo, leaves...) and recycled materials (oil tanks, plastic containers...) combined with locally traditional architectural characteristics. - ability for mass production (in modules), and ability for the villagers to make their building themselves. -educative use: The engineering solutions will serve as useful educational examples for geo-hydrology, physics (light diffusion, light), aerodynamics (ventilation), biology (photosynthetic, planting), agriculture	
	  Fig. 3.3.25 – 3.3.27: Blooming Bamboo House, plan and section, and exploded view of the construction. Source: H&P Architects.		

3.4.4 Structural Elements and their materials

3.4.4.1 Floating Platform or Buoyancy blocks

To enable the house of floating different floating materials can be used: bamboo platforms, Styrofoam platforms and plastic barrel platforms (Adi et al., 2020). Pre-cast pontoon & EPS blocks can be used as buoyancy blocks, but an EPS block will be more beneficial (Mohamad et al, 2012). The buoyant force acting on the structure is applied by means of buoyancy blocks. The density of the blocks or platform should be lower than the water's density. The floating platform comprises a structural subframe that is attached to the underside of the house and supports buoyancy blocks, which enables flotation.

3.4.4.2 Grid for buoyancy blocks

The purpose of the grid is to hold all the blocks in place while providing a level surface for the base of the house. Grids are made of lightweight materials such as steel, wood, etc.

3.4.4.3 Foundation

A foundation is needed to transfer the load of the superstructure to the ground and to support the mooring poles. This foundation is similar to the concrete footings usually provided.

3.4.4.4 Vertical Guidance Posts

The subframe also includes extensions that connect the vertical guidance poles near the house's corners. These poles can be telescoped out of the ground to resist lateral forces arising from wind and water flow. The mooring poles are usually large poles made of iron, keeping the house stable in one place and only permits vertical motions when the buoyancy fore acts on the surface of the buoyancy blocks (Sharma & Srivastava, 2022).

3.4.4.5 Roof, walls and inner partitions

In an amphibious house, floating concrete should be used instead of heavy concrete to reduce the structure's weight. For the walls and the roof, besides wood EPS is recommended as this is a low-cost, lightweight, fire-resistant, heat- and sound insulating, water- and moisture-repellent panel. This is a sandwich panel with calcium silicate board, expanded [polystyrene, cement and sand.

3.4.4.6 Self-sealing breakaway connection

The sewer and gas lines are connected to the house via a self-sealing breakaway connection, which has the advantage that in the event of a flood, the house will not be obstructed by the sewer and gas lines. A self-sealing link is a kind of valve that works automatically when the pipe is stretched.

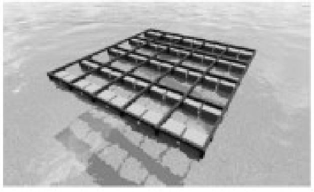
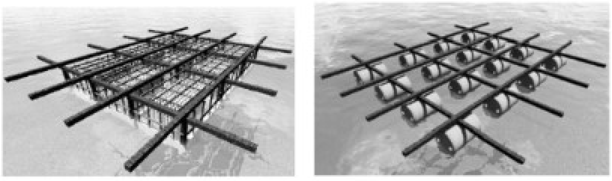
3.4.4.7 Materials

Nguyen (2021) has examined potentials of floating architecture development in Vietnam by analyzing different materials for feasible and affordable pontoons which can be used as the floating platform/buoyancy blocks (see fig. 3.4).

He concluded that metal pontoon has advantages such as strong and affordable and wide recyclable possibility. As steel can be used for the reinforced bars to tight the different parts of the structure together. And aluminum is a possibility for covering the outside part of the blocks in case the inner material does not stand effects of water. However it is not sustainable to produce and could affect the natural environment and the human's health negatively.

Concrete pontoons however would be a feasible and affordable option. It is resistant to corrosion due to salty water, low cost of maintenance, high durability when compared to other materials, lower costs in comparison to steel, low center of gravity which helps stability and good insulation. Negatives: a heavy weight and the water tightness is an important characteristic of concrete to avoid or limit corrosion of the reinforcement. It is necessary to still research more and improve the qualities of the use of concrete.

Figure 3.4: The possibilities of feasible and affordable pontoons

 Plastic Pontoons	 Plastic beverage bottles/ sealed metal or plastic oil drums
 Concrete Caisson	 Steel Pontoon
 Concrete EPS (core EPS and Concrete shell)	 Aluminum Pontoon

3.4.5 Conclusion

Amphibious Housing is becoming a more popular flood-proofing method for the building industry. The concept is based on the Archimedes' principle and when designing different amphibious housing variations of structures and materials is possible.

Often concrete boxes are used to provide buoyance as they are easy to build and are durable as material. To protect the concrete from water, aggregates can be used. Building materials for the frame can differ from bamboo to wood.

Water is mostly supplied by flexible pipes and electricity is generated through solar panels. The LIFT house is an example of an affordable and self-sustaining amphibious house made of renewable construction materials. When expanding the units, designs of the Maas Bommel, Ban San Village show and Blooming Bamboo House more possibility.

For the Cham's stilt housing typology an affordable and suitable flood-resistant amphibious method could be Integrating vertical guidance posts and buoyance under the house, which is also being used by retrofitting the homes in the An Giang project and LIFT House in India, would be the best method. Because it has a smaller intervention in the structure compared to other methods as adding a concrete box under the home. Also this method ensures the home to be adaptable to the flood levels while staying fixed to one place. The materials used for this are made by low-cost materials like wood and steel and the production is manual labor, thus cheap.

Metal pontoon has advantages such as strong and affordable and wide recyclable possibility. However, metal is not sustainable to produce and effects on the environment and human's health. Steel can be used for the reinforced bars to tight the different parts of the structure together. At the same time, aluminum is a possibility for covering the outside part of the blocks in case the inner material does not stand effects of water.

In an aspect of cost and stability, concrete pontoons would be feasible and affordable for floating houses in Vietnam. However, it is necessary to improve and optimize. Positives: resistant to corrosion due to salty water, low cost of maintenance, high durability when compared to other materials, lower costs in comparison to steel, low center of gravity which helps stability and good insulation. Negatives: heavier when compared to other materials and the water tightness is an important characteristic of concrete to avoid or limit corrosion of the reinforcement.

3.5 Summary

1 How does the current stilts typology deal with high temperatures and floods?

To keep housing cool during hot days, the stilts typology has a natural ventilation system: 1) by opening the large window and door to deliver fresh air into the housing by cross-ventilation 2) using light-colored roofs to reflect heat 3) creating a high pitched roof to reduce heat transfer to space below 4) extra airy space on the ground floor created by the stilts helps creating airflow.

To deal with floods: all spatial functions were effectively designed on the first floor, and the floor level was always higher than the peak annual flood.

Noticeable is the usage of local materials in their buildings to reduce construction costs and energy consumption; no need of heavy equipment or technologies, including environmental sustainability, cost-effectiveness, reducing their carbon footprint, supporting local economies, and creating a strong connection to the surrounding environment.

2 What low-cost passive cooling strategies work best for tropical climates?

Based on the case study findings, potential passive cooling techniques for tropical climates would be: (1) improving thermal insulation in the wall, roof or ceiling, (2) increasing natural ventilation by vertical operable vents or a solar chimney which airflow increase during different periods of the year, (3) reducing solar heat gain by solar shading through (operable) louvres in the window or wall, (4) maintaining a low indoor temperature by night ventilation/nocturnal structural cooling through high thermal mass structures, (5) a small courtyard, and (6) microclimate modification and/or urban heat island (UHI) mitigation by cross-ventilation or (7) applying a wetted roof during high temperature of ambient air.

For the stilts typology techniques 1, 2, 3 and 4 would have the most impact on reducing the cooling demand and require less of an intervention in the home structure.

3 How could the flood-resistance of the Stilt housing be improved without high construction or material costs?

Integrating vertical guidance posts and buoyance under the house, which is also being used by retrofitting the homes in the An Giang project and LIFT House in India, would be the best method. Because it has a smaller intervention in the structure compared to other methods as adding a concrete box under the home. Also this method ensures the home to be adaptable to the flood levels while staying fixed to one place. The materials used for this are made by low-cost materials like wood and steel and the production is manual labor, thus cheap.

4 Context Assessment

4.1 Introduction

This chapter explains the more specified context: the site, design basis and climate analysis for the Design Proposals. The site is located in the An Giang province. The stilts houses in this province are one of the most popular typologies. The design base is one existing stilts house made by the Cham ethnic group, of which construction drawings and images are available and being used as base for the test model. For the climate analysis weather data tools from Ladybug is used in scripts in Grasshopper and data from the most nearby city Rach Gia obtained.

4.2 Location

The stilts houses are located in rows in this Cham's Village, see fig. 4.2. This village is located in the An Giang Province, in the North of The Mekong Delta. An Giang is most known for their rice production and aquaculture (Halsema & Seijger, 2023). The nearby Hau River streams parallel with the Tien River from North Asia through An Giang down the East Sea, see fig. 4.1.

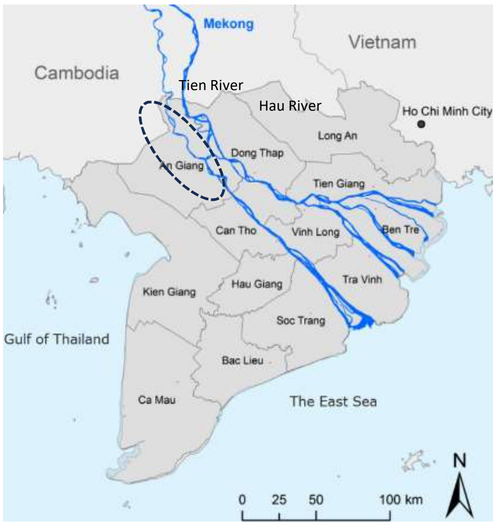


Fig. 4.1: Map of the Mekong Delta. Source: Yen Thuy Duong, modified by author.

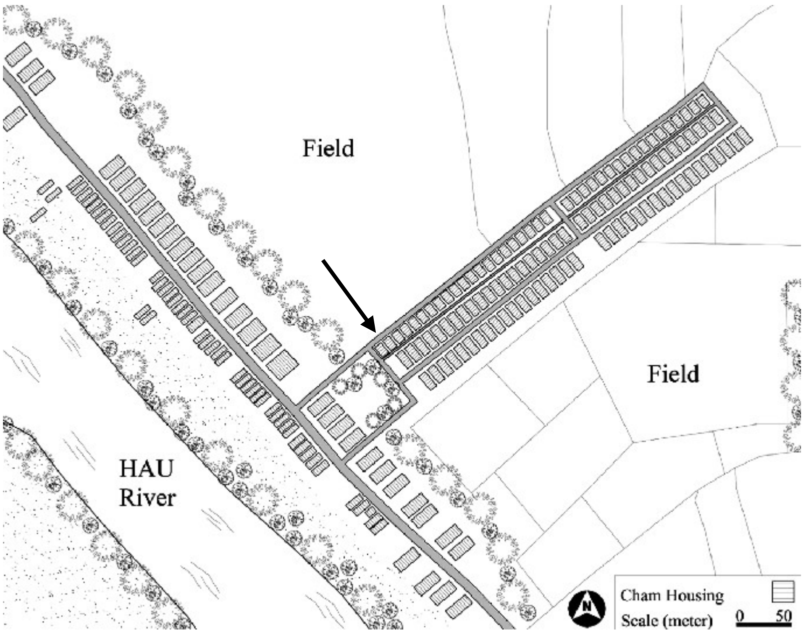


Fig. 4.2: Map of the Cham's Village in An Giang Province. Source: Phuong Pham, modified by author.

4.3 Site and Plans

Fig. 4.3: View to backyard

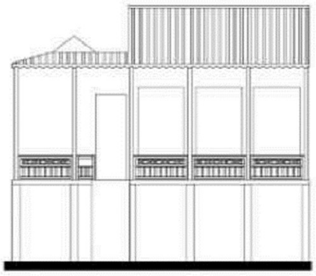


Fig. 4.4: Front View Plan

Fig. 4.5: View from the road.
Source: Pham, 2021

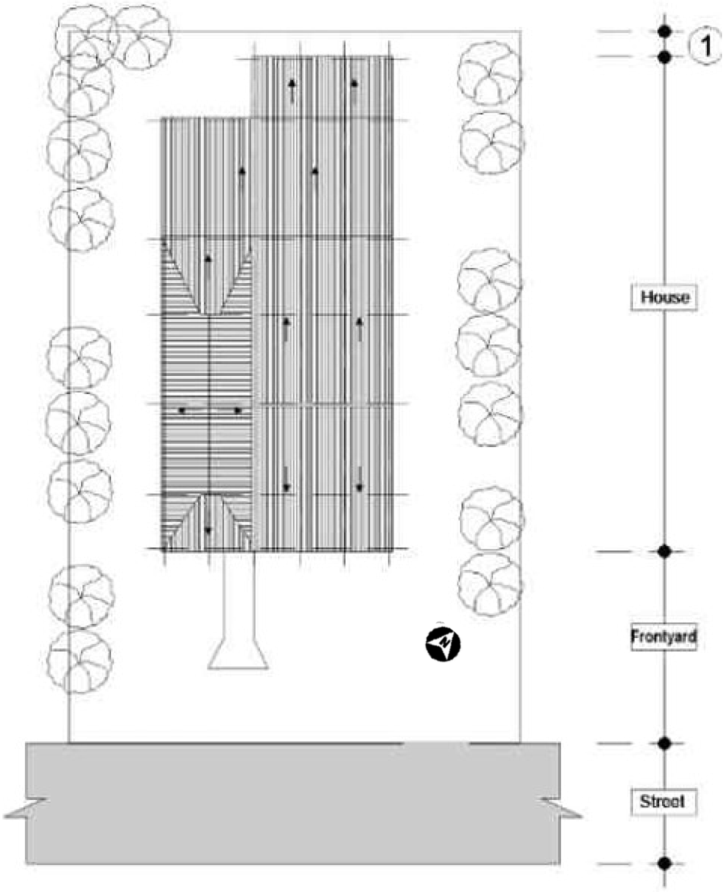


Fig. 4.6: Roof Plan Cham house. Source: Pham, 2021

The stilts house built in the 1990s is accessible from the road with a bridge, which also can be used as an escape route when there is a flood. The house is surrounded by trees which create shade and the roof and veranda offer the residents much protection from (excessive) sunlight. Other stilts housing look similar but might have different colors or wider or smaller shapes, see figures below.

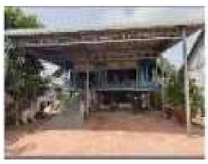
   

Fig. 4.7-4.10: Different Cham housing in An Giang. Source: Pham(2022)

Inside the Cham House there are different spaces; for cooking, family and social activities. The more private activities are located deeper. Below the first floor, if there is no flood, this space will be used as storage.

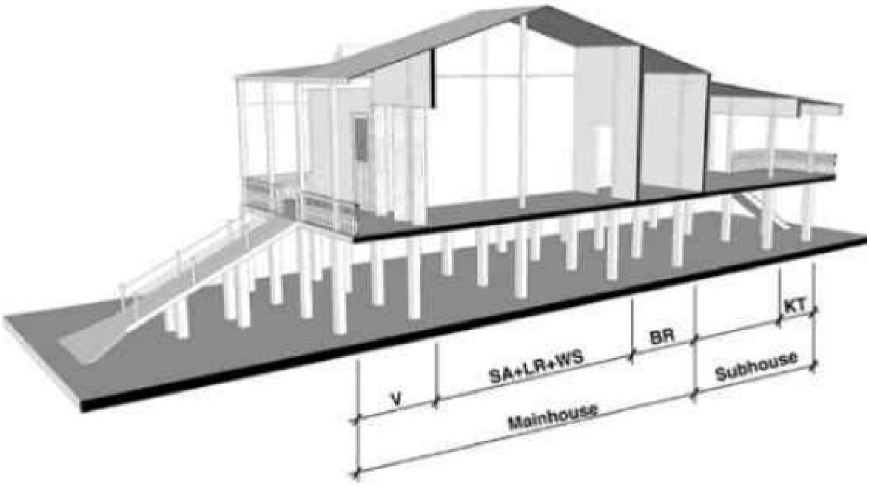


Fig. 4.11: Section Cham House

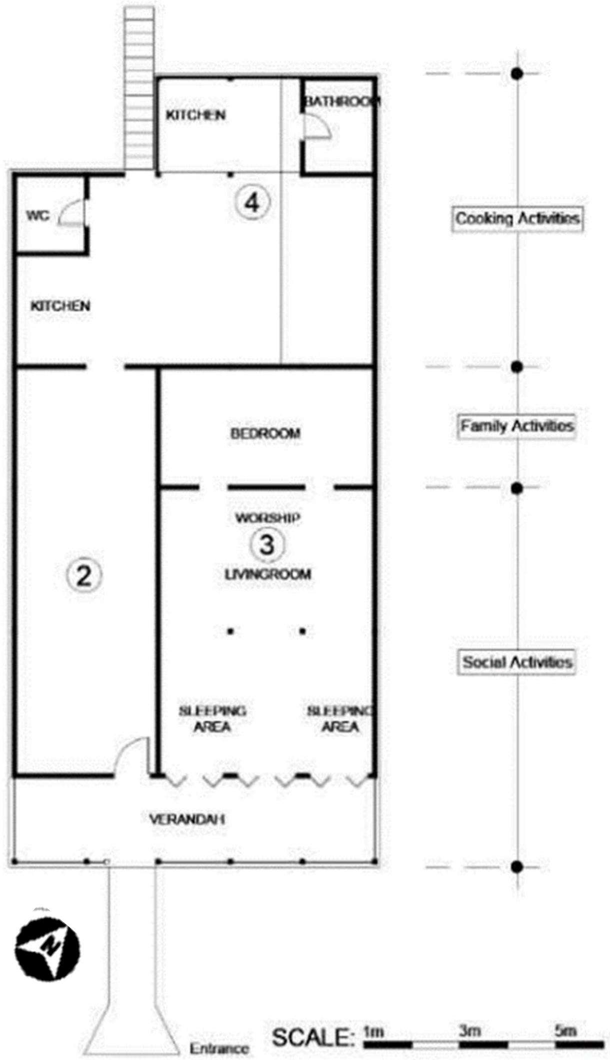


Fig. 4.12: Cham Plan first floor. Source: Pham, 2018

Fig. 4.13: View to kitchen(4)

Fig. 4.14: View to multi-space area (2)

Fig. 4.15: View to worship area(3).

4.4 Weather Analysis

For the Weather Analysis, the weather data(EnergyPlus) from Rach Gia is being used. This is located most near to An Giang. Data from An Giang itself was not available.

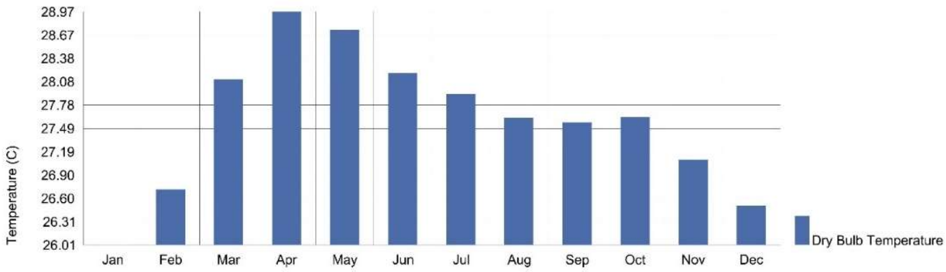


Fig. 4.16: Average Dry Bulb Temperature in Rach Gia. Source: SRC-TMYx

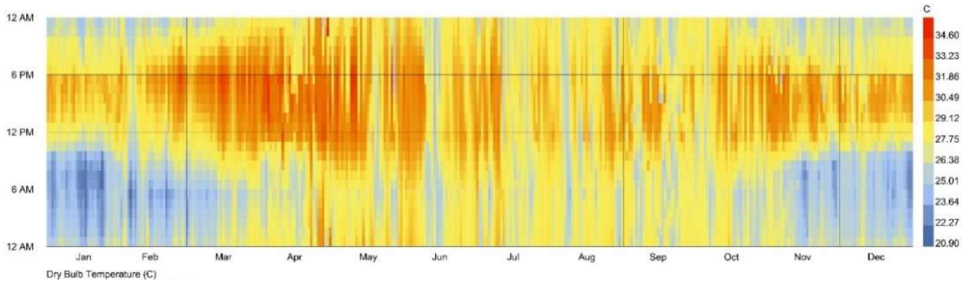


Fig. 4.17: The Annual Daily Dry Bulb Temperature in Rach Gia. Source: SRC-TMYx.

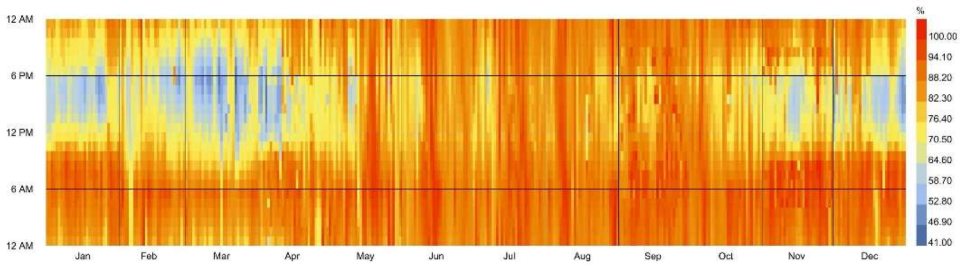


Fig. 4.18: The Annual Daily Relative Humidity in Rach Gia. Source: SRC-TMYx

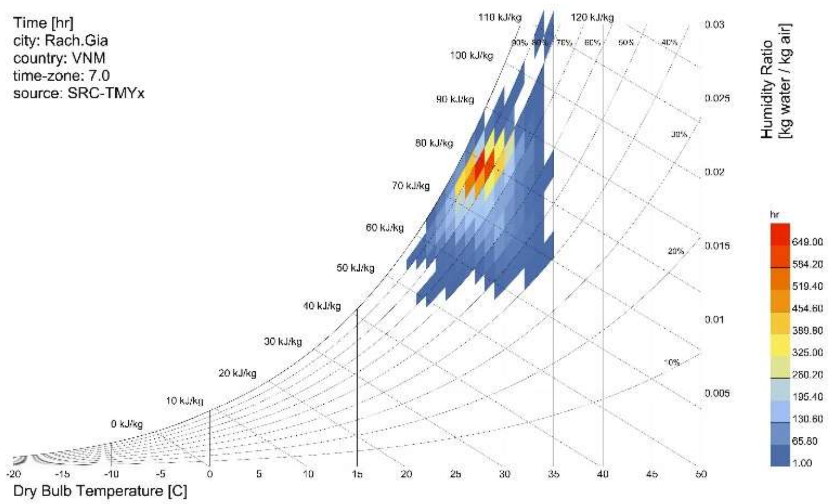
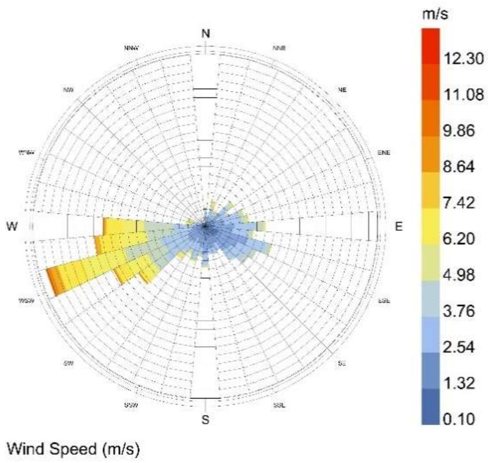


Fig. 4.19: Psychrometric graph Dry Bulb Temperature and Relative Humidity. Source: SRC-TMYx

The average dry bulb temperature is around 27.7 Celsius Degrees, peaking to almost 29 Celsius Degrees in April and May. And the lowest in January and December, with maximum temperatures of 26.5 Celsius Degrees. From 3pm until 12pm are the DBT's the highest during the day. The average Relative Humidity is around 77% throughout the year, peaking in the months of May until November to even 85%. In the late evenings and early mornings are the Relative Humidity levels the highest.



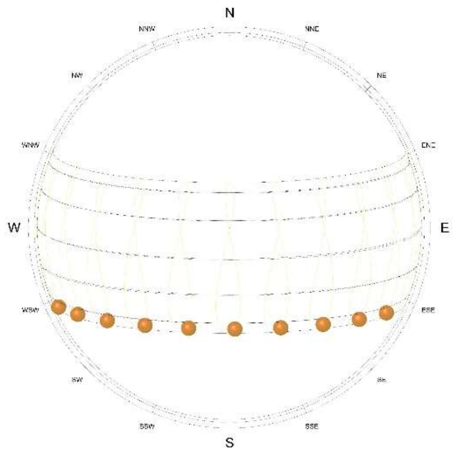
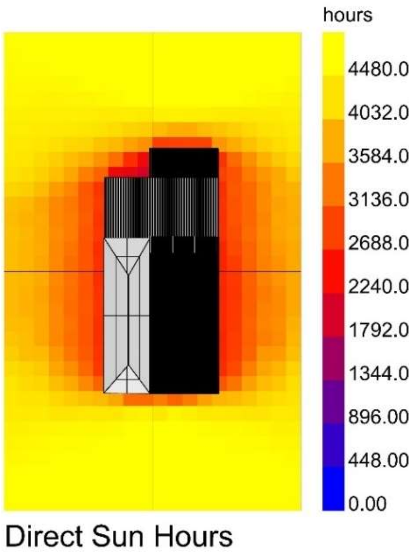


Fig. 4.20: (Left) The Annual Wind Speed and Direction in Rach Gia. Source: SRC-TMYx.
Fig. 4.21: The Sunpath of Rach Gia, on the 1st of January between 8AM-8PM. Source: SRC-TMYx.

The strongest winds come from the South West with an wind speed of approximately 8 m/s and the Sunlight comes both from the South and North but mostly South.



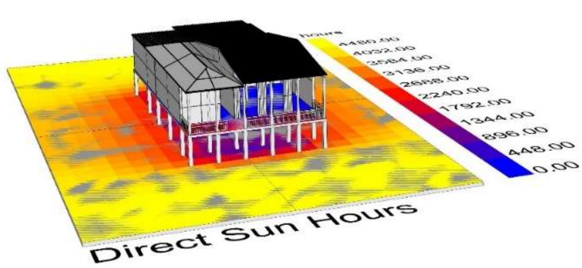


Fig. 4.23 & 4.24: The Annual Direct Sun Hours analysis on the Stilts House; Top view and front view. Source: SRC-TMYx.

The Direct Sun Hours Analysis show that the elevated home prevents solar gain in the basement. This is also created due to the presence of a veranda. This analysis is without shading or trees so in real life the direct sun hours will be reduced by them.

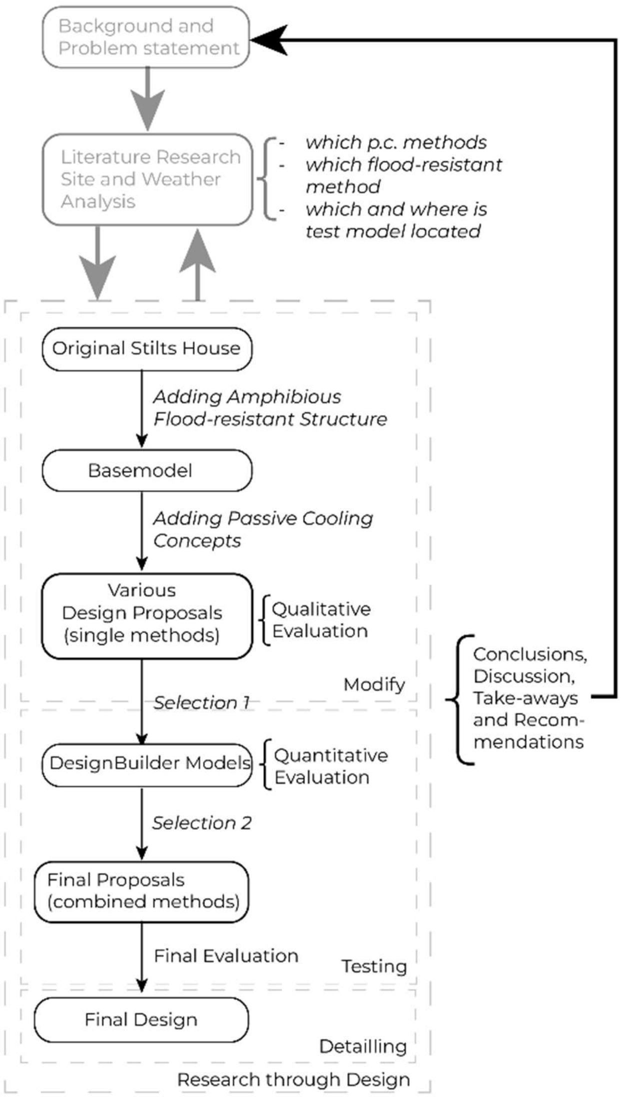
5 Research Through Design

5.1 Introduction

In this chapter, design proposals will be presented to improve the current stilts typology in terms of reducing the energy demand for cooling through passive cooling and strengthening the ability to cope with more frequent and extreme floods. This chapter addresses, tests and evaluates the findings of the literature review. The goal is to answer the research question and discover new findings.

5.2 Methodology

The figure below (5.1) presents an overview of the steps from modifying the test model to testing and detailing a final proposal.



The proposals are based on the outcomes of the literature review: which passive cooling methods should be used, which flood-resistant method increases the flood-resistance and which house and what area can be used as a test case.

The outcomes of the sub questions modify the test model, which forms the base model for the primary design proposals.

The design proposals are variations of the base model, varying from one or more passive cooling strategies.

A qualitative evaluation leads a selection of these proposals to a quantitative evaluation in DesignBuilder.

Fig. 5.1: Methodology Design Research, made by author.

The results of the DesignBuilder simulations show which passive cooling strategies give the best results in terms of the operative temperature, how significant they are, during dry and flood-scenario and possible variations. As well as comparisons between old and new situations. After this quantitative evaluation concepts will be combined or varied which best results lead the design research to a final proposal.

This final proposal will be further detailed and rendered. The final design should form the answer to the research question and other conclusions will be evaluated and discussed. As well as reflecting the method and process, with further recommendations and important take-aways.

5.3 Design Criteria

To state the Design Criteria the following Design Question needs to be answered:

How can we design low-tech flood-resistant amphibious housing with a passive cooling system and which is accessible to low-income people and can effectively be implemented across the tropical climate region?

The Design proposals should:

1. Improve the flood-resistance of the house
2. Add and keep the climate-adaptive qualities of the typology to lower the energy demand for cooling
3. Use affordable and low-tech strategies and methods

5.4 Base Model

For the design proposals there is one fixed case which is the base model. Before suggesting design proposals, the flood-resistance of the model should be improved by adding the amphibious substructure. As this will bring changes to the current structure of the house.

The literature review showed that adding vertical guiding posts to the existing structure is a suitable method for improving stilts houses. Similarly to the BFP retrofit projects. See fig. 5.3.

The house is provided buoyancy through floatation systems anchored to its substructure and is restrained to only vertical movement by using vertical guidance posts, which directs its rise and fall with water during flooding.

To determine how many recycled barrels are needed and what the dimensions need to be, buoyancy and weight calculations have to be made.

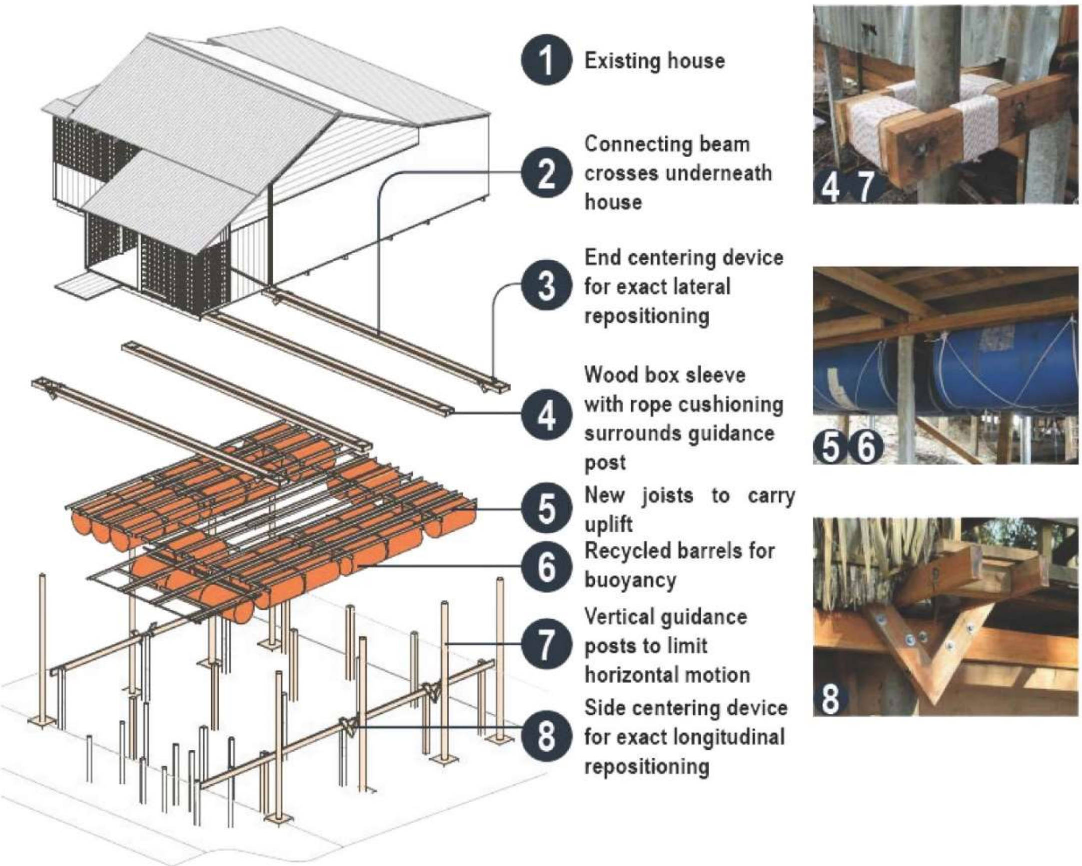


Fig. 5.2: Retrofit method by the BFP applied in the Long An province. Source: Buoyantfoundation.org.

Adding the flood-resistant amphibious structure:

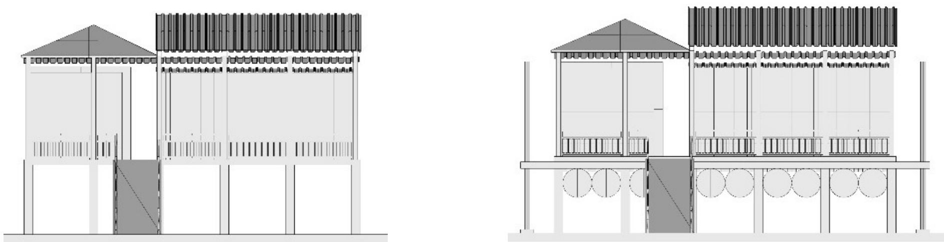


Fig. 5.3: Front View before and after retrofitting, made by author based on drawings Phuong (2018).

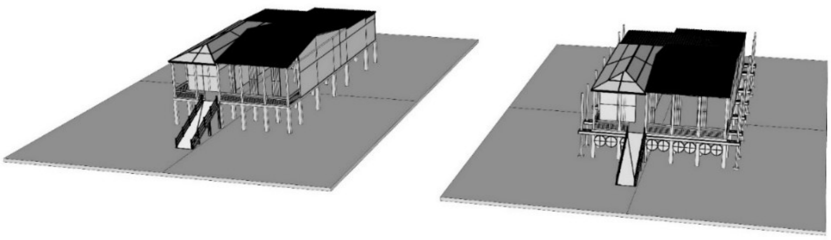


Fig. 5.4: Front Birds View before and after retrofitting, made by author based on drawings Phuong (2018).

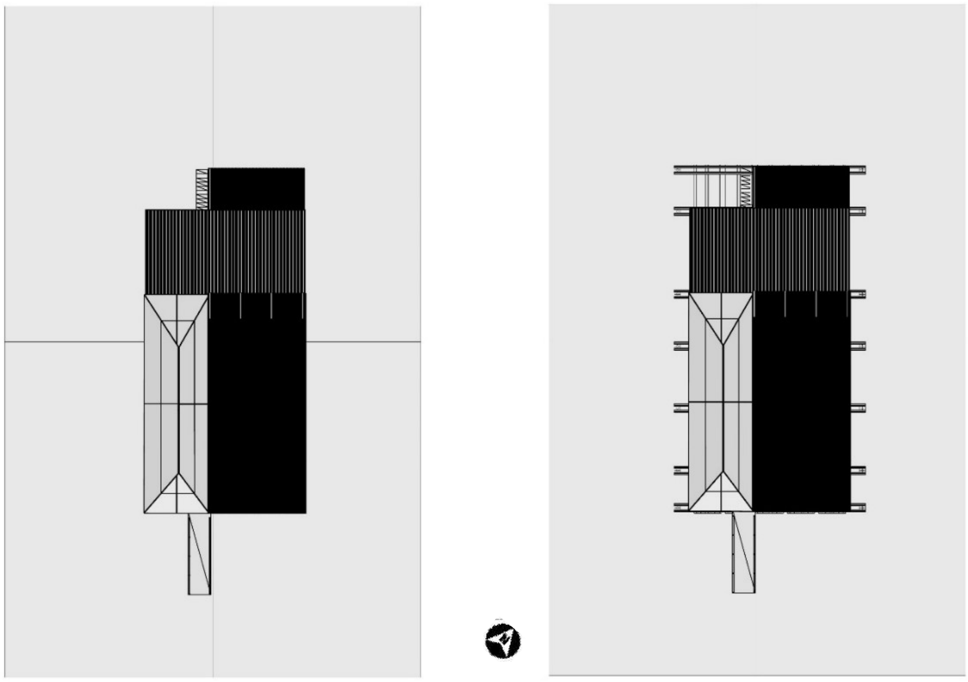


Fig. 5.5: Top View before and after retrofitting, made by author based on drawings Phuong (2018).

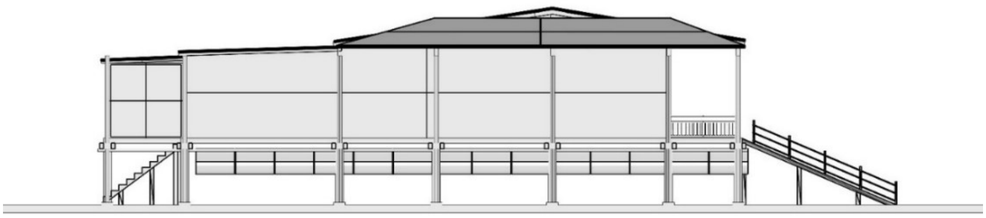


Fig. 5.6: West view after retrofitting, made by author based on drawings Phuong (2018).

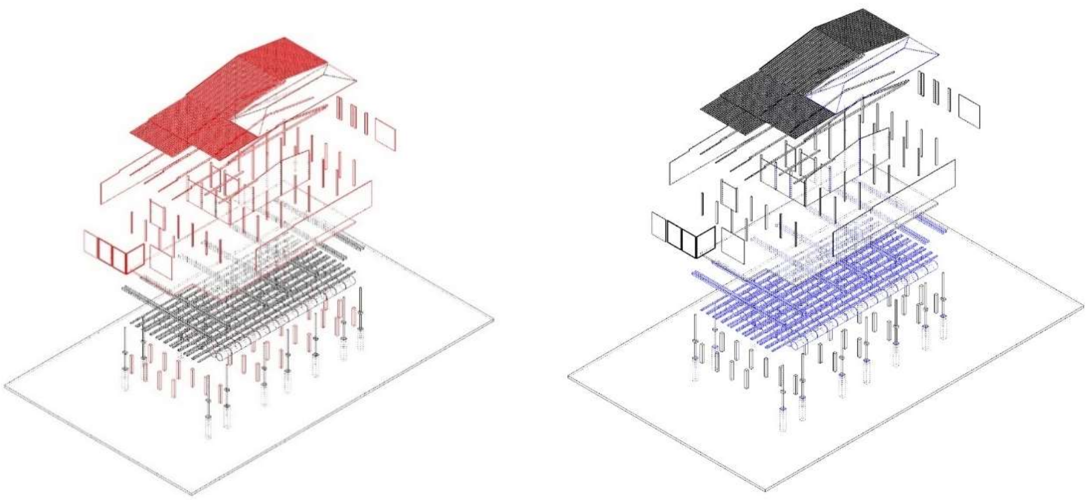


Fig. 5.7: (left) in red: current structure and (right) in blue: added substructure, made by author.

	Element	*Material*	*Density (kg/m3)*	*Volume (m3)*	*Weight (kg)*
Original stilts House	Stumps	Concrete	2400	3.456	8294.4
	Sill	Timber	700	0.007395	51.765
	Posts	Timber	700	0.95	665
	Rafters and beams	Timber	700	0.873	611.1
	Floor	Timber	700	3.72	2604
	External walls	Galvanized steel	7850	1.32	10336
	Internal walls	Plywood	600	1.05	630
	Roof	Galvanized steel	7850	1	7850
	Total				**31042.3**
Amphibious Structure	Recycled Plastic Pontoons	EPS	4.89	49.8	243.5
	Grid	Aluminum Strips	2700	0.11	283.5
	Extra Beams	Timber	700	4.4	3080
					3607
	Vertical guidance posts	Steel	7850	0.65	5102.5
	Mooring poles	Concrete	2400	2.52	6048
	34649.3				

Fig. 5.8: Materials and weights overview Base Model, made by author.

The maximum weight that buoyancy can lift equals the volume of water displaced by the submerged part of the house. For instance, a house weighing about 220 tons displaces around 225 m^3 of water when buoyant. Additionally, according to the Pontoon Principle, the house's mass or volume must be less than the density of water.

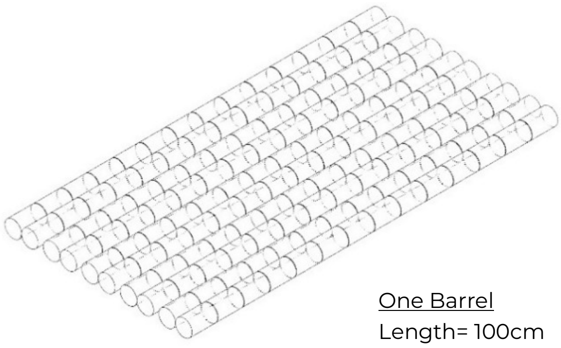


Fig. 5.9: Buoyancy Base Model, made by author.

Dead weight = around 35 ton, so around 35 m3 of water is displaced.
Pontoon volume = 49.8 m3 > dead weight
The Live Load of the house will consist of the occupancy of people, furniture, wind, etc. It is estimated that this total number will not exceed 14.8 ton.
The additional vertical guidance posts should support the house against the forces of the wind and potential waves.

5.4 Design Proposals

To enhance the passive cooling ability of the house, several passive cooling strategies, based on the literature review and best suited to the tropical climate will be applied to the improved flood-resistant amphibious base model.

1. improving thermal insulation in the wall, roof or ceiling
2. increasing natural ventilation by vertical operable vents or a solar chimney which airflow increase during different periods of the year(tropic roof/double-skin-facade).
3. reducing solar heat gain by solar shading through (operable) louvres in the window or wall(overhangs).
4. maintaining a low indoor temperature by night ventilation/nocturnal structural cooling through high thermal mass structures

The current housing typology of the Cham ethnic group show that the airy space under the house and between the stilts and overhangs are significant to reduce heat gain and keep natural ventilation and cooling as much as possible, see fig. 5.10 below. The structure itself is lightweight thus, thermal mass won't be the first option to choose. The chosen test model has not many windows as the current openings are mostly located between the connection of wall and roof, possibly minimizing heat gain by the sun (see fig. 5.3-5.7).

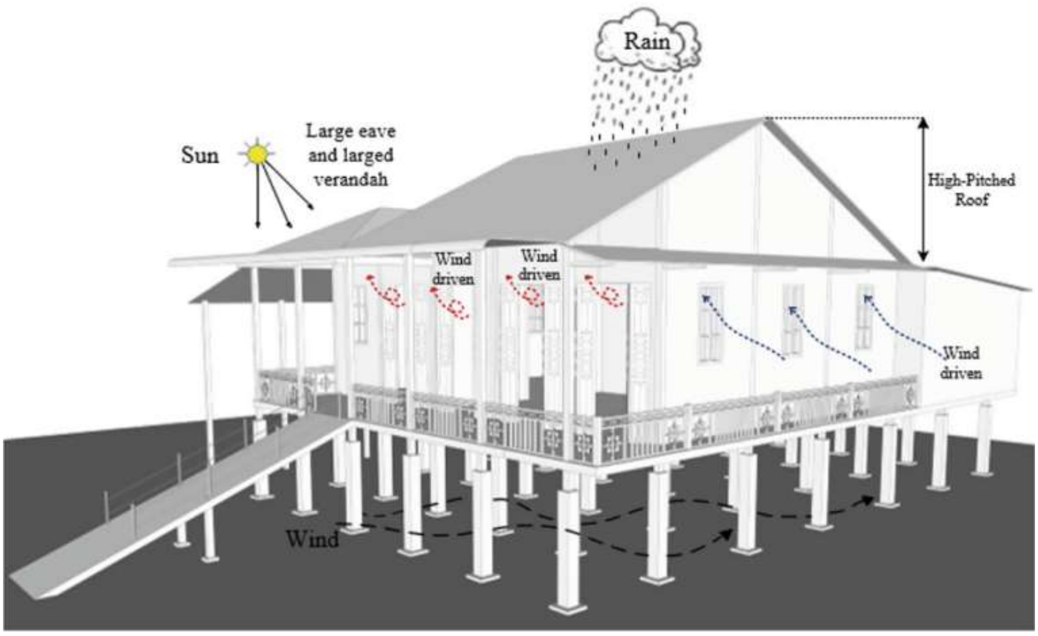
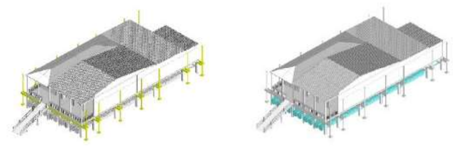


Fig. 5.10: Sustainable Architecture Characteristics of a Cham Stilts Typology (Pham et al., 2024)

The goal is to integrate them as much into the new building structure and avoid heavy interventions that only give small improvements. Thus a qualitative evaluation will select the best options to simulate further and bring new insights. On the next page are the proposals presented in an overview.

Passive Cooling Methods	Concept	*Concept Variations*				
A. Wind/ Natural Ventilation	Through air flow through buoyancy layer	Barrel configuration 1	Barrel configuration 2	Barrel configuration 3	LWC Buoyancy	Floor Vents
B. Shading	Through louvres	Louvres	Overhang			
C. Thermal Insulation	Adding insulation to walls and roof	5 cm Glass wool				
D. Combined	As an extra ventilative and sunprotective skin	Double-skin facade	Tropic Roof			

Integration of these elements from the Amphibious structures:

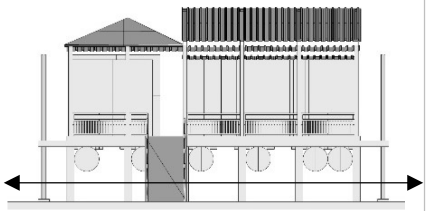
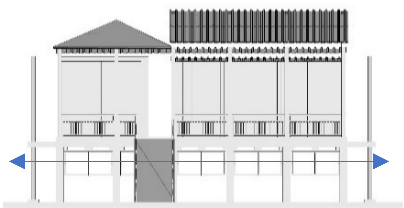
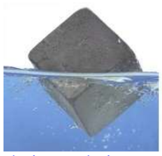


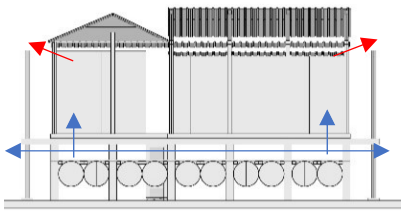
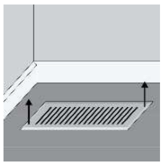
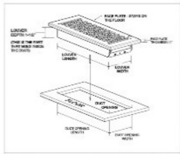
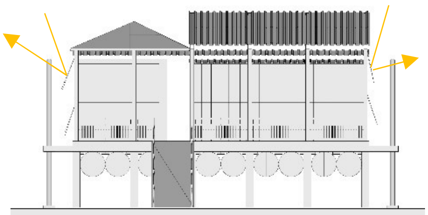
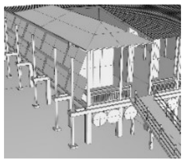
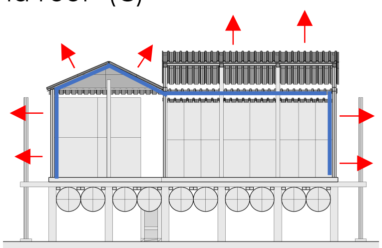
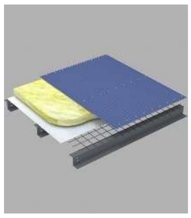
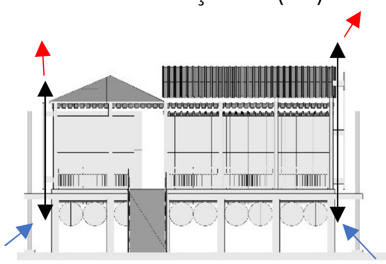
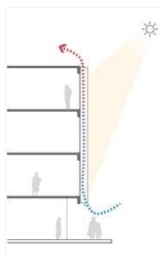
Vertical Guidance Posts	Buoyancy Elements

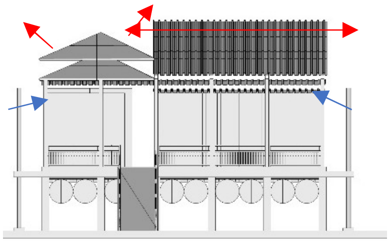
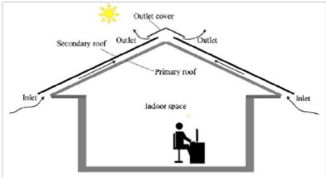
Fig. 5.11: Overview Design proposals: Integration variations of passive cooling methods to the flood-resistant amphibious structure. Based on the Cham's Stilts Typology, made by author.

To explain the design proposals more further:

Base Model

	Design Proposal	Description
A. Wind/natural Ventilation	"Barrel Configuration 1" (A1) 	This proposal is a variant with a different barrel configuration. Where the main goal is to create airflow under the house while it is floating on water(when the barrels touch the water surface).
	"Barrel Configuration 2" (A2) 	This proposal is also variant with a different barrel configuration. The whole floating structure is more lower leveled. Where the main goal is to create airflow under the house while it is floating on water(when the barrels touch the water surface).
	"Barrel Configuration 3" (A3) 	This proposal is a also variant with a different barrel configuration. Where the main goal is to create airflow under the house while it is floating on water (when the barrels touch the water surface).
	"LWC Buoyancy" (A4) 	This proposal allows airflow to continue under the house with light-weight concrete as material. This has also been experimented with larger floating villages.   Source: Lightweight Concrete (LWC) - Types & uses (2017)

	“Floor Vents” (A5) 	This proposal allows air under the floor to exchange with inside air. To enable/enhance the effect the buoyancy is placed lower.   Source: registerandhardware.com (n.d.)
B. Shading	“Louvres” (B1) 	 This proposal involves adding exterior louvres to the façade. This element can be attached to the vertical guidance posts. These can extra support the louvres. Enabling the user with the possibility of adjusting the shade to their own liking.
	“Overhang” (B2) 	This proposal involves extending the current roof edges and creating a greater overhang. Protecting the home against heat gain from the sun entering the home.
C. Thermal Insulation	“5 cm Glass Wool in walls and roof” (C) 	 This proposal involves adding 5cm glass wool in the exterior walls and roofs. Absorbing radiant heat and preventing heat transfer. As well as noise(rain). Source: cattuongcorp.com
D. Combined	“Double-skin Façade” (D1) 	 This proposal involves adding an extra skin to the existing structure. The structure can be supported by the vertical guidance posts and aims to reduce the heat gain during the day. Source: archdaily.com

<table>
<tr><td></td><td>“Tropic Roof” (D2)
</td><td>The proposal involves adding a secondary roof to the existing structure. It aims to decrease heat gain from the roof, through a ventilative layer above the current roof.


Source: (Zhang et al., 2016)</td></tr>
</table>

Fig. 5.12: Design Proposals (passive cooling strategies), made by author.

5.5 Qualitative Evaluation

In this evaluation the design proposals are evaluated based on an estimation of different factors; buoyancy ability, size of intervention, compatibility with user etc.

Proposal	Evaluation
A1	Buoyancy layer might lack support due to less barrels and reduced density.
A2	Buoyancy layer is complete however, the structure might need more support because the house doesn’t directly float on the buoyancy. It needs to be tested if the indoor temperature is reduced by the lowered buoyancy.
A3	Buoyancy layer is less dense and might affect the buoyancy force that carries the house. Air flow is not guaranteed.
A4	The design needs to be tested and water might flow inside the structure.
A5	This should be tested. In some Vietnamese typologies floors have a hole to enable fishery businesses.
B1	The louvres could prevent heat gain. However openings are located high. An overhang or double-skin could give a similar effect as well.
B2	Extending the roof edges with an overhang could be a simple but significant improvement
C	Adding an insulative layer is a relatively simple and could give significant results.
D1	The double-skin façade will act as an insulating layer and expectedly reduce heat gain. The implantation can be made with several materials. Needs to be tested.
D2	The tropic roof can solve the heat gain inside the house. The implementation can also be made from different materials. Needs to be tested

Fig. 5.13: Qualitative Evaluation Design Proposals

For the next evaluation the following proposals will be simulated and the Operative Indoor Temperature will be measured:

1. (A2) Creating an airgap between the buoyancy and the first floor
2. (A5) Allowing air exchange between inside and outside through floor vents

3. (B2) Extending the roof edges with an overhang of 40cm
4. (C) Adding 5cm glass wool insulation in the wall and roof
5. (D1) Transforming the roof into a Tropic Roof
6. (D2) Transforming the façade into a Double-skin Façade

Proposal A1 and A3 seem unfeasible due to lack of buoyancy. Proposal B1 can be seen as a similar strategy to the Double-skin façade as it creates an extra outer layer/shade to the existing façade. And proposal A4 will be too detailed to simulate in DesignBuilder. The primary goal is to test if the ventilative space under the house actually gives positive effects to the Base model. As well as how significant each proposal can be for reducing the operative temperature.

5.6 Quantitative Evaluation 1: DesignBuilder

In this evaluation the selected proposals will be further tested through simplified DesignBuilder models and software.

The weather data of Rach Gia will be used, which is located close by the original village of original location. The simulation period is one of the week with the highest peak temperatures during the year.

The simulations are based of five groups with each one passive cooling strategy, except for the first group which is general information about the differences of the operative temperature during flood and dry context of the original and base model:

<u>Group I: The Original Stilts House and Base Model during flood and dry scenario</u>

Does the Operative Temperature increase/decrease after transforming the original stilts house into an amphibious flood-resistant house and or does it change during a flood? How significant is this?

Includes simulations of:

a. Original Stilts House
b. Flooded Original Stilts House
c. Base Model
d. Flooded Base Model

<u>Group II: Base Model and Passive Cooling by Natural Ventilation/Wind, during flood and dry scenario</u>

Does lowering the buoyancy of the Base Model or integrating floor vents decrease the Operative Temperature? And what if It is combined? how significant is this?

Includes simulations of:

a. Base Model
b. Base Model with Floor Vents
c. Flooded Base Model with Floor Vents
d. Base Model with Lowered Buoyancy
e. Flooded Base Model with Lowered Buoyancy
f. Base Model with Lowered Buoyancy and Floor Vents
g. Flooded Base Model with Lowered Buoyancy and Floor Vents

<u>Group III: Base Model and Passive Cooling by Shading</u>

Does extending the overhang with 40cm decrease the Operative Temperature? If so, how significant is this?

Includes simulations of:
a. Base Model
b. Base Model with extended overhang with 40 cm

<u>Group IV: Base Model and Passive Cooling by Thermal Insulation</u>

Does applying insulation of 5 cm Glass Wool to the walls and roof decrease the Operative Temperature and how significant is this?

Includes simulations of:
a. Base Model
b. Base Model with insulated walls and roof of 5cm Glass Wool

<u>Group V: Base Model and Passive Cooling by Multifaceted Interventions</u>

Can a Tropic Roof or Double-skin façade decrease the Operative Temperature? If so, how significant is this?

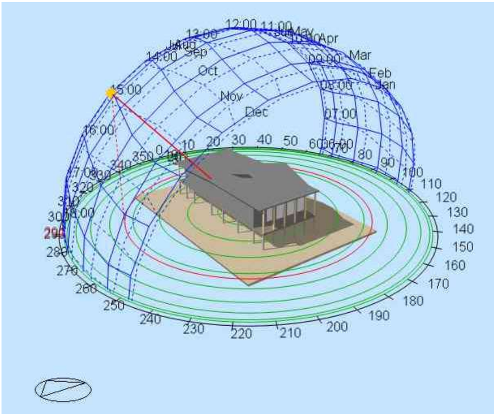
Includes simulations of:

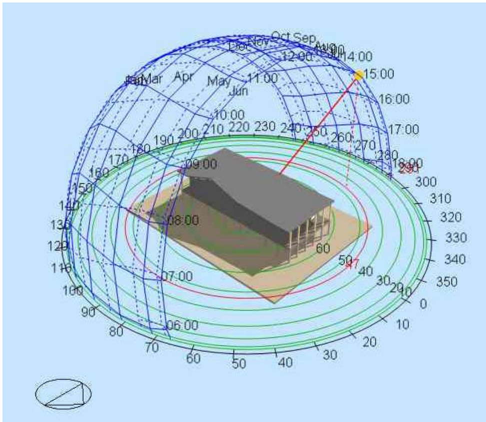
a. Base Model
b. Base Model with Tropic Roof
c. Base Model with Insulated Tropic Roof
d. Base Model with Insulated Tropic Roof and extra Vents
e. Base Model with Double-Skin Façade open only on the sides
f. Base Model with Double-Skin Façade with open on all sides

Input Settings and Materials:

1.	Walls	*Uninsulated lightweight metallic cladding*
2.	Floor	*Timber floor*
3.	Structure	*Timber and concrete*
4.	Inner Partitions	*6mm plywood*
5.	HVAC	*no heating, no cooling*
6.	Systems on/off	*only lighting*
7.	Occupancy (people/m2)	*0.0188*
8.	Activity	*bed/living/kitchen*

	winter	summer
Outside temperature (Celsius)	*22.1*	*34.1*
Wind velocity (m/s)	*4.7*	*0*

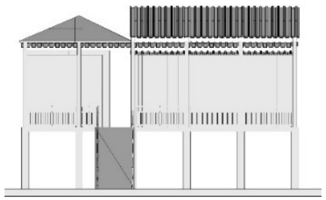




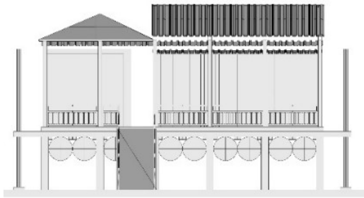
Sun path diagram on July 15th 3am

Heating Setpoint Temperatures	
Heating (Celsius)	5.0
Heating set back (Celsius)	5.0
Cooling Setpoint Temperatures	
Cooling (Celsius)	*50.0*
Cooling set back (Celsius)	*50.0*
Humidity Control	
RH Humidification setpoint (%)	*10.0*
RH Dehumidification setpoint (%)	*90.0*
Ventilation Setpoint Temperatures	
Natural Ventilation	
Indoor min temperature control	*no*
Indoor max temperature control	*no*
Minimum Fresh Air	
Fresh air (l/s-person)	*10.0*
Mech vent per area (l/m-s2)	*0.0*
Lighting	
Target Illuminance (lux)	*100*
Default display lighting density (W/m2)	*0*

Group I: The Original Stilts House and Base Model during flood and dry scenario

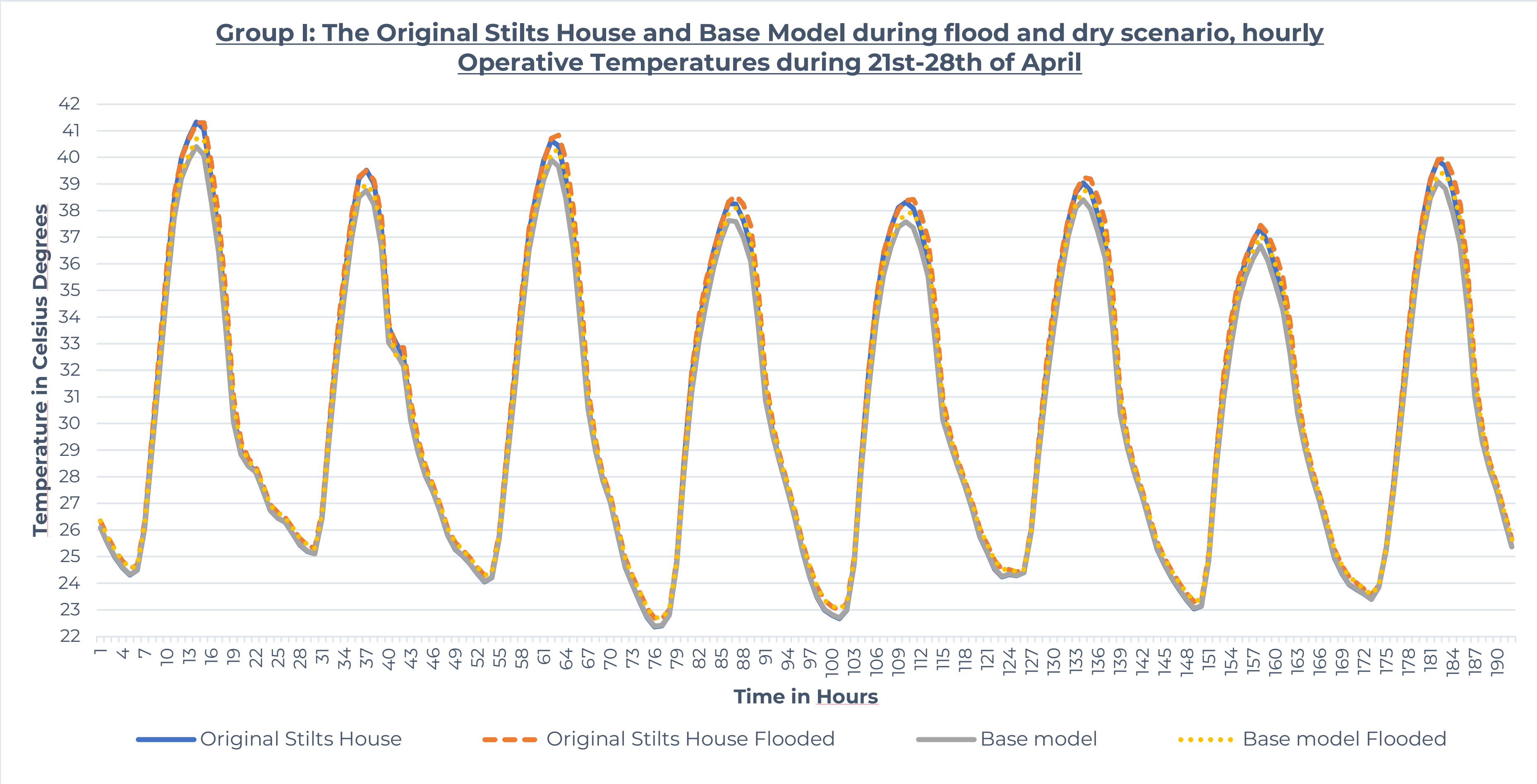


Original Stilts House



Base Model

Flood Scenario is made by building Standard Component Blocks with a height of 1m. The Component Block's material is Water and Shades and Reflects.



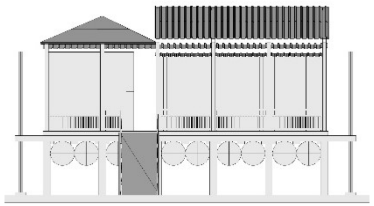
Does the Operative Temperature increase/decrease after transforming the original stilts house into an amphibious flood-resistant house(Base Model)?

- It seems like the Operative Temperature will decrease with ca. 1 degree Celsius.

Does it change during a flood? How significant is this?

- The flood of 1m seems to increase the operative temperature, however the impact is minimal.

Group II: Base Model and Passive Cooling by Natural Ventilation/Wind, during flood and dry scenario

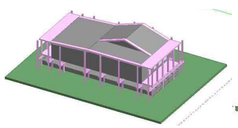
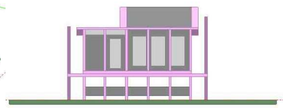
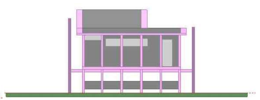
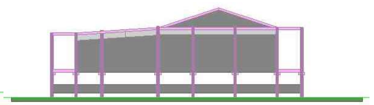
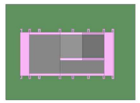


(a) Base Model

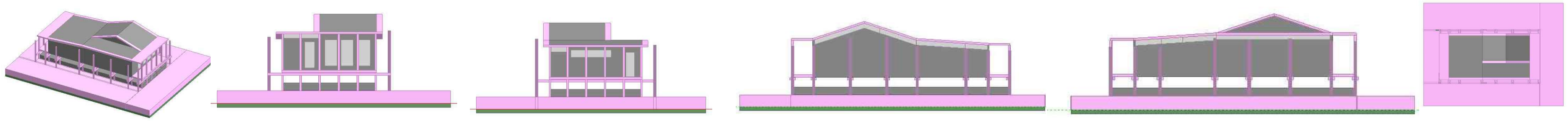
(c)Base Model with Lowered Buoyancy

Simulations of:

a. Base Model
b. Flooded Base Model
c. Base Model with Floor Vents
d. Flooded Base model with Floor vents
e. Base Model with Lowered Buoyancy
f. Flooded Base Model with Lowered Buoyancy
g. Base Model with Lowered Buoyancy and Floor Vents
h. Flooded Base Model with Lowered Buoyancy and Floor Vents

DesignBuilder Model	*Axonometric*	*Front*	*Back*	*East*	*West*	*Top*
e. Base model with lowered buoyancy						

f. Flooded
Base model
with lowered
buoyancy



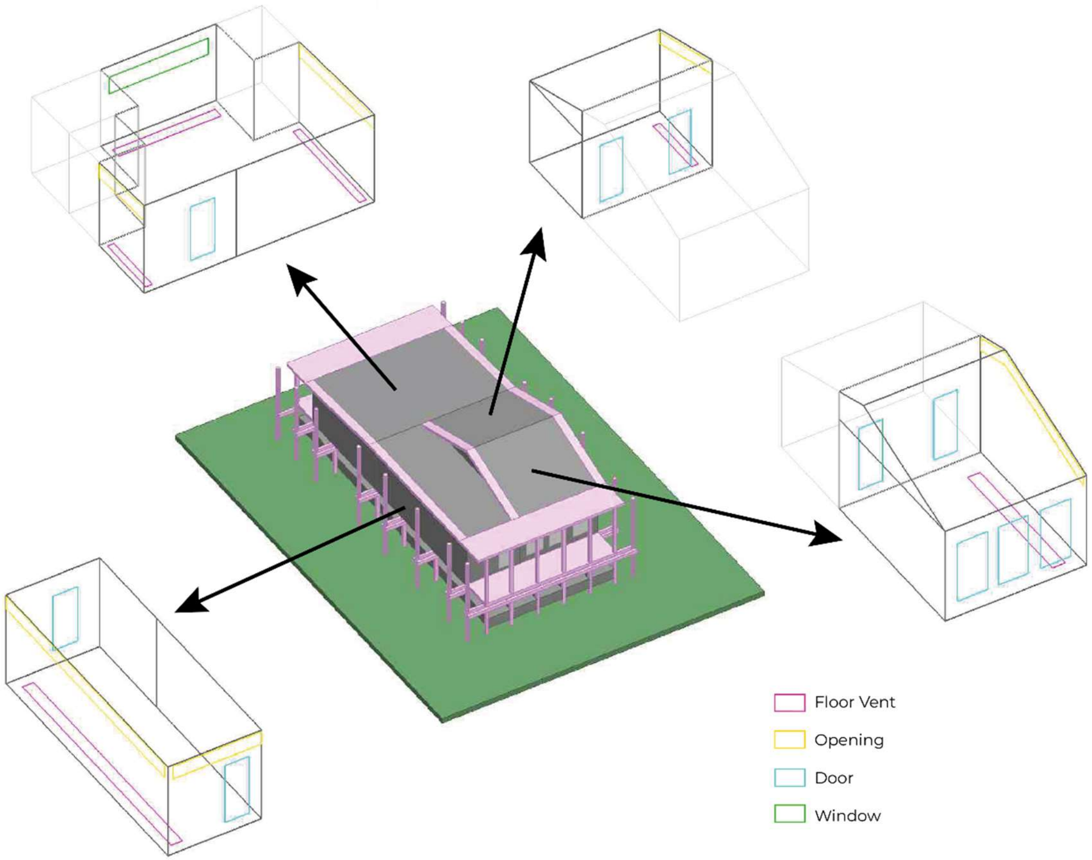
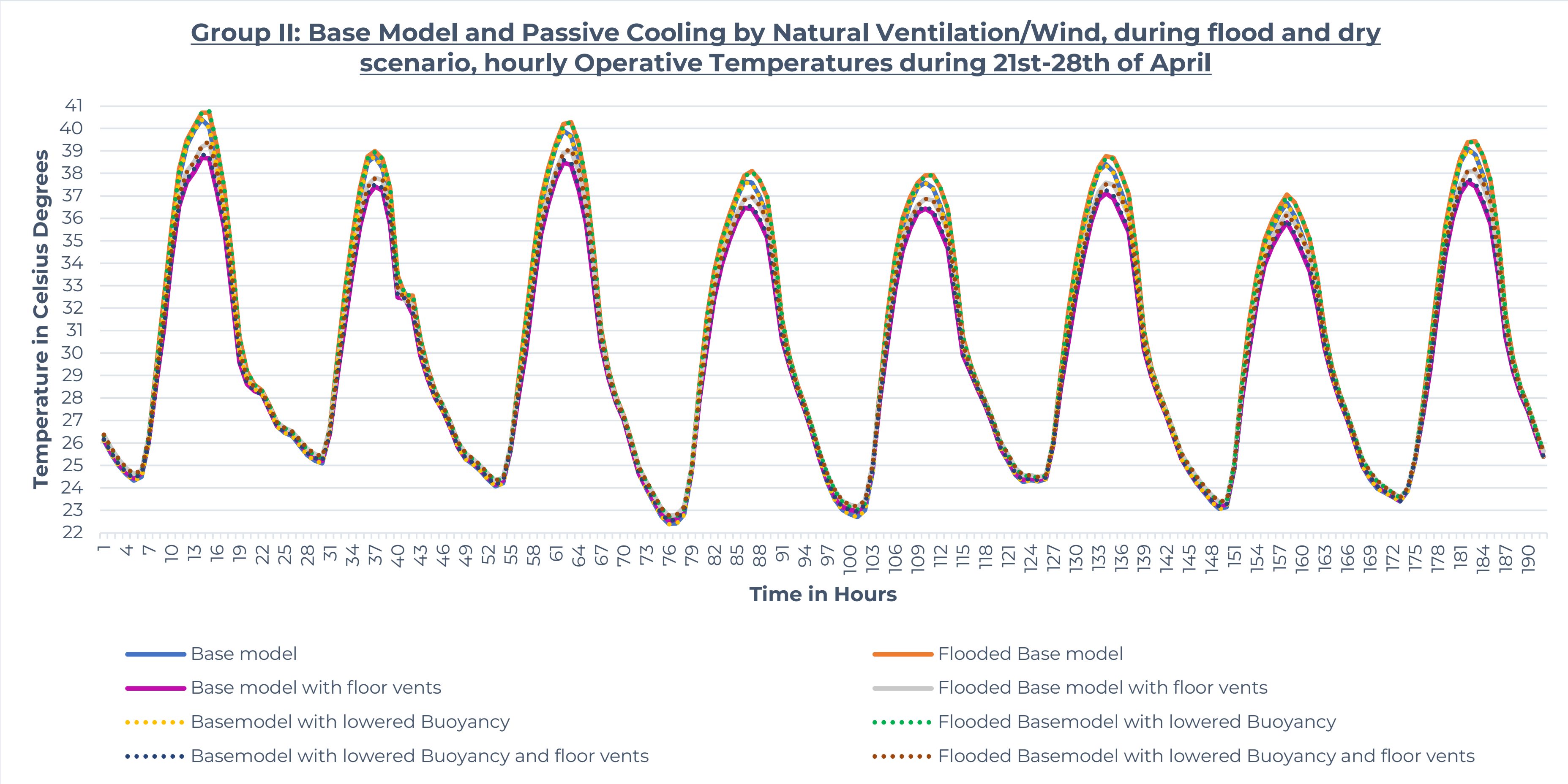


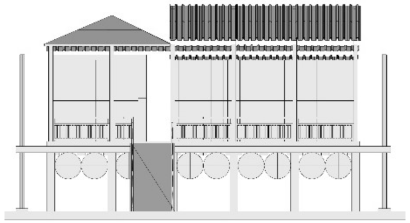
Fig: Base Model and opening types



Does lowering the buoyancy of the Base Model or integrating floor vents decrease the Operative Temperature? And what if It is combined? how significant is this?

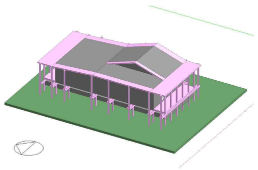
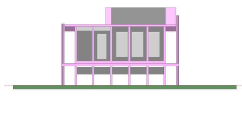
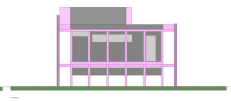
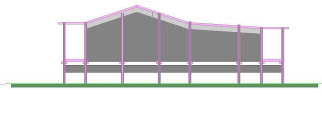
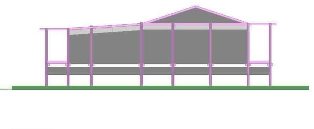
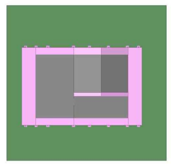
- Lowering the buoyancy doesn't decrease the operative temperature during dry or flooded context. It even increases during flood. Integrating additional Floor vents does decrease the operative temperature with 1 – 2 Degrees Celsius both with high or low placed buoyancy.

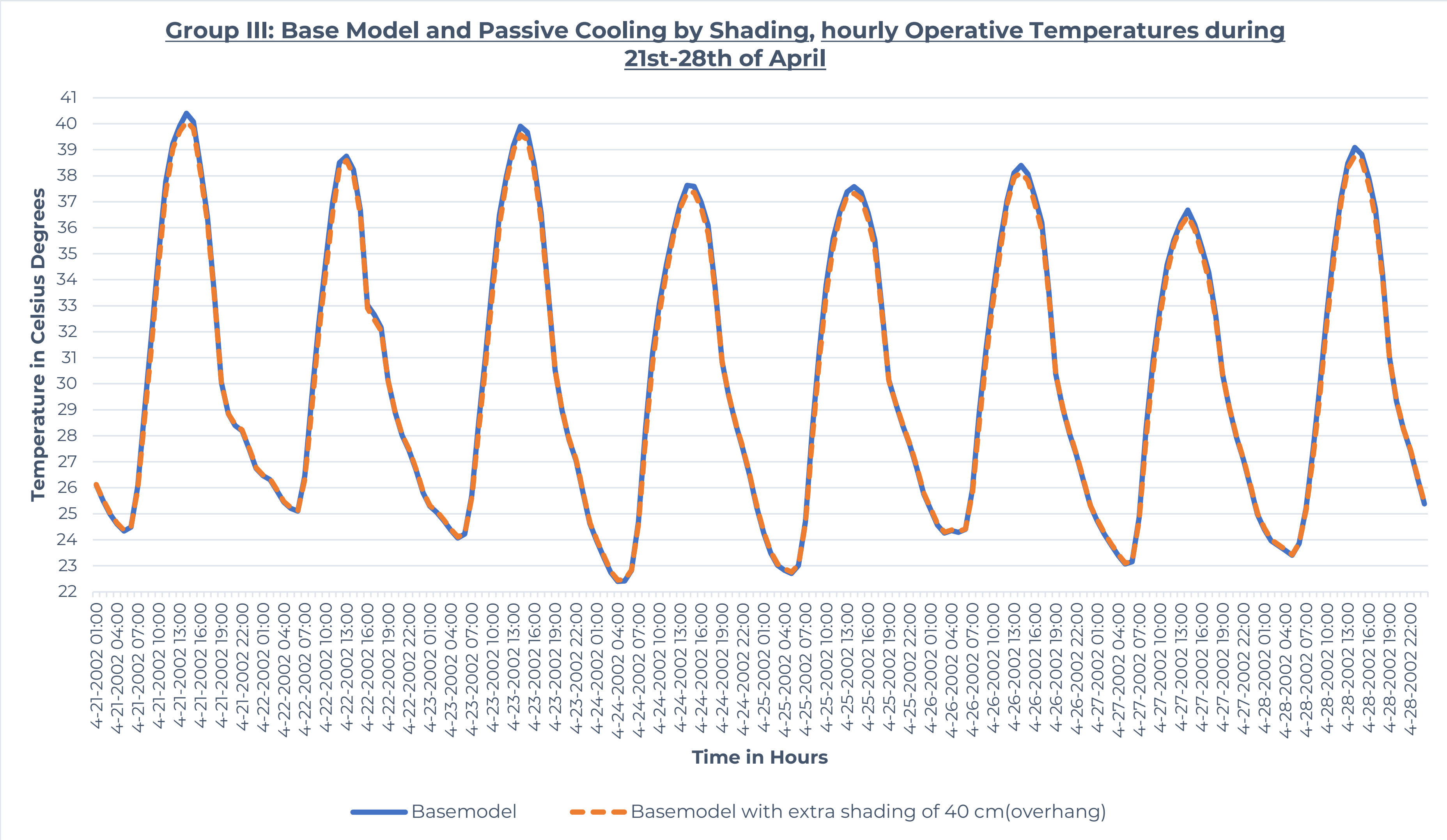
Group III: Base Model and Passive Cooling by Shading



a. Base Model

b. Base Model with extended overhang

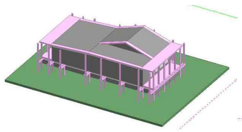
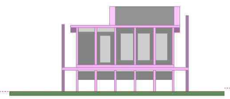
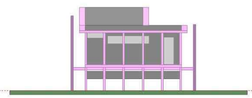
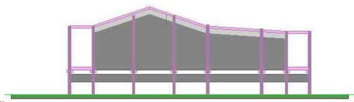
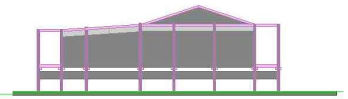
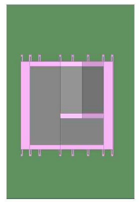
DesignBuilder Model	*Axonometric*	*Front*	*Back*	*East*	*West*	*Top*
b. Base model with extended overhang 40cm.						

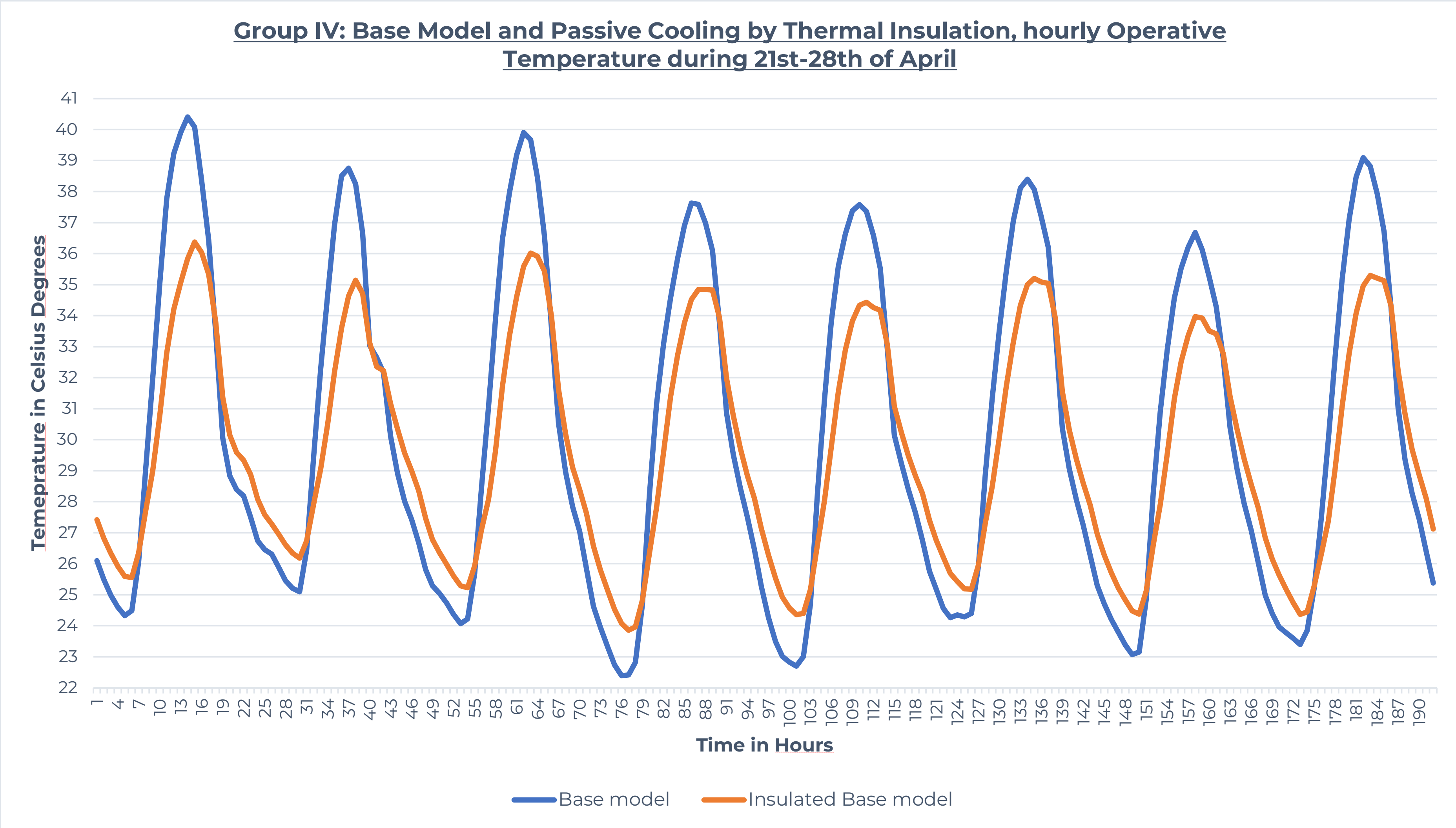


Does extending the overhang with 40cm decrease the Operative Temperature? And how significant is this?

- Extending the overhang with 40cm gives a minimal difference of the Operative Temperature compared with the Base Model

Group IV: Base Model and Passive Cooling by Thermal Insulation

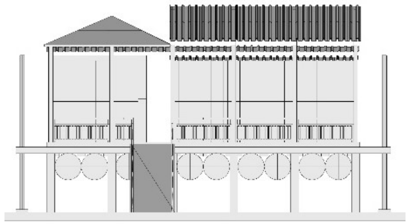
DesignBuilder Model	*Axonometric*	*Front*	*Back*	*East*	*West*	*Top*
b. Insulated Base model						



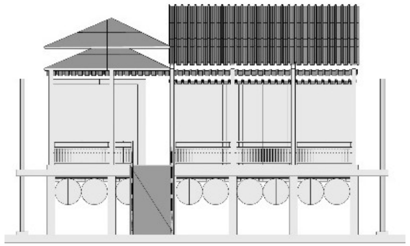
Does applying insulation of 5 cm Glass Wool to the walls and roof decrease the Operative Temperature and how significant is this?

- Insulating the walls and roof can decrease the Operative Temperature with 2 - 4 degrees Celsius.

Group V: Base Model and Passive Cooling by Multifaceted Interventions



a. Base Model

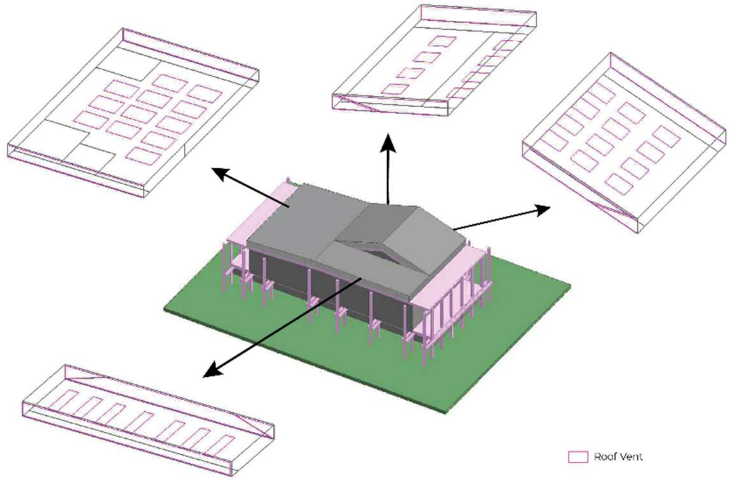


Tropic Roof

b. insulated

c. non-Insulated

d. insulated and Extra Vents

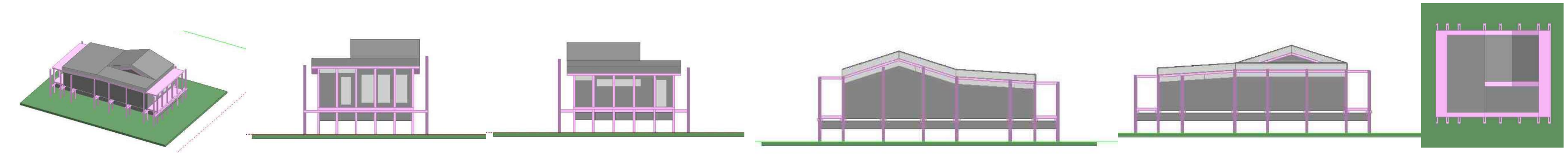
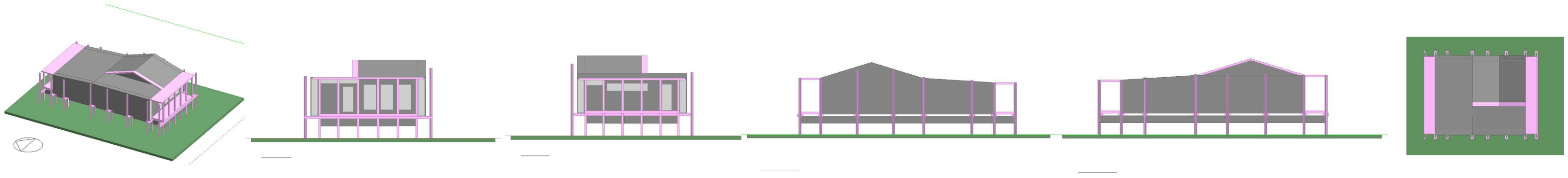
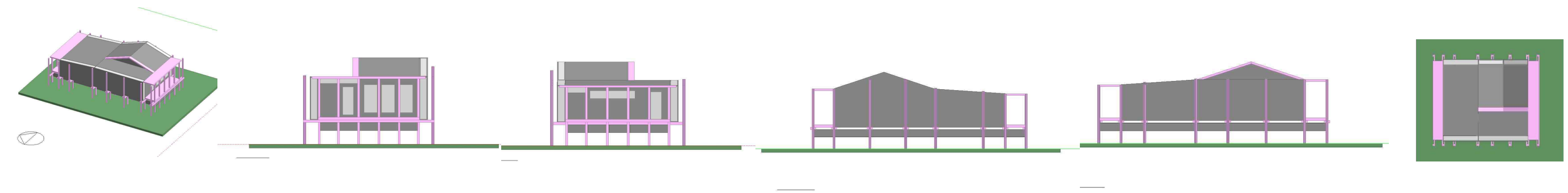


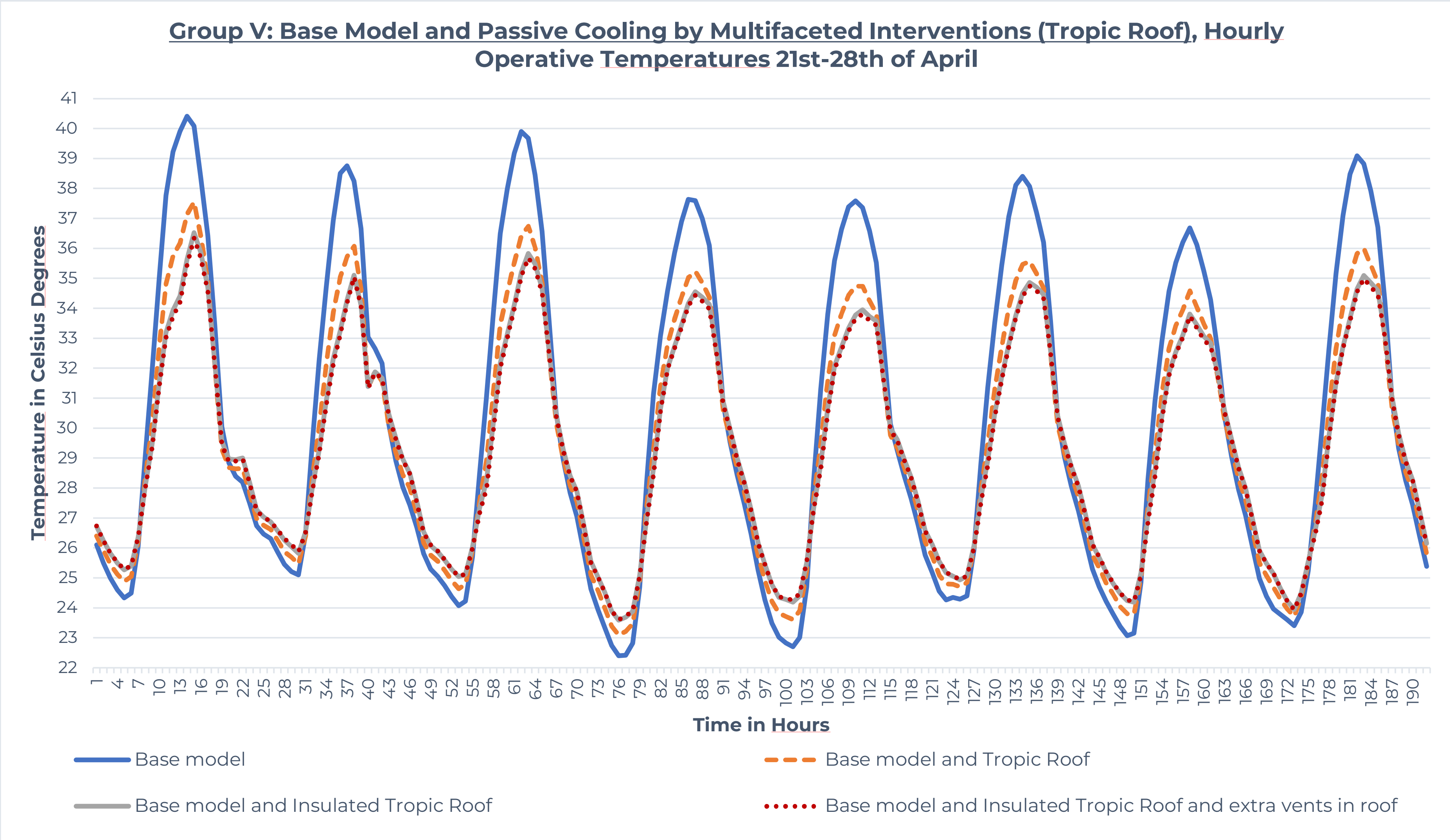
Fig, Tropic Roof and extra vents

Double-skin Facade

e. Openings on Sides only (see fig. next page)

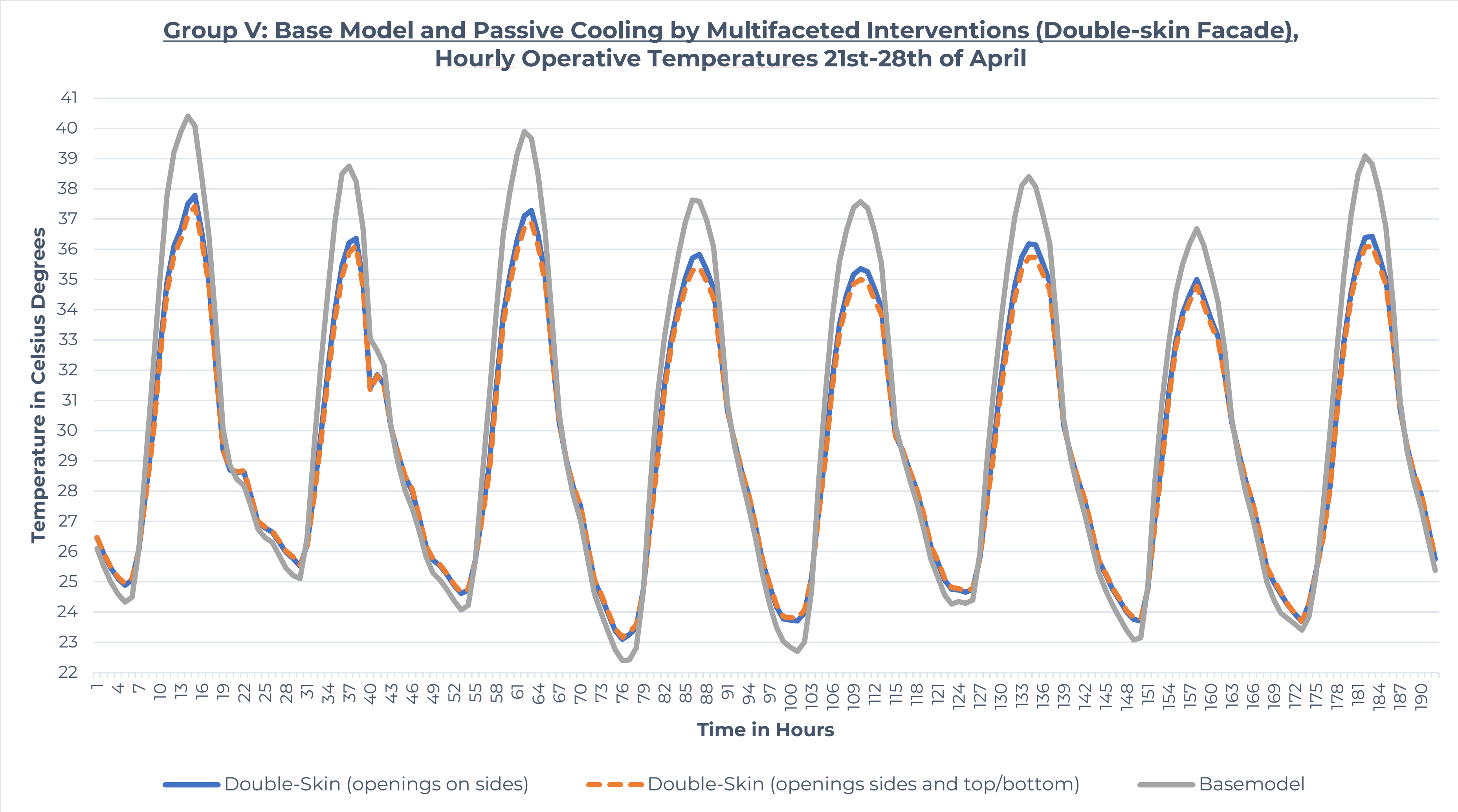
f. Openings all sides

DesignBuilder Models	*Axonometric*	*Front*	*Back*	*East*	*West*	*Top*
b/c/d. Base model with Tropic roof						
e. Base model with Double-Skin Facade (openings on sides)						
f. Base model with Double-Skin Facades (openings on all sides)						



How much can a Tropic Roof or Double-skin façade decrease the Operative Temperature?

- An insulated Tropic Roof can decrease the Operative Temperature with 2.5 – 4.5 Celsius Degrees.



How much can a Tropic Roof or Double-skin façade decrease the Operative Temperature?

- A double-skin façade with openings on all sides can decrease the Operative Temperature of the Base Model with 2 – 3 Celsius Degrees

Summary findings:

I. General information differences of Operative Temperature during flood and dry context of the Original and Base model

Does the Operative Temperature increase/decrease after transforming the original stilts house into an amphibious flood-resistant house(Base Model)?

- It seems like the Operative Temperature will decrease with ca. 1 degree Celsius.

Does it change during a flood? How significant is this?

- The flood of 1 m seems to increase the operative temperature, however the impact is minimal.

II. Passive Cooling by Natural Ventilation/Wind

Does lowering the buoyancy of the Base Model or integrating floor vents decrease the Operative Temperature? And what if It is combined? how significant is this ?

- Lowering the buoyancy doesn't decrease the operative temperature during dry or flooded context. It even increases during flood.
- Integrating additional Floor vents does decrease the operative temperature with 1 – 2 Degrees Celsius both with high or low placed buoyancy (during both dry and flood scenarios).

III. Passive Cooling by Shading

Does extending the overhang with 40cm decrease the Operative Temperature? And how significant is this?

- Impact is minimal. Could be that current overhangs are sufficient enough.

IV. Passive Cooling by Thermal Insulation

Does applying insulation of 5 cm Glass Wool to the walls and roof decrease the Operative Temperature and how significant is this?

- Insulating the walls and roof of the base model can give a reduction of ca. 4 Celsius Degrees, compared to the base model.

V. *Passive Cooling by Multifaceted Passive Cooling Interventions*

How much can a Tropic Roof or Double-skin façade decrease the Operative Temperature?

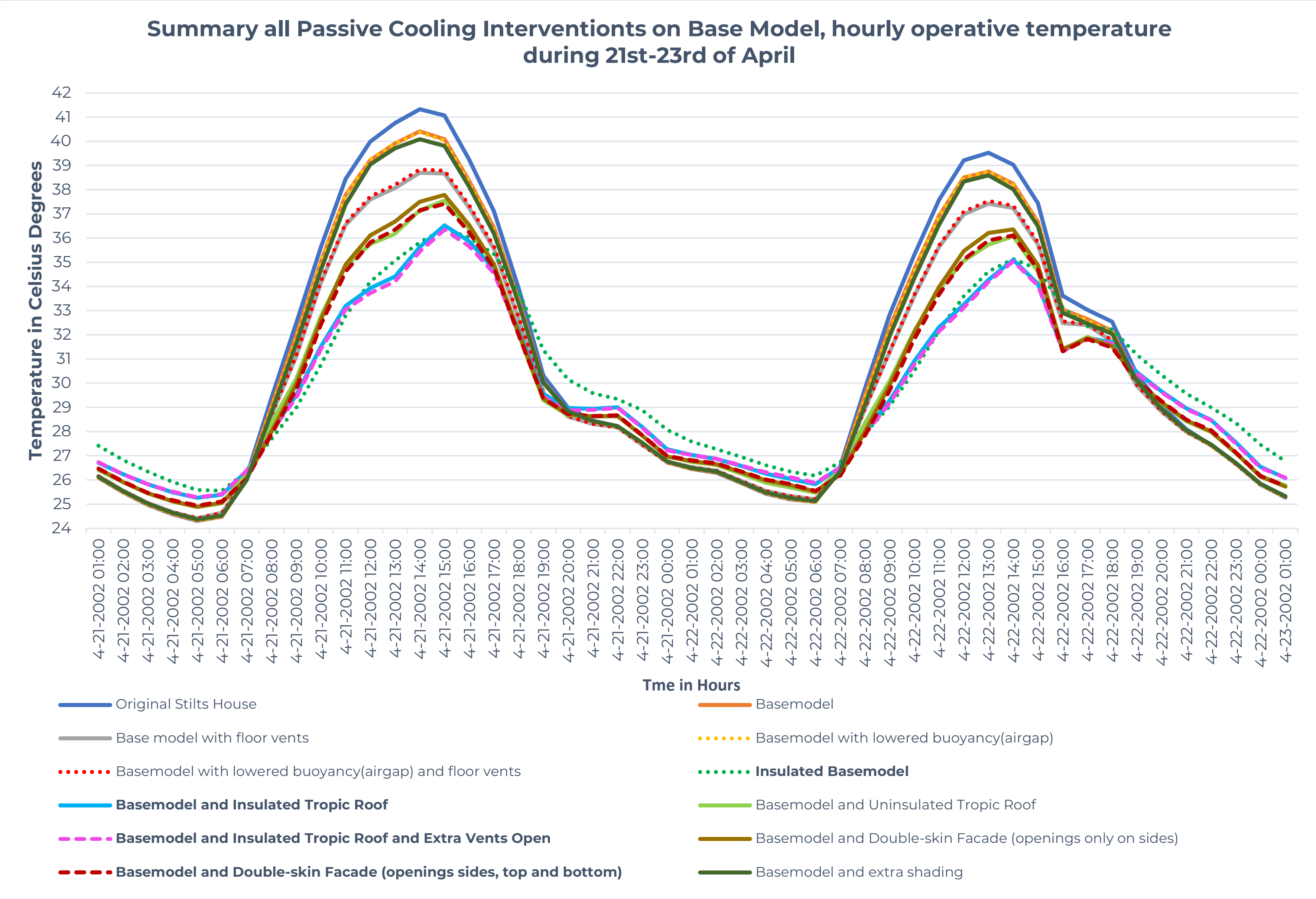
- An insulated Tropic Roof can decrease the Operative Temperature with 2.5 – 4.5 Celsius Degrees.
- A double-skin façade with openings on all sides can decrease the Operative Temperature of the Base Model with 2 – 3 Celsius Degrees. Compared to a double-skin façade with openings only on the sides, gives a reduction of 1.5-2.5 Celsius Degrees.

So to conclude in terms of passive cooling by natural ventilation; the best single strategies for passive cooling are building an insulated tropic roof and applying insulation to the walls and roof. As they can give the greatest reduction to the operative temperature: 2.5-4.5 and 4 Celsius Degrees, compared to the base model.

A double-skin façade can give a reduction of 2-3 Celsius Degrees and Floor Vents 1-2 Celsius Degrees, compared to the base model.

Extra openings in the tropic roof doesn't necessarily give a greater impact. And opening on the top and bottom of a double-skin façade can give a difference of 0.5 Celsius Degrees, compared to a double-skin façade with only openings on the sides.

A summary of all the Single Passive Cooling interventions on the base model during 48hrs can be seen on the next page.



Summary all Passive Cooling Interventions on Base Model, hourly operative temperature during 21st-23rd of April
Temperature in Celsius Degrees
42
41
40
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
4-21-2002 01:00
4-21-2002 02:00
4-21-2002 03:00
4-21-2002 04:00
4-21-2002 05:00
4-21-2002 06:00
4-21-2002 07:00
4-21-2002 08:00
4-21-2002 09:00
4-21-2002 10:00
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4-21-2002 13:00
4-21-2002 14:00
4-21-2002 15:00
4-21-2002 16:00
4-21-2002 17:00
4-21-2002 18:00
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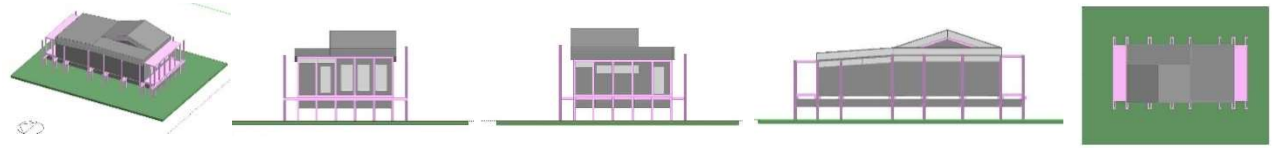
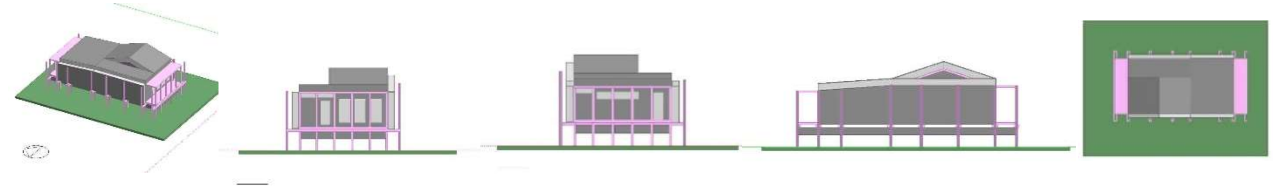
4-21-2002 21:00
4-21-2002 22:00
4-21-2002 23:00
4-21-2002 00:00
4-22-2002 01:00
4-22-2002 02:00
4-22-2002 03:00
4-22-2002 04:00
4-22-2002 05:00
4-22-2002 06:00
4-22-2002 07:00
4-22-2002 08:00
4-22-2002 09:00
4-22-2002 10:00
4-22-2002 11:00
4-22-2002 12:00
4-22-2002 13:00
4-22-2002 14:00
4-22-2002 15:00
4-22-2002 16:00
4-22-2002 17:00
4-22-2002 18:00
4-22-2002 19:00
4-22-2002 20:00
4-22-2002 21:00
4-22-2002 22:00
4-22-2002 23:00
4-22-2002 00:00
4-23-2002 01:00
Tme in Hours
Original Stilts House
Basemodel
Base model with floor vents
Basemodel with lowered buoyancy(airgap)
Basemodel with lowered buoyancy(airgap) and floor vents
Insulated Basemodel
Basemodel and Insulated Tropic Roof
Basemodel and Uninsulated Tropic Roof
Basemodel and Insulated Tropic Roof and Extra Vents Open
Basemodel and Double-skin Facade (openings only on sides)
Basemodel and Double-skin Facade (openings sides, top and bottom)
Basemodel and extra shading

5.7 Quantitative Evaluation 2: DesignBuilder

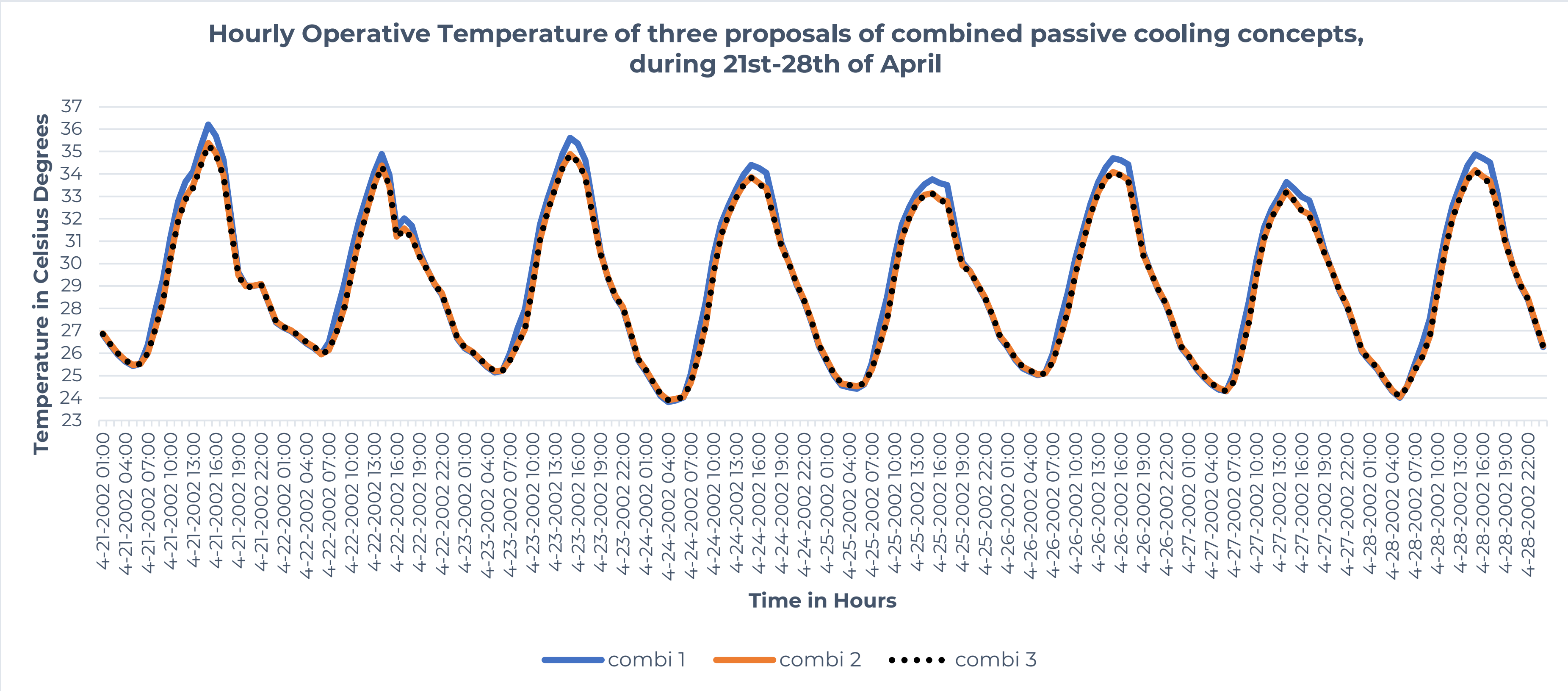
To further increase the impact on the operative temperature, three variations of combinations are made to simulate:

DesignBuilder Model	*Axonometric*	*Front*	*Back*	*East/West*	*Top*
Combi 1: Insulated Base Model and insulated Tropic roof, Floor Vents					
Combi 2 Insulated Base Model and insulated Tropic roof, Floor Vents and Double-skin façade					
Combi 3 Insulated Base Model and insulated Tropic roof, Floor Vents and Double-skin façade. V2					

The differences between the models is that combination 2 and 3 have an additional double-skin façade and between both they differ in a different connection of the wall and roof. As the (tropic) roof of combination 3 is extended over the façade instead of discontinued before the double-skin façade like in combination 2.

The research question is*: Does combining the following methods lead to better results and how significant is that?*

1. *Insulated walls and roof, Insulated Tropic Roof and Floor Vents*
2. *Insulated walls and roof, Insulated Tropic Roof and Floor Vents and a double-skin façade*
3. *Insulated walls and roof, Insulated Tropic Roof and Floor Vents and a double-skin façade (roof over façade)*

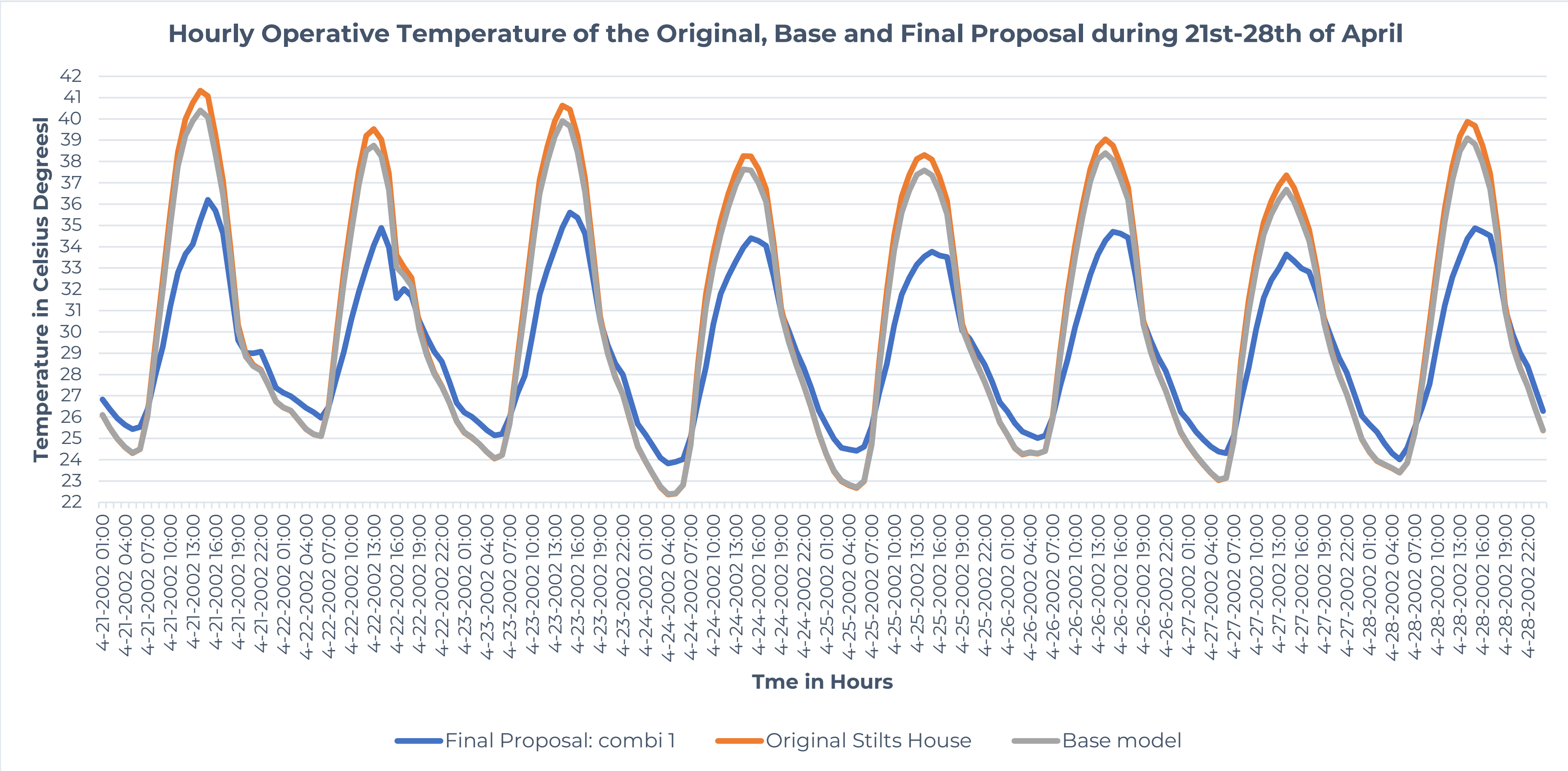


Does combining the following methods lead to better results and how significant is that?

1. *Insulated walls and roof, Insulated Tropic Roof and Floor Vents*
2. *Insulated walls and roof, Insulated Tropic Roof and Floor Vents and a double-skin façade*
3. *Insulated walls and roof, Insulated Tropic Roof and Floor Vents and a double-skin façade (roof over façade)*

- The outcome of the simulation shows that the combinations give similar results; adding a double-skin façade can give a reduction of the Operative Temperature less than 1 Degrees Celsius. It is therefore for the user worth considering whether purchasing a new façade is worth it. Combination 1 will be continued for detailing as the final proposal/design.

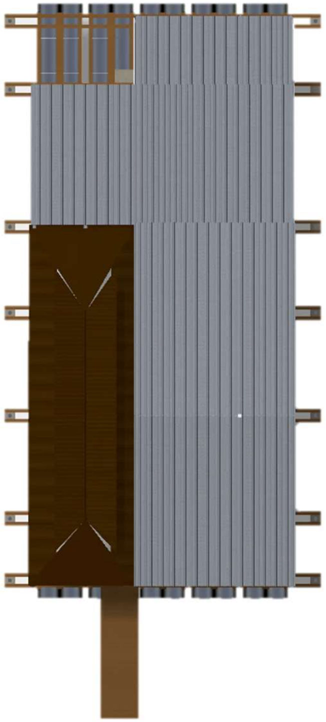
This figure shows the difference in Operative Temperature between the Original, Base and Final Proposal:



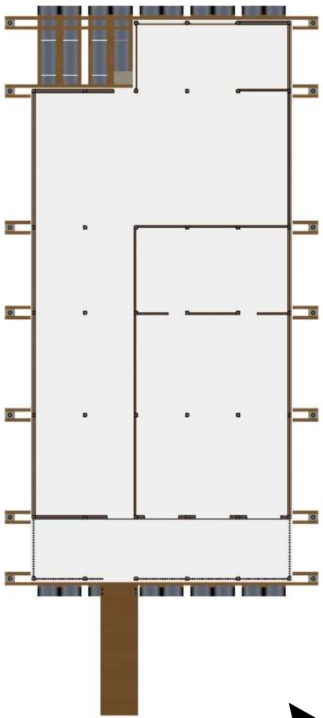
Transforming the Original stilts house into a flood-resistant amphibious house can reduce the Operative Temperature with max. 1 degrees Celsius and integrating insulation in the walls and roof, an insulated Tropic Roof and Floor Vents can reduce this temperature with max. 4 degrees Celsius. So the total reduction of the Operative Temperature is ca. 5 degrees Celsius.

5.8 Final Design

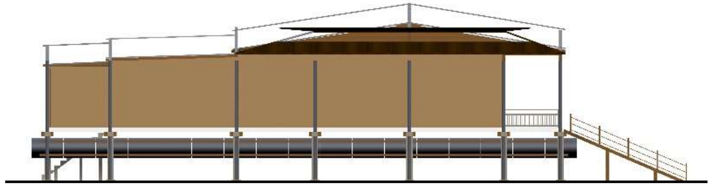
Top View



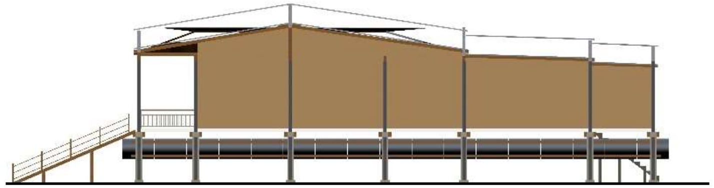
First Floor



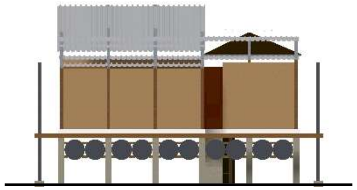
1:250



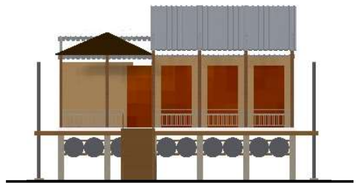
West View



East View



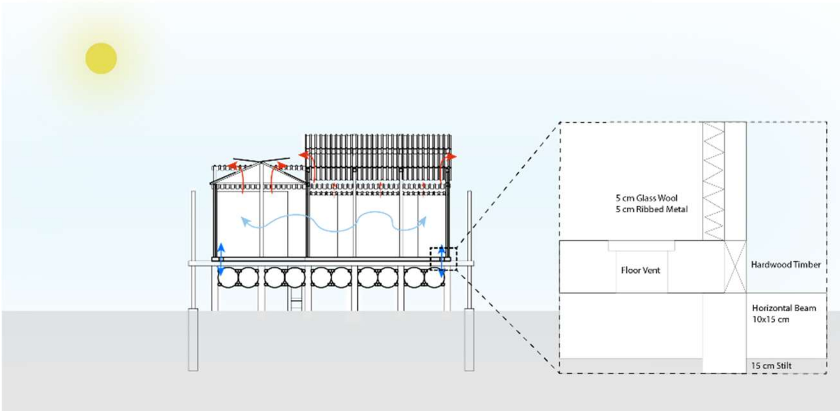
Front View



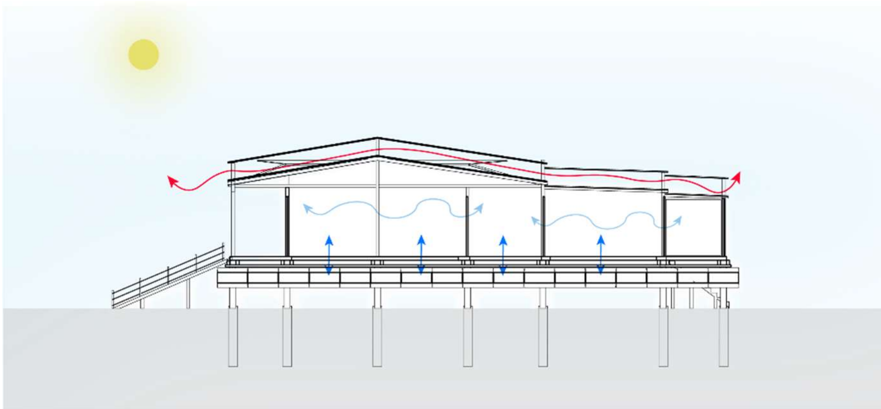
Back View

1:300

Cross Section

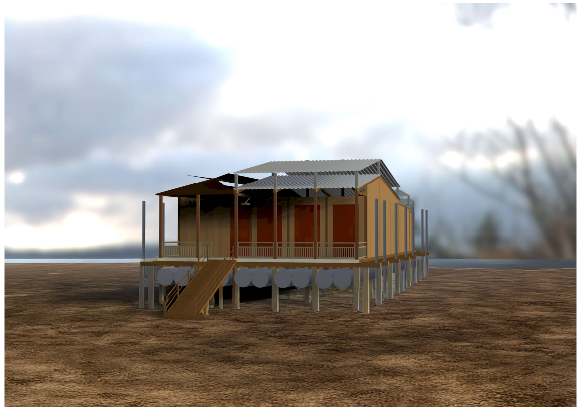


Longitudinal Section



1:300



6 Discussion

The research problem emphasizes the lack of studies on low-tech flood-proofing techniques suitable for developing countries like Vietnam. It also explores the integration of passive cooling methods, addressing the dual challenges of flooding and extreme temperatures.

Literature reveals that current residents live in housing typologies rooted in ancestral designs, utilizing traditional techniques developed over the years. These homes are constructed using local materials drawn from the natural environment.

The experiment offers new insights into the interplay between passive cooling techniques and flood-resistant structures, demonstrating that these elements can synergistically enhance each other. This integration can effectively lower indoor temperatures and bolster flood resilience in a cost-effective, low-tech manner.

Specifically, incorporating insulation in walls and facades can reduce operational temperatures by 4 degrees, while implementing a tropical roof can lower temperatures by 0.9 degrees.

The effectiveness of integrating dual interventions in design largely depends on the designer's approach. Simulations indicate which interventions successfully reduce the operative temperature; for example, while lowering buoyancy and creating direct airflow to the floor may not necessarily decrease indoor temperatures, the incorporation of floor vents can be effective. Thus, the integration of passive cooling methods and flood-resistant amphibious housing structures is not always essential for achieving better results. Each can function well independently without hindering the other.

When addressing flooding, designing for water-related contexts is crucial. However, investigating this remains challenging, as existing software does not accommodate water as an environmental factor. It accounts for water reflection, which results in a slight temperature increase, but fails to facilitate concrete analysis of passive cooling techniques that leverage cool water temperatures for functions such as heat sinking, evaporation, or enhanced natural ventilation. Further investigation is therefore recommended to explore additional bioclimatic cooling techniques as potential solutions.

The implications of this research for local communities are significant. By developing affordable flood-proof housing with passive cooling features, residents can experience improved living conditions, enhanced comfort, and increased safety from flooding. These innovations not only promote resilience against climate change but also empower communities by utilizing locally sourced materials and traditional knowledge. This approach fosters community engagement and can lead to sustainable development that is culturally relevant and environmentally sound.

Consequently, the design question—"How can we design…"—can be reframed as "How can we validate designs that incorporate flood-resistant amphibious housing with passive cooling interventions?"

7 Conclusion

How can low-tech amphibious housing lead to passive cooling to lower energy demands and create flood-resistant housing? (Mekong Delta)

Amphibious housing enables flood-resistant designs to adapt to the fluctuating water levels of the Mekong Delta, which experiences annual monsoon seasons and regular flooding. Traditional houses are increasingly less resilient to extreme weather events, making amphibious housing a viable solution for climate-adaptive living.

A related challenge is the rising temperatures and increasing cooling demands inherent to the tropical climate. According to the literature review, effective passive cooling strategies for these climates include:

1. Improving thermal insulation in walls, roofs, and ceilings.
2. Increasing natural ventilation through vertical operable vents or solar chimneys, which enhance airflow during different seasons (e.g., tropical roofs and double-skin façades).
3. Reducing solar heat gain with shading techniques, such as operable louvres in windows or overhangs.
4. Maintaining low indoor temperatures through night ventilation and nocturnal structural cooling via high thermal mass materials.

Simulations demonstrate that transforming a traditional stilt house into a flood-resistant amphibious home can reduce the operative temperature by a maximum of 1 degree Celsius. Furthermore, integrating insulation in the walls and roof, along with an insulated tropical roof and floor vents, can lead to a maximum temperature reduction of 4 degrees Celsius. Thus, the total potential reduction in operative temperature could be approximately 5 degrees Celsius.

To facilitate future design processes for climate-resilient housing, design software must undergo significant development. This should include a greater emphasis on floating design and the incorporation of multifaceted solutions. Key areas of focus should be passive cooling strategies, such as insulation and ventilation, as well as their floating and waterproof capabilities.

In addition to material properties and design, it is crucial to consider the structure's ability to withstand wave forces, wind, and varying loads. These factors must be integrated into the design process.

Furthermore, the software should address risks related to mold, aquatic life, and insects, as well as considerations for water filtration and waste disposal. Integrating comprehensive strategies for flood resilience and passive cooling is essential, as these issues are interconnected and can significantly affect the overall effectiveness of housing designs.

Moreover, design software should include tools that enable the simulation of environmental conditions and the assessment of various materials and techniques in real-world scenarios.

By developing these features, designers will be better equipped to make informed decisions that enhance the sustainability and durability of housing in the face of climate change. This approach not only improves the functionality of structures but also promotes the health and well-being of their occupants and surrounding ecosystems.

8. Reflection

My graduation project reflects a deep engagement with the challenges of Climate Design and Extreme environments, particularly in the context of tropical climates. The primary objective of my research was to explore low-cost, low-tech strategies to address the dual issues of extreme heat and frequent flooding, with a special focus on vulnerable areas such as Vietnam. By incorporating passive cooling methods and designing for flood resilience, the project sought to develop sustainable, adaptive architectural solutions that do not rely on active cooling systems or necessitate relocation.

The project's foundation was built upon an extensive literature review, which provided a comprehensive understanding of the issues at hand and informed the transition from the problem statement to a research-through-design approach. This process was integral in connecting theoretical frameworks with practical design solutions. It allowed me to not only identify the core challenges faced by communities in tropical flood-prone regions but also explore innovative ways to mitigate these issues through architectural design.

A key part of the project involved creating design proposals and simulating their performance in DesignBuilder. The choice to model an existing house added a layer of realism and practicality to the research, allowing me to assess how passive cooling methods would work in real-world settings. By simulating the performance of flood-resistant amphibious houses, I aimed to test the impact of various passive cooling strategies—such as natural ventilation, shading, and material selection—on the thermal comfort of these structures.

One of the strengths of using DesignBuilder was its ability to simulate the effect of temperature changes due to the reflective properties of water when surrounded by it. While the software lacked the capacity to simulate water bodies directly, this feature allowed me to gain insights into the complex relationship between water and heat in a tropical context. This was a significant strength of the project, as it enabled me to approximate the environmental effects that would be present in real-world flooding scenarios, albeit in a simplified form.

However, one of the weaknesses of the simulation process was the inherent limitations of the software when it came to modeling detailed designs. The need to simplify the test models meant that some of the finer aspects of the design proposals could not be fully explored or simulated. While this allowed me to focus on the core essence of each proposal, it also restricted my ability to conduct a fully comprehensive analysis of the designs' performance under flood conditions. This limitation in detail is something I would aim to address in future research, potentially by using more advanced simulation tools or software capable of handling more complex environmental factors.

Despite these challenges, the process of simulation also became an avenue for further research and idea generation. By adjusting the variables in the models, I was able to explore different design possibilities and understand the range of effects that various passive cooling strategies could have. This iterative process of testing and refining the design proposals provided valuable insights that helped shape the final outcomes of the project.

The results of these simulations, though limited by the tools available, offered a starting point for understanding the potential of passive cooling in flood-resistant housing. While the outcomes can be seen as preliminary tests, they provide a foundation for future research and development. Validation in real-world settings will be critical in determining the actual applicability of these design strategies. The limitations of the current tools highlight the need for more advanced simulation environments, but they do not detract from the potential of these findings to inform climate-adaptive architecture.

The overarching aim of the project was to contribute to the field of climate-adaptive architecture, particularly in the context of low-cost and low-tech solutions. By focusing on materials and techniques that are affordable and accessible, the project aims to reduce the embodied CO_2 emissions associated with building construction while also making these solutions available to a wider audience. This is especially important for communities living in vulnerable areas, where the impacts of climate change—such as rising temperatures and increasing flood risks—are felt most acutely. Through this project, I sought to highlight the importance of designing for these marginalized populations and demonstrating that climate resilience does not always have to rely on high-tech, resource-intensive solutions.

In conclusion, this project has been a journey of discovery, combining theoretical research with practical design applications to address real-world challenges. While there are limitations to the tools and models used, the insights gained offer a valuable contribution to the ongoing discourse on climate-adaptive architecture. By emphasizing passive cooling, flood resilience, and low-cost solutions, this research hopes to inspire further innovation in the field, ultimately contributing to more sustainable and equitable design practices for those most affected by climate change.

Two Extra Reflective Questions:

1. What changes and improvements are needed in current software to better design for future climate contexts?

Future climate contexts involve challenges such as rising temperatures, increased rainfall, sea-level rise, and more frequent flooding. Current design software is limited in its ability to simulate environments that include water bodies or sites heavily affected by water. Most tools focus on solid ground components, neglecting crucial factors like the thermal properties of water, which are vital for designing resilient structures in flood-prone areas.

To improve the design process for future climates, software should be enhanced to incorporate water as a dynamic environmental element. This could include simulating water's thermal behavior, such as using water as a heat sink, its cooling properties, and how water interacts with building materials. Integrating hydrodynamics, material erosion, and the performance of water-friendly materials would also be essential for more accurate simulations. Additionally, the ability to model floating designs and structures that respond to changes in water levels would be invaluable for designing climate-adaptive housing. These improvements would provide architects and designers with better tools to validate and optimize structures in diverse and challenging environments.

2. Could flood-resistant amphibious housing still be viable in 100 years?

In the long term, if the environment surrounding amphibious housing becomes unsuitable for habitation—due to extreme flooding or other factors—these homes could still remain useful. The flexible nature of amphibious houses means they can be detached from their vertical guidance posts and foundations, allowing them to float freely. This adaptability could enable homeowners to relocate their structures to safer areas while retaining their homes.

Moreover, with potential enhancements or the addition of structural support, these floating homes could continue to serve residents even in extreme conditions. While the specific location may need to change due to environmental factors, the core concept of amphibious housing offers a future-proof solution for dealing with climate-related challenges, ensuring that people can keep their homes while adapting to shifting landscapes.

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