CLIMATE CUSTOMIZED FAÇADE

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A PREFABRICATED FAÇADE SYSTEM CUSTOMIZED
FOR ECUADORIAN CLIMATE REGIONS

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ABSTRACT

The Ecuadorian construction sector lacks thermal comfort standards, causing building's design to disregard the existing variations between the climatic regions in the country. Indoor comfort levels are generally poor, encouraging the use of unsustainable cooling and heating systems. A building´s envelope plays an important role in the energy and environmental performance of a building. This research investigates whether indoor comfort can be improved by renovating existing facades with a prefabricated facade system that can be mass-customized to respond to different types of climate conditions. A project that uses state-of-the-art technologies, such as CNC milling, to mass-customize construction elements is the WikiHouse. It provides construction solutions with multiple variations, easy assembly processes and the demountability of its components. It guarantees its reusability and reduces the high demand for resources in the construction industry. This research focuses on the design of a facade system that can be mass-customized by combining the construction system of the WikiHouse project and multiple layers with different properties to build one modular and symmetric component with several variations. The replication of the components variants on an existing building´s facades should improve the indoor comfort by responding to the localtions weather. During this research, components variants are developed, by using computational prototyping and simulations. The most suitable components combinations for each facade orientation are selected. This study highlights the influence of climate factors in all its design steps, as well as setting a circular workflow throughout the manufacture, use and return processes. The final outcome of this study is a prefabricated facade system that can be mass-customized to respond to different types of Ecuadorian climate conditions to improve the current indoor comfort levels and allows its demountability and reusability.

1. INTRODUCTION

A building´s envelope plays an important role in the energy and environmental performance of a building, affecting its indoor comfort levels. Since the Industrialization, façade design has evolved significantly through the application of accurate weather simulations and new technological production methods. The manufacturing-processes development provided by the Industrialization was taken as an advantage to develop new building systems that combine the design, the construction and the economy in a unitary process in which the multidisciplinary working groups would allow to shorten the division between the architect, the engineer and the builder (Gropius, 1956). The vision of housing as a product, resulting from rigorous planning of an efficient and economic assembly line, was a decisive influence in the development of prefabrication and modular construction in Europe and North America (Fernández, 2011). The German architects Walter Gropius (1883-1969) and Konrad Wachsmann (1901-1980) developed one of the first prefabricated building systems, The General Panel system, in 1942 (Imperiale, 2012). Prefabrication provides solutions with easy assembly processes and the demount ability of its components.

The location to be studied in this research is Ecuador, located in South America. With particular geographic characteristics, this country shows a wide range of climate regions. Ecuadorian vernacular construction systems respond to these specific weather characteristics across the country. In contrast, the current local socio-economic factors make the Ecuadorian construction sector particularly disconnected from its climate context, with buildings that do not respond to local weather characteristics. Consequently, the majority of the existing buildings, found around Ecuadorian regions, show poor indoor comfort levels (Ledesma & Rivera, 2018). This research sees an opportunity for prefabrication to upgrade the indoor comfort of the existing buildings in Ecuador. Contemporary projects, such as the Wiki House, use the advantage of this technique, which is the time and costs savings when matching activities are grouped and the assembly line producers work at a place where skilled labour is available. The aim of this project is to provide the local fabrication of components manufactured by a network of local micro-factories, using digital fabrication tools. The system provides a rapidly assembly to millimetre precision.

To mass customize a façade system that responds to different weather conditions, prefabrication provides the advantage that changes and updates can be easily made and produce multiple exact copies of the same element. New technologies, such as CNC have emerged, that use this technique for multiple exact replications of construction components. CNC stands for Computer Numerical Control. Here, the integration of design, engineering and fully digital production can significantly reduce failure and provide the possibility of mass customization. This results in a construction system that responds to different requirements while been produced in great quantities and quality.

Finally, the construction sector produces 23% of the total CO2 emissions of global economics activities (Huang, 2017). The grand majority of the current building systems are based on a linear workflow (Cradle-to-gate), starting with the extraction of resources, processing, assembly, use and finally, demolishment. Therefore, reducing the resources consumption of new and existing buildings is a crucial issue. This research aims to find a sustainable solution, to improve the indoor comfort of Ecuadorian existing constractions, where the final product can be locally produced, using local resources, and providing its reusability by an easily demountable system.

Chapter two introduces the research framework of the thesis project, the research questions and objectives. The third chapter presents a literature review about customization and the building envelope in relation to indoor comfort. The forth chapter clarifies the general requirements that the design should meet respopnding to its context. Chapter fifth defines the requirements that should be integrated in the final design according to the literature review and available opportunites and resources. The sixth chapter shows the development of the concept based on a research-by-design approach. Chapter seven shows an overview of the design and presents the customization features. Chapter eight, nine and ten show the design´s assesment based on computational prototyping and simulations. Finally, chapter eleven and twelve present the conclusions and reflection.

2. RESEARCH FRAMEWORK

2.1. PROBLEM STATEMENT

Ecuadorian construction normative lacks Thermal Comfort Standards, causing building's design to adopt a prototype construction for the ease of optimizing construction time and lowering costs but disregarding variations between climatic regions in the country (Ledesma & Rivera, 2018).

The climate regions in Ecuador present variations depending mostly on their altitude. The two predominant climate types are tropical and temperate. Because Ecuador is located on the equator line, it presents minimum monthly weather variations. On the other hand, the extreme variations in temperature vary between daytime and night-time. A building's façade is the main factor that influences the indoor comfort of users, therefore it´s elements need to provide the necessary flexibility to respond to these variant weather characteristics. The vernacular constructions systems that used to respond to Ecuadorian weather have been replaced by generic buildings with no indoor comfort standards.

In 2010, the operational energy in residential buildings was nearly seven times the embodied energy in all newly produced building materials (Ecorys, 2014). This research explores an alternative to upgrade the existing buildings in Ecuador, by customizing a prefabricated façade system that responds to the different climate characteristics of Ecuador´s regions and translate it into a prefabricated façade system that allows its local production and reusability to meet a circular workflow.

2.2. OBJECTIVE

This research aims to develop a prefabricated façade renovation system that can be customized to respond to different climate regions and construction standards in Ecuador, consisting of several functionalized components. These modular components will be assembled and placed with different configurations, materials and functions to guarantee customization for different climate and assembly possibilities.

2.3 SUB-OBJECTIVES

- To gain knowledge on existing construction systems that respond to the specific Ecuadorian weather characteristics.-
- To specify the main construction standards in Ecuador that the façade system should respond to.
- To research previous and contemporary prefabricated façades to gain knowledge on their functions, materialization and systems.
- To study customizable façade systems to explore available products that respond to variant weather characteristics.
- To define the façade requirements that should be fulfilled in Ecuador´s climate regions.
- To gain knowledge on demountable façade that allows the reusability of the system.

2.4. RESEARCH QUESTION

After a detailed and exhaustive literature analysis of the local conditions in Ecuador in relevance with the existing façade systems, the resulting need or research question is:

> *¨How can a prefabricated façade system be mass-customized, for Ecuadorian climate regions and its existing building stock, to upgrade the indoor comfort, while providing a circular workflow based on local production, the use of local resources and the reusability of the system? ¨*

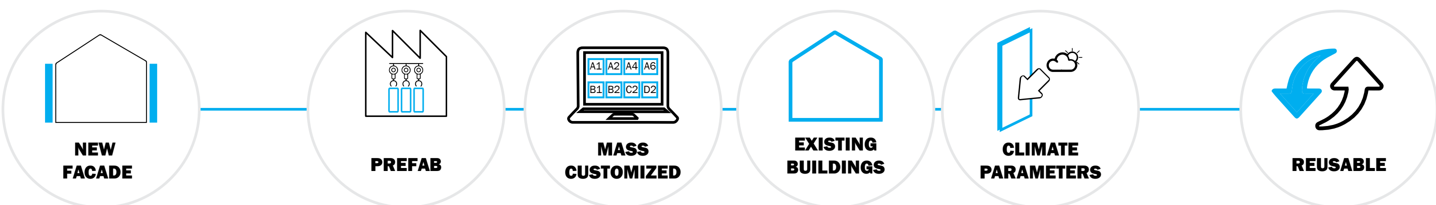


Figure 1: Objectives of the research project. Own illustration.

2.5. SUBQUESTIONS

- How do the sun orientation and wind predominant direction affect the renovation of an existing facade in Ecuador?
- What role do new technologies play in the improvement of existing building methods?
- What are the available techniques and technology used in facade mass customization?
- How can a prefabricated façade system improve the indoor comfort of the existing building stock of Ecuadorian climate regions?

2.6. METHODOLOGY

In this chapter, the methodology used for this research is detailed as a sequence of steps to be taken along the process to reach the final objective. In this process, a need has to be satisfied under various parameters while analysing the context, regulations and the required resources. Based on this literature study, a concept for the research is developed. Next, a first design or output is presented, leading to digital simulations that will provide the needed feedback to test the product and improve it. Finally, after testing the design, a final product is detailed with the conclusions, recommendations and reflection. This process is detailed in the figure below.

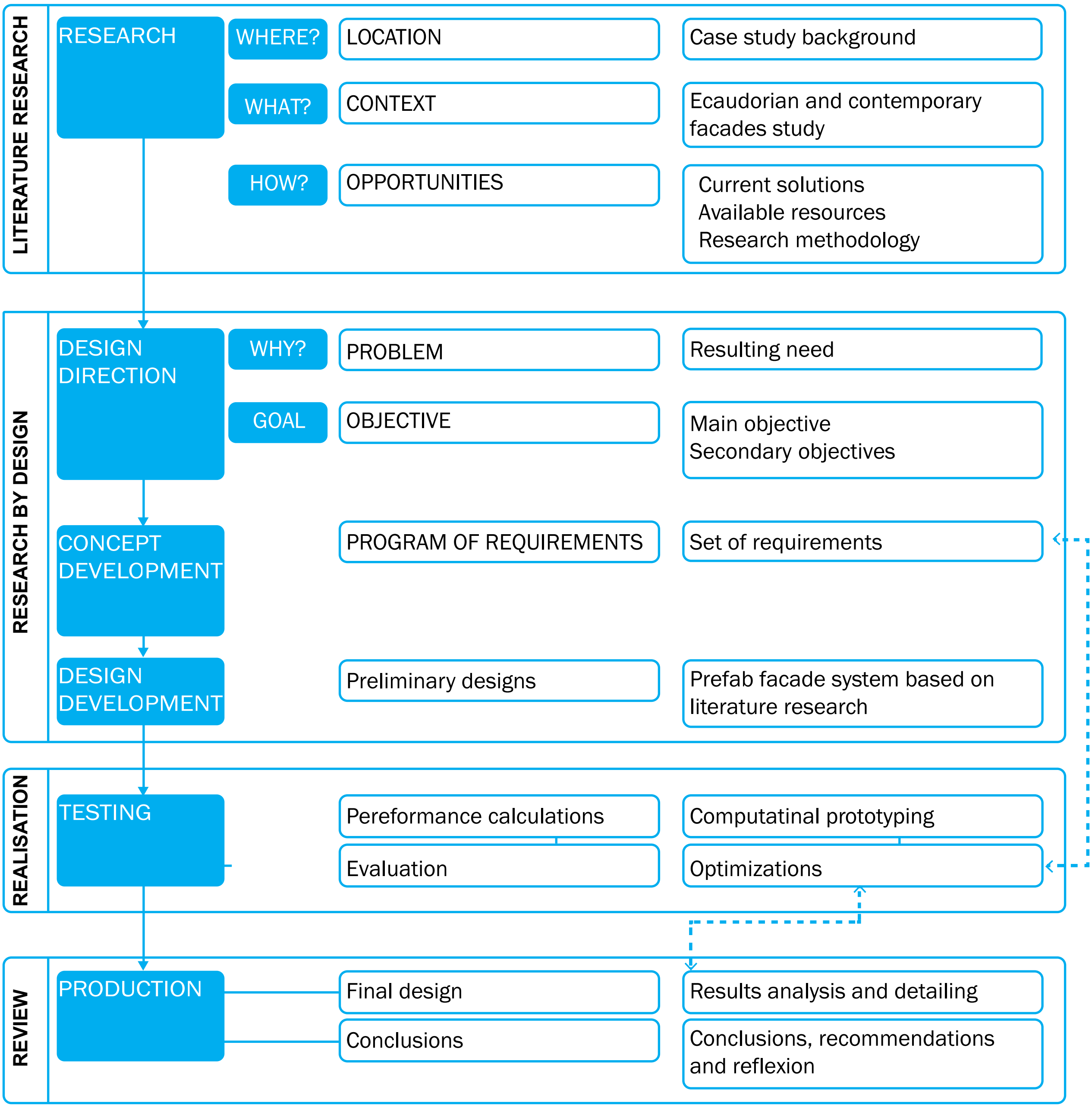


Figure 2: Methodology based on product development. Own illustration

2.7. SOCIETAL AND SCIENTIFIC RELEVANCE

Main cities of Ecuador have grown with informal settlements at the city's periphery. For example, in the capital, Quito, 60% of the buildings are informal constructions (Jácome, 2017). The majority of the construction sector in Ecuador is undertaken with concrete blocks, thus it is one of the cheapest and most available construction elements. Ecuador lacks thermal comfort standards causing building's design to disregard the environment and local climate. This research project aims to provide an alternative solution for improving this existing building stock´s indoor comfort. A clear guide for designers, builders and especially unskilled labour is presented in this document. The aim is to present clear parameters and solutions to upgrade the poor indoor climate conditions around the different climate regions of Ecuador.

III

3. CUSTOMIZATION AND THE BUILDING ENVELOPE

3.1. PREFABRICATION

This research aims to use the opportunity provided by state-of-the-art technologies found in Ecuador that support a sustainable, reusable, and flexible design/manufacturing process. CNC technology has been recently imported to Ecuador. CNC stands for Computer Numerical Control. It is a machine with a tool-holding head whose movements are controlled by a computer. It is a subtractive manufacturing technology: parts are created by removing material from a solid block using a variety of cutting tools (Zwart, 2019). CNC machines can carve complex 3D shapes and cut 2D contours out of panels (Odom, 2019). It allows one to design in CAD software, create a CAM setup (Computer-Aided Manufacturing), and produce a physical sample of this design very quickly (Odom, 2019). The benefit is that changes and updates can be easily made on the CAM set up to improve it and produce multiple exact copies of the same object.

This technology allows a quick and accuratly cut out on a wide variety of sheet-materials stock (wood, plastic, metal, etc.) in multiple shapes and forms (Odom, 2019). This technology is now been used by designers around the world in construction projects, such as the WikiHouse, by Architecture 00 in London. These projects aim is to make it possible for anyone to design, share and download homes which are adaptable to different needs and be cheaply "printed" and assembled by unskilled labour. Building blocks are put together as a smart 3D puzzle and only dry connections are used. The big advantage of this is that the entire building can be easily assembled and disassembled. Because of the standardization of components, the elements are reusable and interchangeable, while allowing easy customization for different needs. The integration of design, engineering and fully digital production can significantly reduce failure costs in the construction process compared to current building practice.

The WikiHouse project is based on Segal's construction method, where a simplified process is used to build cheap and fast housing. Starting with a modular grid, standard sheet materials are used. The modular approach meant that the building allows easy adaptation or expansions into the future. The use of no "wet-trade" (for example, no plastering or masonry), makes the construction process simpler for unskilled labour. The ten principles of the system are:

Figure 4: The ten principles of the WikiHouse system (Architecture00, 2019)

This research takes this system's approach and uses CNC technology to experiment with the WikiHouse construction system to improve it and customize it to respond to Ecuadorian climate regions. This system provides the advantage of developing an open, easy to use, low-management platform for the community to share files instructions, research, knowledge and challenges.

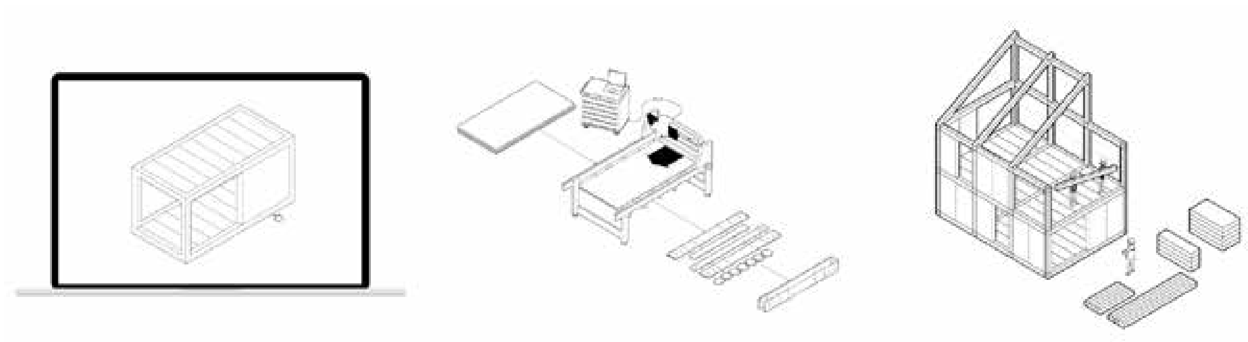


Figure 3: The WikiHouse production system, (Architecture00, 2019)

3.2. FAÇADE SYSTEM DEVELOPMENT

For this project, the study of previous and current product development shows a clear path to follow when developing a new façade system for a specific location. First, a review of international requirements for a new product is analysed. The changes, throughout history, are the result of the relationship between designers, manufacturers, builders and clients. A timeline graph is used to understand the variations linked to the development of a new product across the last 300 years. The Industrial Revolution transformed the manufacturing processes with mechanical and electromechanical methods, leading to the mass production of standardized products. Here, the final product must meet three main

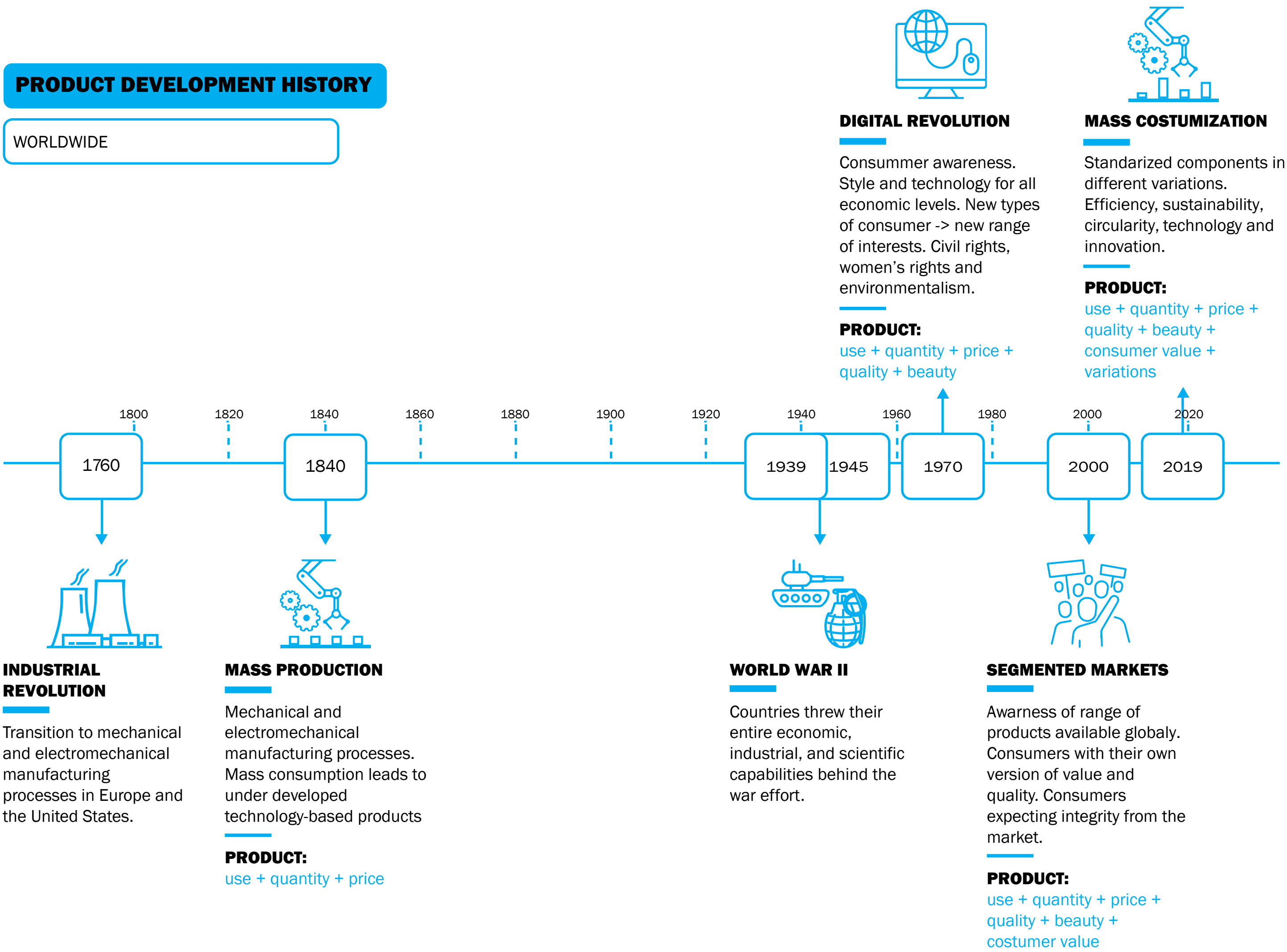


Figure 5: Timeline of the international impact of new products development. Own illustration

requirements: a certain use, high levels of quantity and a reduced price. On the other hand, the digital revolution leads to consumer awareness, where a wide range of interests introduced two new requirements: quality and beauty. By 2020, new technologies have allowed mass-customization of mass-produced components, responding not only to mass production, but also the customization based on each consumer's needs.

To develop a new product in Ecuador, it is important to understand the relationship between developers, manufacturers and clients on a local scale. Been a developing country, Ecuador has had a different path, compared to developed countries in North America or Europe. This evolution, also trough the past 300 years, is shown in the timeline below.

In the case of Ecuador, the industrial revolution reached its peak just before World War II and its war against Peru. This produced a decrease in local production but also the increase in raw materials exportation. Here, the products needed to respond to a specific use, large quantities and low prices. After the Petroleum and Banana Boom, the Digital Revolution and the introduction of the dollarization, Ecuador reached the international level of mechanical and electro-mechanical production processes. This required that new products need to meet new necessities, such as beauty and the customization for different users need.

As a conclusion, the development of a new product, been a façade system for this research, must meet current local Ecuadorian requirements. Where, not only large quantities of components must be produced to allow a cheap production, but also customization for different user's needs.

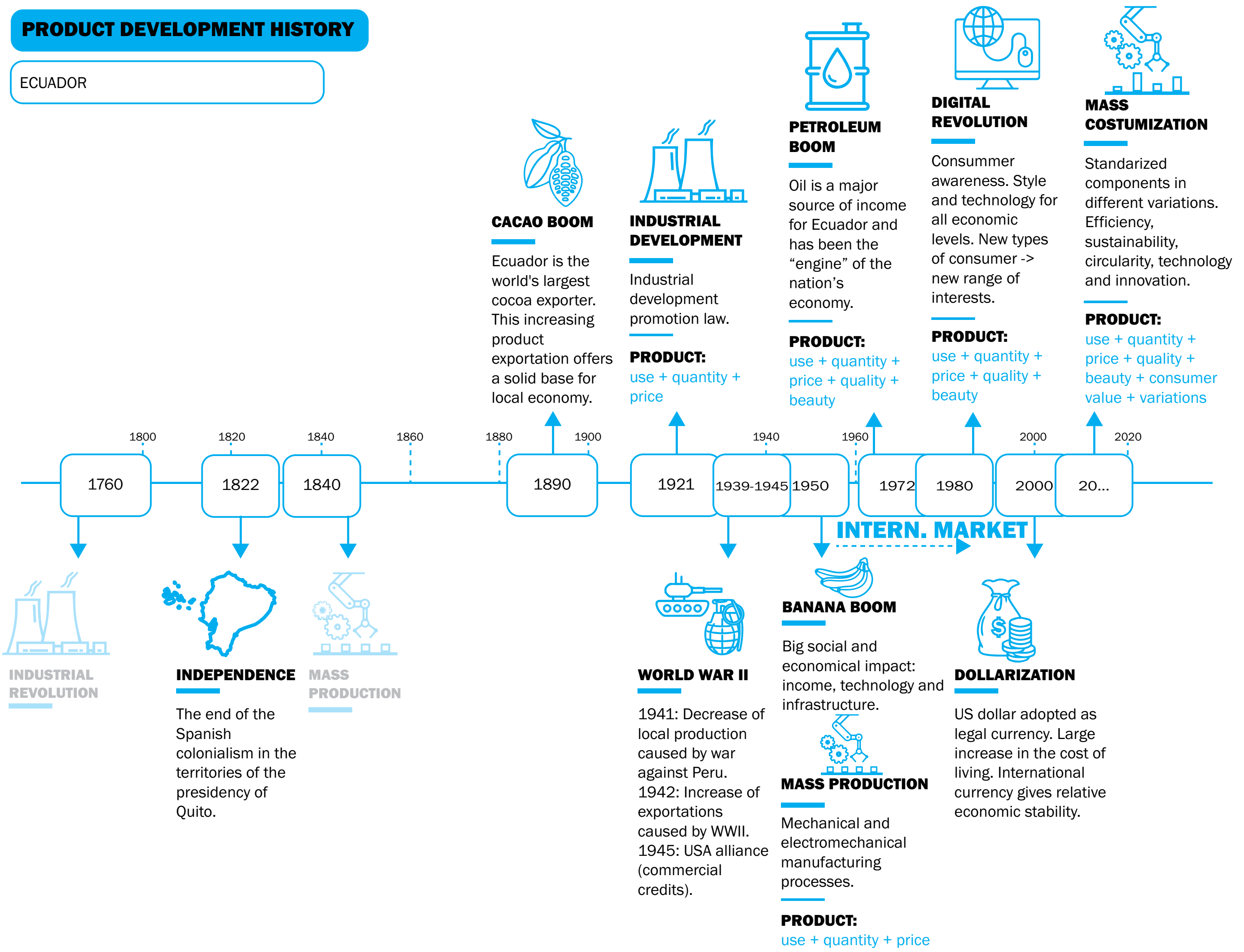


Figure 6: Timeline of Product Development impact in Ecuador. Own illustration

IV

4. CONTEXT & REQUIREMENTS

4.1. FAÇADE FUNCTIONS

The performance of the components of a building envelope cannot be adequately categorized utilizing only static performance metrics, such as U-values and g-values (F. Pacheco Torgal, 2016). This is due to the fact that in climate customized façades the variations of these parameters, due to the changing context, cannot be omitted.

Thomas Herzog, on his Façade Construction Manual (2017), states that facades are protective shells, offering protection from weather and enemies, and have been the first and most important reason for building. His manual presents the main functions of a building's envelope, from the outside to the inside. The envelope should include functions that offer protection from large fluctuations on the external climate conditions (solar radiation, air temperature, humidity, precipitation and wind) and provide minimal fluctuations in the internal climate conditions (comfortable temperature and humidity levels, quantity and quality of light, the inflow of fresh air and tolerable airspeeds, comfortable acoustic environment, provision of view of the outside, separating the private from the public, mechanical and fire protection).

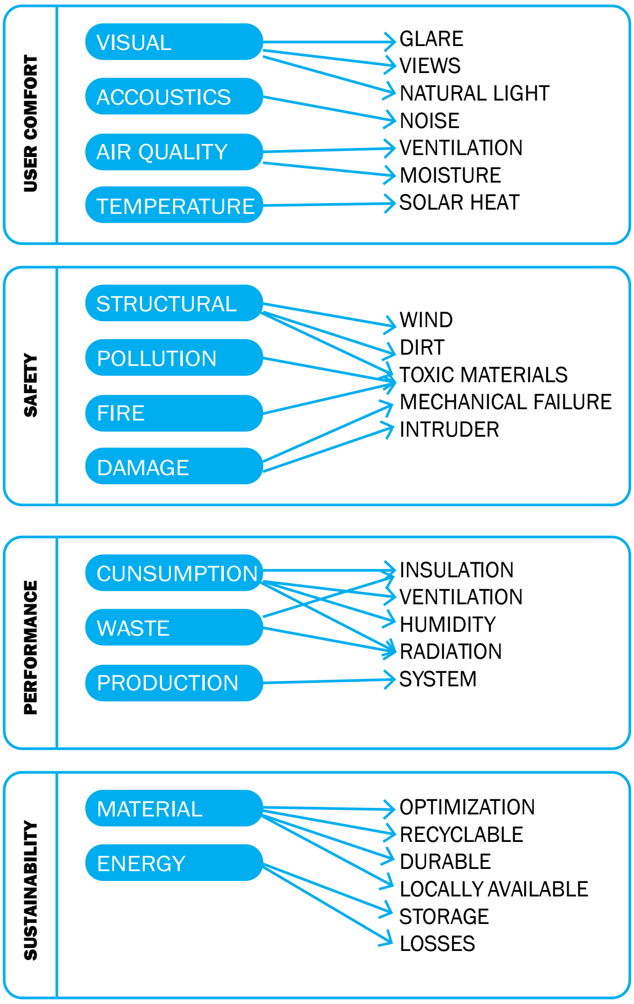


Figure 7: Façade functions categories. Own illustration.

This research focuses on the user's comfort requirements, with sustainability as the base for the design process.

4.2. THE CLIMATE IN ECUADOR

The first climate factors to be taken into account are the site weather conditions and its variations. Ecuador is located in South America, limits to the north with Colombia, to the south and the east with Perú and to the west with the Pacific Ocean, which separates it from the Galápagos Islands. It is divided by the Andes volcanic mountain range, that crosses the country from north to south, leaving a coastal plain on its western flank and the east, the Amazon.

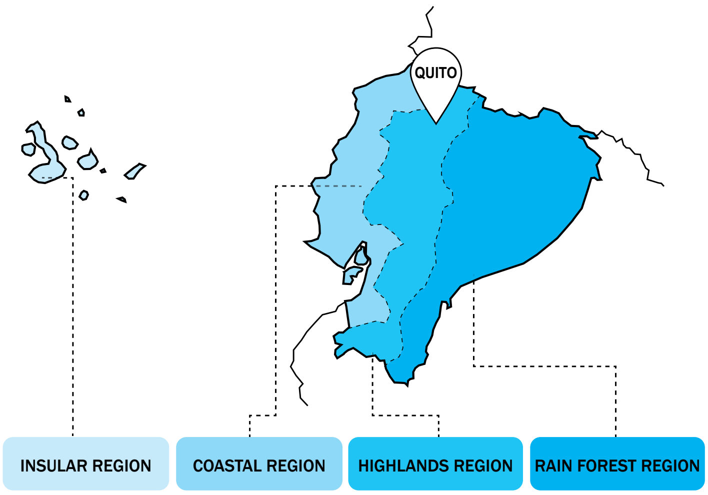


Figure 8: The main climatic regions of Ecuador. Own illustration.

Due to elevation variations of the land, Ecuador shows a difference in climate between the coast and highland areas. The coast and the lowlands feature a lot of jungle and enjoy a tropical climate, whereas the higher inland elevations have a cooler climate. The Andes Mountains represents one of the main features of the geography of the country, with many volcanoes with snow caps. The tropical Amazonian

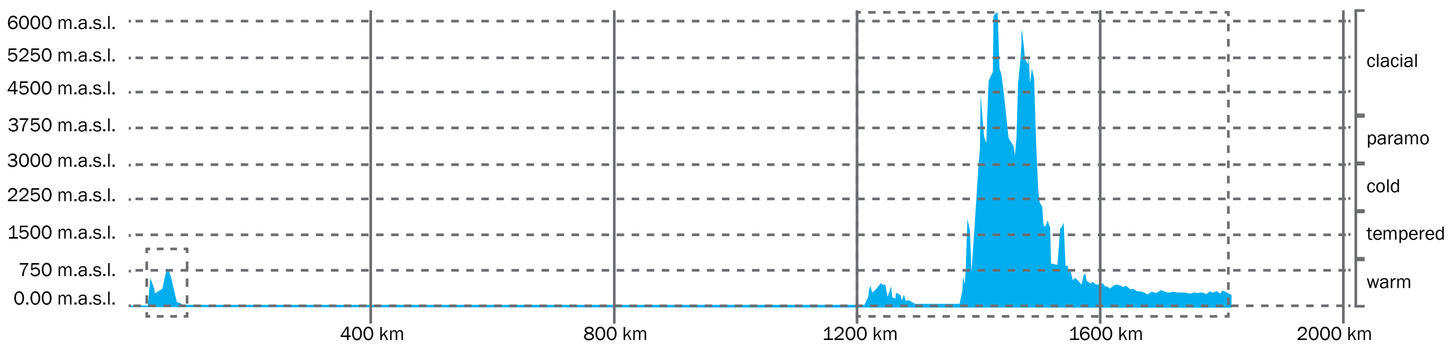


Figure 9: Ecuador's altitude variations and main regions. Own illustration.

area is formed by a dense and green forest vegetation. The volcanoes, scattered across the country, include the Cotopaxi Volcano, which is an active volcano and is 5 897 meters in height, the Pichincha Volcano at 4,784 meters and the Chimborazo at 6,267 meters. The coastal region of the Ecuadorian geography is relatively flat, with altitude level similar to the rain forests.

For a better understanding, a comparison is made with the Netherlands´ climate and geography. With a maximum altitude of 322 m.a.s.l., the Netherlands presents similar climate conditions all over the country. Its variations depend on maritime currents mostly. This is shown in the figure below.

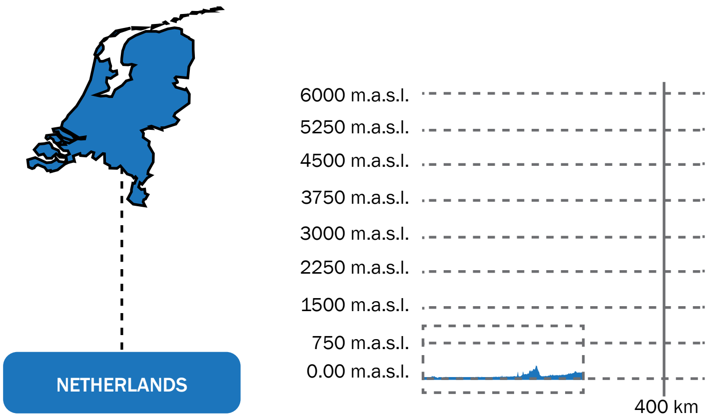


Figure 10: The Netherlands territory and altitude variations, Own illustration

The second climate factor, to be taken into account for this research, is the environment physical variations due to climate change. In 2010 a total of 44500 million tons of equivalent carbon dioxide -6.46 per person- were emitted to the atmosphere. This creates a general trend of increased heat-trapping and warming of the Earth´s surface (ADB, 2013). Over the Earth´s history, the climate has changed considerably due to natural processes, but in the last 50-100 years, these changes have been much bigger and faster than before (P.R. Shukla, 2019).

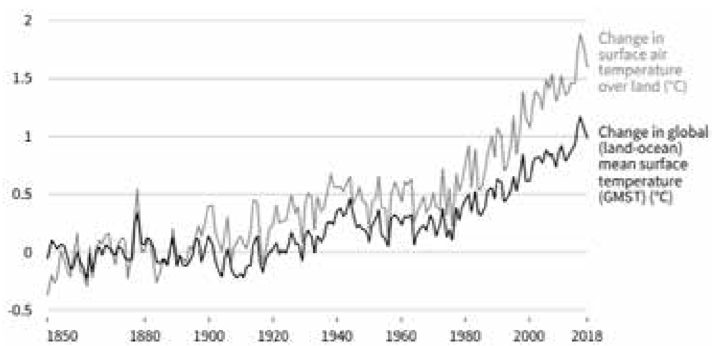


Figure 11: Change in temperature from 1850 to 2018. Source: IPCC, 2018

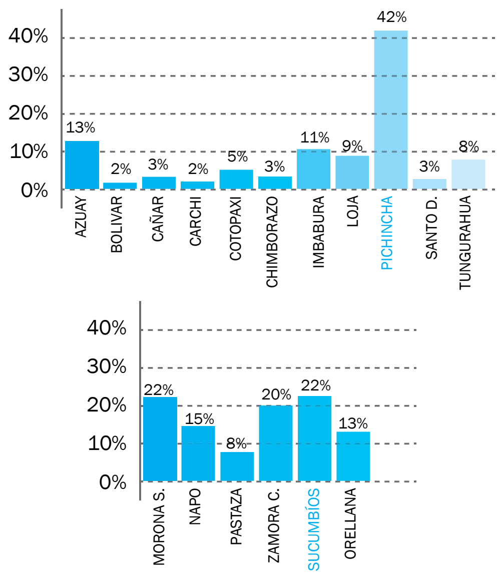


Figure 12: Construction sector growth in the highlands (top) and rain forest (bottom) region. (Camacho & Fraga, 2012)

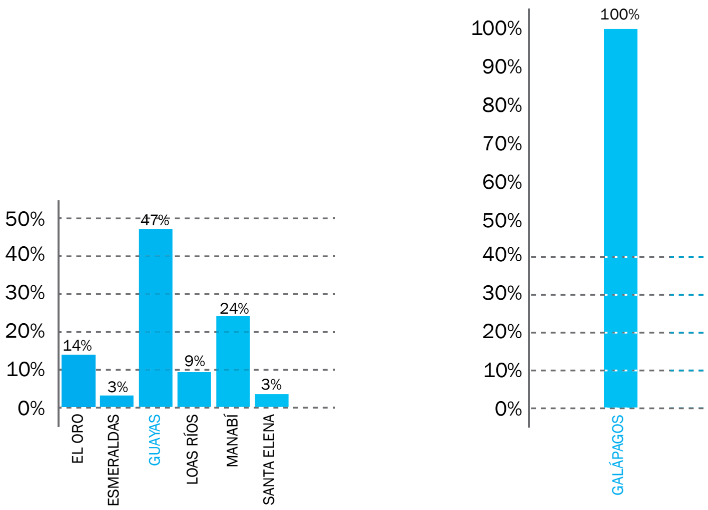


Figure 13: Construction sector growth in the insular (left) and coastal (right) region. (Camacho & Fraga, 2012)

An analysis of each region compares its construction sector growth, number of inhabitants, climate conditions and its variations. As shown in chapter 1.1.2, the rapid urban population growth demands a fast and sustainable housing development. The main four climate regions and its construction sector growth per provinces are shown in the following figures.

The four main regions are detailed in this section. First, a province in each region is taken as an example. This way, more accurate climate data can be detailed. Then, the main climate differences are explained to combine similar ones and take the most representative and extreme climate conditions in Ecuador.

- Insular region (31 000 inhabitants): Galápagos Province (25 000 inhabitants)

- Coastal region (8 304 000 inhabitants): Guayas Province (3 573 000 inhabitants)

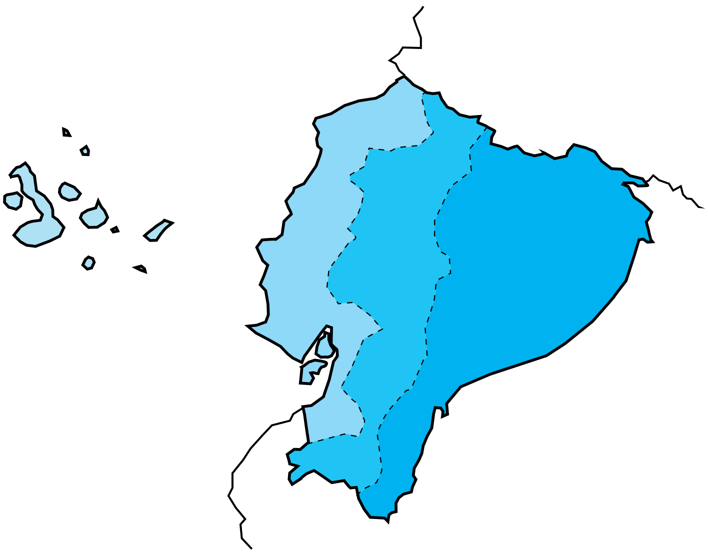
- Highlands region (7 505 000 inhabitants): Pichincha Province (2 577 000 inhabitants)

- Rain forest region (899 000 inhabitants): Sucumbíos Province (177 000 inhabitants)

It can be concluded that the Coastal and the Highlands regions are the most populated ones, with the highest growth in its construction sector. Therefore, the most relevant locations for this research to improve the indoor comfort levels of the existing building stock.

The 2017 Ecuadorian Meteorology yearbook, taken from the National Institute of Meteorology and Hydrology in Ecuador, shows the climate characteristics on the four main regions.

First, monthly maximum and minimum air temperature values in each region, are shown in Figure 15. Here, the main two differences are between Pichincha (highlands), with a minimum of 0°C and a maximum of 30°C, and the rest of regions with a minimum of 16°C and maximum 34°C (INAMHI, 2017).



GALAPAGOS INSULAR	0 - 1707 M.A.S.L. 20°C - 35°C WARM/TROPICAL CLIMATE DEPENDS ON OCEAN CURRENTS
COASTAL LOWLANDS	0 - 1700 M.A.S.L. 25°C - 36°C WARM/DRY CLIMATE TO THE SOUTH HUMID TROPICAL TO THE NORTH
ANDES HIGHLANDS	1800 - 6310 M.A.S.L. 7°C - 21°C DRY/SEMI-HUMID TEMPERED CLIMATE WET-HIGH MOUNTAIN COLD CLIMATE
AMAZON RAIN FOREST	100 - 800 M.A.S.L. 15°C - 40°C RAINY TROPICAL FOREST CLIMATE

Figure 15: Four main climate regions in Ecuador. Own illustration.

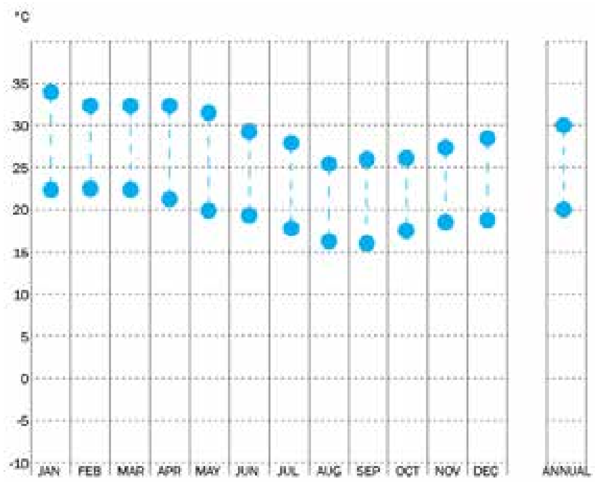


Figure 15: Temperature range: Galapagos-Insular. Own illustration

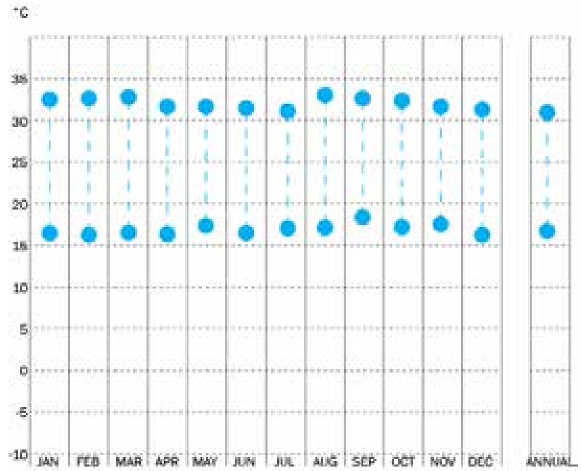


Figure 18: Temperature range: Sucumbíos-Rain forest. Own illustration.

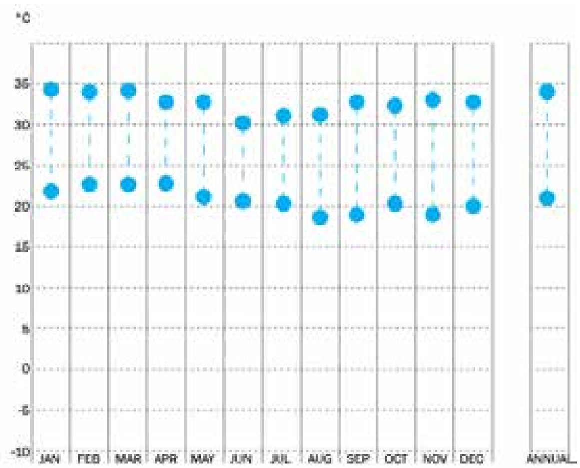


Figure 16: Temperature range: Guayas-Coastal. Own illustration.

Second, the monthly maximum and minimum precipitation values, as well as the annual sum, are analyzed. Here, a different situation appears for the Galapagos and Guayas Provinces: El Niño Phenomenon. It is associated with warm and very wet weather in April to October along the coasts of Ecuador, causing major flooding whenever the event is strong or extreme (WeatherWorld, 2010). This phenomenon values are shown in graphs 14 and 16 by the hollow blue circle.

Here, the main differences are seen between the Rain forest region, with a maximum of 740 mm/m2, and the rest of regions with an average maximum of 350 mm/m2. These conditions vary when El Niño Phenomenon causes high rainy seasons at irregular intervals of two to seven years, and lasts nine months to two years (NOAA, 2009), with a maximum of 1125 mm/m2 (INAMHI, 2017).

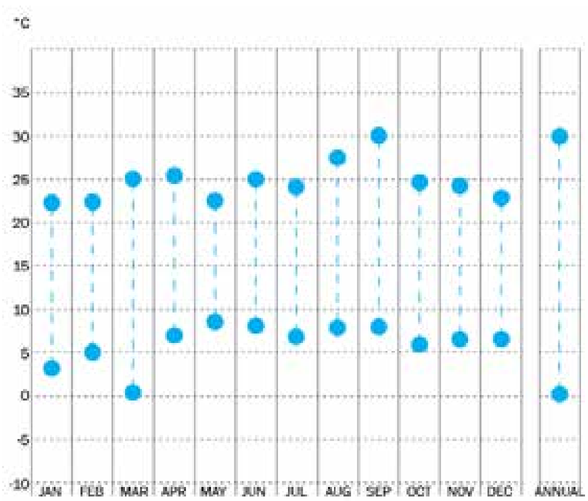


Figure 17: Temperature range: Pichincha-Highlands. Own illustration.

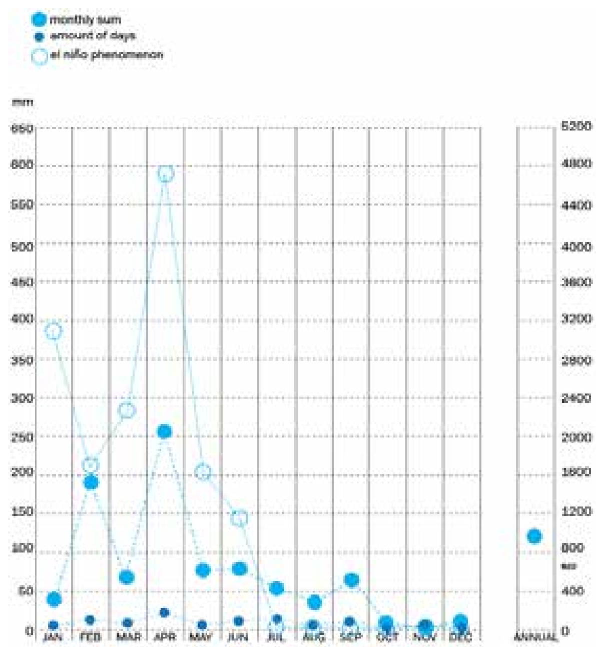


Figure 20: Precipitation: Guayas-Coastal. Own illustration.

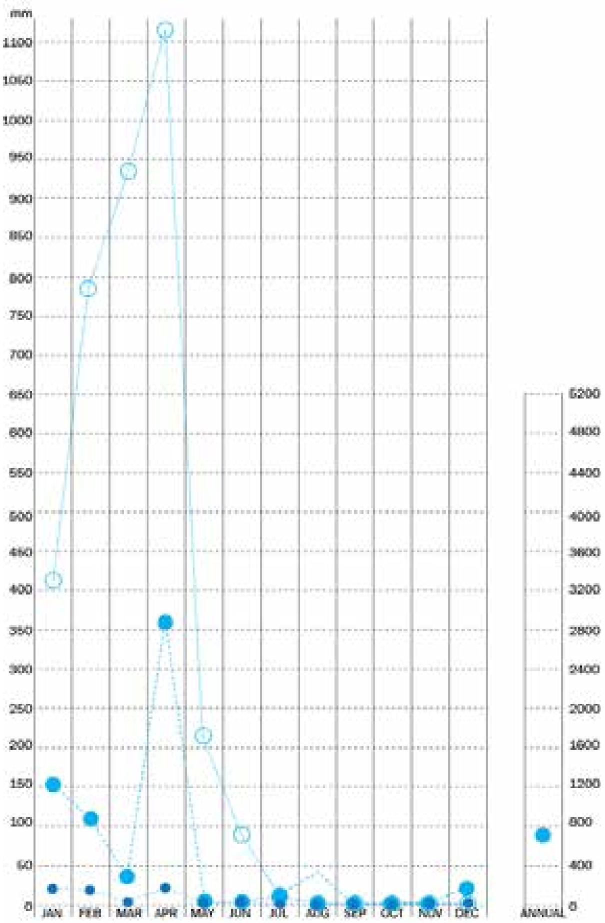


Figure 19: Precipitation: Galapagos-Insular. Own illustration.

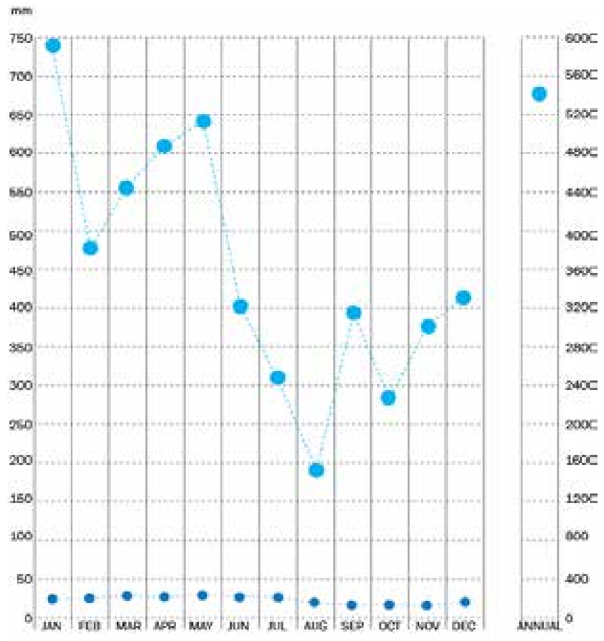


Figure 22: Precipitation: Sucumbíos-Rain forest. Own illustration.

Third, the monthly wind speed and annual sum values are studied. Here, the highest speed stays between 4 and 11 m/s. Speed values below 13 m/s do not represent a threat for structures or construction envelopes. This also includes the rainy and windy season during El Niño in the Coastal and Insular region, with a maximum of 12 m/s (INAMHI, 2017).

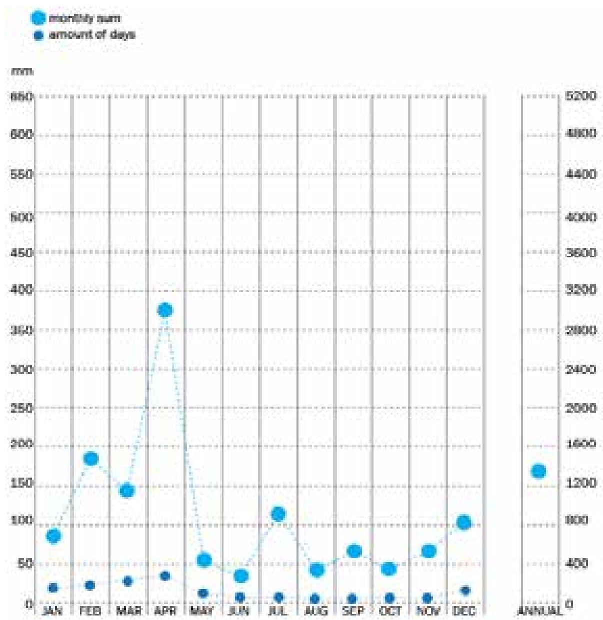


Figure 21: Precipitation: Pichincha-Highlands. Own illustration.

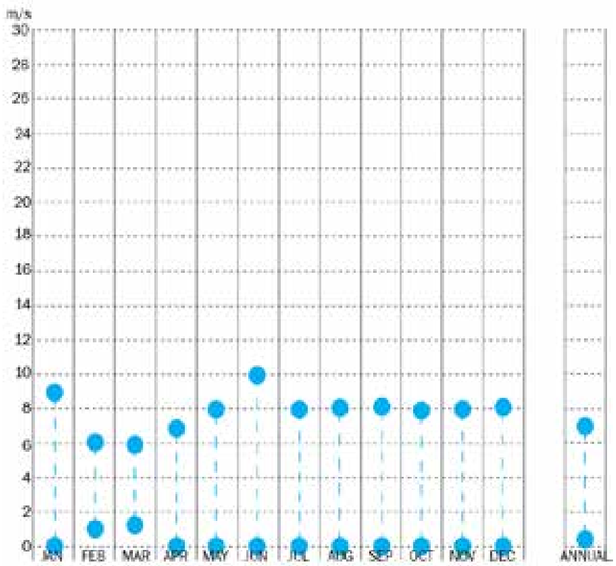


Figure 23: Wind speed: Galapagos-Insular. Own illustration.

Forth, monthly and annual relative humidity data is analyzed. Here, the main difference is found in the Rain Forest, coastal and insular regions, with constant high-minimum relative humidity values around 65%, compared to the Highlands region with more variations between each month, with a minimum of 51% on March and 31% on November (INAMHI, 2017).

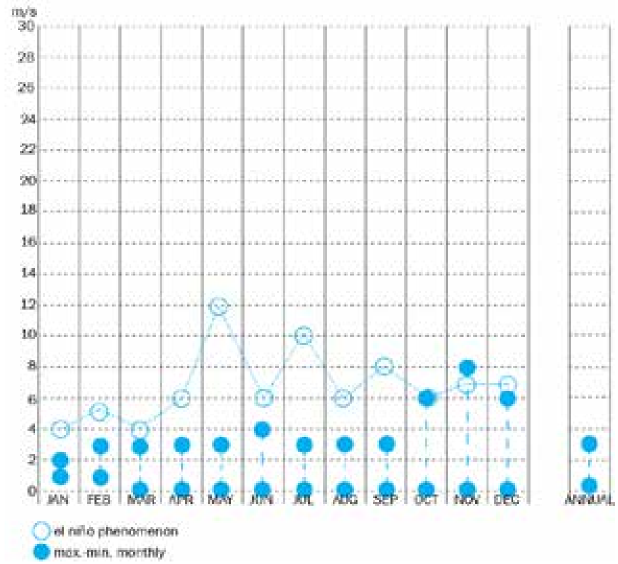


Figure 24: Wind speed: Guayas-Coastal. Own illustration.

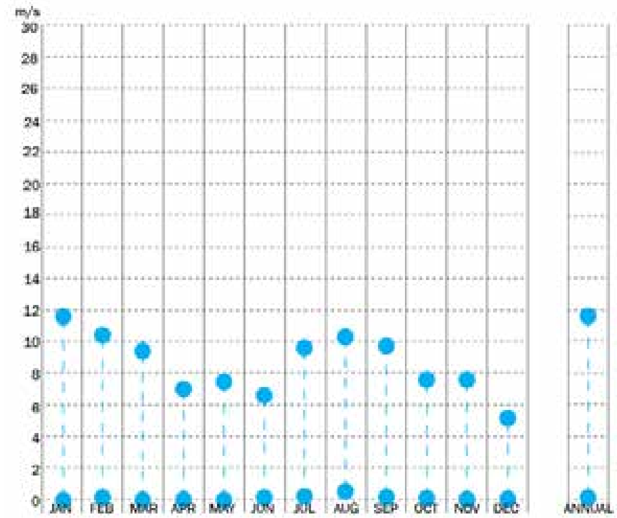


Figure 25: Wind speed: Pichincha-Highlands. Own illustration.

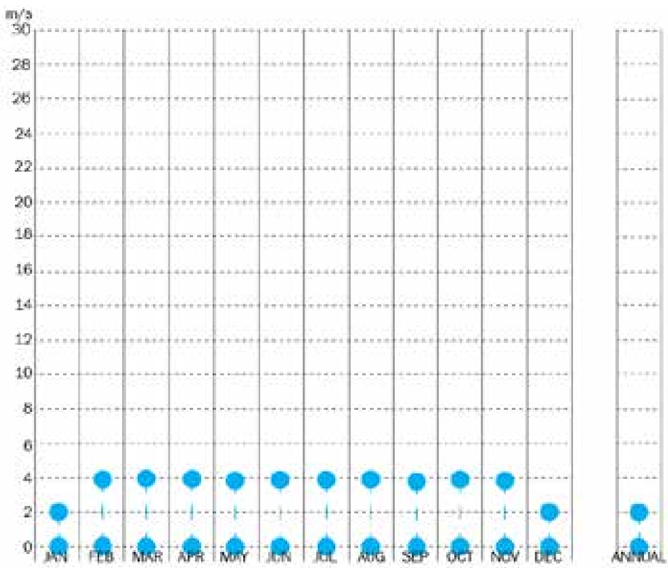


Figure 26: Wind speed: Sucumbíos-Rain forest. Own illustration.

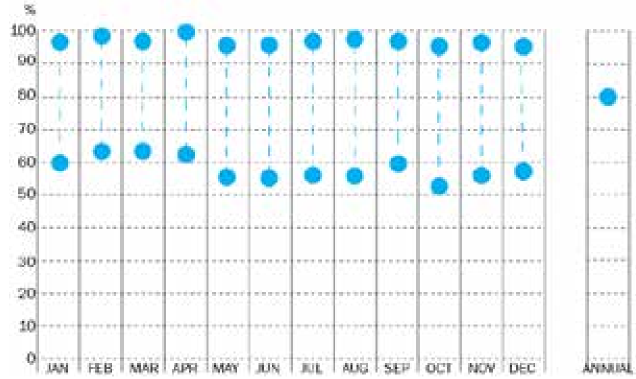


Figure 27: Relative humidity range: Galapagos-Insular. Own illustration.

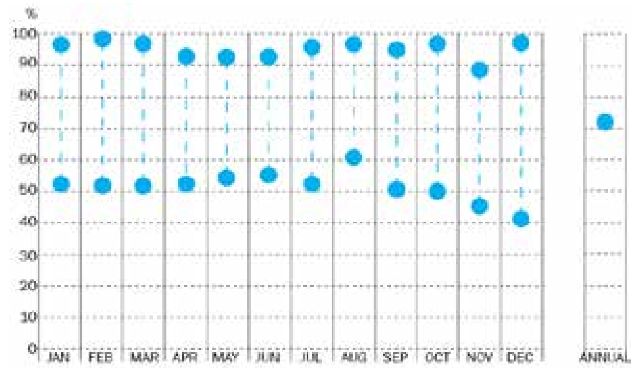


Figure 28: Relative humidity range: Guayas-Coastal. Own illustration.

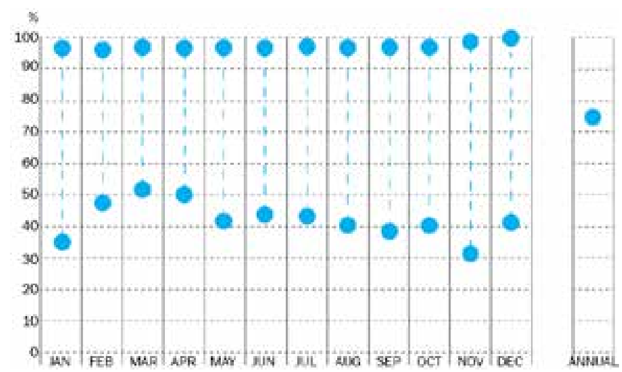


Figure 29: Relative humidity: Pichincha-Highlands. Own illustration.

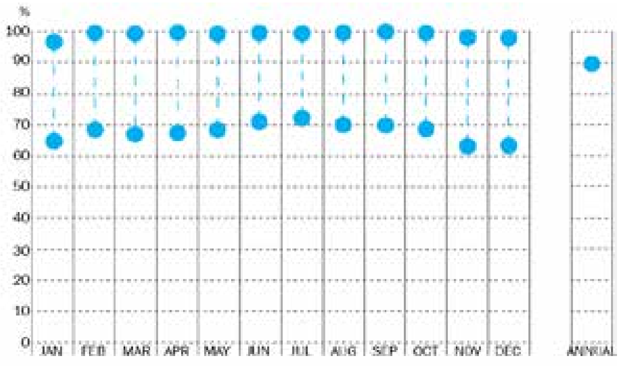


Figure 30: Relative humidity: Pichincha-Highlands. Own illustration.

Finally, the direct sun radiation values are shown in figures 20 and 21. Here, the main difference is found between Highlands/Insular and an annual average of 2000 hours and Coastal/Rain forest with an average of 1100 hours (INAMHI, 2017).

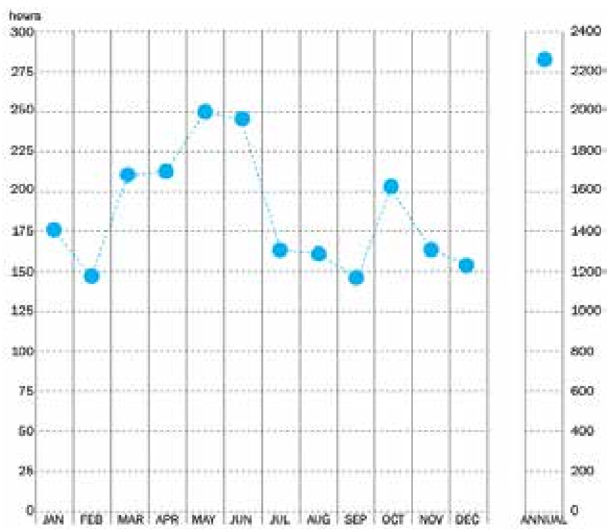


Figure 31: Direct sun radiation: Galapagos-Insular. Own illustration.

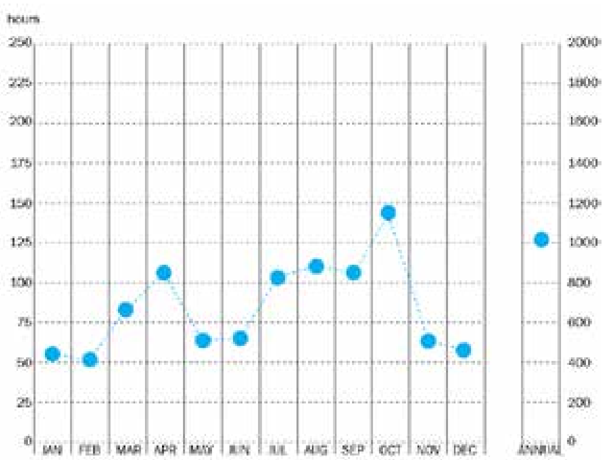


Figure 32: Direct sun radiation: Guayas--Coastal. Own illustration.

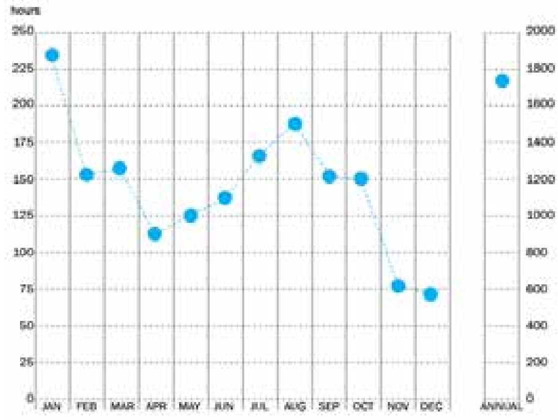


Figure 33: Direct sun radiation: Pichincha-Highlands. Own illustration.

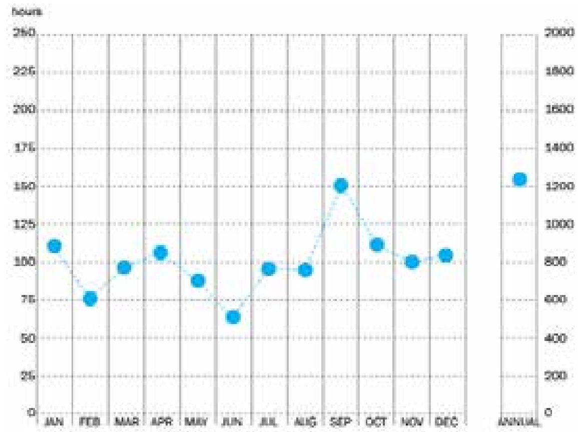


Figure 34: Direct sun radiation: Sucumbíos-Rain forest. Own illustration.

After the detailed analysis of each region, two main climate types can be differentiated:

1- Temperate climate (Highlands Region), with daily temperature variations between 0 and 30°C.

2- Tropical climate (Insular, Coastal and Rain forest Region), with daily temperature variations between 16 and 34°C.

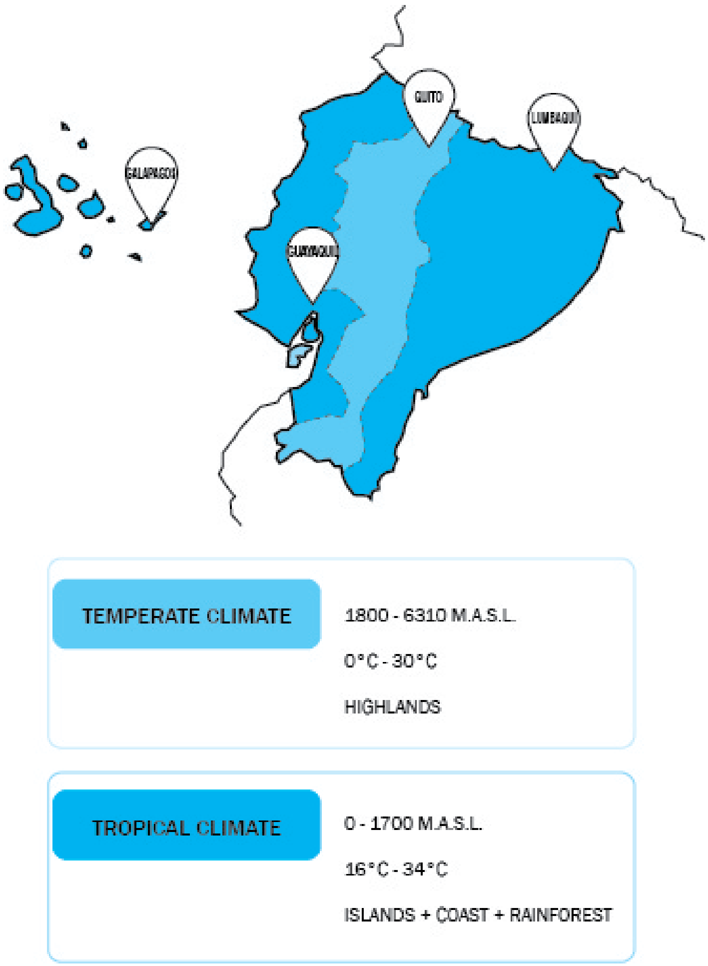


Figure 35: Temperate and Tropical are the chosen climates as the best representatives of extreme climate conditions in Ecuador. Own illustration.

In conclusion, the main fluctuations are found in the temperature values, between daytime and night-time. The Temperate climate is defined by its minimum temperature near 0°C but below 18°C, also with maximum temperatures of 30°C, constructions located in this type of weather, can present discomfort values for the user at its peak outdoor temperatures. This change in temperature and the high level of direct solar radiation provides the opportunity for passive cooling and heating solutions.

On the other hand, the Tropical climate presents high temperatures all year long, also with day and night time variations between 16 and 34 °C. Constructions need to be protected mainly from the high levels of direct solar radiation and open to natural ventilation.

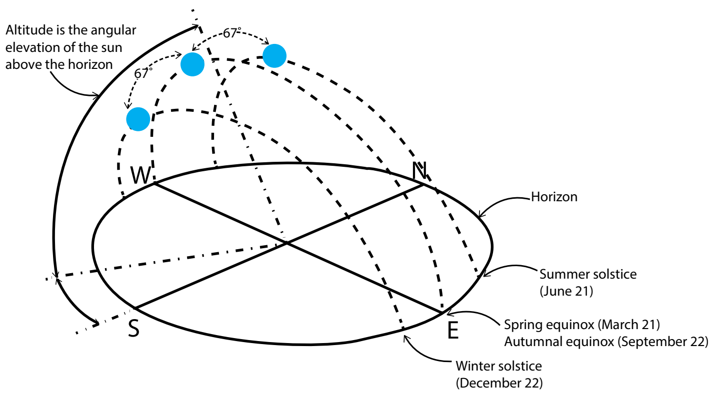


Figure 36: Sun path across Ecuadorian territory. Own illustration.

Site analysis is the process of studying the contextual parameters that influence the location of a specific building, layout, orientation, shape and enclosure. The climate parameters analysed and compared between the two main climate types are:

1. Altitude
2. Precipitation
3. Wind direction
4. Wind speed
5. Relative humidity
6. Sun path
7. Direct solar radiation
8. Air temperature
9. Resistance to earthquakes
10. Resistance to storms
11. Resistance to floods

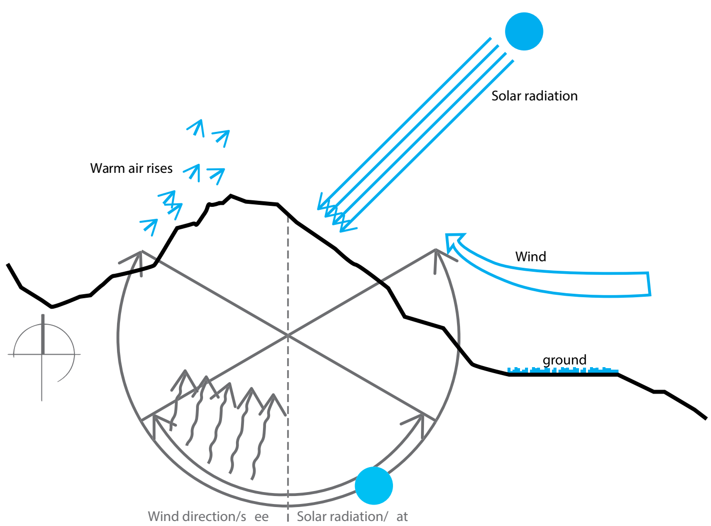


Figure 37: General weather parameters. Own illustration.

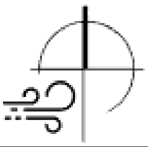
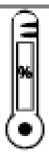
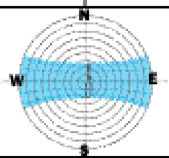
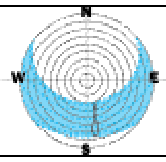
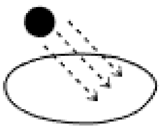
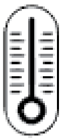
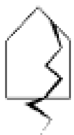
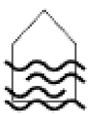
SYMBOL	PARAMETER/UNITS	TEMPERATE CLIMATE	TROPICAL CLIMATE	NETHERLANDS
	ALTITUDE [m.a.s.l.]	1800 to 6310	100 to 800	-7 to 322
	PRECIPITATION (annual sum) [mm/m2]	1350	5400	933
	WIND DIRECTION (preduminant) [N,E,W,S]	morning: south afternoon: north	morning: south afternoon: north	west to south-west
	WIND SPEED (average/max. monthly) [m/s]	5 (average) 20 (max.)	1.1 (average) 4 (max.)	4 (average) 33 (max.)
	RELATIVE HUMIDITY (average monthly) [%]	75	90	86
	SUN PATH (altitude, azimuth) [°]			
	DIRECT SOLAR RADIATION (annual sum) [hours]	1750	2250	1550
	AIR TEMPERATURE (daily min. and max.) (winter vs summer) [° C]	0 to 30 daily	16 to 34 daily	-7 to 11 daily winter 23 to 32 daily summer
	RESISTANCE EARTHQUAKES (advice) [on/off]	ON high	ON high	ON low
	RESISTANCE STORMS (advice) [on/off]	OFF	ON low	ON medium
	RESISTANCE FLOODS (advice) [on/off]	OFF	ON medium	ON low

Figure 38: Climate parameters: detailed and compared with the Netherlands. Own illustration.

4.3. THERMAL COMFORT

The goal of this research is to improve the indoor comfort levels of existing constructions in Ecuador, by designing a façade system that can be placed on an existing one while responding to the two main climate regions of Ecuador. One with high temperature and humidity levels, all year long (Tropical Climate), and a second one with daily fluctuating temperatures (Temperate Climate).

The final performance of the proposed design will be assessed under specific thermal comfort levels for occupants. These levels are based on the Adaptive comfort model, where it is proven that if a change occurs that produces discomfort, people react in ways which tend to restore their comfort (Santamouris, 2013). As a result, the acceptable comfort range is widened than the expected from previous international comfort standards.

A distinction is made between building alpha and beta. Alpha is used for buildings in which the windows can be opened and where the users can influence the indoor thermal climate. While beta applies to buildings with sealed facades and centrally controlled air conditioning. As far as the maximum and minimum admissible indoor temperatures are concerned, the limits relate to the operational temperature, accepted as the mathematical average of the air temperature and the radiation temperature. (Linden, 2013).

The starting point for a standard situation is an 80% level of acceptance of the limits. This can be raised to 90% for buildings where an extra high level of quality is sought. The limits for 65% acceptance can be used as a reference point for existing buildings (measurements in older buildings following complaints), or for temporary (emergency) buildings - these limits should not be breached. However, in all cases, it has to be accepted that the occasional transgression will occur in exceptionally hot periods, to prevent the need for installing extremely large items of equipment. (Linden, 2013)

Here, it is stated that the minimum indoor temperature to reach adaptive comfort can be 18°C and the maximum 32°C.

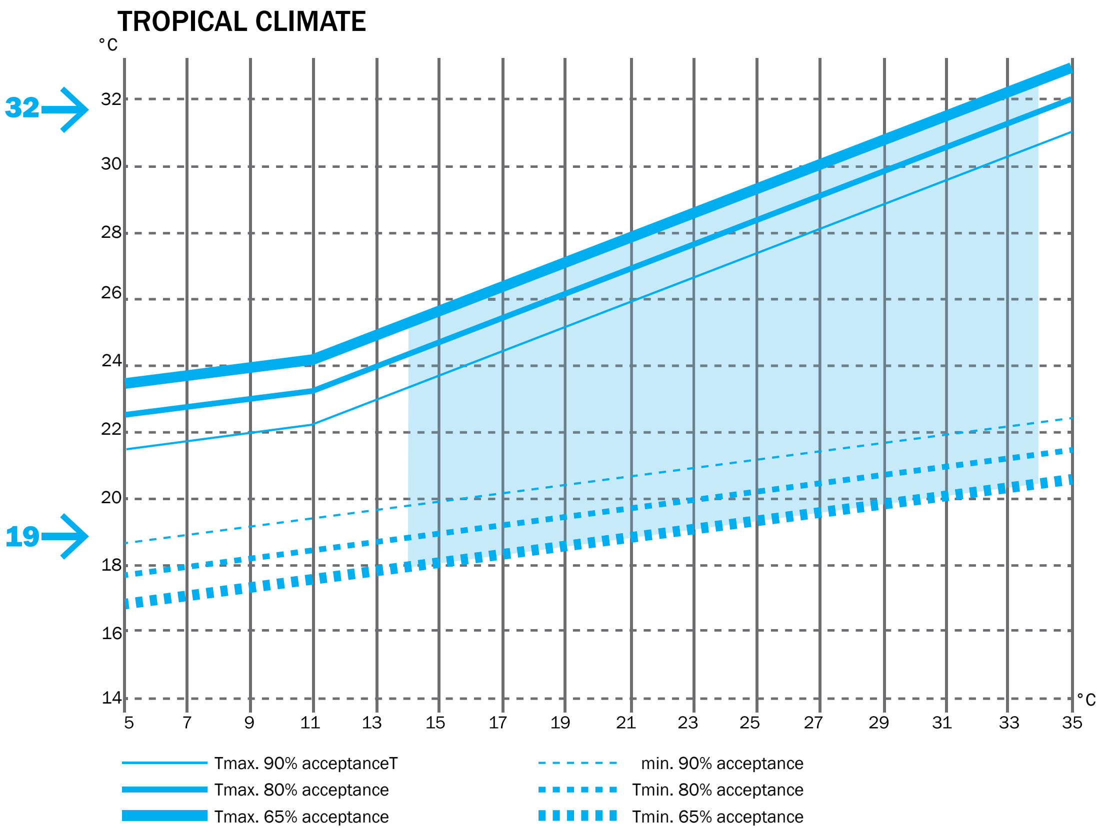


Figure 38: Adaptive comfort chart for a Tropical Climate. Own illustration.

On the other hand, in a Temperate Climate, the minimum indoor temperature can be 16°C and the maximum 31°C. During the season when heating may be used (with average outdoor temperatures below 10 to 15 °C), there is effectively no such thing as an alpha building/climate. The effect of behavioural adaptation (such as clothing) does still play a role, but psychological adaptation no longer does so. For that reason, the same operational temperature is used for alpha buildings/climates as for beta types, when Tout is below 10-12 °C.
The lower limits for 65, 80 and 90% acceptance levels have been included in the graph, shown with dotted lines. For both alpha and beta types of building/climate, the lower limits for buildings with sealed facades are used. Where the lower limits are approached, it is assumed that the perception of the building's users, in both types, will be around the same and that the windows will be closed. The figures apply to a general office setting and other comparable situations (Linden, 2013).

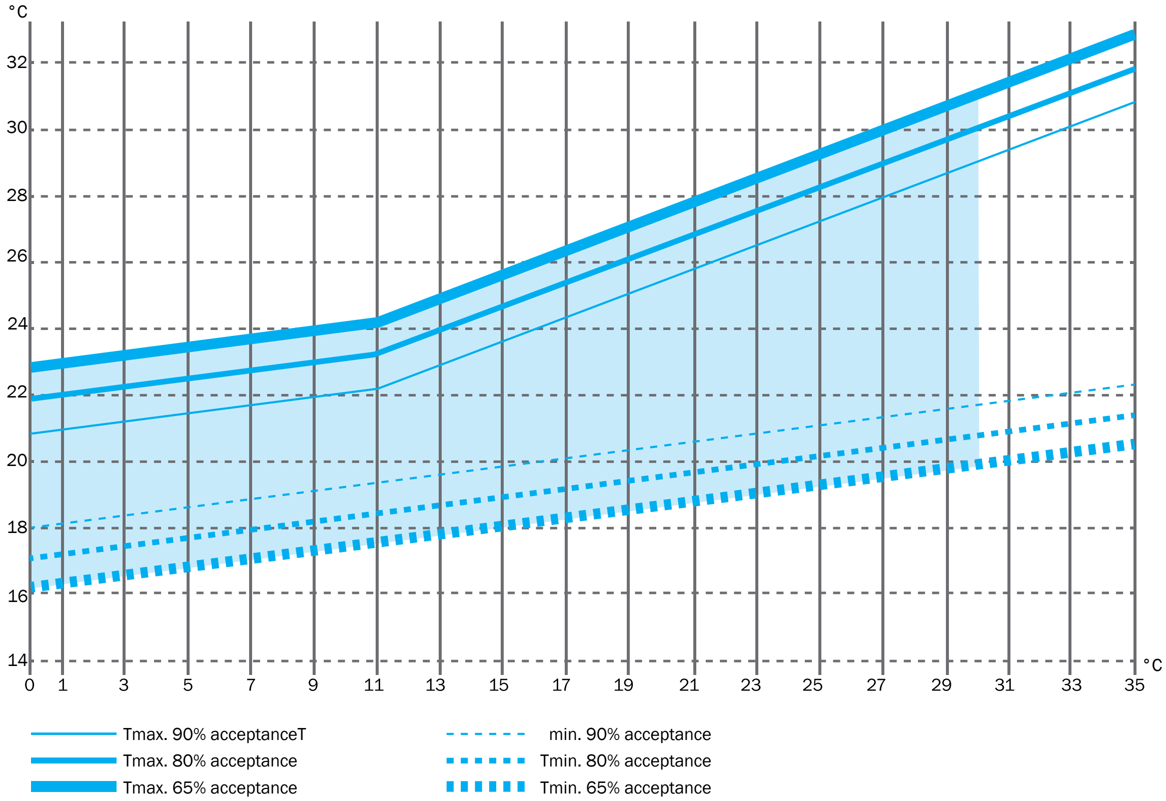


Figure 39: Adaptive comfort chart for a Temperate Climate. Own illustration.

4.4. FAÇADE TYPOLOGIES IN ECUADOR

Here, a study on the local façade typologies is shown. This shows relevant information to be considered when designing a façade system to improve these existing constructions.

The majority of the building stock in Ecuador is made out of concrete hollow blocks or bricks. These elements are the most economic and available ones around the country.
Contemporary architecture designers are reinterpreting the use of this construction element and producing innovative designs with low construction costs.

There are different construction elements used, for example, precast concrete, adobe, metal finishes, etc. The most common one remains been the concrete hollow blocks, for its economic and availability value.

Figure 40: Local private and social buildings with concrete blocks.
Source, Cabezas, 2018

4.5 LOCAL FAÇADE SYSTEMS

An overview of the most common building systems used in each region of Ecuador is analysed to understand its specific characteristics. A classification of on-site building systems is shown below.

The most used on-site system is the concrete block and brick. More traditional construction systems can be found around the different regions, where vernacular architecture is used to respond to specific weather parameters.
A classification of prefabricated building systems is analysed below, including local and imported technologies.

A clear trend for sandwich panels can be seen, when using prefabricated systems. Two solid layers are combined as a component, either by an insulation material or an air cavity. Most of these prefabricated systems are imported to Ecuador, with the exemption of the first one (Wooden Panels). This wooden sandwich is produced by a local architecture studio for a residential project, which is located in the Highlands Region.

In conclusion, contemporary construction systems respond completely to a low price and time necessity. Where a standardized component is replicated multiple times to produce a building´s envelope in minimum time and budget. On the other hand, the vernacular construction systems found in Ecuador, respond to the specific weather characteristic of the construction site. Therefore, an analysis of this type of architecture is shown in the next section.

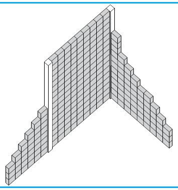
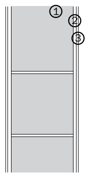
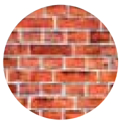
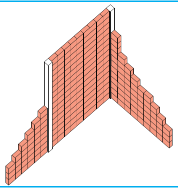
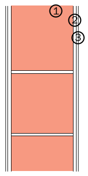
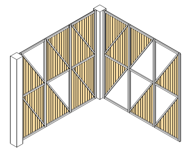
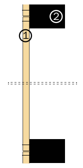
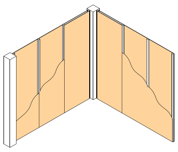
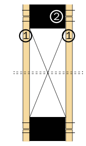
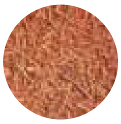
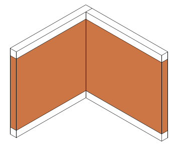
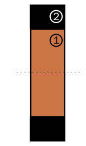
	MATERIAL	3D VIEW	LAYERS	GALAPAGOS INSULAR	COASTAL LOWLANDS	ANDES HIGHLANDS	AMAZON RAIN FOREST
BUILT ON SITE	CONCRETE BLOCKS 		 ① CONCRETE WALL ② PLASTER LAYER ③ PAINT LAYER	✓	✓	✓	✓
	BRICKS 		 ① BRICK WALL ② PLASTER LAYER ③ PAINT LAYER	✓	✓	✓	✓
	BAMBOO 		 ① BAMBOO ② WOOD	✓	✓	✗	✓
	WOODEN PANELS 		 ① MDF/OSB ② WOOD/METAL	✗	✗	✓	✗
	RAW EARTH 		 ① ADOBE ② CONCRETE	✗	✗	✓	✗

Figure 41: Current on-site building systems by region. Own source

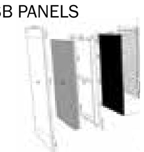
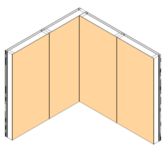
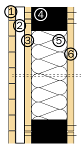
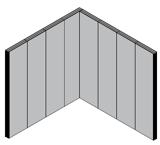
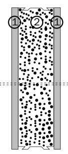
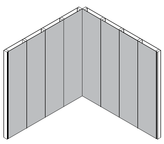
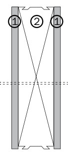
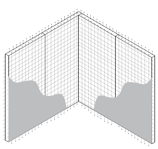
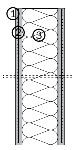
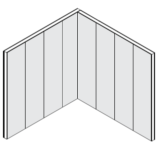
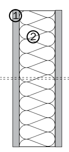
	MATERIAL	3D VIEW	LAYERS	GALAPAGOS INSULAR	COASTAL LOWLANDS	ANDES HIGHLANDS	AMAZON RAIN FOREST
PREFABRICATED	MDP/POLYSTYRENE/ OSB PANELS 		 ① CHARRED TIMBER CLADDING ② PINE STRIP ③ OSB ④ PINE STRUCTURE ⑤ PILYSTYRENE ⑥ MDP	✗	✗	✓	✗
	FIBER REINFORCED CONCRETE/ POLYSTYREN PANELS 		 ① FIBER CEMENT ② CONCRETE-POLYSTYRENE	✗	✓	✓	✗
	GYPSUM/CAVITY PANELS 		 ① FIBER REINFORCED CONCRETE ② CAVITY	✓	✓	✓	✗
	HORMI2 		 ① CONCRETE POURED ON SITE ② METAL MESH ③ POLYSTYRENE	✗	✓	✓	✗
	STEEL/POLYURETHANE OR POLYSTYREN PANELS 		 ① FIBER REINFORCED CONCRETE ② POLYSTERENE	✗	✓	✓	✗

Figure 42: Current prefabricated building systems by region. Own illustration.

4.6 VERNACULAR ARCHITECTURE

In this section, examples of vernacular construction systems are presented. This information presents important knowledge that can be applied to contemporary and innovative façade systems. This way, the advantages of the new technologies can be exploited while designing a façade system that responds to a specific location.

The first climate type is the Temperate Climate, where low temperatures are reached at night time and high temperatures at day time. Examples or Temperate Climate architecture are shown below.

Figure 43: Vernacular building systems in the Temperate climate. Own illustration.

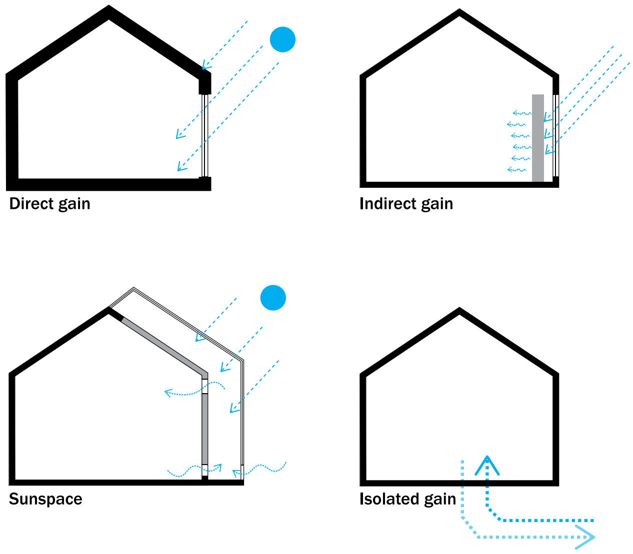


Figure 44: Passive heating strategies used in the Temperate Climate. Own illustration.

These types of constructions are enclosed and heavy. By using thermal mass, the building can storage the heat provided by direct sun radiation during the day. On the other hand, a closed envelop with small opening guarantees the storage of the heat on the inside of the space and fewer heat losses that would occur through a more permeable envelope.

In conclusion, the main heating strategies to be used in a Temperate Climate are direct sun-heat gain and storage. The diagrams below illustrate these design principles. These strategies can be translated into a façade system that allows the entrance of direct sun heat, as well as retaining the heat inside of the building with a multi layered envelope. The diagram below shows different options of a multi-layered envelope that can be opened or closed, depending on the outdoor temperatures.

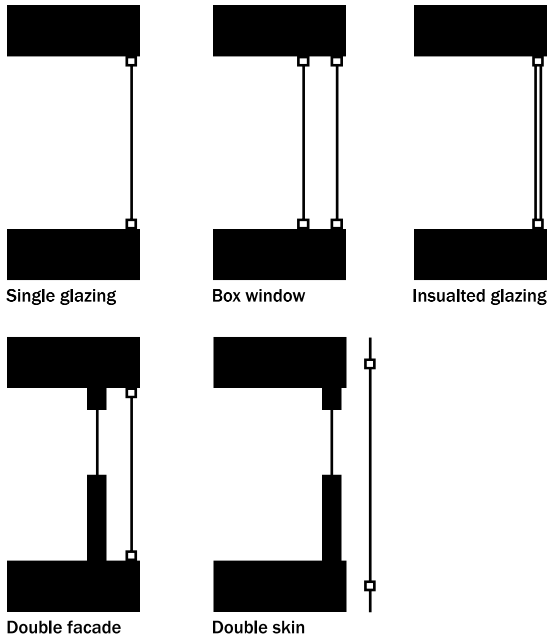


Figure 45: Façade strategies for Temperate Climate. Own illustration.

In the Tropical Climate, the most important strategies are: shading and ventilating. The permeability of the envelope provides constant natural ventilation. The use of large rooftops, projects constant shade on indoor spaces, preventing its overheating. Compared to the Temperate vernacular architecture, the Tropical Climate architecture is much more permeable, light and opened. Examples of projects found in this type of climate are shown below.

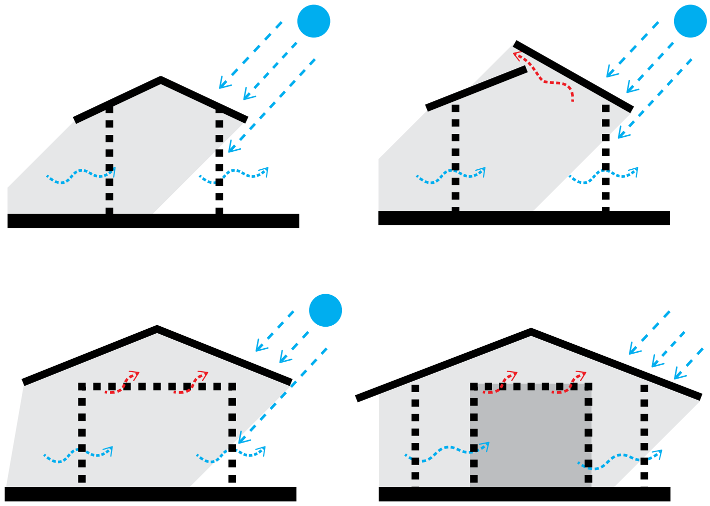


Figure 47: Passive heating strategies used for Temperate Climate. Own illustration.

Figure 46: Vernacular building systems found in the Tropical climate.

In conclusion, the main strategies to be used in a Temperate Climate are natural ventilation and shading systems.
These strategies can be translated into a façade system that blocks the entrance of direct sun heat, as well as allowing the natural ventilation of the indoor spaces. The diagram below shows different options of a multi-layered envelope that can be opened or closed, depending on the outdoor temperatures. Translating these principles to a building´s envelop leads to a permeable façade that allows natural ventilation that, with the use of different types of shading systems, protects the indoor space from the direct solar radiation.

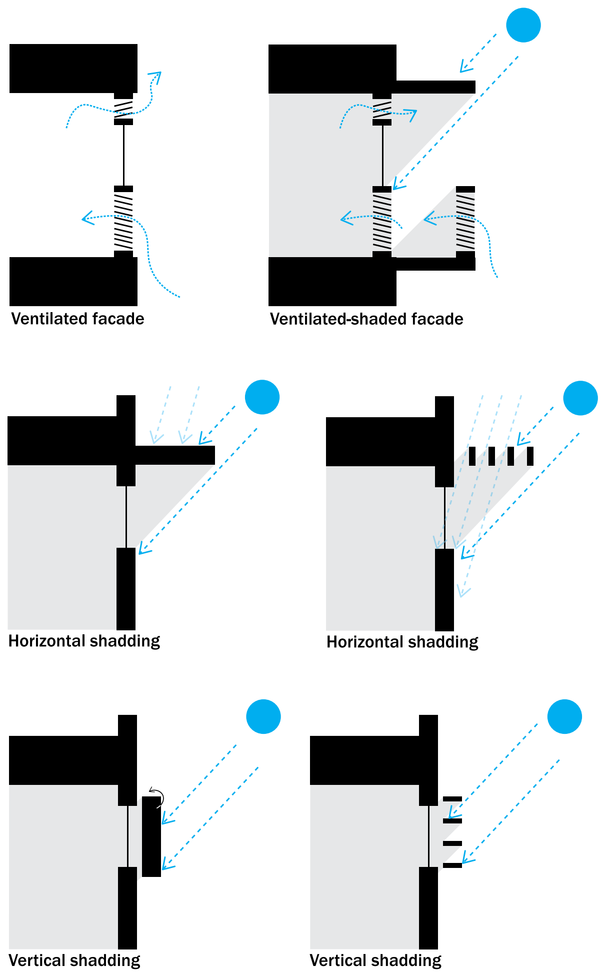


Figure 48: Façade strategies for Tropical Climate. Own illustration.

4.7. CONSTRUCTION STANDARDS

An analysis of the existing building stock needs to be made to gain knowledge about the parameters that the new façade systems needs to meet. Here, the most common façade typologies are simplified in volumes and sections.

This study shows four main façade typologies that can be found across Ecuador´s regions. Starting with the simplest one, the Flat typology is one of the most common ones to be built, with a regular and straight envelope. The variations that this typology can have includes different types and sizes of openings. The most common one can be found all over the country with the standardized curtain wall completely covered with glazed surfaces.

The second is the Terraced typology, with small or large cantilever elements. This typology is very common to be found on informal constructions, where each story gets larger, to get more floor area as the construction goes up.

The third one is the Balcony typology. This is also very common to find all over the country. With different types of balconies, this typology has the advantage of projecting shade into the indoor spaces, while providing outdoor space for the users.

The last one is the Boxes typology, where small and large elements are placed on the envelope to meet with the designer's preferences, instead of responding to the site climatic characteristics.

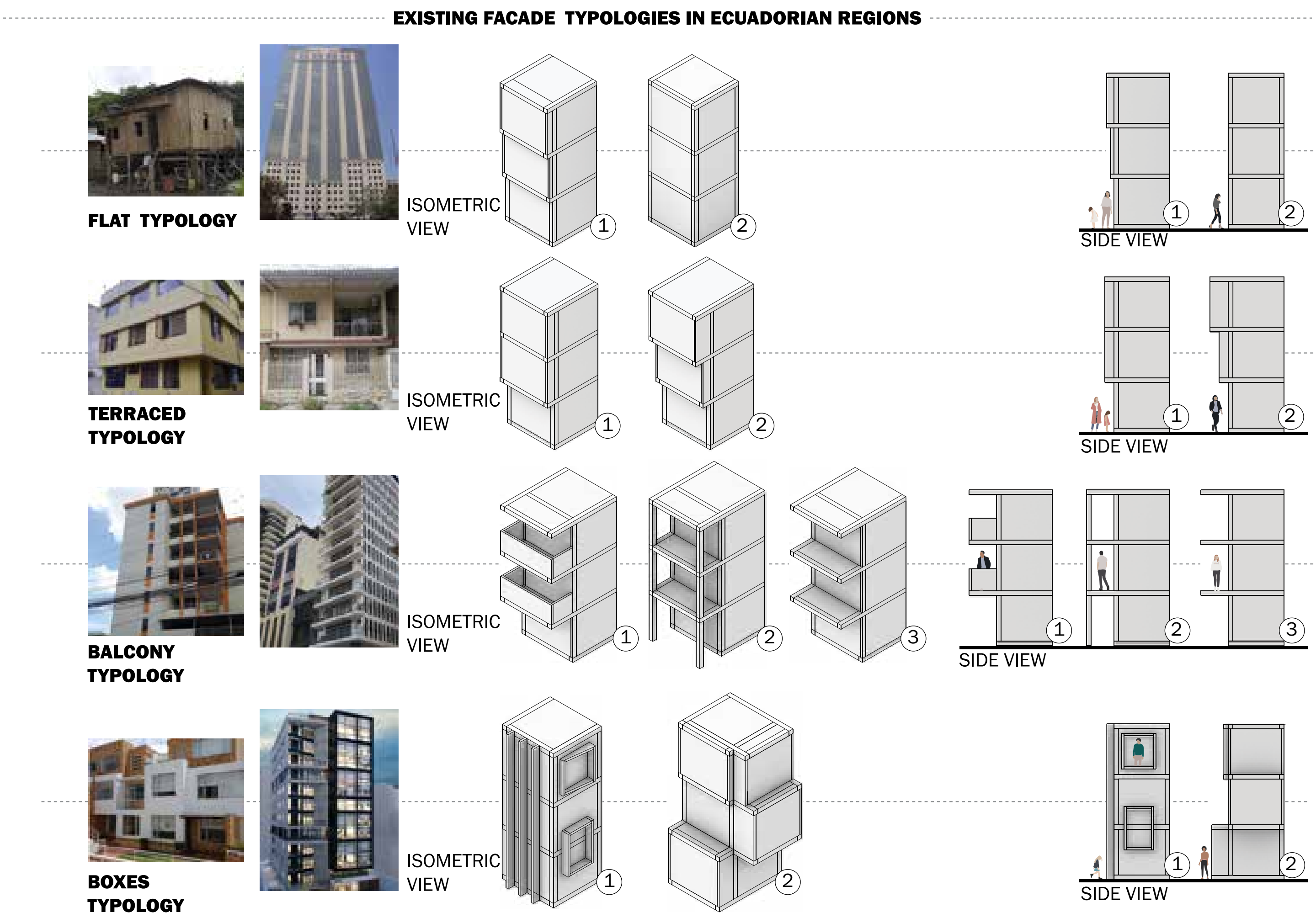


Figure 49: Existing construction typologies. Own illustration.

V

5. FAÇADE REQUIREMENTS

After analysing the location, context and available opportunities, the first approach of requirements is detailed in the following illustration.

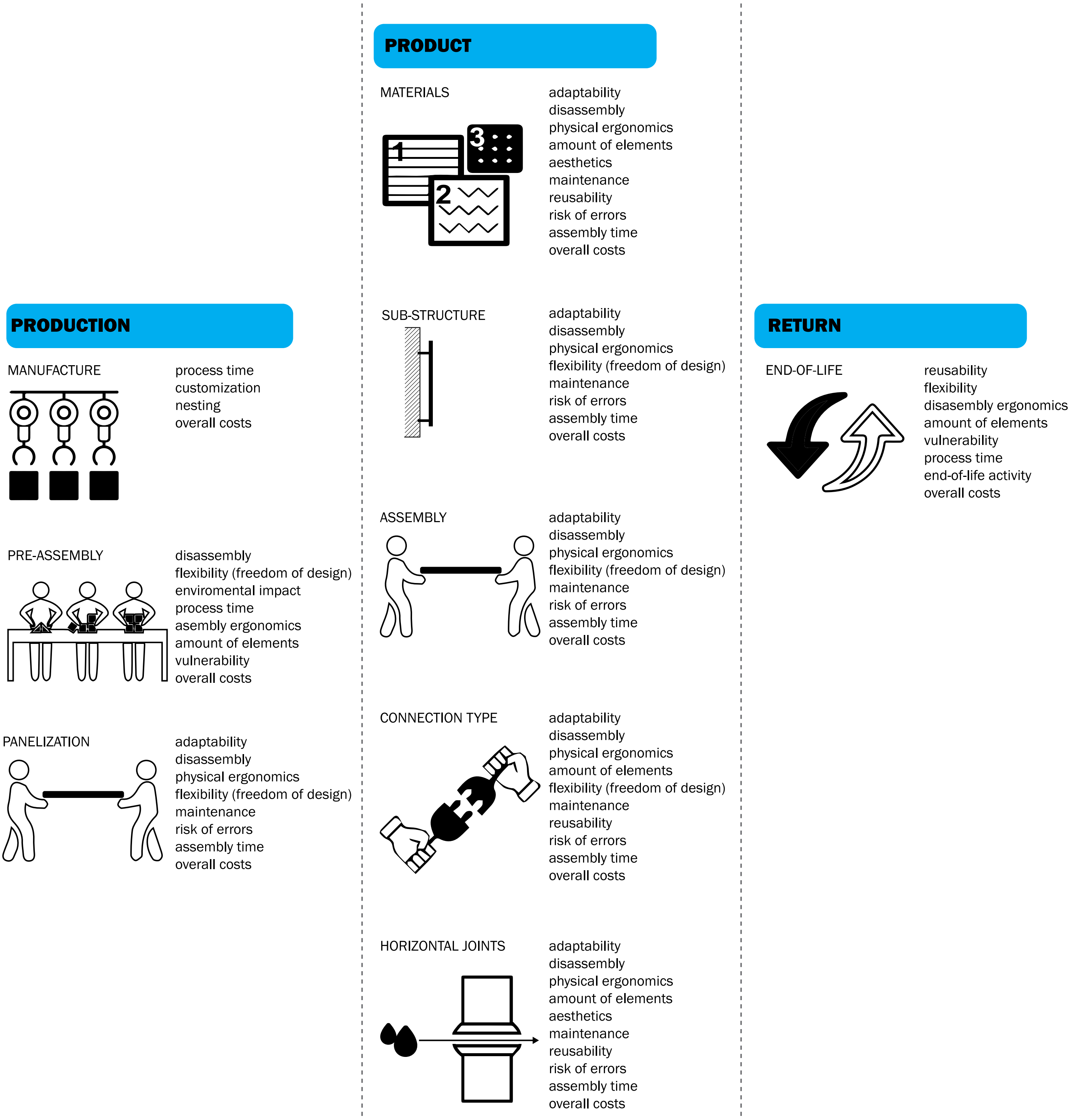


Figure 50: List of requirements for a façade system development. Own illustration.

This list includes all the general requirements that a façade system must meet. Here, great importance to a circular workflow is given, where the production, the product and the return are linked and set as steps within one single process. This allows the project to have a clear base to assess the final product.

To focus this research to a clear final objective, a final list of requirements is detailed in illustration 52. The most relevant requirements are marked with three blue dots. The requiremetns marked with two blue dots are also important for this research but during the design process, these could be neglected or left as secondary, if it is needed.

First, a manufacturing process is presented, where the main factors to be considered is customization of the system and pre-assembly time.

The mass customization responds to the main objective of this research, which is to design a façade system that can be easily personalized to respond to different weather characteristics.

The weather adapatability ensures the right performance of the façade system in different types of climate. The pre-assembly time is important to take into account, thus the production time should be controlled and respond quickly to the market demand. On the other hand, the assembly addaptability of the system is one of the most important objectives of the research, thus the final goal is to renovate the existing buildings of Ecuador. This means that the system must allow the customization, not only for different climate parameters, but also to be placed on different façade typologies.

This research aims to develop a façade system that can be mounted by unskilled labour. So, the disassembly and assembly regonomics are crucial parameters to be met, to assure quick and easy assembly of the system, as well as its reusability.

To transport the façade system easily and reach difficult construction sites, the sizing and vulnerability of the components need to be considered, so a standard transportation unit can carry the system without compromising its safety.

The maintenance and lifespan are important factors to be considered, thus the façade system must be demountable and reusable. Also, a low maintanance and long lifespan guarantees the sustainability and circular workflow of the entire process.

As a result of these requirements, the façade system will be easily demounted, reusable and remanufactured when needed. The design process will take these factors into account within every decision.

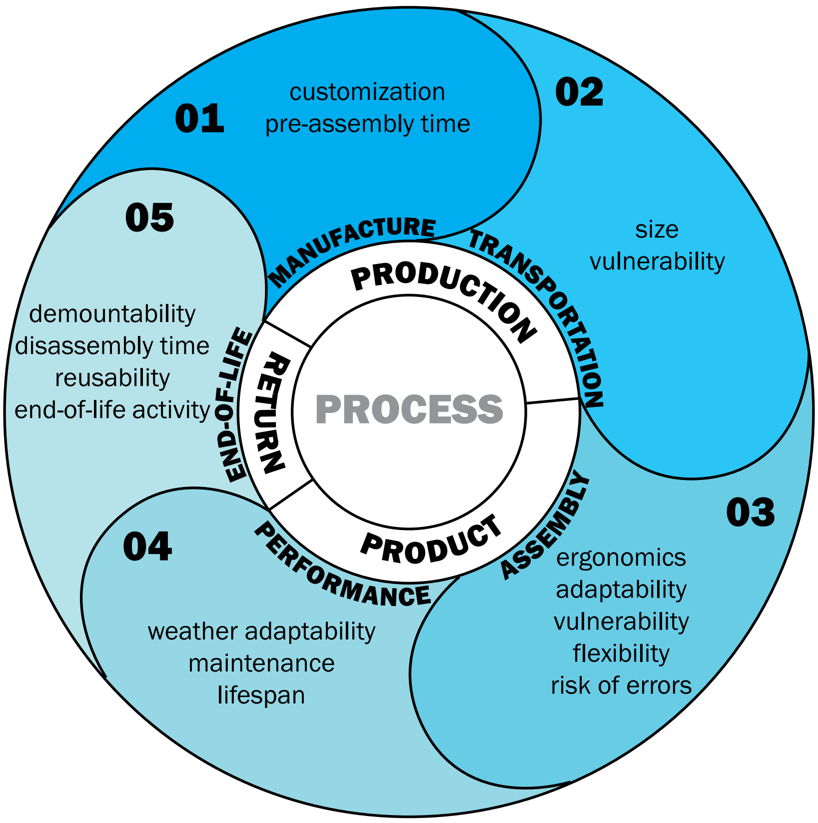


Figure 51: Process criteria. Own illustration.

MASS CUSTOMIZATION

“Is a result of digital technology and manufacturing tool development. The objective can only be realized in its full potential if an end-to-end delivery process is implemented, eliminating potential inefficiencies”.

ASSEMBLY ADAPTABILITY

In order to be successful a “combination of local, economic, and labour factors” must be considered” This research has an specific location with detailed facade typologies to be analyzed for instalation flexibility.

ASSEMBLE ERGONOMICS

“Improved ergonomics in the assembly system will reduced fatigue and increased safety. Amplifing human energy will increase the final output in terms of levels of control, precision, accuracy, and quality.”

TRANSPORTATION

“Major consideration in the design of elements and how they come together in the overall structure, breaking down elements based on shipping limits, types connections, and protection of subassemblies against any damage”.

MAINTENANCE

Involves functional checks, servicing, repairing or replacing of necessary devices, and supporting utilities in the system. If the system need lowe values of maintenance, overall costs decreas and its lifespan improves.

WEATHER ADAPTABILITY

The main focus of this research falls on weather adaptability. It is the ability of the system to be flexible enough to be adapted under different weather or climatic conditions.

DISASSEMBLY

The ability of a system to be disassembled provides the option to reuse it multiple times without damaging the material, joints, panels, modules or components.

REUSABILITY

The reusability and recyclability of building components can lead toward significant reductions in energy, transportation costs, waste; and massive savings of time, frustration, injury, and redundancy on the job site.

VULNERABILITY

The state of panels, modules, and components being exposed to the possibility of being damaged or harmed, either at the manufacture, tranportation, assembly, performance, or end-of-life activity.

PRE-ASSEMBLY DIFFICULTY

“This refers to components, panels, or modules that are pieced together with parts to create elements to be assembled onsite. Factory production must be expedited leaving final assembly to craft of construction as much as possible in the factory and as little as possible onsite”.

IMPORTANCE

Figure 52: Requirements definition and level of importance (by number of blue dots). Own illustration.

VI

6. CONCEPT DEVELOPMENT

In this chapter, a concept for the design is detailed, starting with a preliminary case study, then the conclusions or knowledge that contribute to this research. Finally, the concept development for the façade system design is shown in detail.

6.1. PREFABRICATION CASE STUDIES

An evaluation of four prefabricated building systems is shown in this section. This is a result of literature review, analysis and interpretation. The five case studies are chosen, firstly by its relevance on this research, and by its contribution to façade systems design. The chosen cases include one of the first prefabrication systems, by the architects Wachsmann and Gropius. Then, one of the most common, contemporary and prefabricated systems internationally. Third, a local system that responds to specific weather characteristics in Ecuador. Forth, an example of prefabrication that uses new technologies to provide the mass customization of the system to meet personalized requirements. Finally, a multi-layered façade system that uses modular elements to improve the indoor comfort of constructions.

a. General Panel System

The General Panel system was designed by Konrad Wachsmann and Walter Gropius, both German architects. This system is the one of the most important and first examples of a prefabricated modular construction system. In 1942, this system provided a new level of three-dimensional sophistication. It is formed by a closed system, meaning that it is made of proprietary building materials designed for that system only. Its panels are assembled by the “Jointing System”, which is based on 2-, 3- and 4-way connections between panels. The entire system is based on one panel type that can be used as exterior walls, interior partitions, floors, ceilings and roof.

b. SIP Panel System

The SIP panel is a high-performance building system for residential and light commercial construction. SIP stands for Structural Insulated Panels. It consists of sandwich panels with a foam core between two structural facings. The most common material to be used is OSB. These panels are manufactures under factory-controlled conditions and can be customized to fit nearly any building design. The fact that it is built off-site allows a rapid construction process, where the final personalized panels arrive at the construction site, ready to be mounted and guarantee its performance. One of the main advantages of this system is its easy and quick montage.

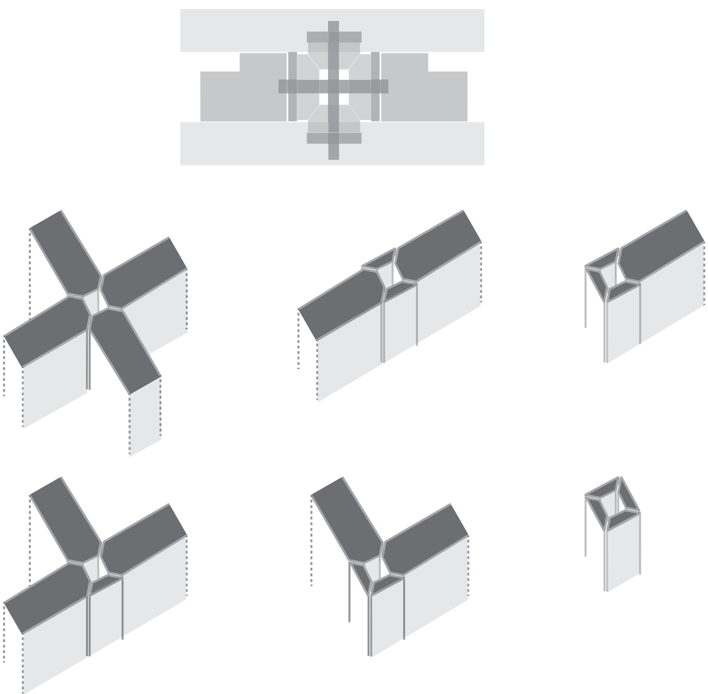


Figure 53: General Panel System connections. Own illustration.

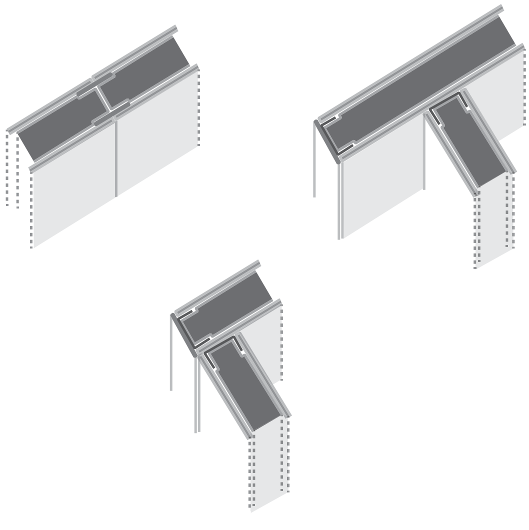


Figure 54: SIP Panel System overview. Own illustration.

c. Charred Wooden Panels

This is a locally produced prefabricated panel. It uses local materials with low-tech assemblies. In this system, 90% of the material used is pine wood. Solid wood for the floor structure, truss walls and mezzanine and OSB boards as the internal and external cladding of the panels. Recycled charred wood is brushed and used for the external cladding to protect the entire structure from the rain.

This system was designed by an Ecuadorian architecture studio for a project located in the Highlands region of Ecuador. This project aims to build your own home with local resources and low technology. Therefore, the mass production was not considered and every panel was built by hand by unskilled labour. It explores a multi-layered panel with a cladding on the outside and an insulated sandwich panel on the inside. One of the benefits of this system is that the components are light enough to be mounted by 2 people. Also, the combination of layers with different properties leads to the remarkable performance of the system.

d. Wiki House System

This case is chosen as a perfect example of mass customization with the use of state-of-the-art technologies. It uses standardized parts that can be easily customized to adapt to different conditions. This project aims to provide the local fabrication of components manufactured by a network of local micro-factories, using digital fabrication tools. The system provides a rapid assembly to millimetre precision. It is designed to be mounted by unskilled labour, by providing an Open Source construction set. This set has been tested and approved by professionals but it can also be downloaded and adapted and tested by anyone. The main goals of this project are the use of local resources, to share the information, to lower the waste, to design for disassembly and to include all types of labour.

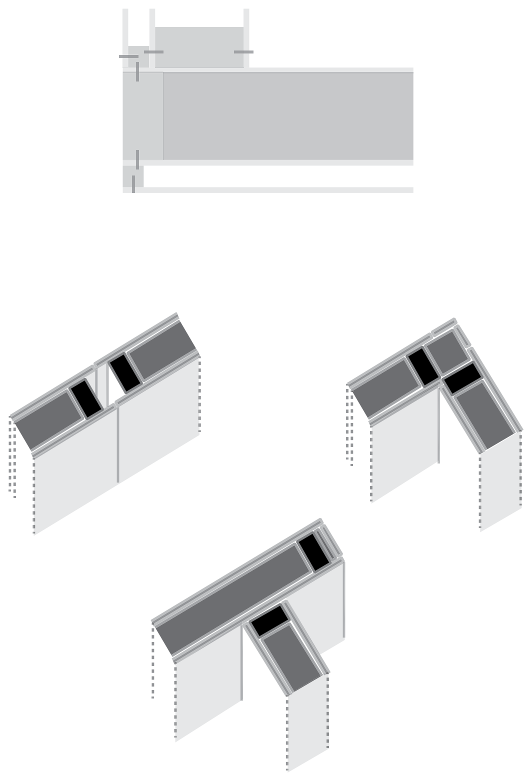


Figure 55: SIP Panel System overview. Own illustration.

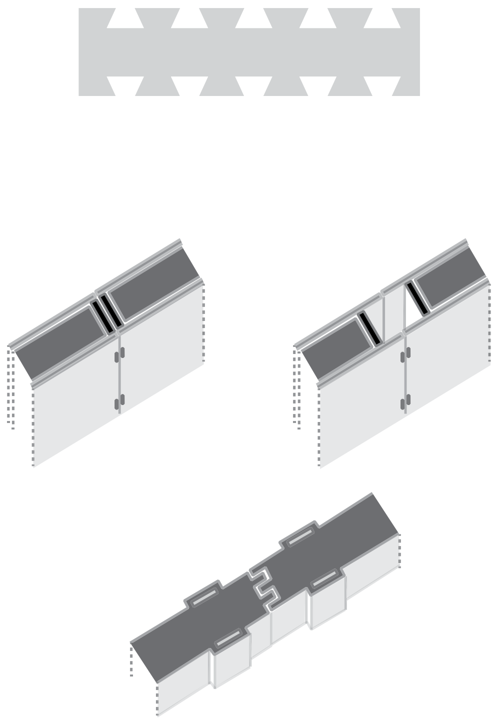


Figure 56: Wiki House System overview. Own illustration.

e. The SELFIE facade module

SELFIE (Smart and Efficient Layers for Innovative Envelopes) is a modular curtain wall system that allows easy installation of customized components that can be placed with different geometric configurations, materials and colours. It uses modular components of 0,90x1,40m, with opaque or transparent layers. The components are made out of multiple layers that with different combinations, provide different types of functions. It uses an automated control system that actives certain functions when needed. The system includes layers of PCM, IR treated glass, photovoltaic ceramic or metals and special paints that improve the quality of air.

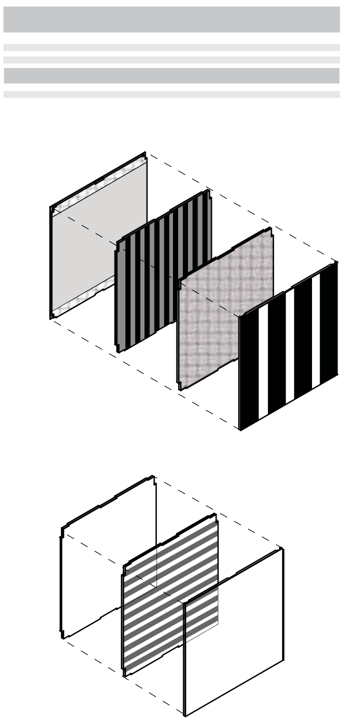


Figure 57: SELFIE Facade System overview. Own illustration.

6.2. CASE STUDIES EVALUATION

An assessment of these five systems is shown in this section. This analysis is based on the list of requirements that were set for this research in chapter 5. These requirements have different values of importance within the research. These levels are shown in the illustration below, with the number of blue dots for each requirement. The assessed references are scored with a scale of 0 to 2. If the referent meets entirely with the requirement, it is scored with the number 2. If it meets only partially, it is scored with the number 1 and if it does not meet with the requirement, it is qualified with the number 0. In the end, a final score is given for every case study, by multiplying the importance of the requirement by each score.

This analysis is based on literature research. Here, the technical information that was found for each product differs from each other. This research is limited by schedule and resources; thus, a scientific study of every requirement is not possible. Nevertheless, with the use of literature research, a general idea of each system can be accomplished.

The main objectives of this research are shown in the previous illustration, highlighted by three blue dots. Here, the mass customization for weather and assembly adaptability, its easy montage, demount ability and reusability are the main goals. Therefore, prefabricated and customizable constructions systems, such as the SIP, WikiHouse and SELFIE, have a score of 2 points. Allowing the easy personalization of the system with the use of new technologies is one of the main advantages of these systems. These products are manufactures under factory-controlled conditions that result in extremely strong, energy-efficient and cost-effective systems.

The assembly ergonomics of all these products scores 2, meaning that all these products are designed to be mounted easily by a few workers. While the assembly on site is very easy and rapid, the pre-assembly time and difficulty of the WikiHouse, SIP and SELFIE are higher. This is, either the result of skilled labour guarantees the manufacturing process and final performance of the component, or a complex construction system that needs complex pre-assembly processes. This is the case of the SELFIE project, where state-of-the-art technologies are used for every component to have a function that will be activated by an automated system. This is why this system has a score of 0 at the pre-assembly difficulty.

To conclude, the prefabricated construction systems that meet the most important requirements for this research are the WikiHouse and the SELFIE system. First, the WikiHouse uses CNC technology for mass customized components that can be personalized for any time of construction typology. Also, its mount ability designed for unskilled labour, allows the final consumers to personalize a tested product for their necessities. Then, the SELFIE system provides the mass customization of components that respond to different climate parameters by the combination of layers with different characteristics. Therefore, a combination of the construction system of the WikiHouse and the multilayers concept of the SELFIE project is the ideal solution for this research.

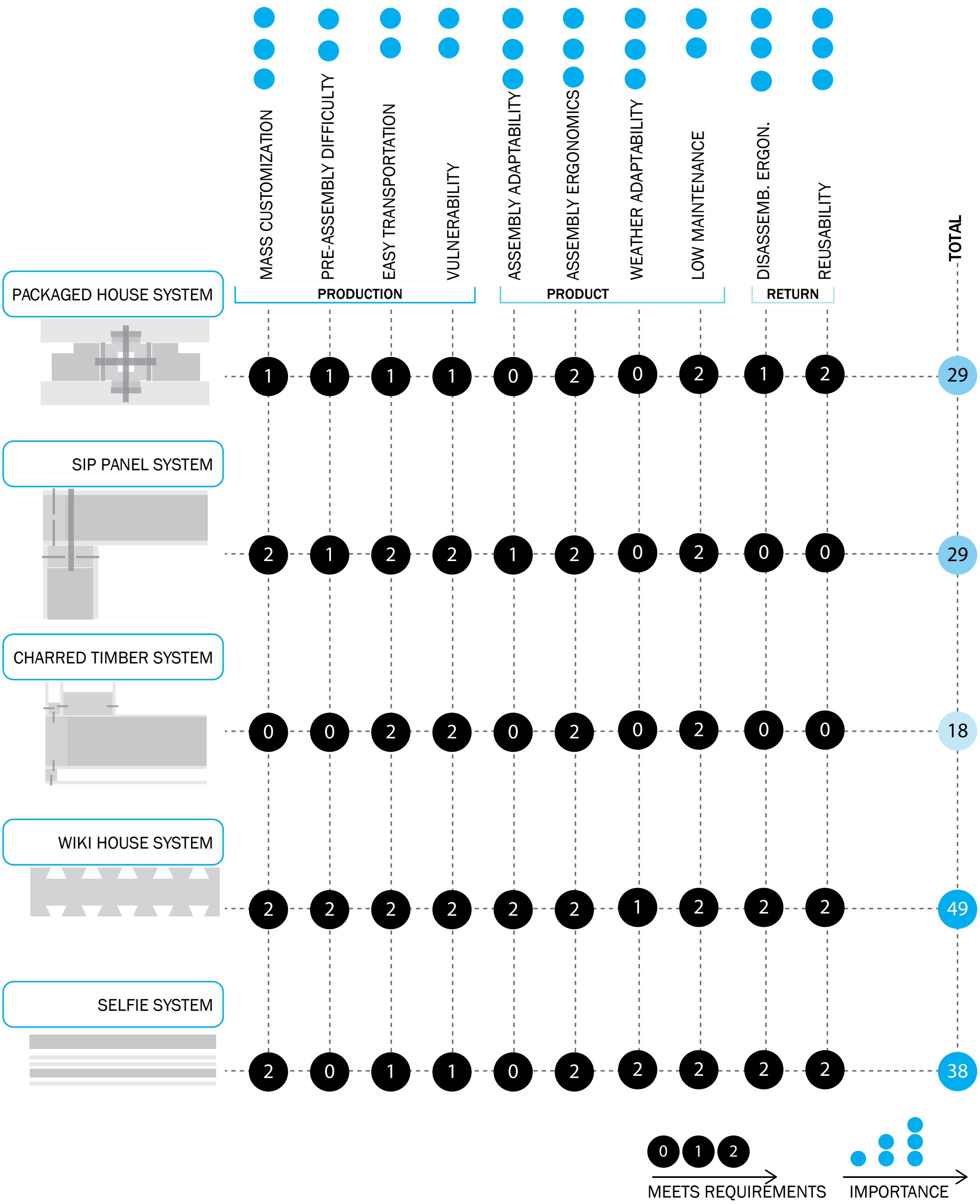


Figure 58:Prefabrication references analysis. Own illustration.

6.3. DESIGN CONCEPT

After the literature review of the context, the location study, available solutions and case studies, it can be concluded that the concept that leads this research is based on a circular workflow of a prefabricated façade system that can be mass-customized to improve the indoor comfort level of existing buildings in the different Ecuadorian climate regions. It is locally manufactured, with local resources and transported to the site location, to be easily mounted by any type of labour, allowing demount ability to reuse the system multiple times.

As stated in the previous chapter, a prefabricated construction system with demountable connections and local manufacture can be combined with a multi-layered system that provides different types of functions depending on its combinations.

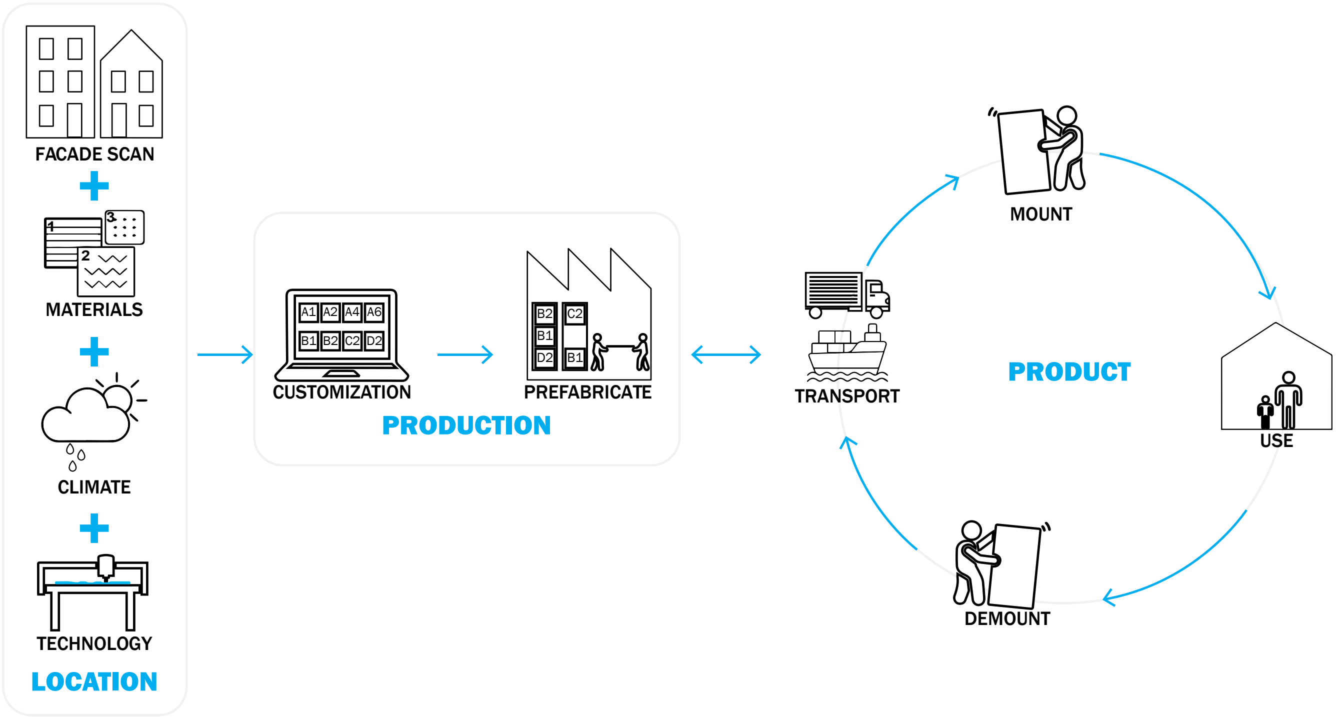


Figure 59: A circular workflow for a customized façade system. Own illustration.

VII

7. DESIGN DEVELOPMENT

Here, a summary of the façade system is made to understand all the steps taken to provide a solution to improve the indoor climate quality of the Ecuadorian construction stock on different climate regions

7.1. APPLICATION PRINCIPLES

The main focus of the design responds to the local climate conditions in Ecuador. It is important to mention that, because Ecuador is located on the Earth´s equator, it shows specific climate conditions of this condition. Principally, it´s location allows the sun to reach 67°C to south in November, December and January, as well as 67°C to north during May, June, and July. This means that a façade system will perform differently, depending on its orientation to the sun and prevailing wind direction.

The function of each façade can be defined by stating its orientation according to the sun and wind predominant direction.

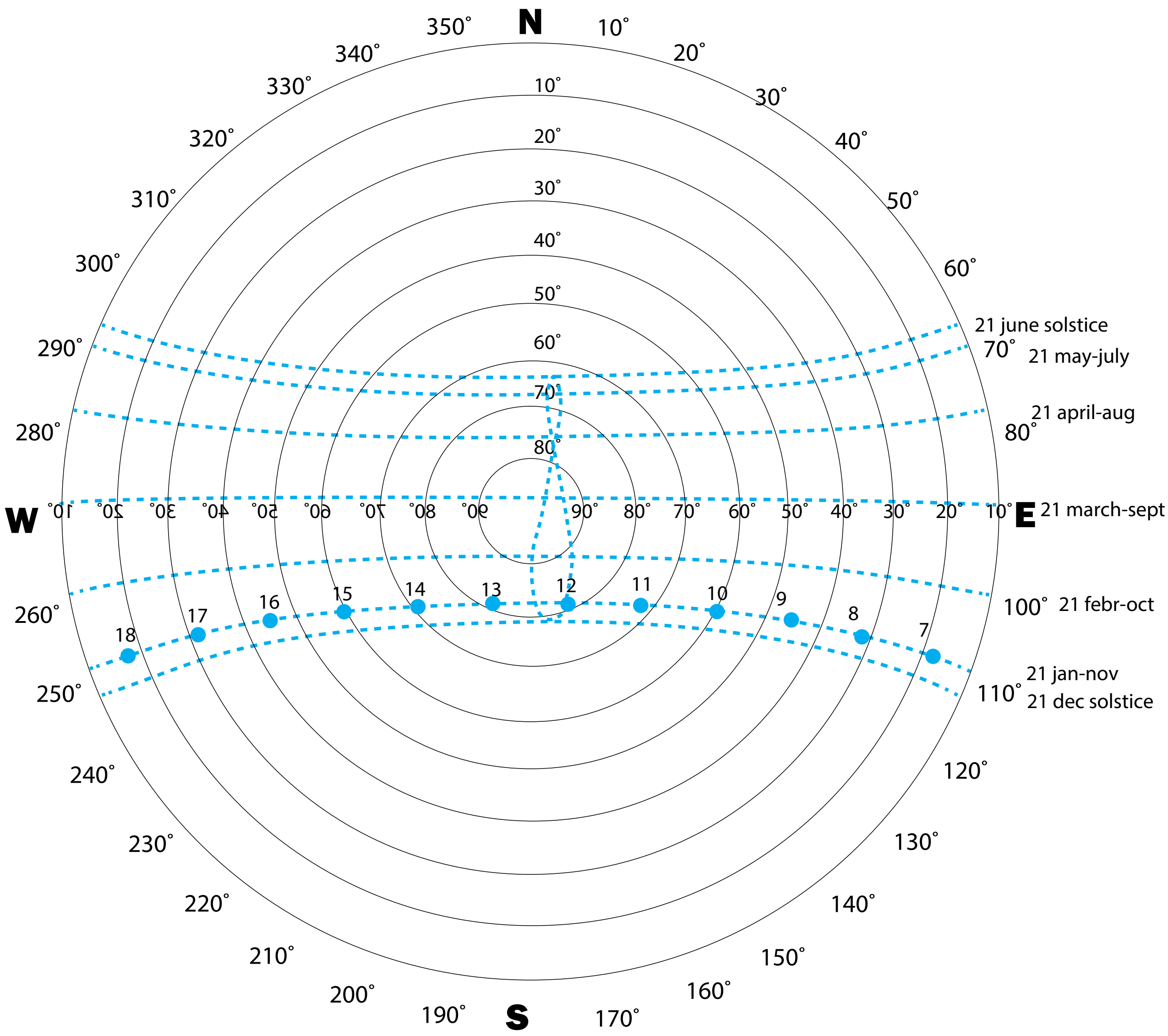


Figure 60: Sun path in Ecuador´s regions. Own illustration.

TEMPERATE CLIMATE

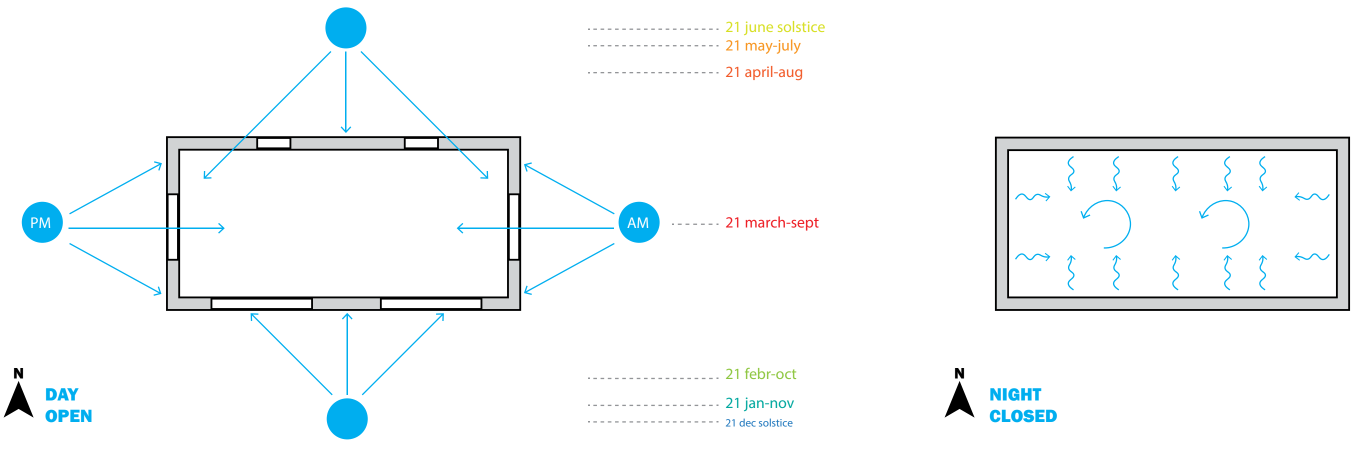


Figure 61: Functions of facades depending on its orientation to the sun path. Own illustration.

In a Temperate Climate, the north facade needs to protect the indoor space from direct sun heat, thus the months of July, September and August, the maximum temperature is 30°C. On the other hand, the night temperature is always low, therefore the construction needs to store the heat on the inside, so this can be used when outdoor temperatures reach levels of discomfort (below16°C and above 30°C, according to Adaptive Comfort levels).

The predominant wind direction in the Temperate climate is north-east and east. These two façades need to allow the entrance of natural ventilation.

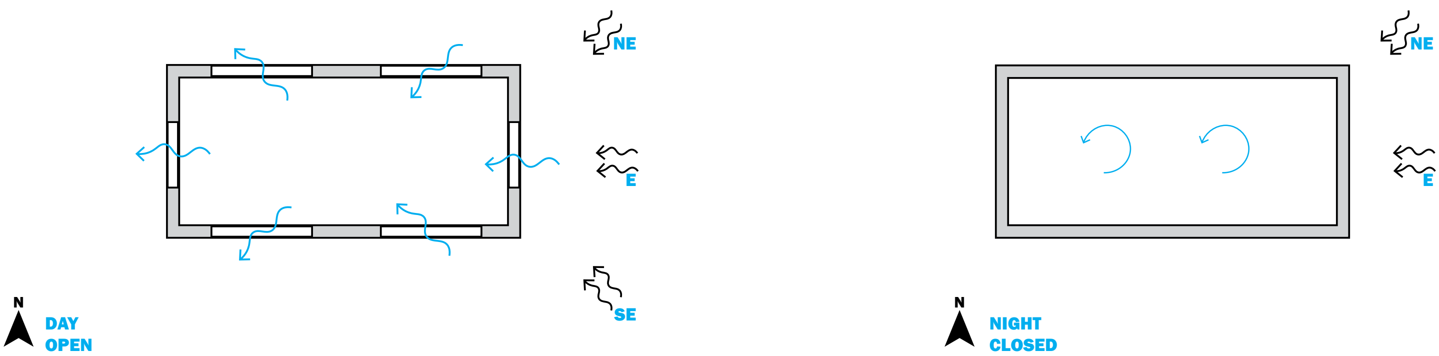


Figure 62: Functions of facades depending on its orientation with respect to the predominant wind direction. Own illustration.

TROPICAL CLIMATE

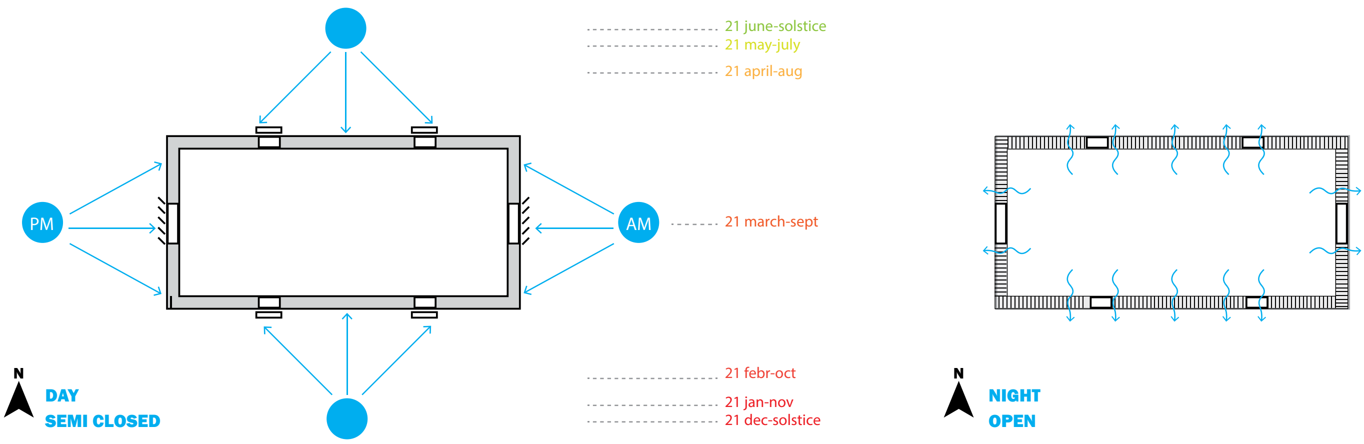


Figure 63: Functions of facades depending on its orientation to the sun path. Own illustration.

In the Tropical climate, all façades need to be as closed as possible, especially the south and east façade. Here, the direct solar radiation needs to be prevented, thus the maximum temperatures are always high, with 34°C all year long. This would produce the overheating of the indoor climate, reaching levels of discomfort (above 32°C, according to Adaptive Comfort levels).

The natural ventilation is the second strategy to be used, by stating the predominant wind direction. In the Tropical climate, the wind blows from the north and north-west.

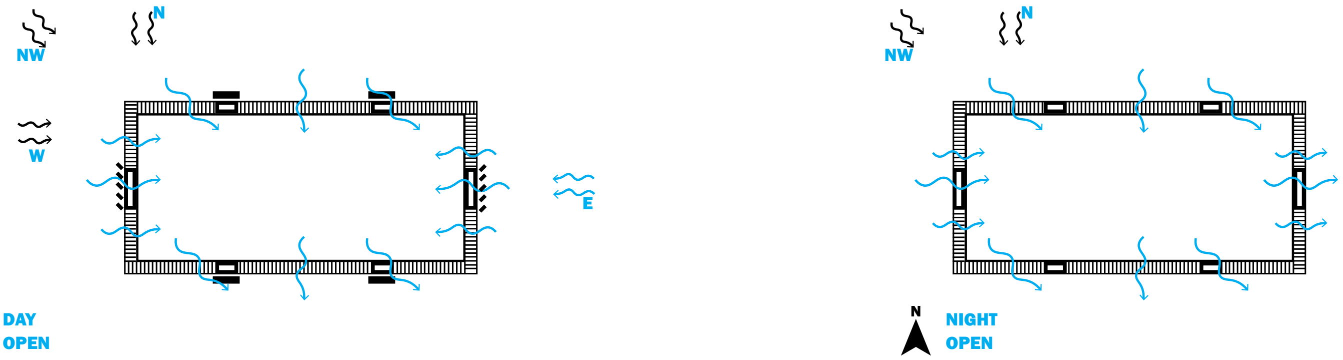


Figure 64: Functions of facades depending on its orientation with respect to the predominant wind direction. Own illustration.

7.2. CUSTOMIZED FAÇADE SYSTEM

A façade system may reach different levels of prefabrication, as shown in the figure below. Starting with elements, then components, which can be replicated to form panels and finally, modules.

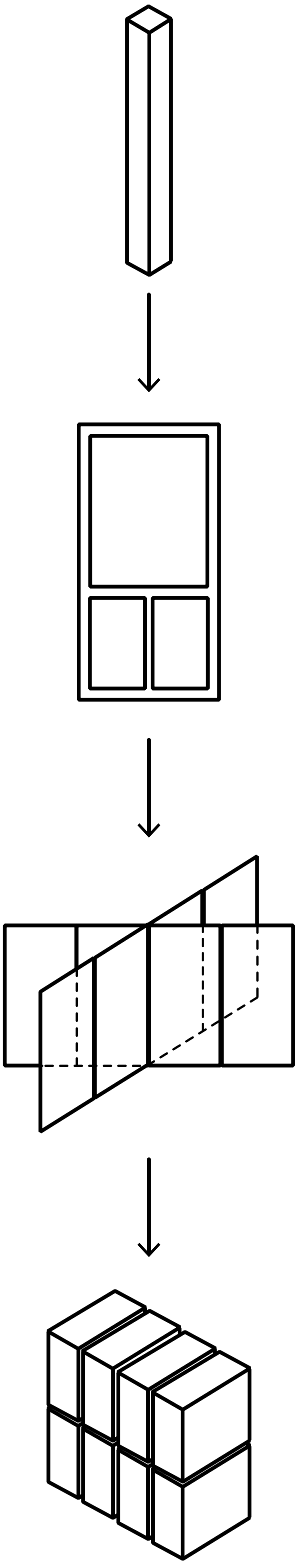


Figure 65: Sun path in Ecuador´s regions. Own illustration.

7.3. LAYERS

To meet the customization requirements for this research, multiple layers with different characteristics can be combined. This way, one standardized component can be formed by different layers combinations, meeting with different climate parameters. These layers can be formed by sheet-materials, that can be processed by CNC machines to achieve intricate details for connections.

An overview of multiple sheet-materials is made to classify them according to its properties. A summary of this analysis is shown in Appendix 3. Comercial sheet materials, such as clear glass, Eterboard, Ekopak and Eternit, can be easily found in Ecuador. The rest of the listed materials present feasible opportunities for recycling local waste materials in Ecuador. Products like ECO-OH or CEMPLAAT are made out of recycled materials, such as plastics, wood, antural fibers, etc. Technologies to recycle materials are already been used in Ecuador. This is the case of Ekopak, a sheet material made out of recycled tetra pack packaging.

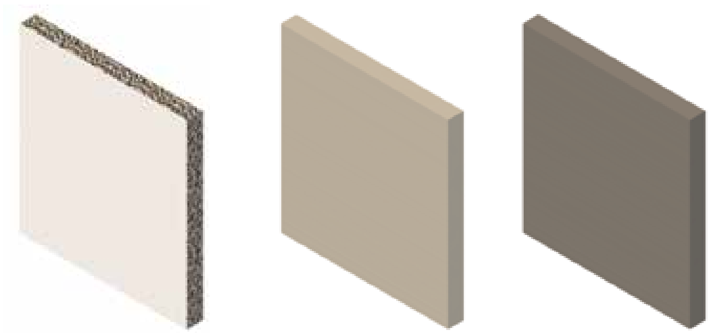
Insulating a facade serves to increase the heat resistance of the construction. either to maintain the heat no the inside or the outside of the building. This leads to a reduction in energy loss and an improvement in levels of comfort. For the insulation elements, three different materials are chosen: Recypanel, Rockwool and Wool. These three elements provide different properties, that can be combined with other layers, to form an insulated component.

The elements for collection are the two types of glassing possibilities: fixed or operable window. These elements are made out of 2 layers of clear glass and a cavity of 2 cm on the inside.

The water protection element is made out of Stockboard, a water-proved recycled rubber sheet, with a U value of 5 W/m2K. In combination with other elements, two types of components can be built. First, a water barrier for the cladding system. Second, a moisture retardant layer that should always be applied on the warm side of the construction (Linden, 2013).

The sun protection layers provide different shading systems. Its implementation depends on the façade orientation. For example, a north façade in the temperate climate needs to be protected from the direct sunlight. Because the sun is almost perpendicular to the rooftop, a horizontal shading system is an ideal solution. On the other hand, a facade that faces the east or west needs operable blinds that can be opened or closed, depending on the outdoor temperature.

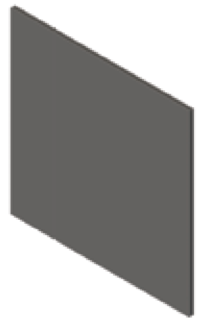
INSULATION



CODE	U VALUE	CODE	U VALUE	CODE	U VALUE
1.10	.22 W/m2K	1.20	.18 W/m2K	1.30	.33 W/m2K

Figure 67: Insulation layers. Own illustration.

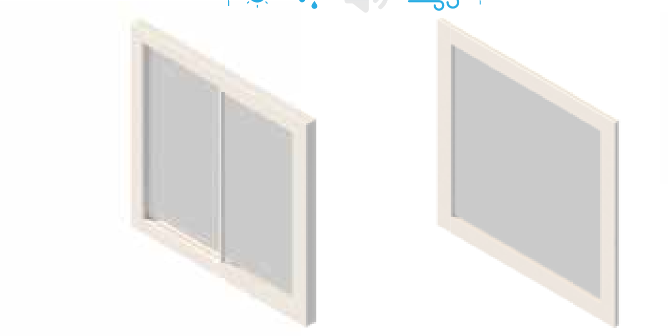
WATER PROTECTION



CODE	U VALUE
3.1	5 W/m2K

Figure 67: Water protection layer. Own illustration.

COLLECTION

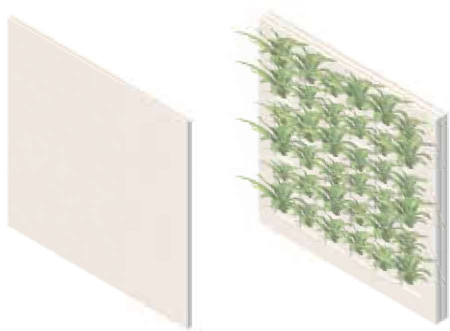


CODE	U VALUE	CODE	U VALUE
2.1	1.97 W/m2K	2.2	1.97 W/m2K

Figure 67: Heat and light collection layers. Own illustration.

SUN PROTECTION

CODE	U VALUE	CODE	U VALUE	CODE	U VALUE
4.1(	closed)5 W/m2K	4.2-		4.3-	



CODE	U VALUE	CODE	U VALUE
4.42	.5 W/m2K	4.50	.35 W/m2K

Figure 70: Sun protection layers. Own illustration.

For more detailed information see Apendix 1.

Two types of cladding are chosen, one with the possibility to have a ventilated cavity and a second one with no ventilated cavity. The U value of the desired cladding can be improved by using a vegetated element.

Next, a substructure to connect the multiple elements needs to be designed. As concluded by the reference analysis, the combination of the WikiHouse construction system and the multilayers concept of the SELFIE project is the ideal response to a customizable façade system for different climates and constructions.

First, the dimension of the elements, components and panels need to be chosen. Therefore, a study of the existing façade typologies and construction standards in Ecuador is used.

This façade system needs to respond to different construction possibilities. When designing a façade system for renovation, a basic grid can be drawn to standardize or modulate the basic dimensions of the system. The most common standard dimension to be found in existing constructions is 900mm. Commonly, this is the width of doors and height where windows are placed. This provides a clear sizing base, but for this research, the customization of the façade is related to weather parameters, as well as assembly adaptability. Therefore, the 900mm is used as a base for a modular system that allows the replication of symmetric components, but can also be customized to meet any type of construction prototype.

Second, a study of the WikiHouse system is made, in order to understand in detail its connections and assembly process. The main advantage of this system is the flexibility that the

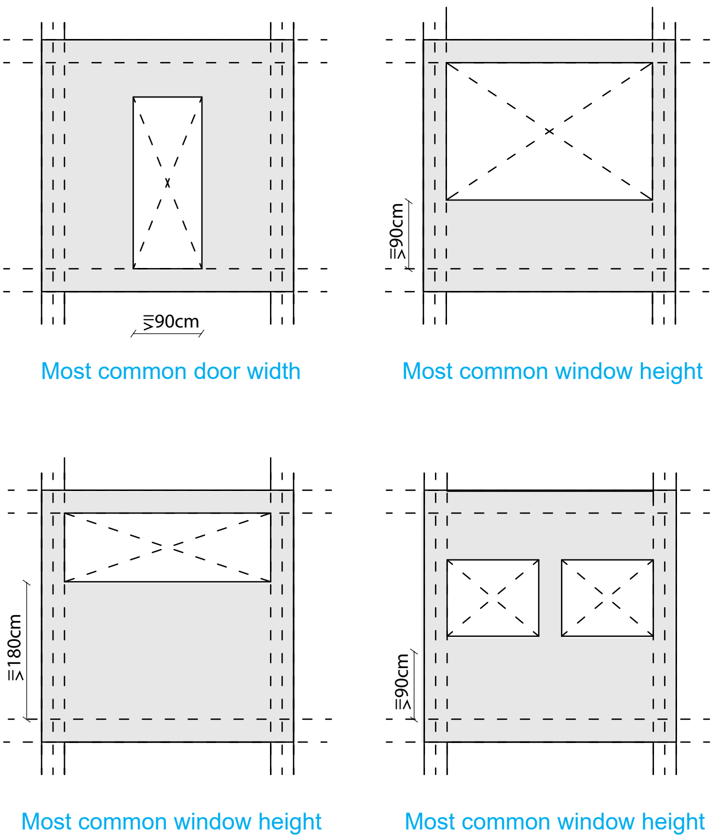


Figure 71: Most common dimensions found across the existing construction sector. Own illustration.

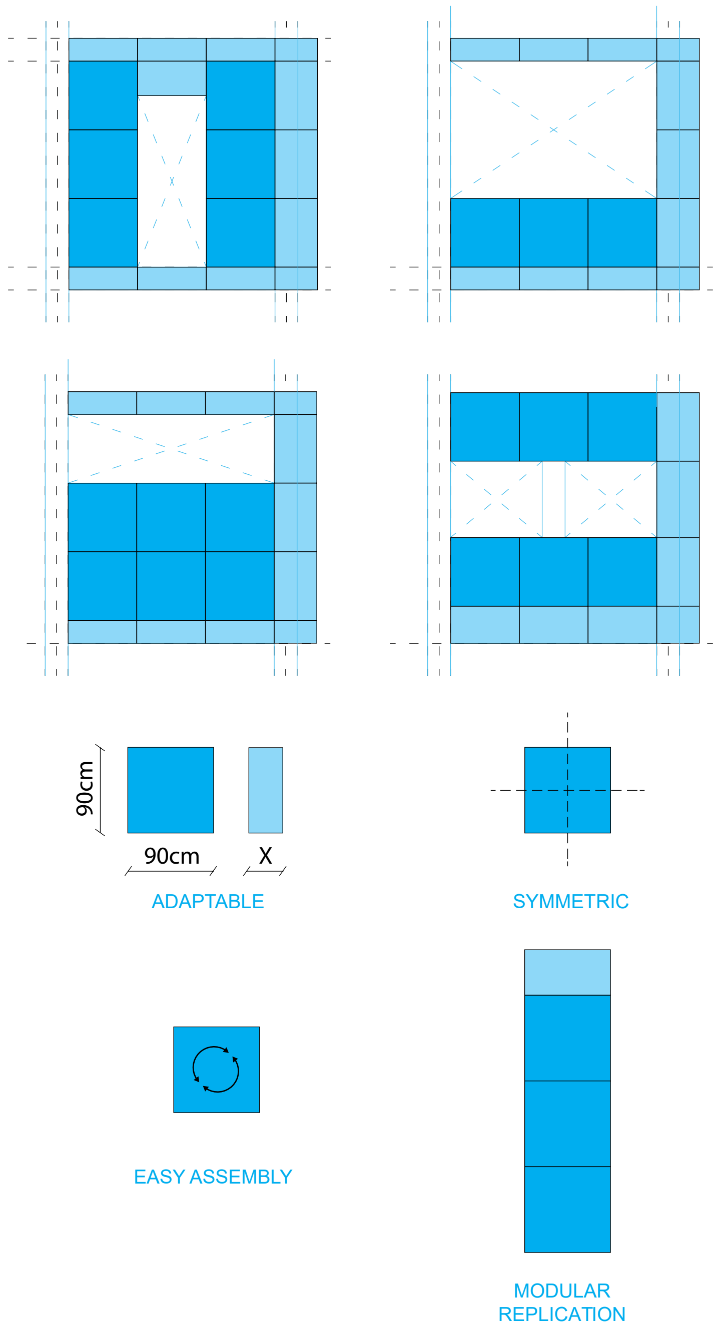


Figure 72: Replication of symmetric components on different existing facade geometries. Own illustration.

CNC milling machinery provides to work with any type of sheet-material. Intricate detailing can be done with high precision levels. This presents a feasible solution to use state-of-the-art-technology that can be found in Ecuador, with different types of sheet materials, from recycled ones to the most technological ones. The opportunity that this technology gives to this research is the ability to place multiple layers in one component, which can be replicated to for panels. An assesment of the WikiHouse connection details is shown here.

The main connections, used by the WikiHousesystem, are placing an extra smaller piece, overlapping, and insertion. An overview if the advantages and disadvantages of these three connections is made, to select the best option for a multi-layered component, that needs to connect, not only the main structure of the components, but also, to hold several layers on the inside and the outside.

The analysis of these connections shows that placing an extra piece between two modules will create a discontinuity between them. This cavity will need to be filled on site, increasing the assembly time, number of elements and risk of errors. The overlapped connection has less elements but also disrupts the continuity of the modules, with a cavity in the middle. The insertion is the best option to be used, thus it allows to place two multiple modules with any gap in between. The easy assembly and disassembly meet with the reusability requirement, stated in previous chapters.

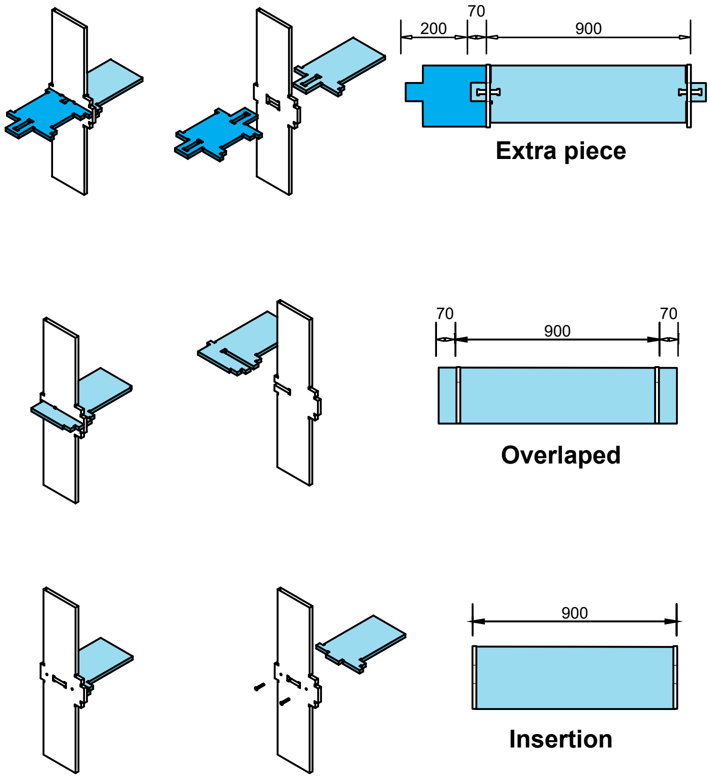


Figure 74: WikiHouse construction and assembly details. Own illustration.

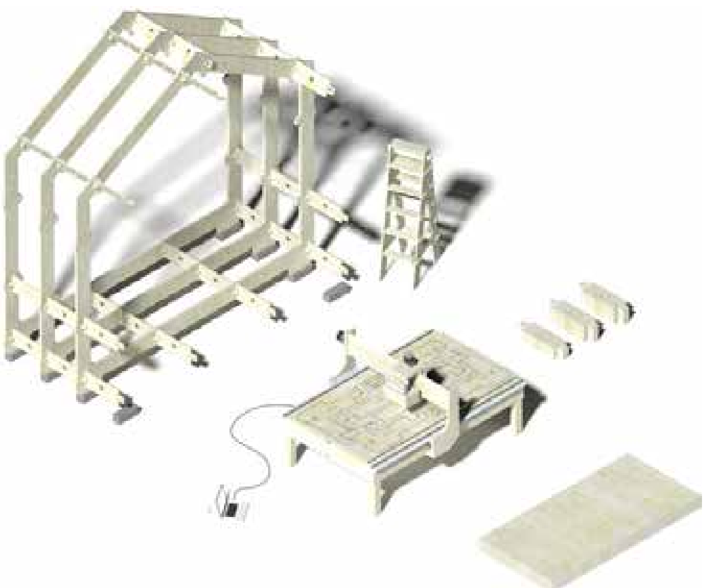


Figure 73: WikiHouse construction and assembly line. (Priavolou, 2019)

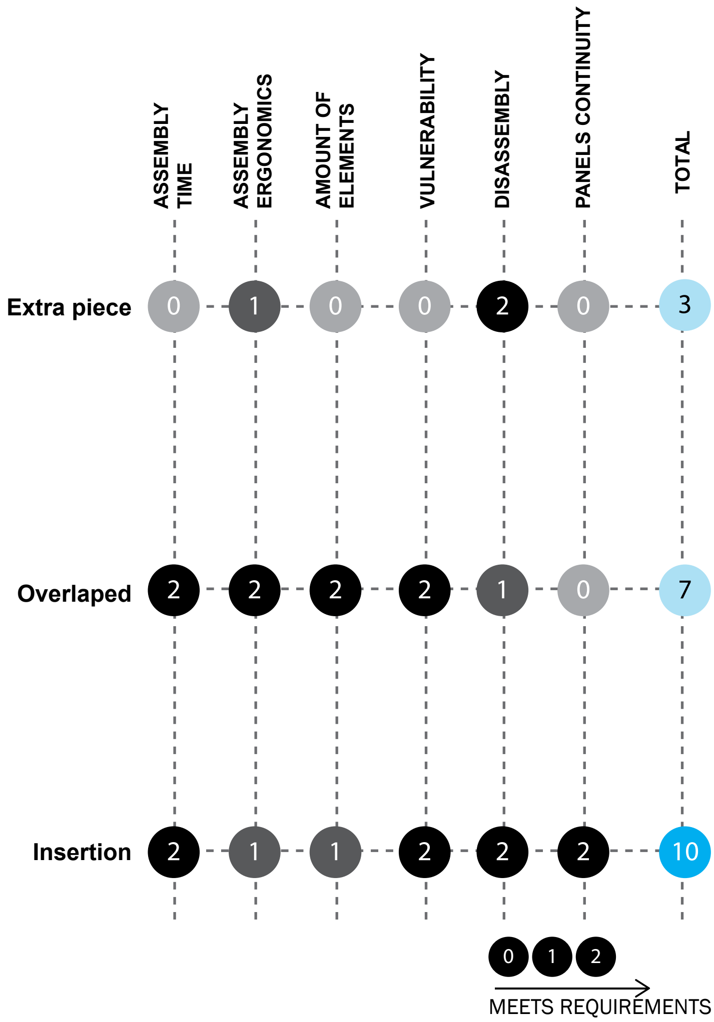
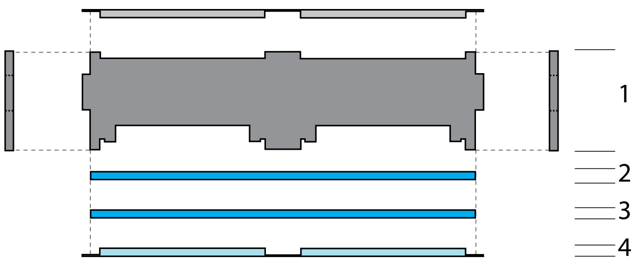


Figure 75: WikiHouse detailed analysis. Own illustration.

7.4. COMPONENTS

After selecting the ideal connection type, a standard module of 900mm is designed, which holds multiple layers. This component structure and system is shown in the following illustration.



1 insulation
2 vapor barrier/glazing
3 ventilated cavity
4 cladding/

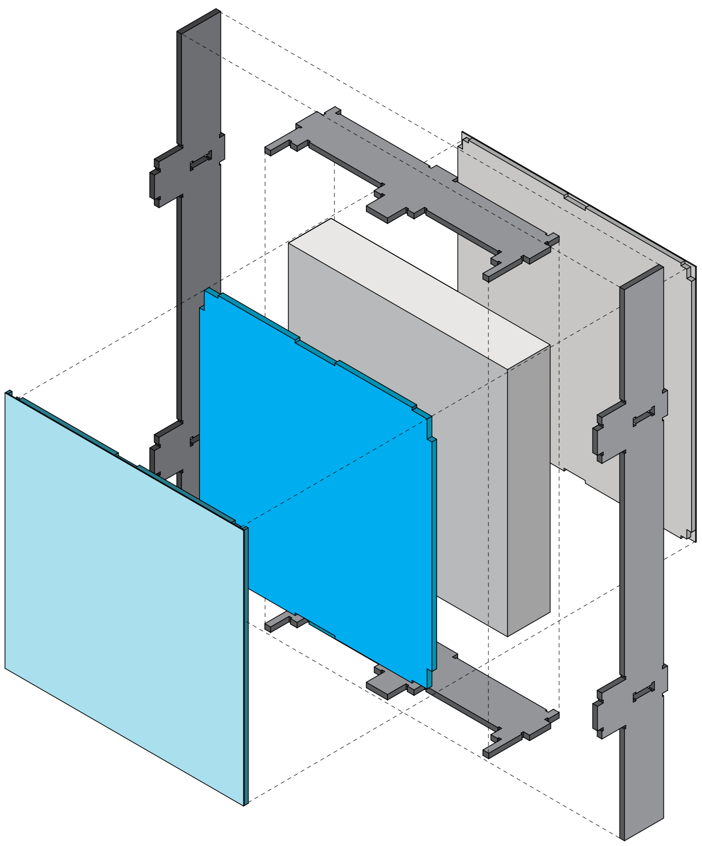


Figure 76: Multilayered component. Own illustration.

The elements to be cut and milled with CNC machines is shown in the figure below.

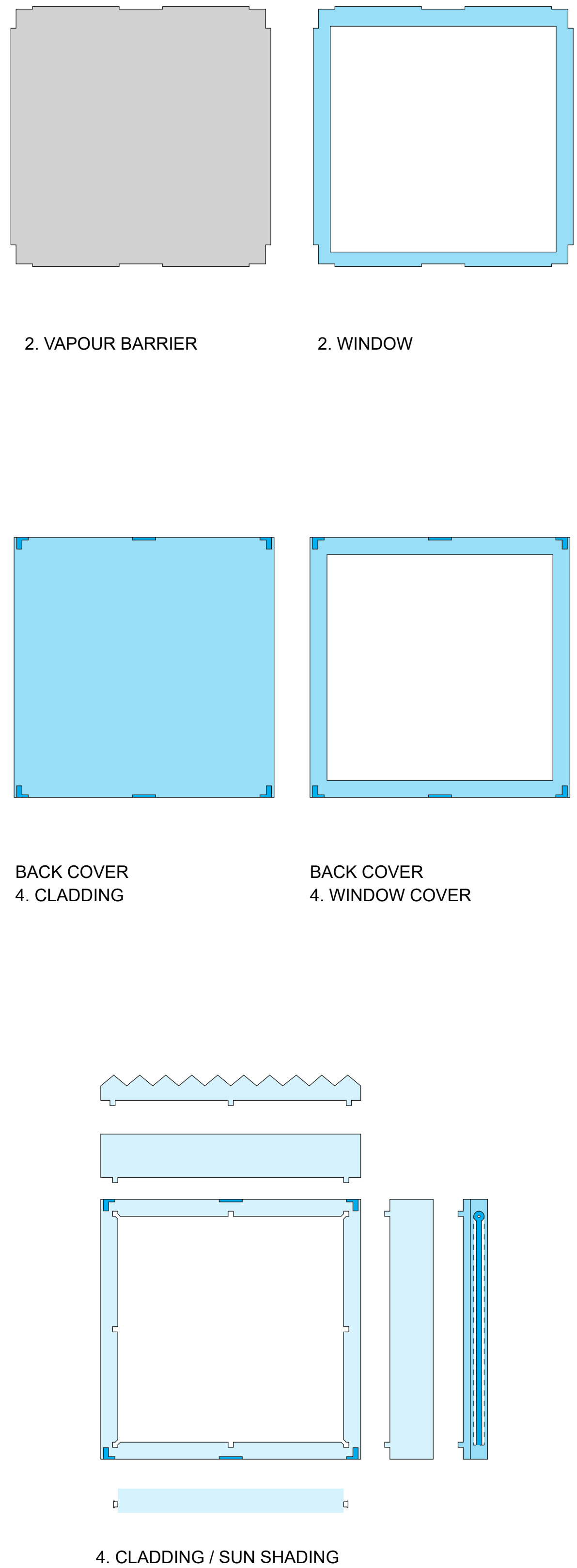


Figure 77: Elements to be cut or milled with CNC machinery. Own illustration.

The modular component combines multiple layers, to allow different functions with the same assembly and connection process. An isometric view of the assembly process is shown below.

The modular component can have, either cladding or opening functions, depending on the combination of layers.

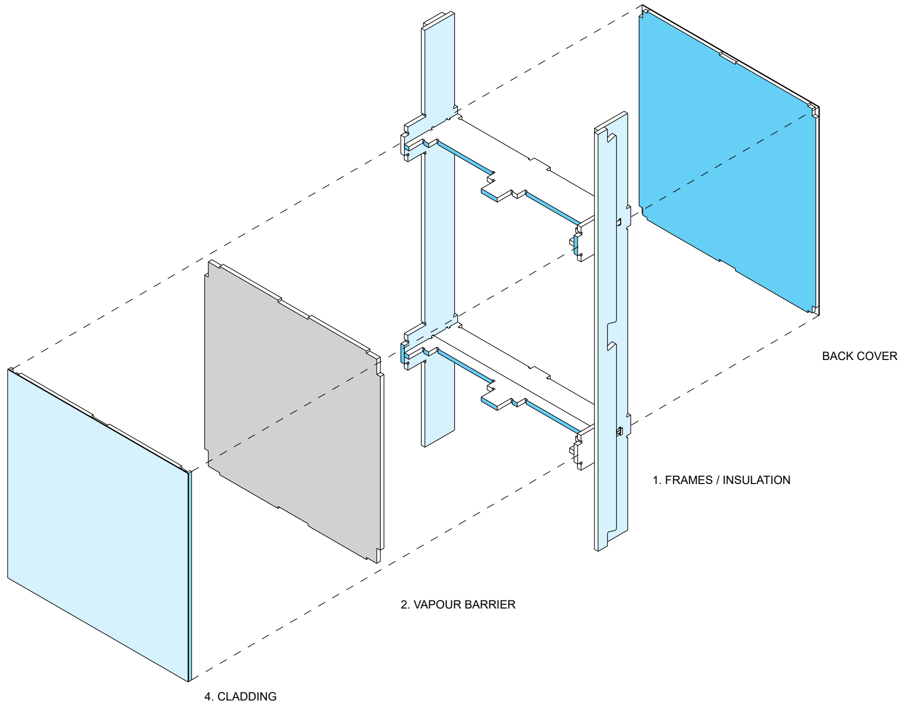


Figure 78: Isometric exploded view of a modular multilayered component. Own illustration.

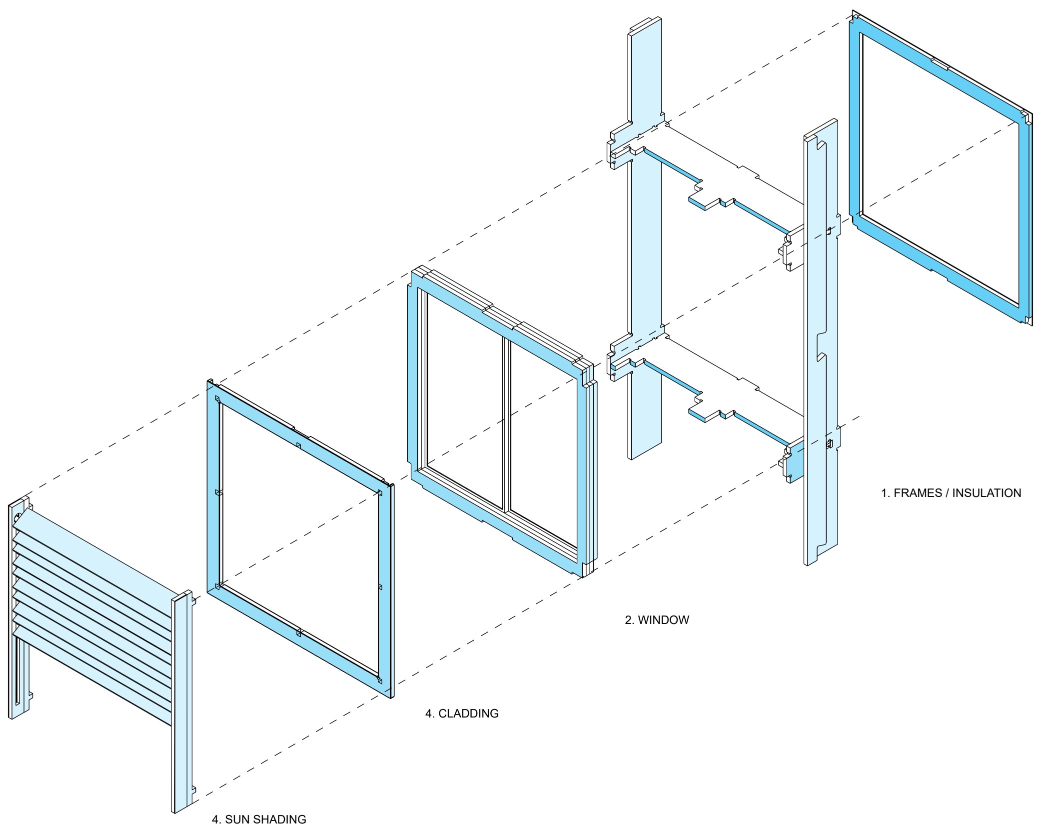


Figure 79:: Isometric exploded view of a modular multilayered component. Own illustration.

The dimensions of the modular component respond to the standard constructions in Ecuador, but also its manufacturing process, where pieces are milled out of sheet materials. The reduction of waste is one of the main advantages of CNC technology.

An example of the elements to be milled from a sheet material is shown in the illustration below. The possibility of milling and cutting customized elements from a sheet material allows the reduction of wasted materials.

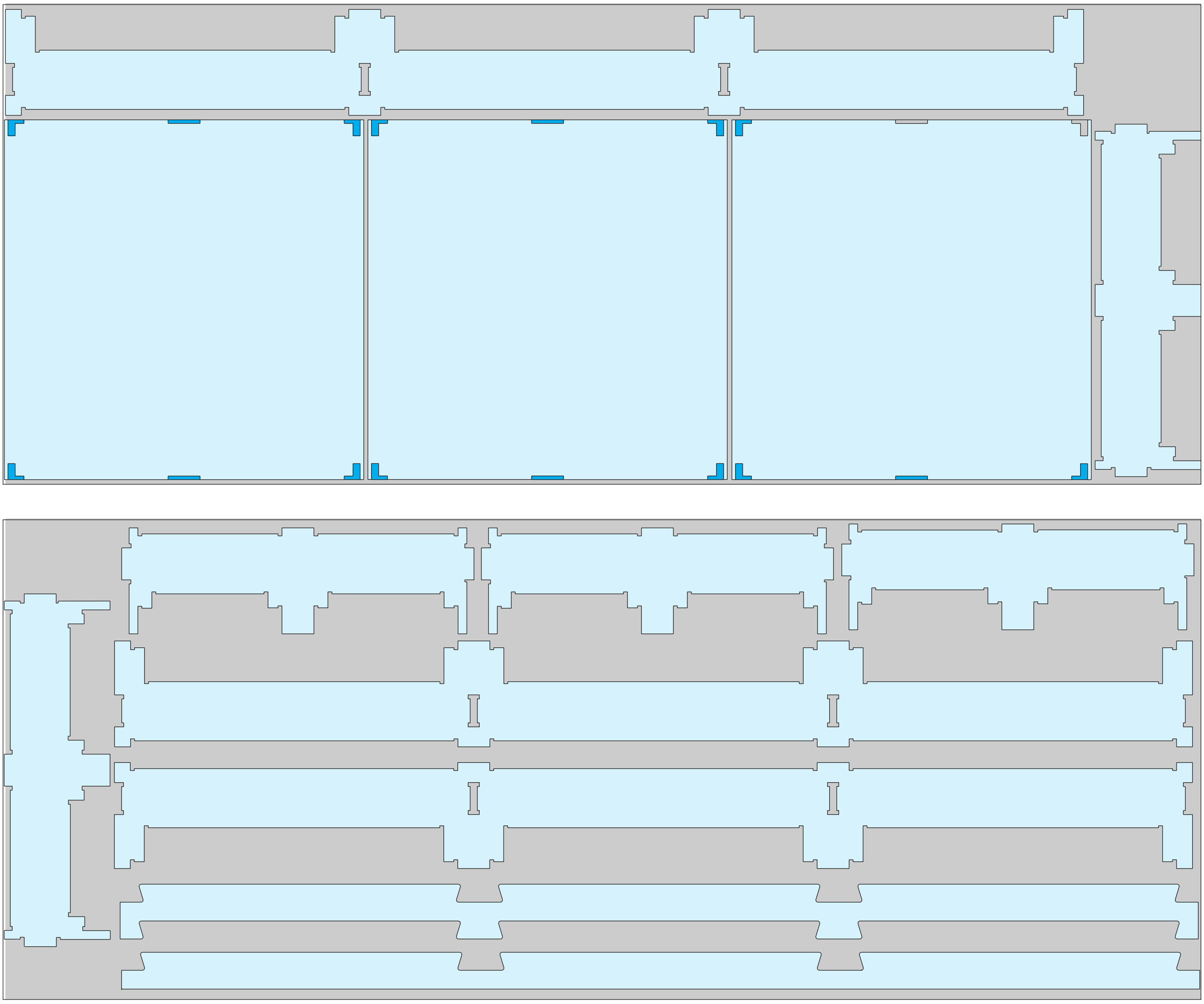


Figure 80: Elements to be cut out from a standard sheet material.

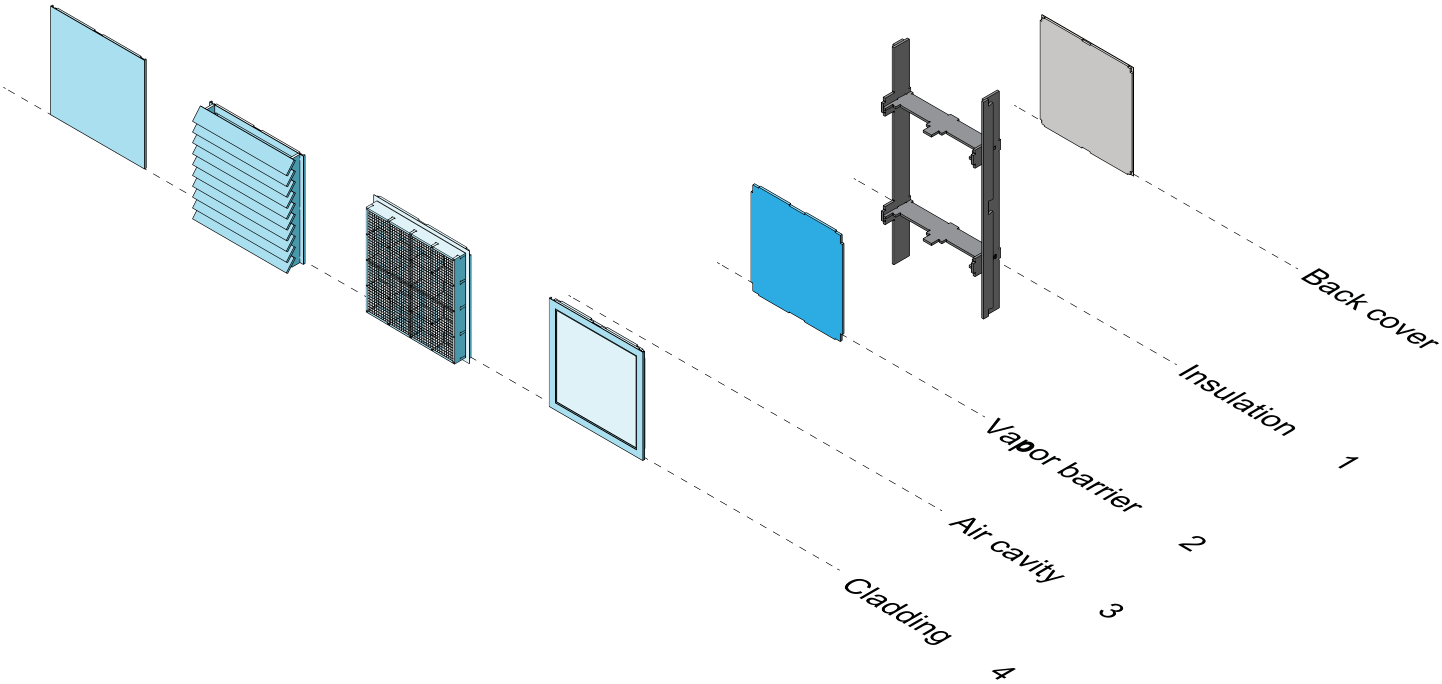


Figure 81: Multilayered component examples. Own illustration.

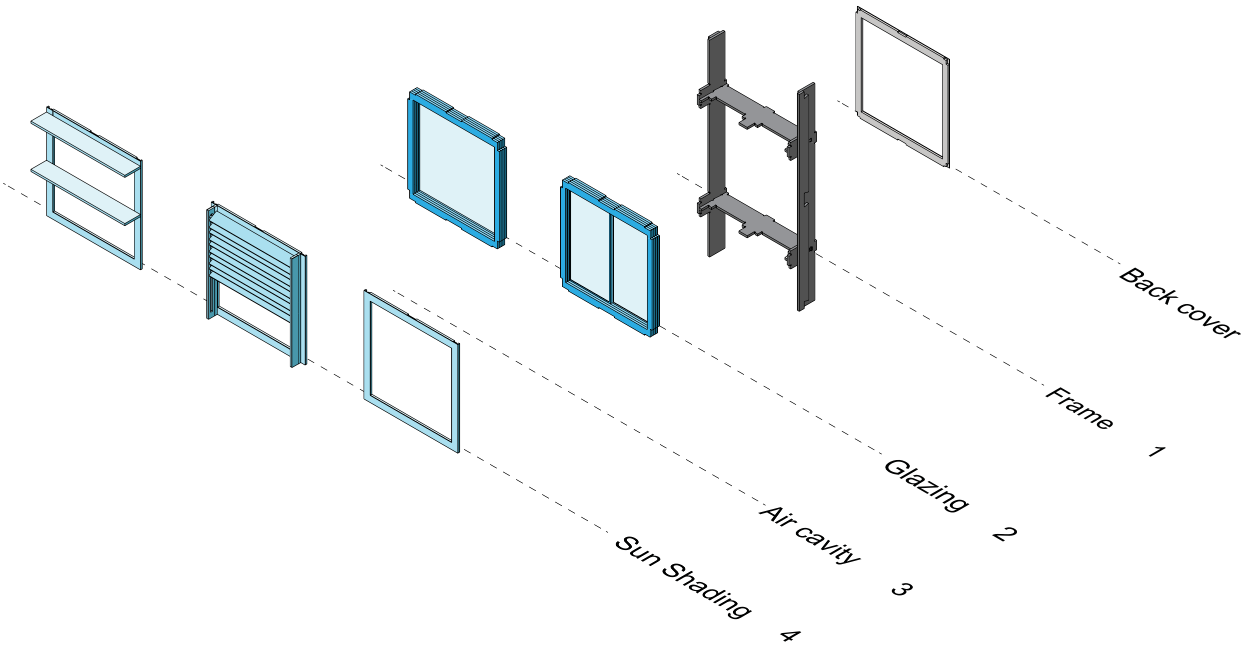


Figure 82: Multilayered component examples. Own illustration.

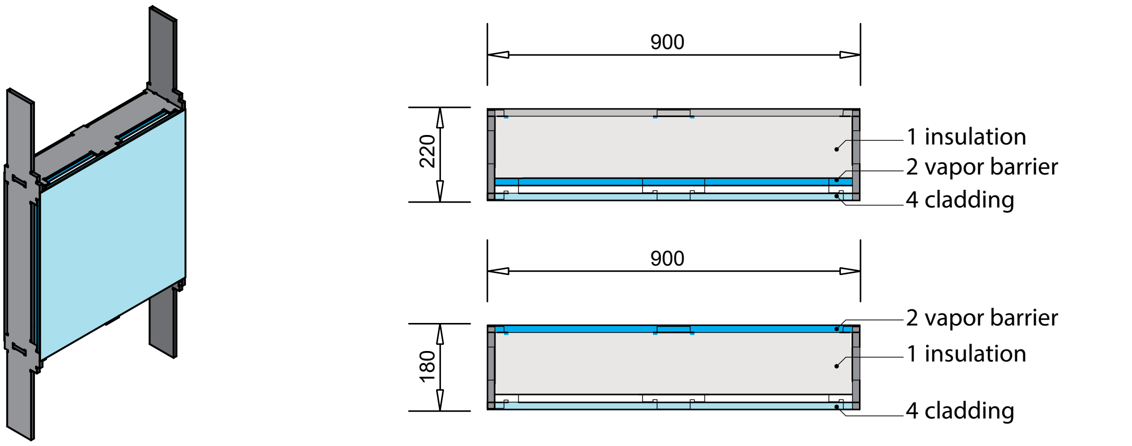


Figure 83: Insulated cladding component. With vapour barrier on the outside or inside. Own illustration.

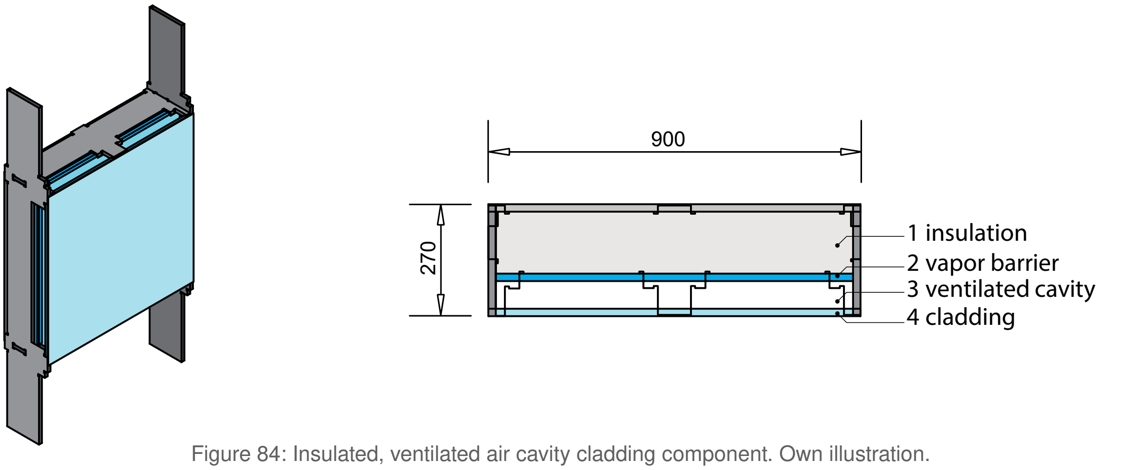


Figure 84: Insulated, ventilated air cavity cladding component. Own illustration.

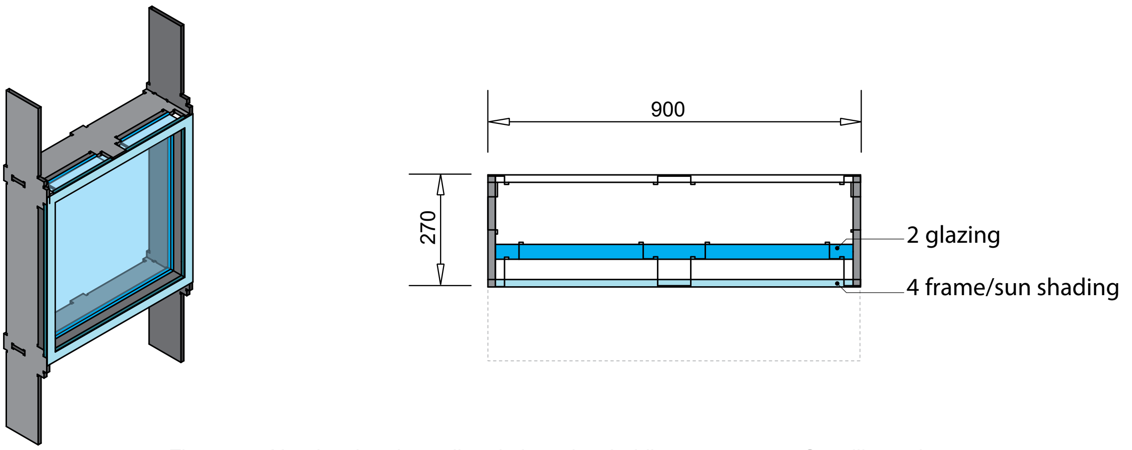


Figure 85: Non-insulated, ventilated air cavity cladding component. Own illustration.

Even though the three components are formed by the same construction system, each one of them has a different function. The first one is an insulated cladding without a ventilated cavity. The second one is an insulated cladding with a ventilated cavity. The third one is a window component that can be transformed into an operable one, or extra features can be added to produce a shading system or even a passive heating system. These functions are explained in detail in the next chapter, where the different combinations of components provide multiple functions to improve the indoor climate of an existing building while maintaining the existing façade. A list of the proposed components is shown next. For more detailed information see attachment 2.

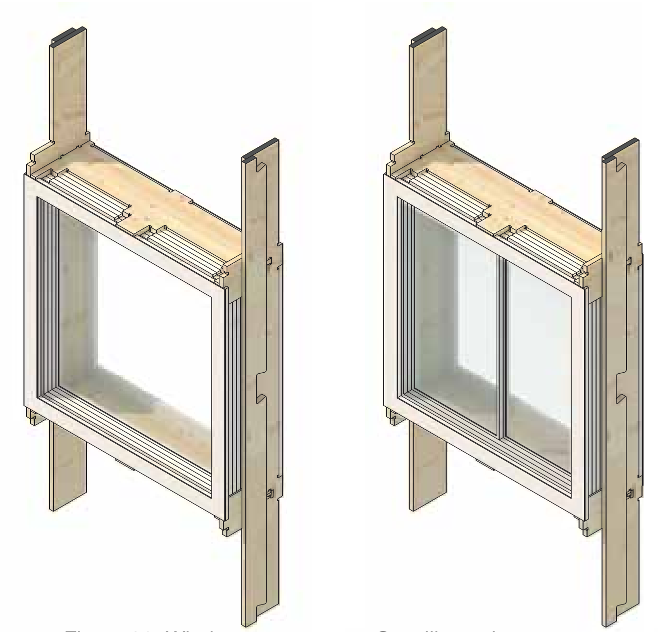


Figure 86: Window components. Own illustration.

First, window components are proposed that have the function of heat and light collection. The first component is a double-glazed fixed window and the second one is a double-glazed operable window that allows natural ventilation.

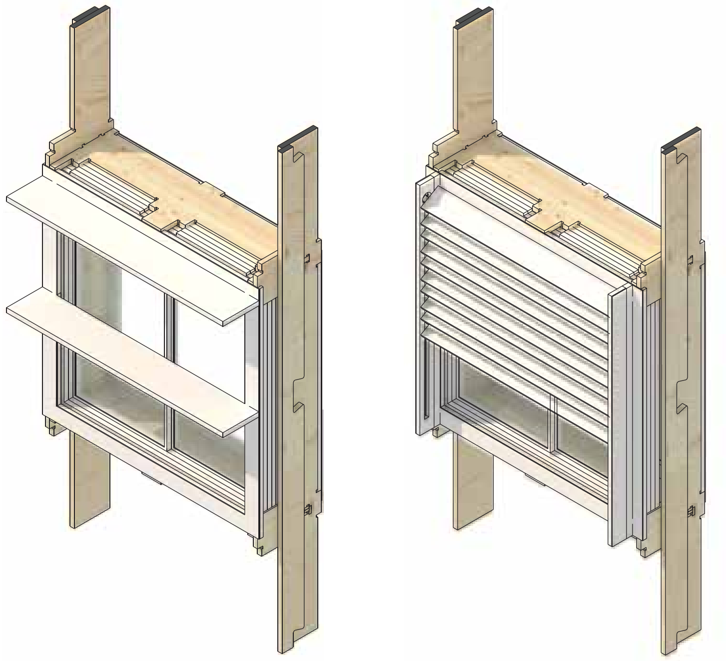


Figure 87: Sun protection components. Own illustration.

Second, a shading layer can be placed on the window components to have the function of sun protection. These components can also be made out of fixed or operable windows to allow natural ventilation, or not.

Also, two type of sun shading systems are porpose, either fixed or operable. The symmetry of the components allows them to be rotated and placed as needed, depending on the sun orientation and position. For example, in Ecuador, the sun that reflects on the north and south facade is always high, around 67° from the horizon line.

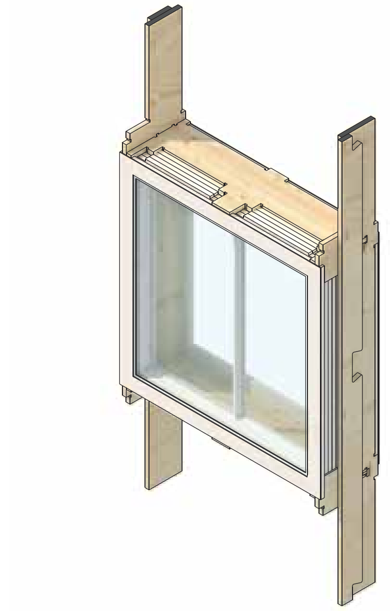


Figure 88: Heat collection component. Own illustration.

A third transparent alternative, where a glazed cladding is placed on the outside of an operable window. These component can be combined with the passive heating module (see figure 85) to preheat the air before entering the building.

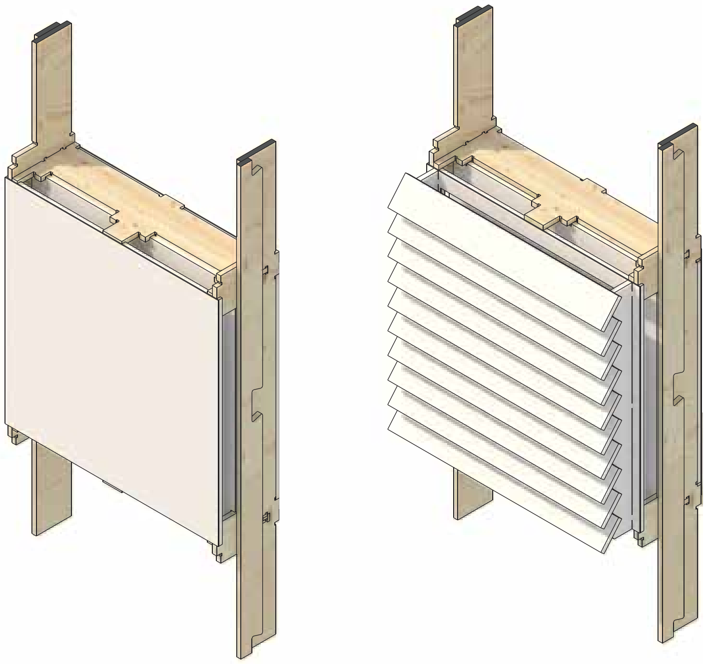


Figure 89: Vnetilated and non-ventilated air cavity cladding components. Own illustration.

The cladding system proposed for this façade system includes a ventilated façade and a non-ventilated or airtight-cavity component.

This components can be place on the outside of an existing wall but also on an existing opening to block or reduce the transmitance of heat and cold between and indoor and outdoor spaces.

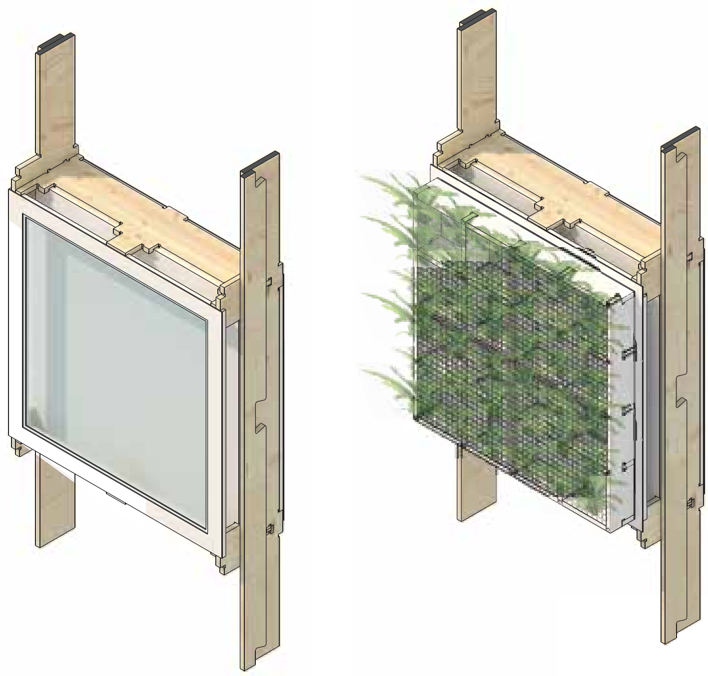


Figure 90: Passive heating and green components. Own illustration.

Two aditional clading systems are proposed. First a passive heating component, with a glazed layer on the outside and insulatin on the inside. Here, the air can be preheated before entering the building and the heat can be stored in the inside of the building by an insulated cladding.

Second, a green module is proposed to protect the existing facade from direct sun radiation and insulate the construction. This allows to regulate the indoor temperature, as well as the possibility to implement air conditioned when extremely high temperatures are reached on the outside.

7.5. PANELS

The combination of components leads to the availability of using one single element that is replicated on a façade, providing multiple functions throughout a building´s skin. The WikiHouse assembly process is again analysed, to select the best connection type for fixing the components between each other and to the existing construction.

The first assembly detail is a simple sliding movement. Here the components can be placed next to each other but no connection between them or with the existing construction is included.

The second assembly type is an interlocking sliding process, where the components are interconnected, but not no assembly with the existing construction is included either.

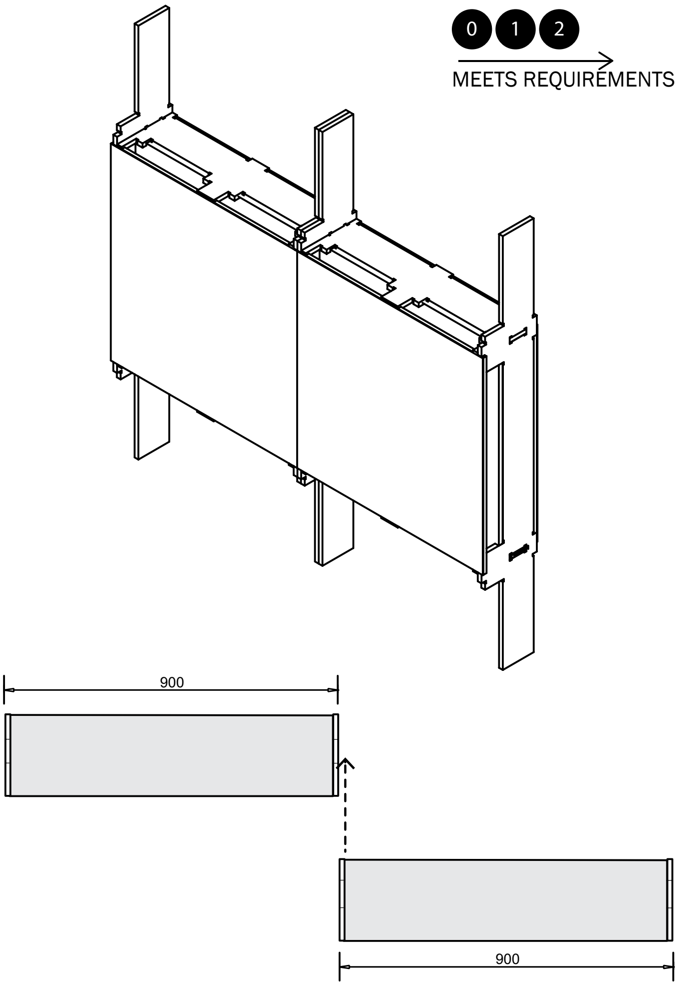


Figure 91: Sliding connection type 1. Own illustration.

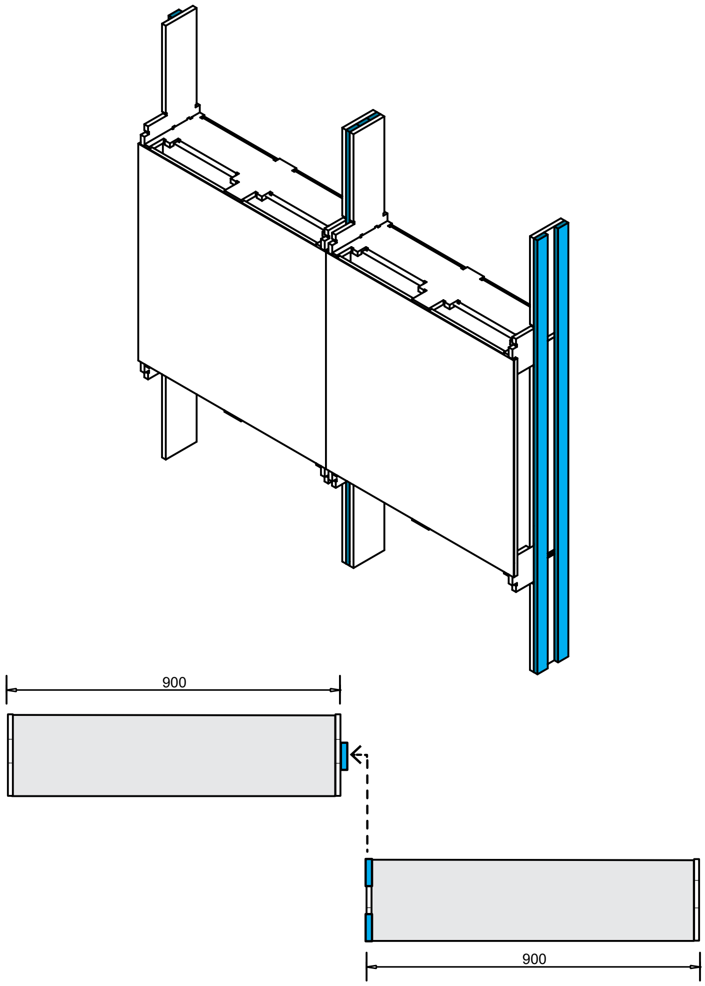
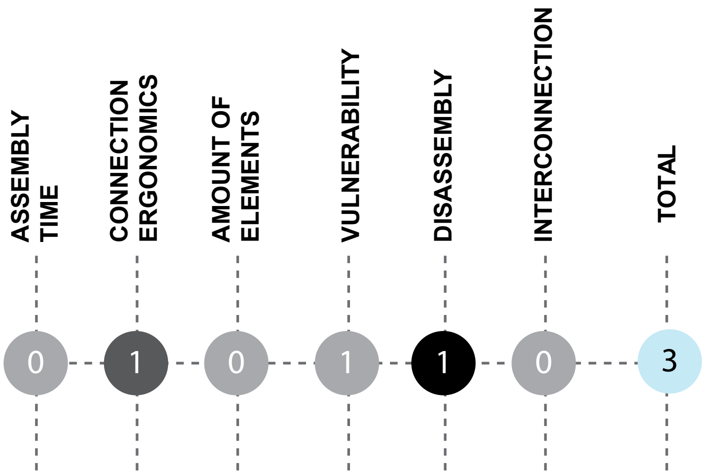
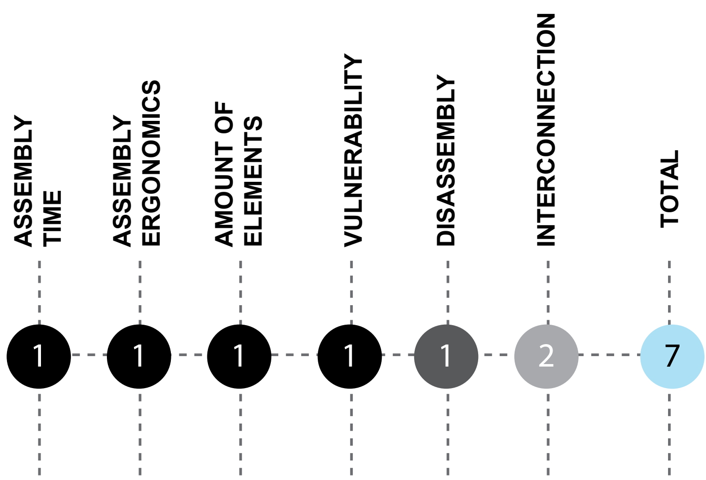


Figure 92: Interlocking connection. Own illustration.





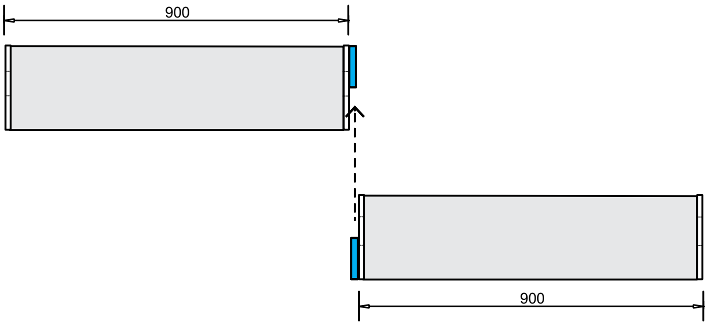
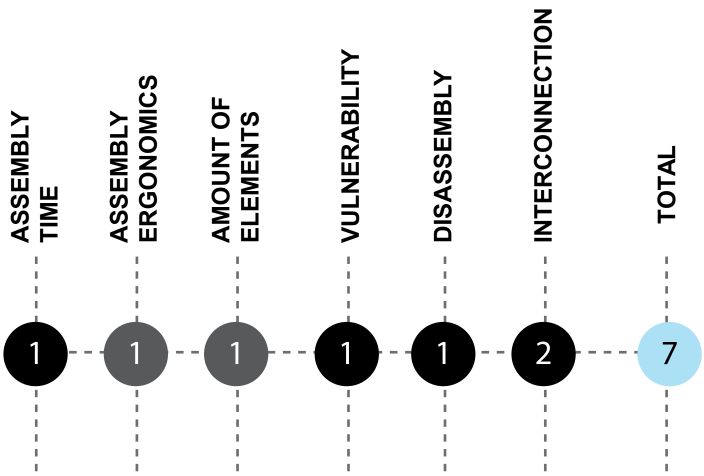


Figure 93: Sliding connection type 2. Own illustration.



Finally, an assembly detailed is chosen, where the side structures include an interlocking element, which connects the two components but also provides a connection with the existing construction. This solution meets the easy assembly and demount-ability requirements, while a modular component can be replicated and connected with more components, and assemble them on existing construction.

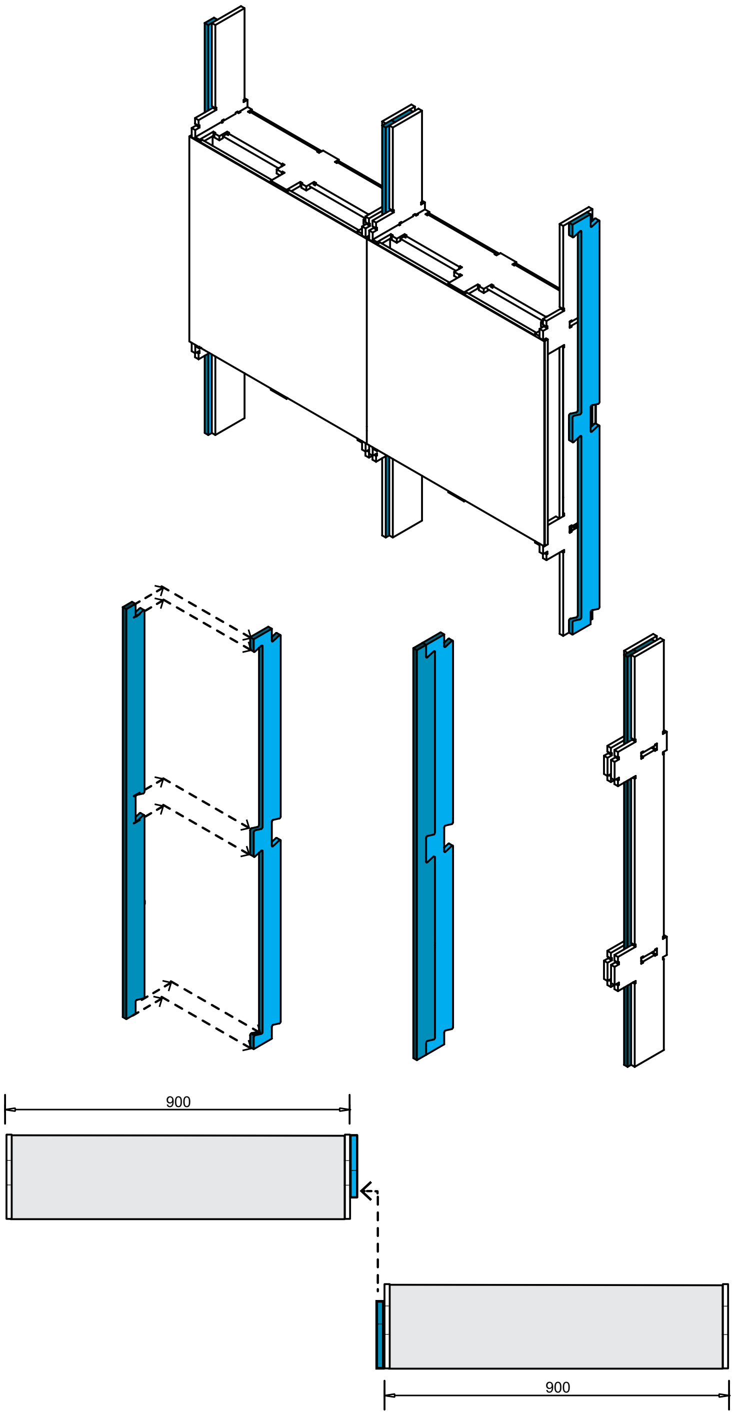
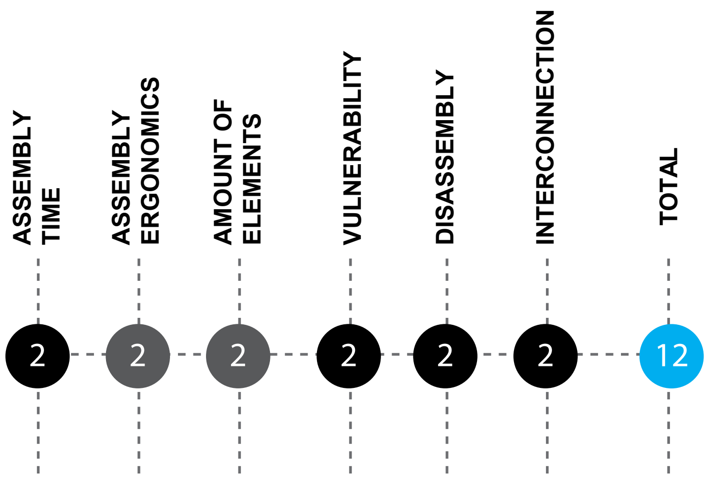


Figure 94: Sliding + interlocking conenction. Own illustration.



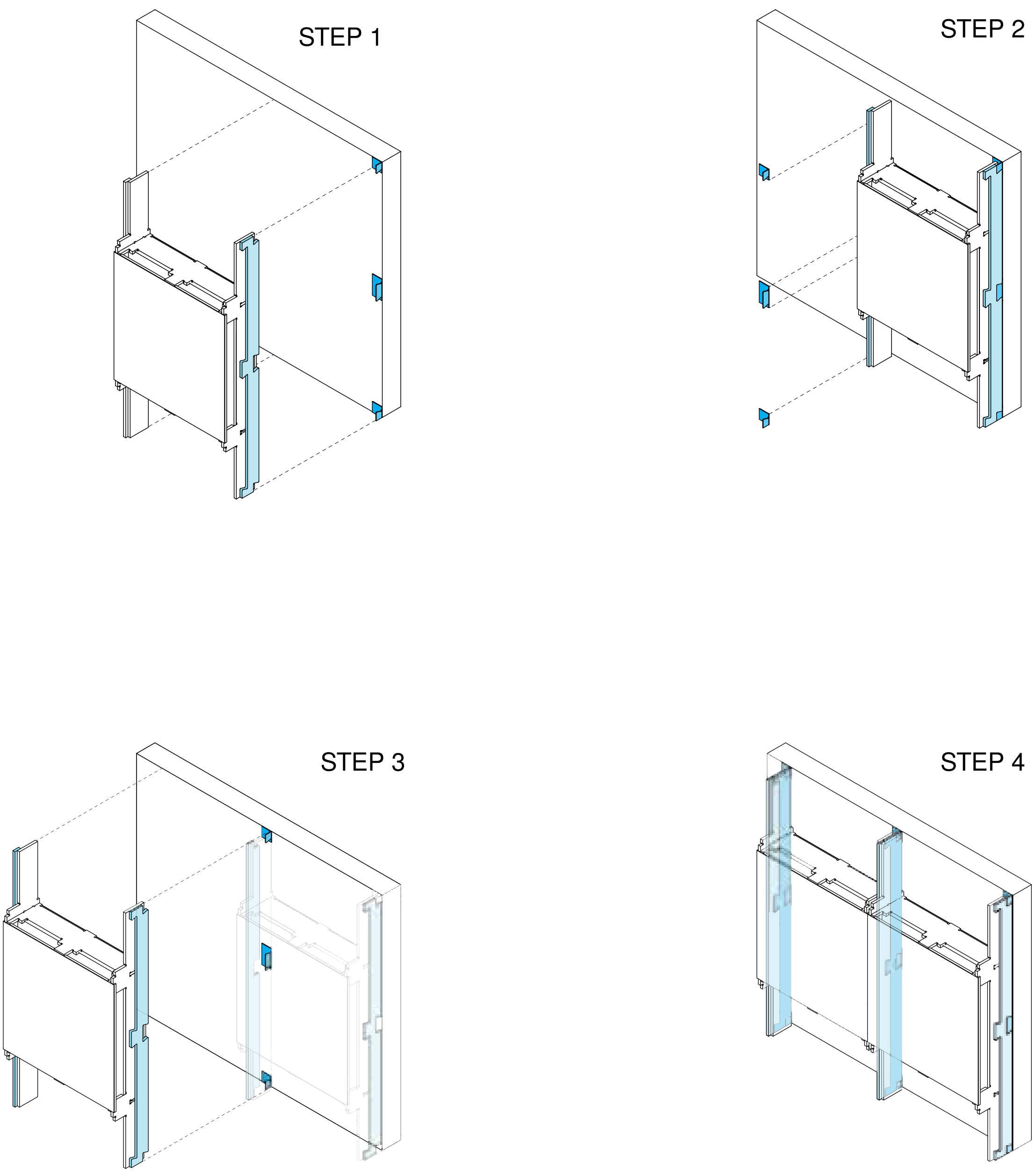


Figure 95: Asssembly process by steps. Own illustration.

Examples of the main combinations of components to renovate an existing facade, are shown in this section.

First, an existing facade with a large opening with single glazing and a single layer of concrete-block wall is shown.

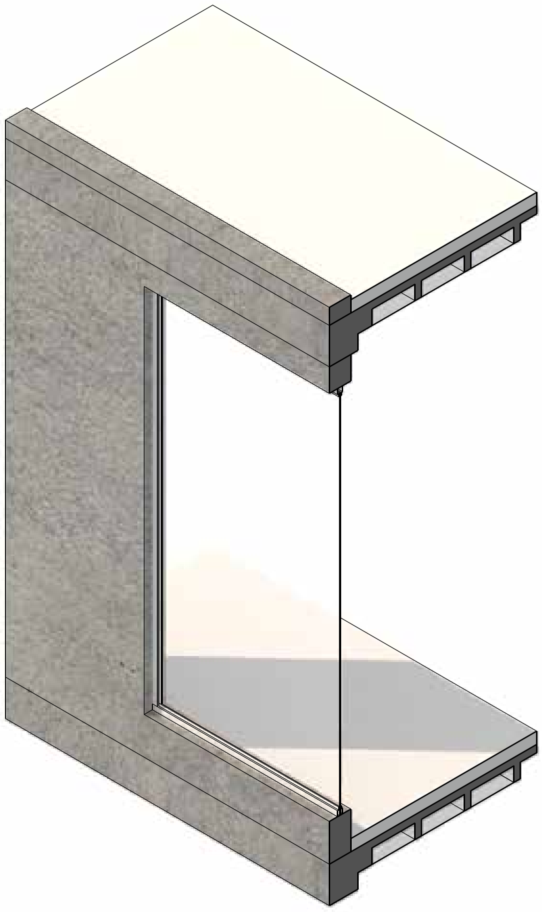


Figure 96: Standard existing facade with large glazing opening, single layer of concrete blocks, no insulation, no shading system. Own

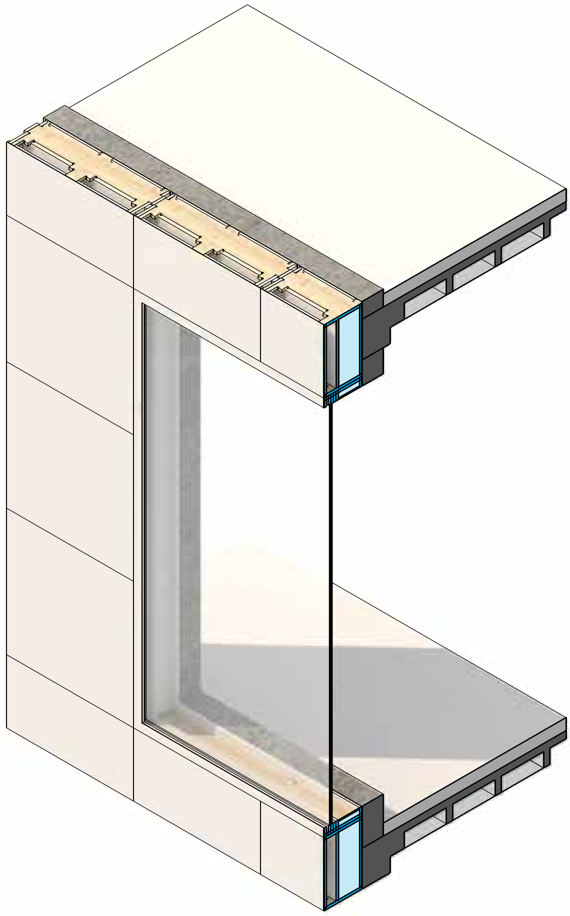


Figure 97: Non-ventilated air cavity cladding and double glazing window components placed on the existing facade. Own illustration.

To improve the indoor comfort of the existing construction, the concrete-block walls can be renovated by placing modules that combine a cladding system (ventilated or airtight), with or without insulation, depending on the climate requirements. Also, the existing opening can be improved with a better performing glass.

As shown in the right image, the same façade typology can be refurbished with a shading system paced on the window. More detailed information about the different renovation options for each climate can be found in Appendix 4.

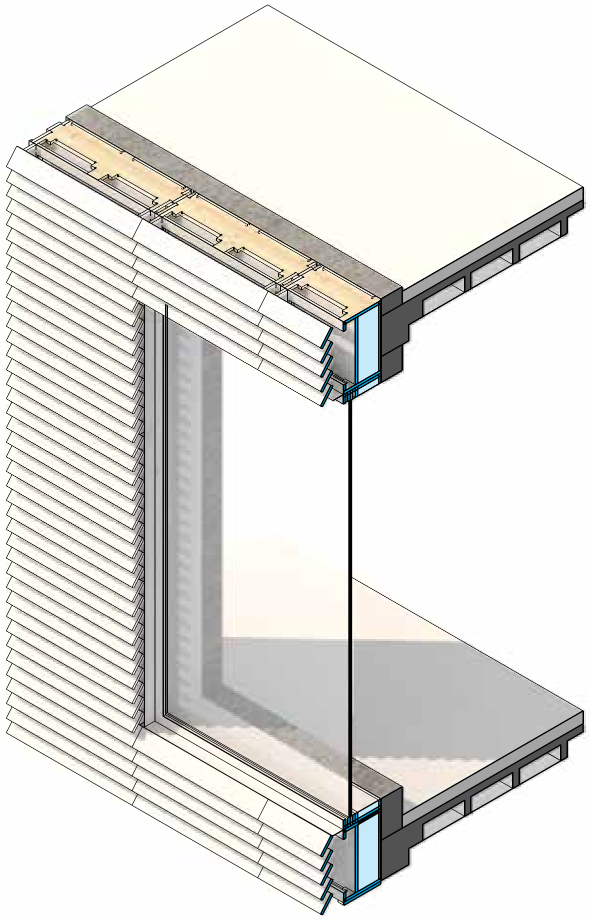


Figure 98: Ventilated air cavity and double-glazing window components placed on existing facade. Own illustration.

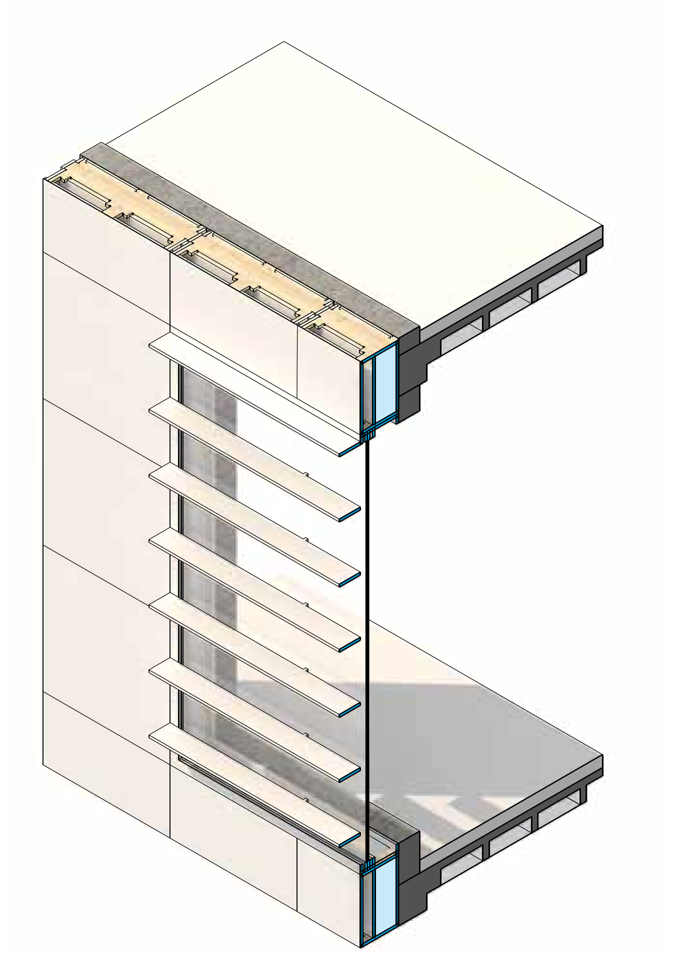


Figure 99: Non-ventilated air cavity cladding, double glazing, fixed horizontal shading components. Own illustration.

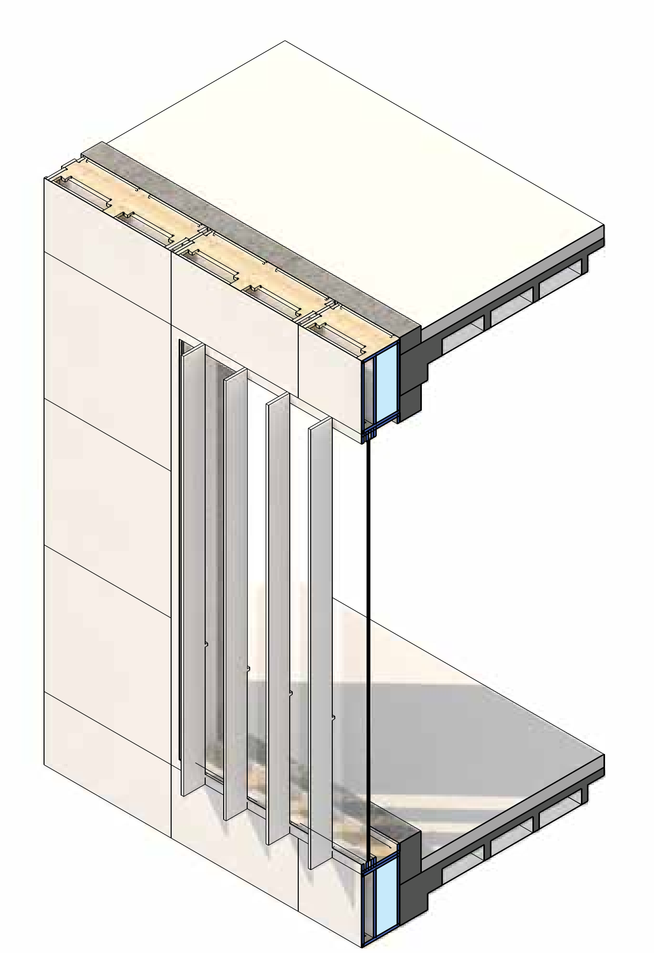


Figure 101: Non-ventilated air cavity cladding, double glazing, fixed vertical shading components. Own illustration.

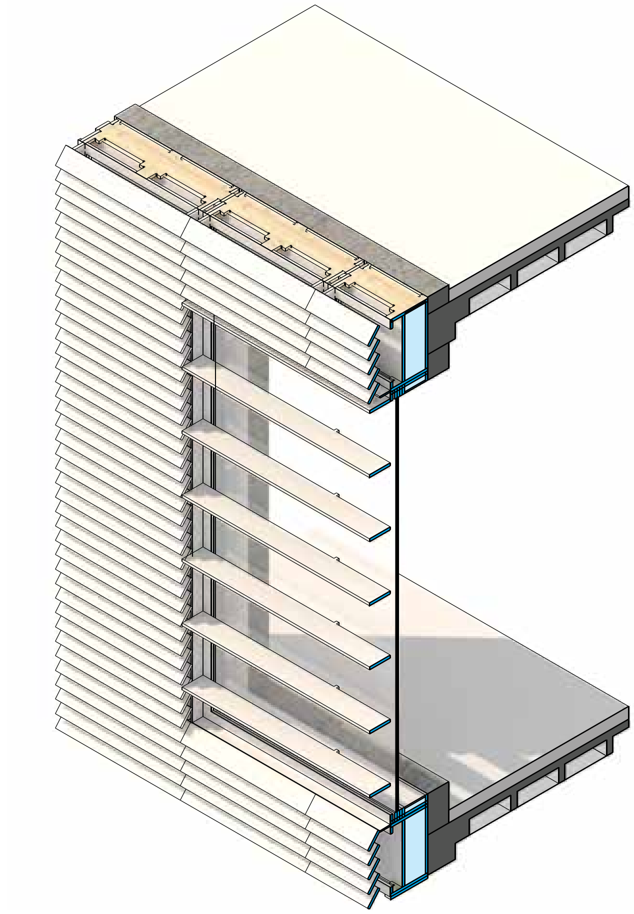


Figure 100: Ventilated air cavity cladding, double glazing, fixed horizontal shading components. Own illustration.

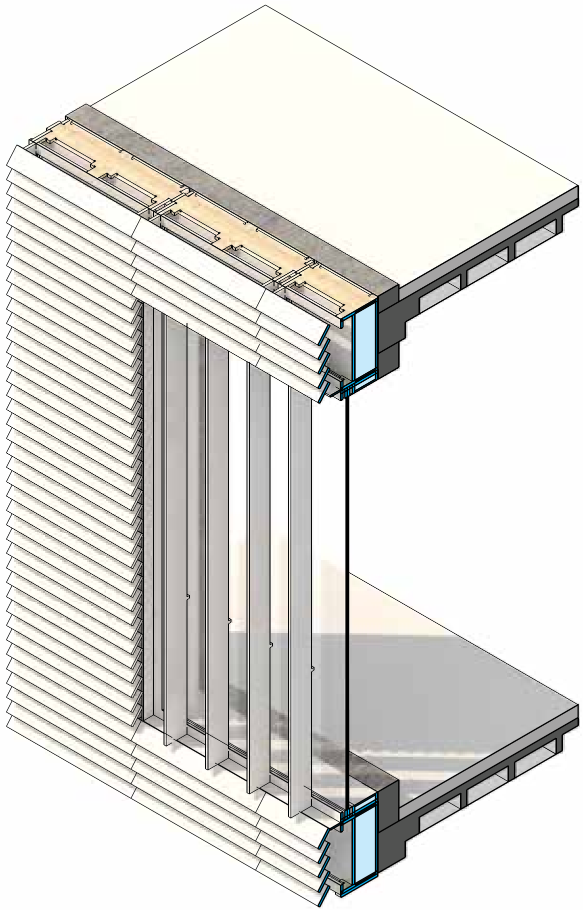


Figure 102: Ventilated air cavity cladding, double glazing, fixed vertical shading components. Own illustration.

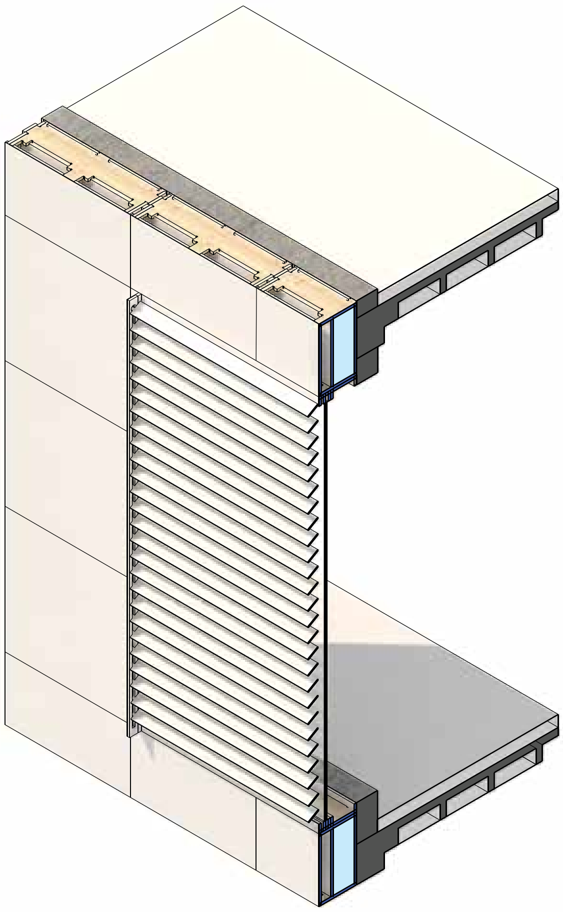


Figure 103: Non-ventilated air cavity cladding, double glazing, operable horizontal shading components. Own illustration.

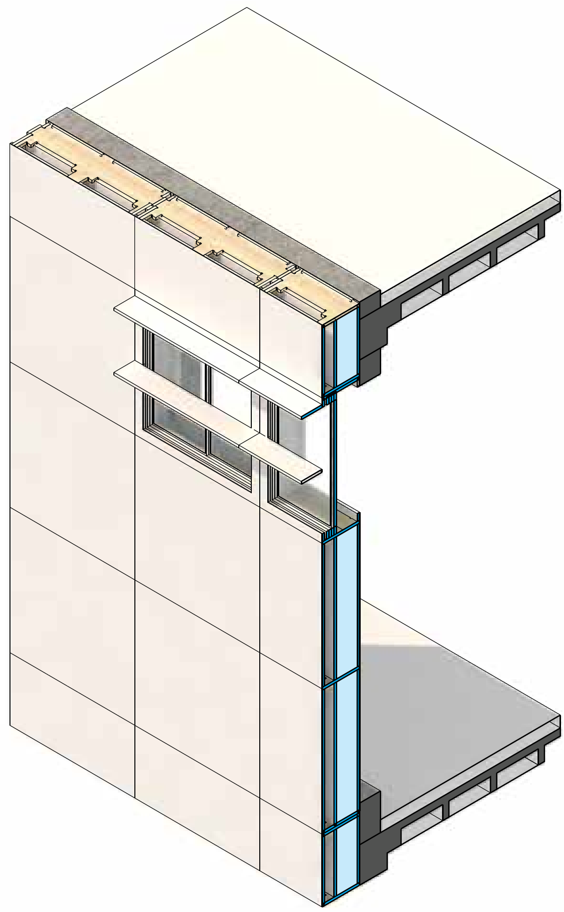


Figure 105: Non-ventilated air cavity cladding, reduced double glazing, fixed horizontal shading components. Own illustration.

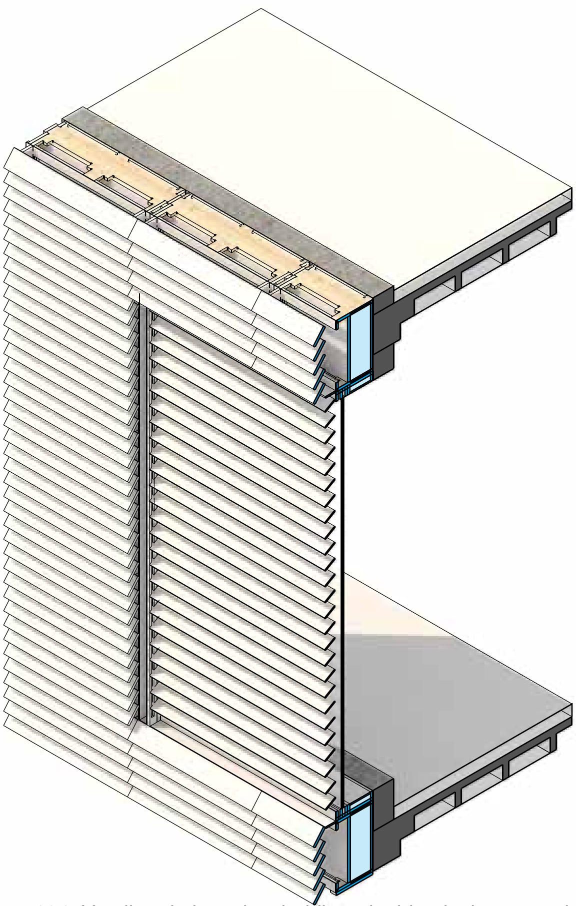


Figure 104: Ventilated air cavity cladding, double glazing, operable horizontal shading components. Own illustration.

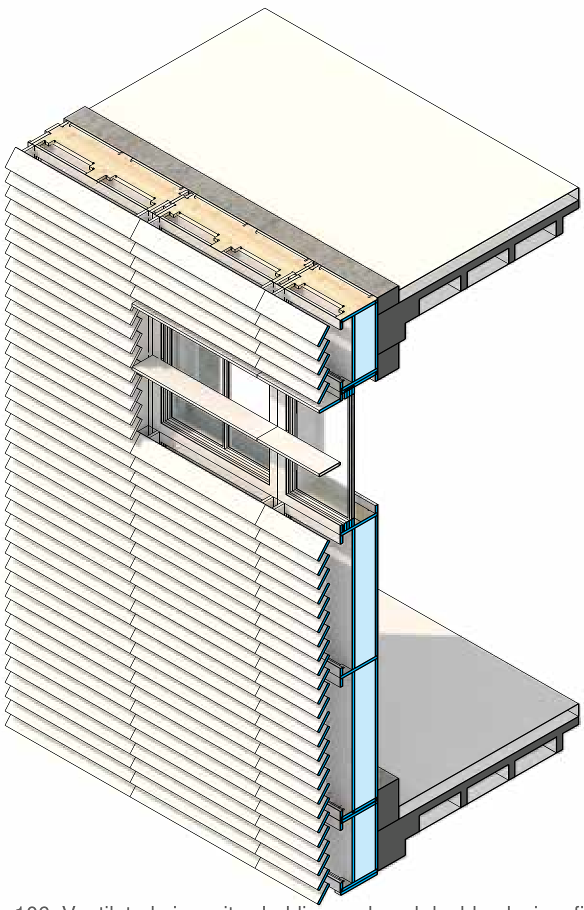


Figure 106: Ventilated air cavity cladding, reduced double glazing, fixed horizontal shading components. Own illustration.

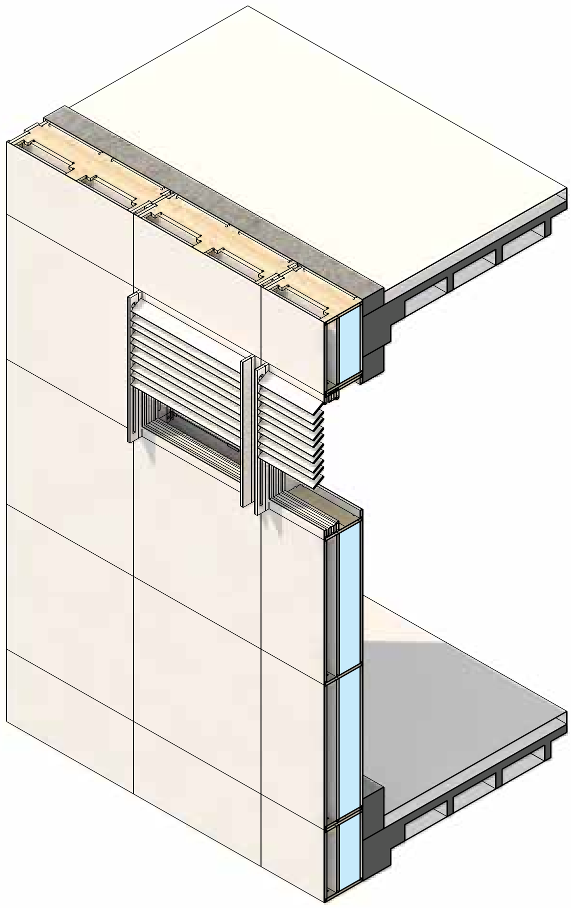


Figure 107: Non-ventilated air cavity cladding, reduced double glazing, operable horizontal shading components. Own illustration.

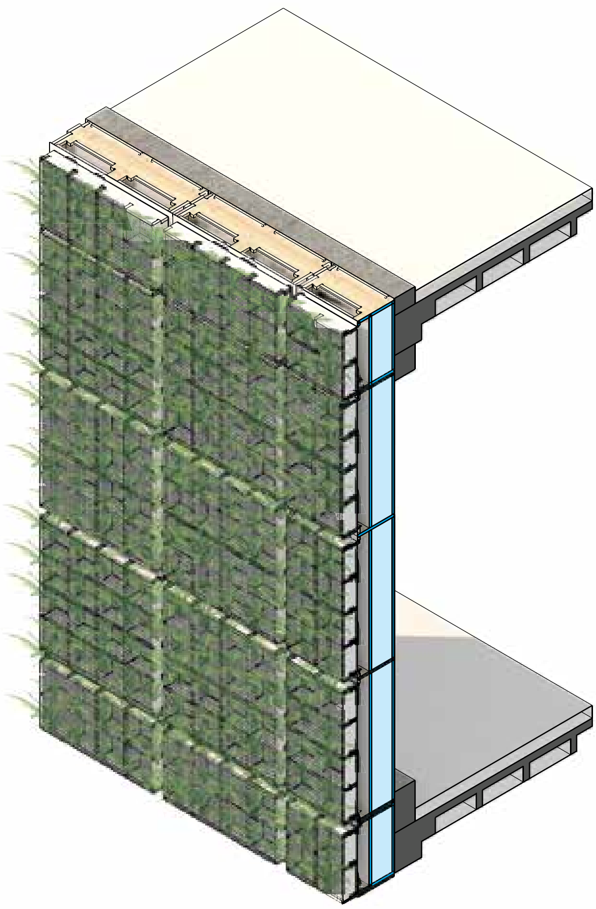


Figure 109: Non-ventilated air cavity cladding, no glazing, green components. Own illustration.

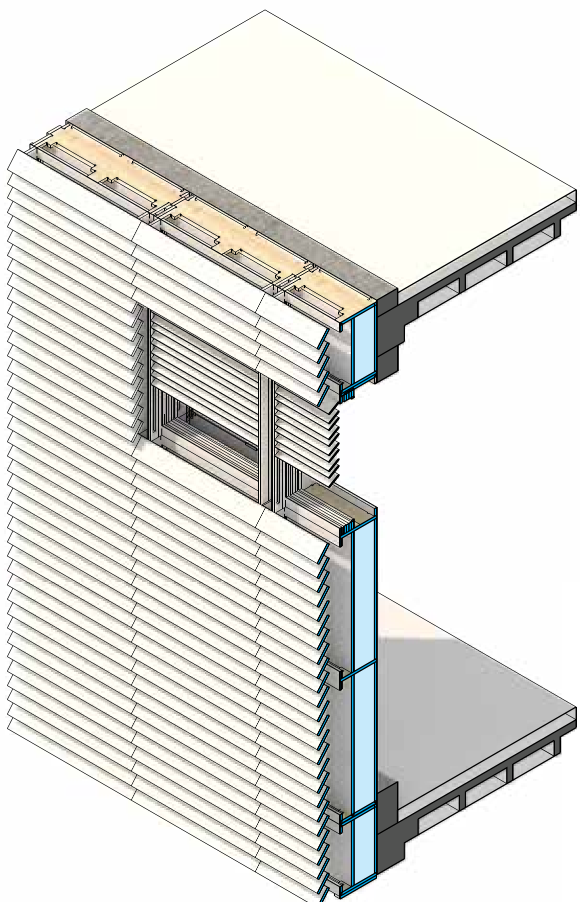


Figure 108: Ventilated air cavity cladding, reduced double glazing, operable horizontal shading components. Own illustration.

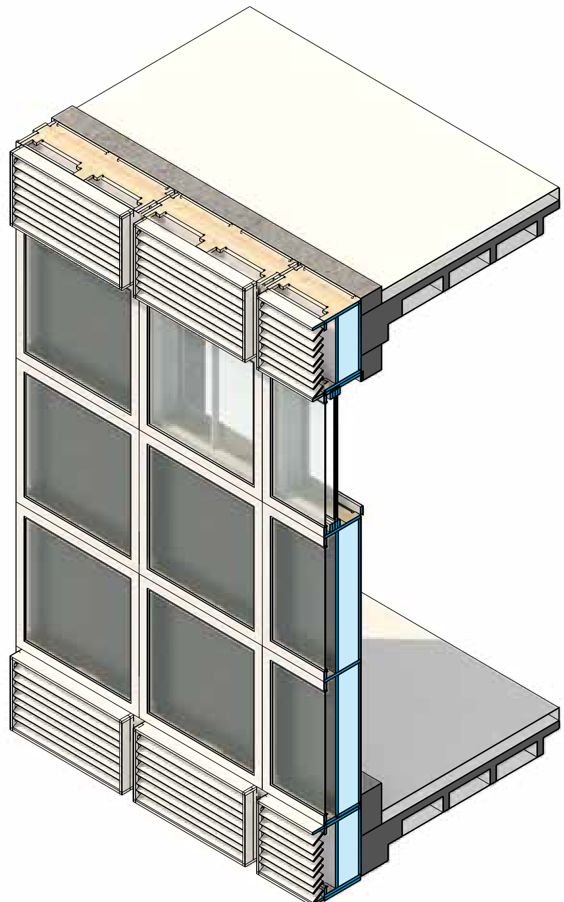


Figure 110: Ventilated air cavity cladding, reduced double glazing, passive heating components. Own illustration.

VIII

8. R-VALUE HAND CALCULATIONS

In this chapter, the UBAKUS online software is used to analyse the multi-layered components and possible combinations of layers.

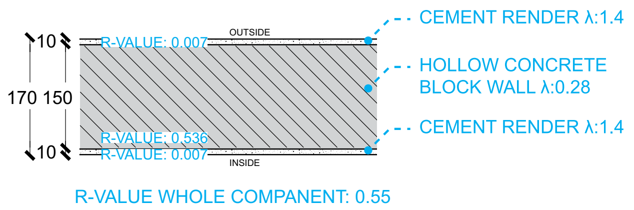


Figure 111: Single layered concrete block facade. Own illustration.

An existing single layered façade is simulated to be placed on a **temperate climate**, to calculate its R-value and general climate performance.

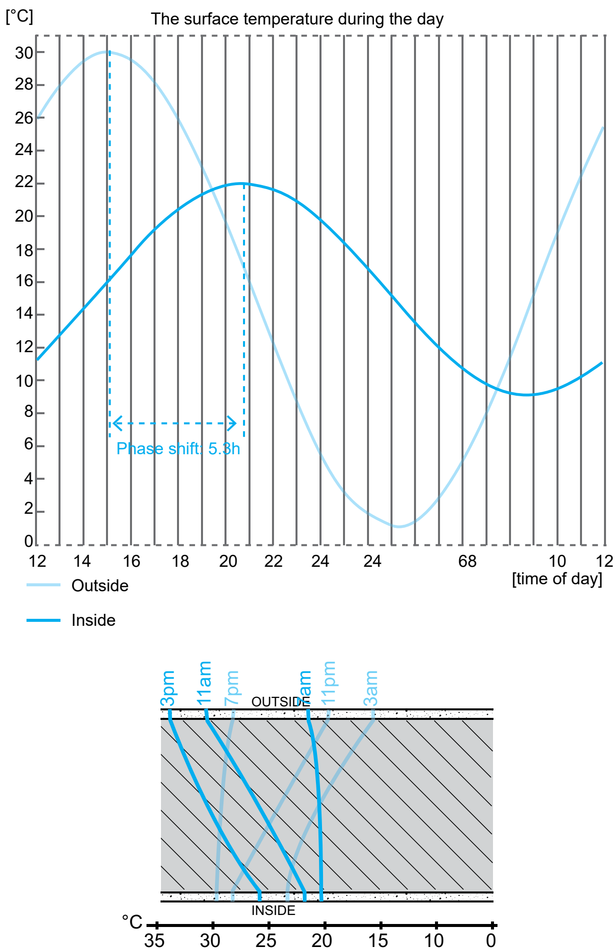


Figure 112: Existing facade performance. Own illustration.

Here, it can be seen that the existing façade has a poor performance, where the indoor temperature fluctuation is very close to the outdoor temperature fluctuations.

Following, an improved façade component is simulated to be placed under the same weather conditions. This new component has added layers, such as insulation, a ventilated cavity and cladding. Here, it is proven that the layered component has an improved R value of 3.44 m2K/W.

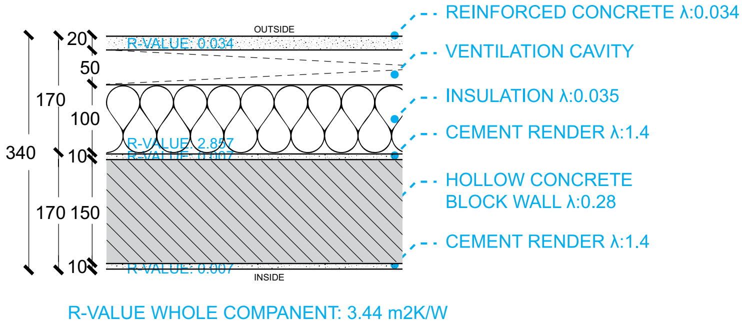


Figure 113: Insulated facade with ventilated air cavity. Own illustration.

After simulating the same outdoor conditions as the previous one, it is shown that the indoor climate is improved, by decreasing the indoor temperature fluctuations.

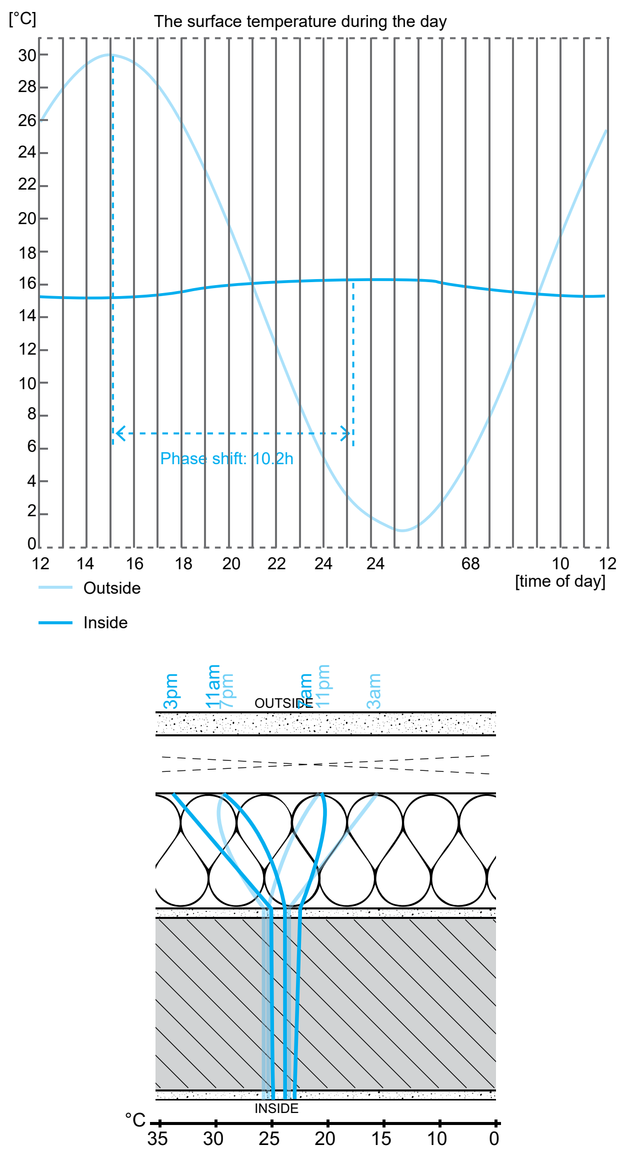


Figure 114: Improved facade performance. Own illustration.

Next, the same simulation is run on a thin and permeable façade, located in a **tropical climate**.

Here, the indoor and outdoor temperature is exactly the same, thus the permeable facade allows the entrance of direct sun heat and the air temperature will always be the same as the outdoor temperature.
Then, an opaque cladding element is placed on the outside of the existing wall.

The results show that, if indoor climate improvement takes only into account static parameters, such as the heat resistance of materials, the results are not realistic.
It can be concluded, that façade renovations can only be tested by including static and dynamic parameters, such as shading, ventilation and heat storage.

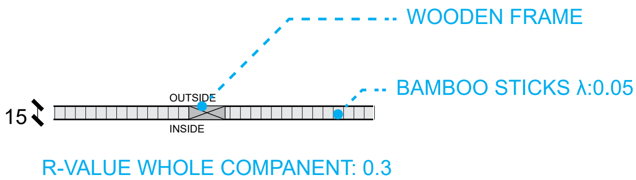


Figure 115: Single layered bamboo sticks facade. Own illustration.

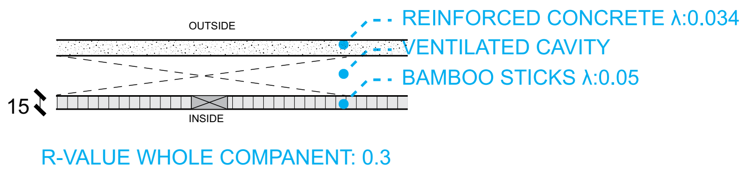
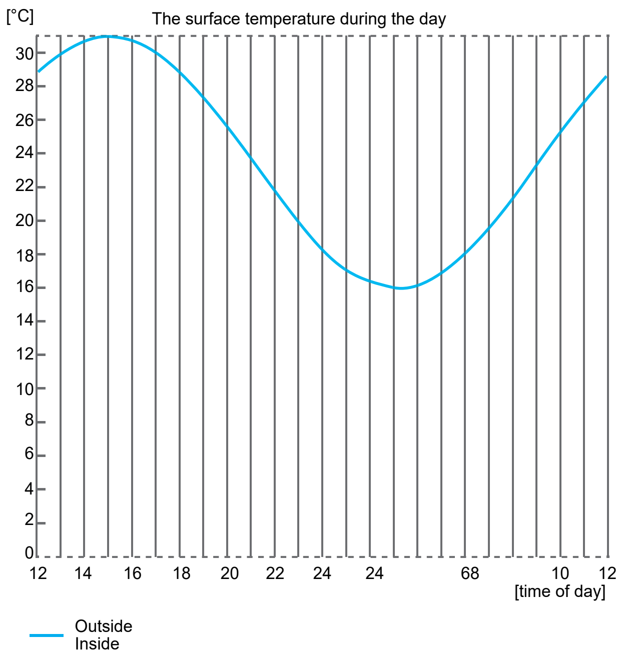


Figure 117: Reinforced concrete cladding with ventilated air cavity. Own illustration.



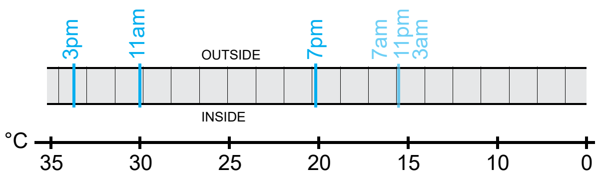


Figure 116: Existing facade performance. Own illustration.

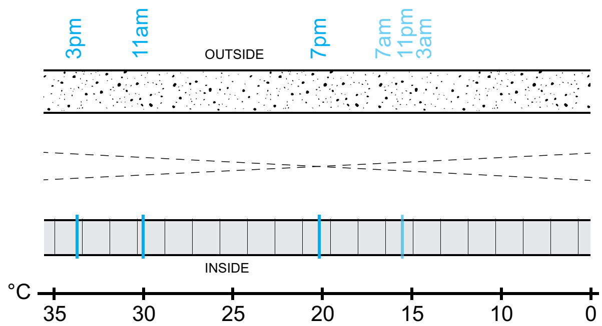


Figure 118: Improved facade performance. Own illustration.

IX

9. SIMULATIONS

9.1. LOCAL CASE STUDIES

For the simulations, local façade and climate standards were taken. For both cases, the city standards were chosen. As shown in the figure below, existing buildings are taken as an example to simulation real construction typologies. Two case studies are simulated, one for a Tropical Climate and a second one for a Temperate Climate.

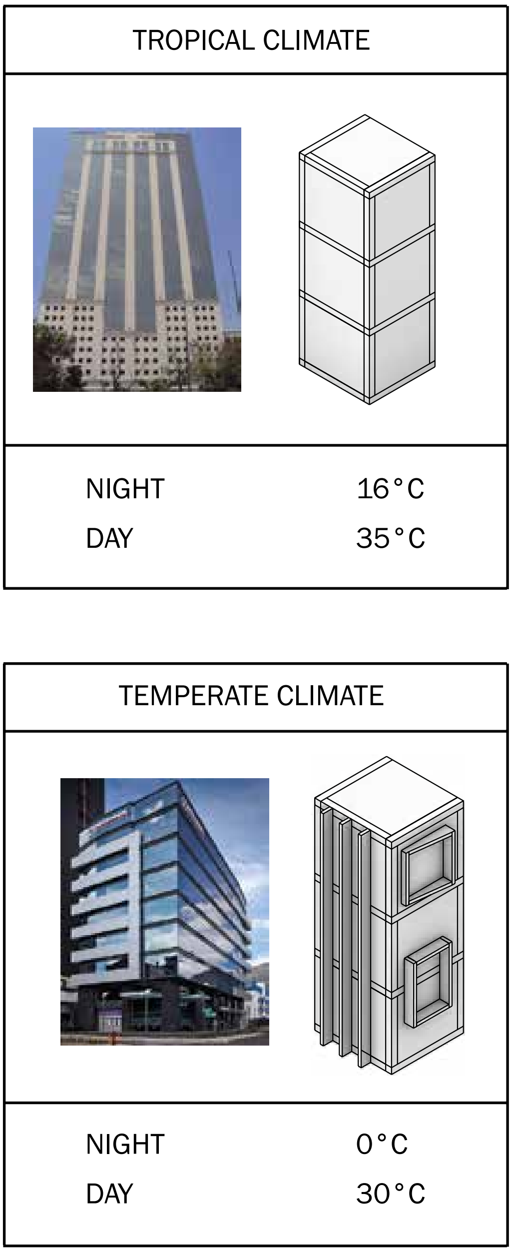


Figure 119: Local case stadies to be simulated for Tropical and Temperate climate. Own illustration.

9.2. TROPICAL CLIMATE SETTINGS

The first simulation, made with the Design Builder software, shows the results of a local, existing building after applying the reference Tropical Climate parameters. This software does not include tropical climate specifically from Ecuador, but a similar one was chosen from the amazon region in Brazil, with the same climate and geographical characteristics. The parameters set for this simulation can be found in Appendix 4, but a summary of the main ones is listed below.

- The outdoor maximum temperature is set to 34°C.

- The minimum outdoor temperature is set to 16°C.

- The prevailing wind direction is set to enter from the N and NW.

- Only natural ventilation is activated. No active heating or cooling systems are enabled, so the indoor temperatures are the real ones.

- A residential template is chosen to simulate real residential parameters.

- The occupancy density is set to 0.02 people/m2.

In order to test the use of different combinations of the proposed components in chapter 7.5, sixteen case studies are set. The first four case studies represent the renovation of an existing building in a tropical climate, these steps are shown in the next page.

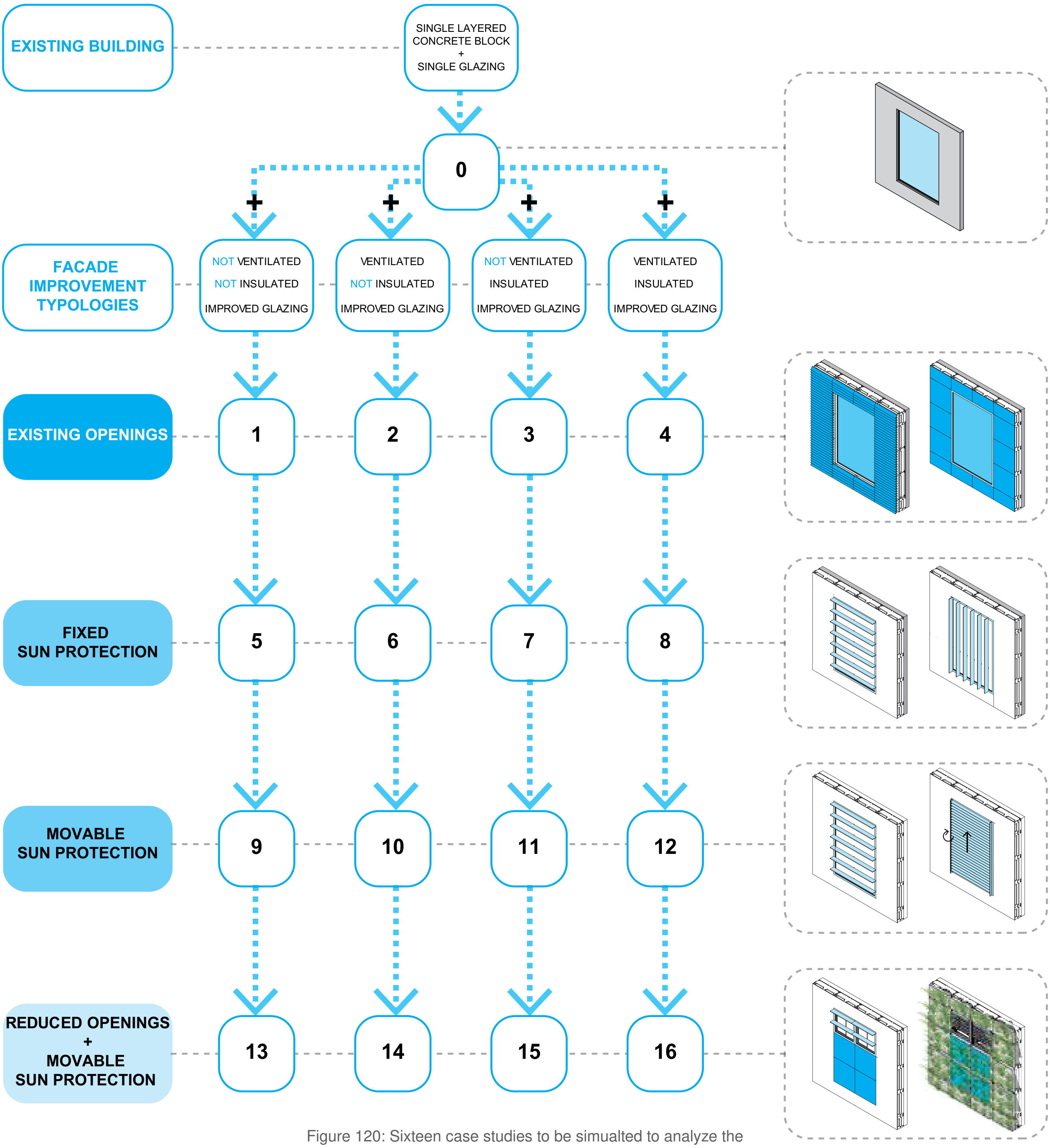


Figure 120: Sixteen case studies to be simualted to analyze the performance of the existing buildings renovation. Own illustration.

First, different cladding systems are tested (case studies 1 to 4), by combining ventilated or non-ventilated air cavities with insulation and no insulation. All case stadies are assumed to have improved double galzing. Then, fixed shading elements are placed on the previous tested façades (case studies 5 to 8). Third, operable shading elements are placed on the east and west facades (case studies 9 to 12). Finally, the openings are reduced and tested in combination with previous improvements (case studies 13 to 16). For more detailed information see Appendix 4.

9.2.1. CONSTRUCTION AND OPENINGS

- An uninsulated, medium weight construction template is set as default.

- The externa walls are set to be built with single layered brickwork, without insulation, plaster on the outside and gypsum on the inside.

- The flat roof is set to be made out of reinforced concrete with plaster on the outside and gypsum on the inside.

- The model infiltration rate is set to be 6. It is maximum infiltration value for existing constructions.

- For the openings, a single glazing, clear, no shading template is set.

- The openings are set to be made out of single gazing of 6 mm.

- The operable space is set to 50% of the entire opening.

9.2.2. SIMULATION RESULTS

An overview of the final results is shown in this section. More detailed information can be found in Appendix 4. The results shown in this section respond to the renovation steps explained in section 10.2.

The existing faced configuration (case study 0) is highlighted with a blue dotted line. The resulting indoor operative temperature is higher than the expected to provide comfort to occupants. For example, on July, with a minimum outdoor temperature of 16°C, according to the adaptive comfort chart, the indoor temperature should stay between 19 and 32°C. As shown in the previous chart, the indoor operative temperature for the existing construction on July is over 28°C during the nigh period and 42°C during the day time, when the peak maximum temperature reaches 34°C.

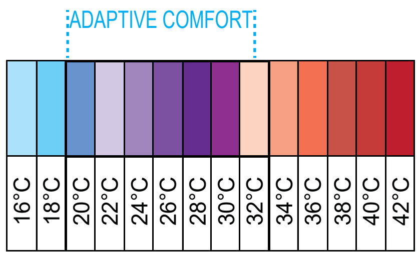


Figure 121: Acceptable indoor temperature range, according to the Adaptive Comfort Model. Own illustration.

CLIMATE DATA	PARAMETERS	UNITS	SIMULATED CASE STUDIES								
			0	1	2	3	4	5	6	7	8
Tout.min. 16°C 6-July 3:00AM	Toperative	°C	28.68	24.19	24.36	24.24	25.48	23.51	23.65	23.49	23.6
	Tradiant	°C	28.94	26.94	27.17	27.02	27.8	26.08	26.27	26.06	26.21
	GAINS window	kW	0	0	0	0	0	0	0	0	0
	LIGHTING	kW	0	0	0	0	0	0	0	0	0
Tout.max. 34°C 23-July 3:00PM	Toperative	°C	42.47	36.64	36.47	36.85	36.76	35.72	35.57	35.83	36.76
	Tradiant	°C	42.36	37.27	37.03	37.57	37.44	35.97	35.76	36.14	36.04
	GAINS window	kW	19.48	11.64	11.64	11.64	11.64	10.77	10.77	10.77	10.77
	LIGHTING	kW	3.35	3.35	3.35	3.35	3.35	3.35	3.35	3.35	3.35

CLIMATE DATA	PARAMETERS	UNITS	SIMULATED CASE STUDIES							
			9	10	11	12	13	14	15	16
Tout.min. 16°C 6-July 3:00AM	Toperative	°C	23.06	23.18	22.91	23.02	25.35	23.42	22.8	22.91
	Tradiant	°C	25.5	25.66	25.31	25.45	25.85	25.94	25.13	25.28
	GAINS window	kW	0	0	0	0	0	0	0	0
	LIGHTING	kW	0	0	0	0	0	0	0	0
Tout.max. 34°C 23-July 3:00PM	Toperative	°C	34.48	34.33	34.49	34.44	32.5	32.39	32.25	32.22
	Tradiant	°C	34.2	34	34.22	34.15	31.5	31.36	31.17	31.13
	GAINS window	kW	6.78	6.78	6.78	6.78	3.1	3.1	3.1	3.1
	LIGHTING	kW	3.35	3.35	3.35	3.35	3.35	3.35	3.35	3.35

Figure 122: Case studies simulation results. Own illustration.

0	1	2	3	4	5	6	7	8
EXISTING	NOT VENTILATED NOT INSULATED IMPROVED GLAZING	VENTILATED, NOT INSULATED, IMPROVED GLAZING	NOT VENTILATED, INSULATED, IMPROVED GLAZING	VENTILATED, INSULATED, IMPROVED GLAZING	NO TVENTILATED, NOT INSULATED, IMPROVED GLAZING, HORIZ.+VERT. LOUVE	VENTILATED, NOT INSULATED, IMPROVED GLAZING, HORIZ.+VERT. LOUVE	NOT VENTILATED, INSULATED, IMPROVED GLAZING, HORIZ.+VERT. LOUVE	VENTILATED, INSULATED, IMPROVED GLAZING HORIZ.+VERT. LOUVE

9	10	11	12	13	14	15	16
NOT VENTILATED, NOT INSULATED, IMPROVED GLAZING HORIZ. LOUVERS + BLINDS	VENTILATED, NOT INSULATED, IMPROVED GLAZING HORIZ. LOUVERS + BLINDS	NOT VENTILATED, INSULATED, IMPROVED GLAZING HORIZ. LOUVERS + BLINDS	VENTILATED, NOT SULATED, IMPROVED GLAZING HORIZ. LOUVERS + BLINDS	NOT VENTILATED, NOT INSULATED, REDUCED GLAZING HORIZ. LOUVERS + BLINDS	VENTILATED, NOT INSULATED, REDUCED GLAZING HORIZ. LOUVERS + BLINDS	NOT VENTILATED, INSULATED, REDUCED GLAZING HORIZ. LOUVERS + BLINDS	VENTILATED, INSULATED, REDUCED GLAZING HORIZ. LOUVERS + BLINDS

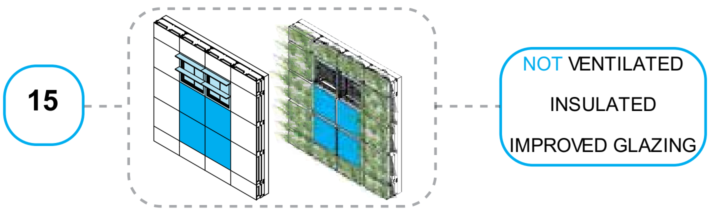
Figure 123: Case studies explanation for the tropical climate. Own illustration.

After applying the different steps explained in the chart above, the final indoor temperature fluctuates between 22.8°C at midnight to 32.25°C at midday (case studies 15 and 16). These indoor operative temperatures are obtained when maximum outdoor temperatures are applied (16°C to 34°C).

Case study 15 represents an insulated, non-ventilated air cavity cladding. The openings are reduced and fixed horizontal shading components are placed on the north and south façaden, while operable shading components on the east and west façade. For more detailed information see Appendix 4.

Case study 16 represents an insulated, ventilated air cavity cladding. The openings are also reduced and fixed horizontal shading components are placed on the north and south façaden while operable shading components on the east and west façade. For more detailed information see Appendix 4.

CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 15
Tout.min. 16°C 6-July 3:00AM	T OPERATIVE	°C	28.68	22.8
	T RADIANT	°C	28.94	25.13
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	T VARIATION	°C		-5.88°C
Tout.max. 34°C 23-July 3:00PM	T OPERATIVE	°C	42.47	32.25
	T RADIANT	°C	42.36	31.17
	GAINS WINDOW	kW	19.48	3.1
	LIGHTING	kW	3.35	3.35
	T VARIATION	°C		-10.22°C



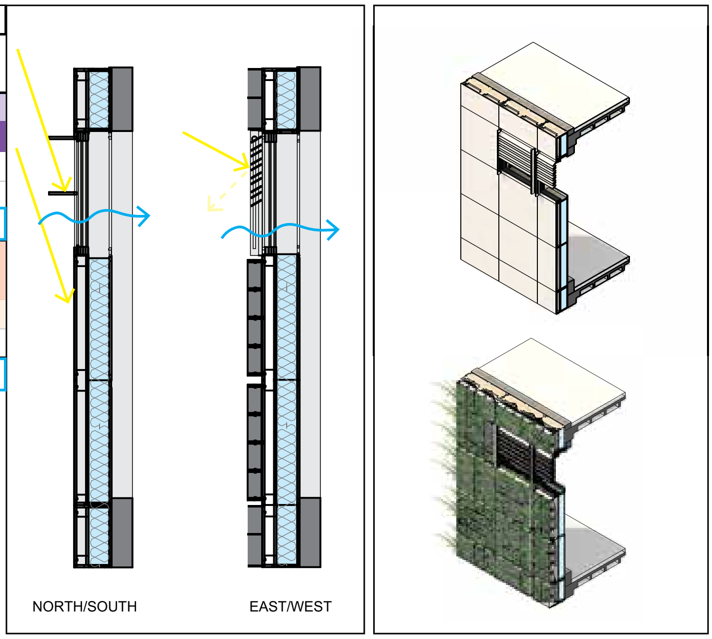
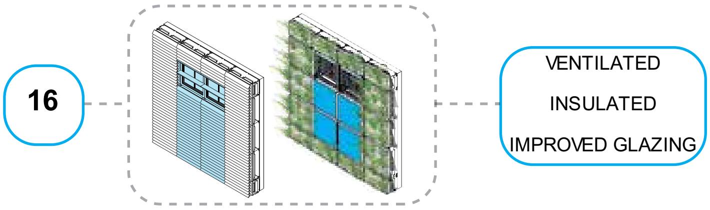


Figure 124: Simulation results of case study 15. Own illustration.

CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 16
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	22.91
	TRADIANT	°C	28.94	25.28
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-5.77°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	32.22
	TRADIANT	°C	42.36	31.13
	GAINS WINDOW	kW	19.48	3.1
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-10.25°C



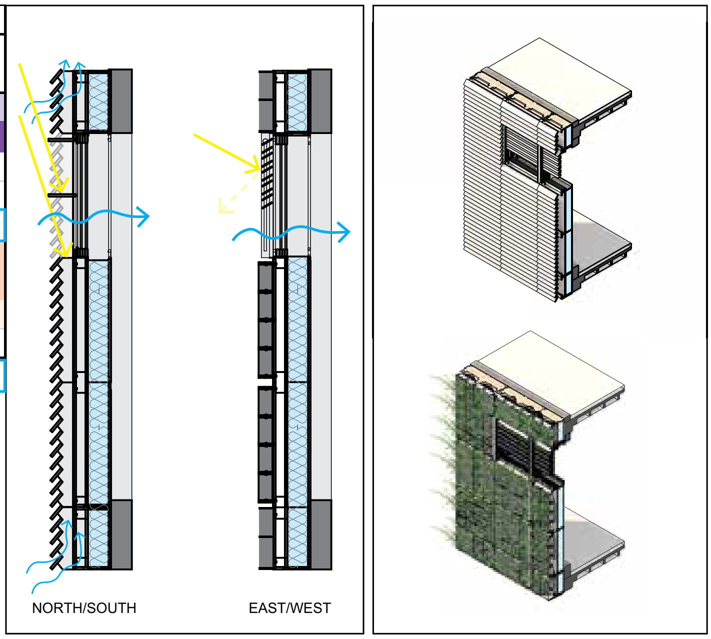


Figure 125: Simulation results of case study 16. Own illustration.

9.3. TEMPERATE CLIMATE SETTINGS

The second simulation, made with the Design Builder software, show the results of a local, existing building after applying the reference Temperate Climate parameters. The detailed parameters set for this simulation can be found in Appendix 4, but a summary of the main ones is listed below.

- The outdoor maximum temperature is set to 30°C.

- The minimum outdoor temperature is set to 0°C.

- The prevailing wind direction is set to enter from the NE and E.

- Only natural ventilation is activated. No active heating or cooling systems are enabled, so the indoor temperatures are the real ones.

- A residential template is chosen to simulate real residential parameters.

- The occupancy density is set to 0.02 people/m2.

9.3.1. CONSTRUCTION AND OPENINGS

- An uninsulated, medium weight construction template is set as default.

- The externa walls are set to be built with single layered brickwork, without insulation, plaster on the outside and gypsum on the inside.

- The flat roof is set to be made out of reinforced concrete with plaster on the outside and gypsum on the inside.

- The model infiltration rate is set to be 6. It is maximum infiltration value for existing constructions.

- For the openings, a single glazing, clear, no shading template is set.
The openings are set to be made out of single gazing of 6 mm.
The operable space is set to 50% of the entire opening.

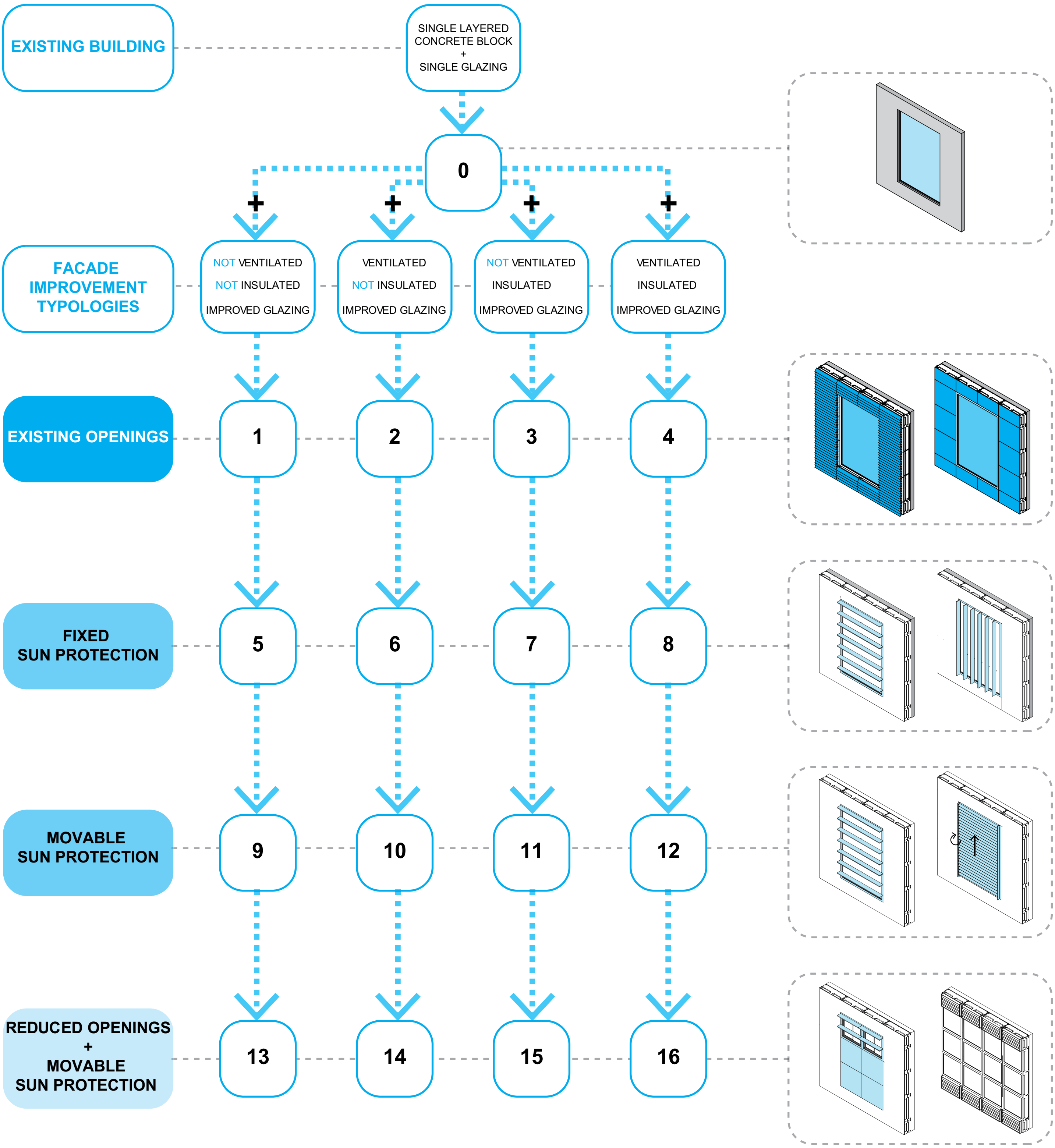


Figure 126: Sixteen case studies to be simualted to analyze the performance of the existing buildings renovation. Own illustration.

9.3.2. SIMULATION RESULTS

The existing faced configuration (case study 0) is highlighted with a blue dotted line. The resulting indoor operative temperature is higher than the expected to provide comfort to occupants. For example, with a minimum outdoor temperature of 0°C and a maximum outdoor temperature of 30°C, according to the adaptive comfort chart, the indoor temperature should stay between 16 and 30°C. As shown in the previous chart, the indoor operative temperature for the existing construction on July is 11°C during the nigh period and 34°C during the day time, when the peak maximum temperature reaches 30°C.

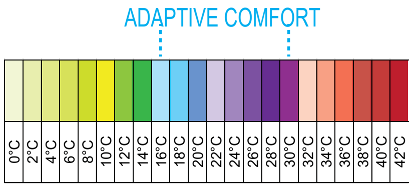


Figure 127: Acceptable indoor temperature range, according to the Adaptive Comfort Model. Own illustration.

CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
			0	1	2	3	4	5	6	7	8
Tout.min . 0°C 2-March 3:00AM	TOPERATIVE	°C	11.03	18.5	17.6	19.8	20.02	16.26	16.8	18.59	18.76
	TRADIANT	°C	12.98	18.69	18.4	20.73	20.95	16.96	17.57	19.48	19.67
	GAINS WINDOW	kW	0	0	0	0	0	0	0	0	0
	LIGHTING	kW	0	0	0	0	0	0	0	0	0
Tout.max . 30°C 8-September 2:00PM	TOPERATIVE	°C	34.83	34.13	34.27	35.06	34.98	33.42	33.34	34.04	33.98
	TRADIANT	°C	35.63	34.85	34.89	35.92	35.81	33.78	33.67	34.6	34.52
	GAINS WINDOW	kW	25.2	18.07	18.07	18.07	18.07	13.59	13.59	13.59	13.59
	LIGHTING	kW	3.35	3.35	3.35	3.35	3.35	3.35	3.35	3.35	3.35

CLIMATE DATA	PARAMETERS	UNITS	CASE 9	CASE 10	CASE 11	CASE 12	CASE 13	CASE 14	CASE 15	CASE 16
			9	10	11	12	13	14	15	16
Tout.min . 0°C 2-March 3:00AM	TOPERATIVE	°C	16.75	17.39	19.4	19.6	19.33	20.08	23.16	23.23
	TRADIANT	°C	17.47	18.15	20.34	20.55	20.2	21	24.25	24.31
	GAINS WINDOW	kW	0	0	10.2 (MIDDAY)	0	0	0	0	
	LIGHTING	kW	0	0	0	0	0	0	0	0
Tout.max . 30°C 8-September 2:00PM	TOPERATIVE	°C	31.38	31.24	31.6	31.56	29.8	29.61	29.92	29.81
	TRADIANT	°C	31.07	30.9	31.35	31.3	29.09	28.87	29.25	29.13
	GAINS WINDOW	kW	10.5	10.5	10.5	10.5	2.96	2.96	2.96	2.96
	LIGHTING	kW	3.35	3.35	3.35	3.35	3.35	3.35	3.35	3.35

Figure 128: Case studies simulation results. Own illustration.

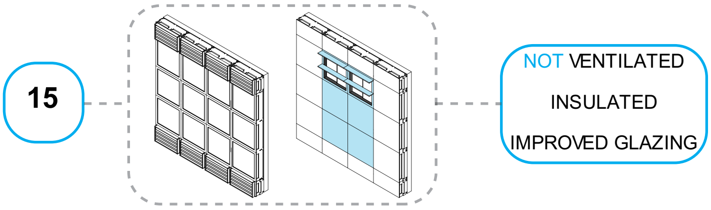
0	1	2	3	4	5	6	7	8
EXISTING	NOT VENTILATED NOT INSULATED IMPROVED GLAZING	VENTILATED, NOT INSULATED, IMPROVED GLAZING	NOT VENTILATED, INSULATED, IMPROVED GLAZING	VENTILATED, INSULATED, IMPROVED GLAZING	NO TVENTILATED, NOT INSULATED, IMPROVED GLAZING, HORIZ.+VERT. LOUVE	VENTILATED, NOT INSULATED, IMPROVED GLAZING, HORIZ.+VERT. LOUVE	NOT VENTILATED, INSULATED, IMPROVED GLAZING, HORIZ.+VERT. LOUVE	VENTILATED, INSULATED, IMPROVED GLAZING HORIZ.+VERT. LOUVE

9	10	11	12	13	14	15	16
NOT VENTILATED, NOT INSULATED, IMPROVED GLAZING HORIZ. LOUVERS + BLINDS	VENTILATED, NOT INSULATED, IMPROVED GLAZING HORIZ. LOUVERS + BLINDS	NOT VENTILATED, INSULATED, IMPROVED GLAZING HORIZ. LOUVERS + BLINDS	VENTILATED, NOT SULATED, IMPROVED GLAZING HORIZ. LOUVERS + BLINDS	NOT VENTILATED, NOT INSULATED, REDUCED GLAZING HORIZ. LOUVERS + BLINDS PASSIVE HEATING	VENTILATED, NOT INSULATED, REDUCED GLAZING HORIZ. LOUVERS + BLINDS PASSIVE HEATING	NOT VENTILATED, INSULATED, REDUCED GLAZING HORIZ. LOUVERS + BLINDS PASSIVE HEATING	VENTILATED, INSULATED, REDUCED GLAZING HORIZ. LOUVERS + BLINDS PASSIVE HEATING

Figure 129: Case studies explanation for the tropical climate. Own illustration.

After applying the different steps explained in the chart above, the final indoor temperature fluctuates between 23.16°C to 29.9°C (case studies 15 and 16). These indoor operative temperatures are reached after applying a ventilated and not ventilated, insulated cladding, also fixed shading elements are placed on the north façade, operable sun shading elements are placed on the east and west façade and a passive heating cladding on the south facade. Case studies 15 and 16 are shown in the illustration below. For more detail please see Appendix 4.

CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 15
Tout. 0-24°C 2-March 3:00AM	TOPERATIVE	°C	11.03	23.16
	TRADIANT	°C	12.98	24.25
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		+12.13°C
Tout. 7-30°C 8-September 2:00PM	TOPERATIVE	°C	34.83	29.92
	TRADIANT	°C	35.63	29.25
	GAINS WINDOW	kW	25.2	2.96
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-4.91°C



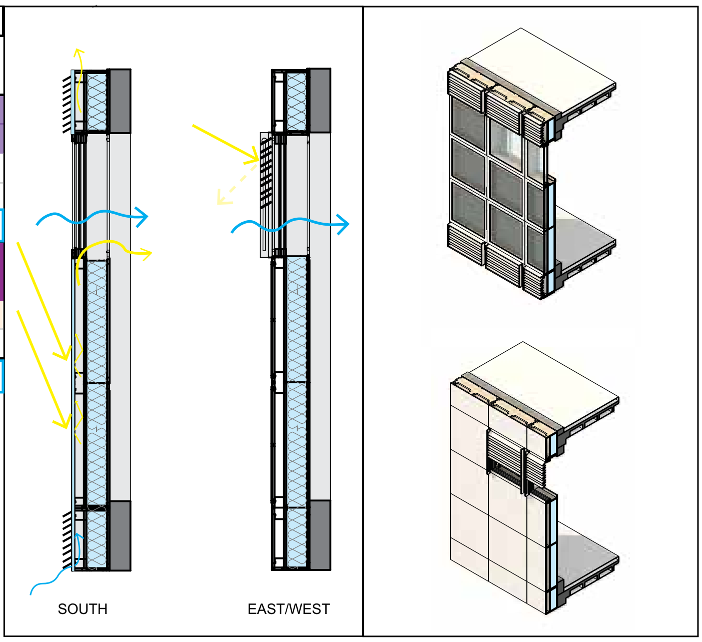
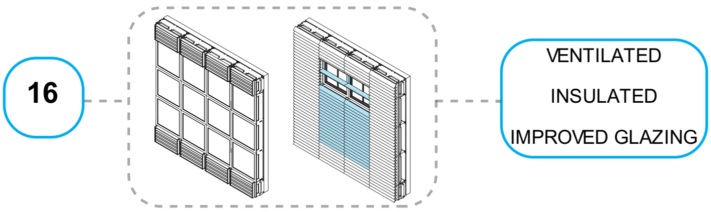


Figure 130: Simulation results of case study 15. Own illustration.

CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 16
Tout. 0-24°C 2-March 3:00AM	TOPERATIVE	°C	11.03	23.23
	TRADIANT	°C	12.98	24.31
	GAINS WINDOW	kW	0	
	LIGHTING	kW	0	0
	TVARIATION	°C		+12.20C
Tout. 7-30°C 8-September 2:00PM	TOPERATIVE	°C	34.83	29.81
	TRADIANT	°C	35.63	29.13
	GAINS WINDOW	kW	25.2	2.96
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-5.02°C



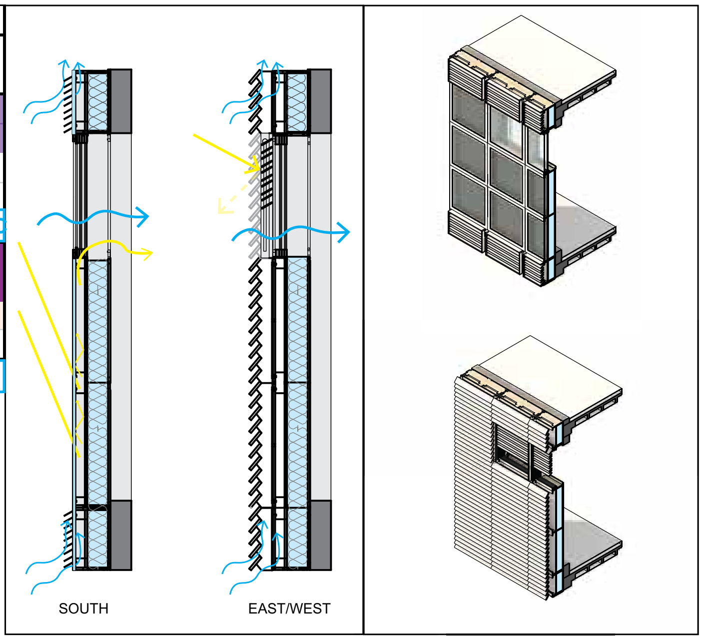


Figure 131: Simulation results of case study 16. Own illustration.

9.4. FINAL ASESSMENT

The final design is compared to the two main references, analyzed in chapter 6. Here, the analysis is based on the list of requirements that were set for this research in chapter 5. These requirements have different values of importance within the research. These levels are shown in the illustration below, with the number of blue dots for each requirement. The assessed references are scored with a scale of 0 to 2. If the system meets only partially, it is scored with the number 1 and if it does not meet with the requirement, it is scored with the number 0. In the end, a final score is given for every case study, by multiplying the importance of the requirement and the indivudual scores.

It can be stated that the combination of both system's advantages provides a complete product. The WikiHouse project provides an easy and quick assembly procces. The CNC technology achieves very accurate detailing manufacture on almost any type of sheet material, which allows to choose low maintanence materials. The reusability of the entire system is guarantied by the the right assembly and diassembly ergonomics of the modular design. On ther other hand, the multi-layered conceot

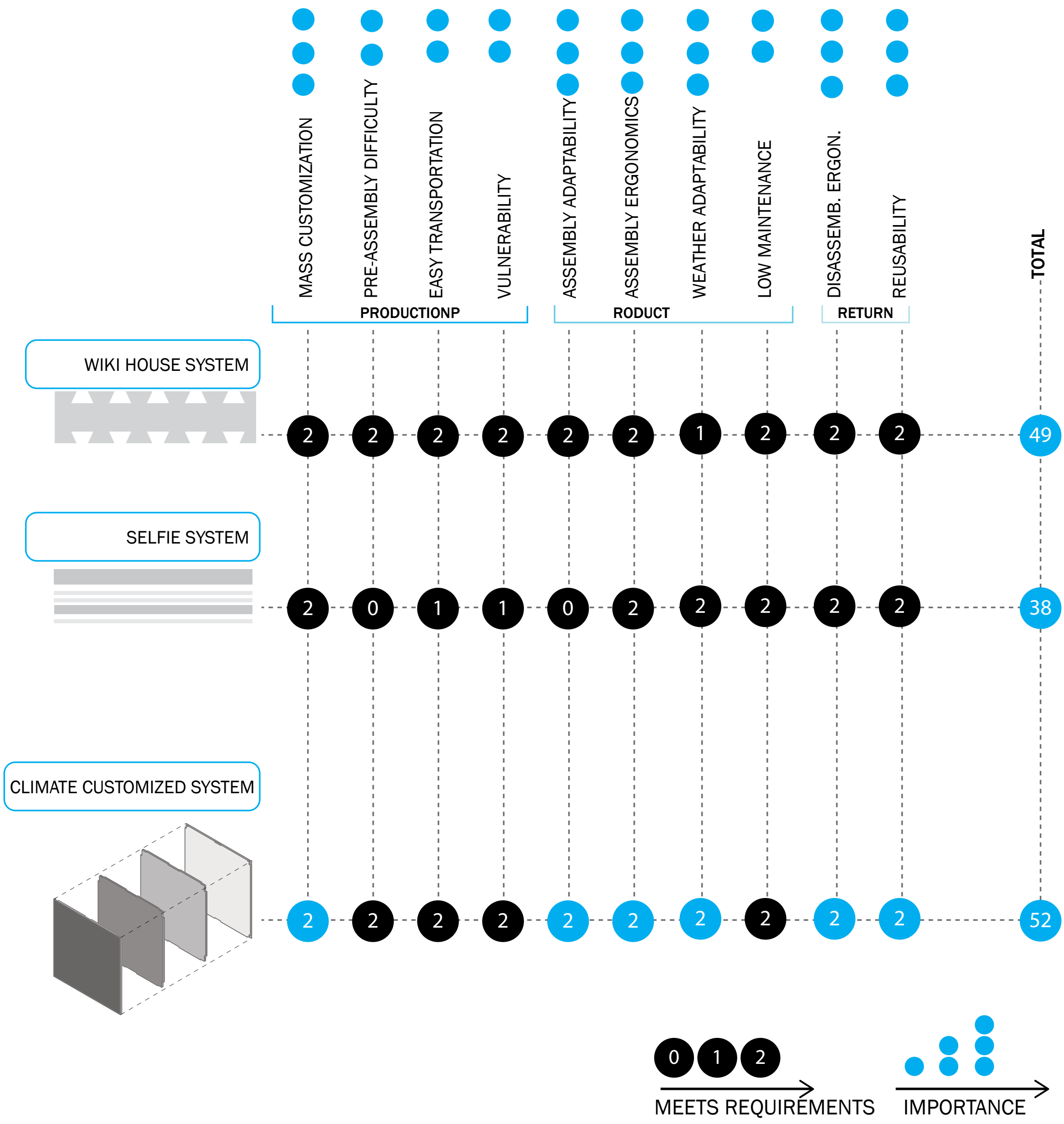


Figure 132: Final asessment. Own illustration.

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10. CONCLUSIONS

In this chapter the research is revised under a critical approach on the final results. While the goal of the project is to design a customizable façade system for the Ecuadorian climate regions, the pursuit of this objective encompassed a wide range of topics - from design and product development, to climate parameters, or from prefabrication processes to dynamic computational prototyping.

10.1. ANSWERING THE RESEARCH QUESTIONS

To summarize this project, all research questions are answered in this section, starting with the sub-questions and concluding with the main question.

Sub-question: "How does the sun orientation and wind predominant direction affect the renovation of an existing facade in Ecuador?"

First, it can be concluded, that a realistic approach for facade development must base its findings on static and dynamic parameters. The sun orientation, and wind prevailing direction, are the main dynamic parameter to be taken for a façade system development. It has been tested and proven in this research, that static parameters can be taking only as a preliminary study of a building's envelope.

Sub-question: "What role does new technologies play in the improvement of existing building methods?"

The study of new technologies that can be used for indoor comfort improvement of existing buildings is one of the most important steps within this research. The use of an open sourced building system, such as the WikiHouse project, allows the designer to use technically testes information and adapt it to personalized needs. This project uses CNC technology to improve the information provided by this existing construction system, representing an important opportunity for this research. The assembly and production line responds to the main design requirements for this façade system design. The integration of multiple layers in this system was based on the analysed refence, SELFIE project. The research provided knowledge on how multi-layered components can provide different functions for a modular façade system. The ability of mass customization is provided by the combination of these two projects. The final design was developed by adding the advantage of mass personalization for different climates of the SELFIE façade and the mass customization for assembly processes from the WikiHouse.

Sub-question: "What are the available techniques and technology used in facade mass customization?"

The two main technologies, used in mass customization, studied in this research are: CNC technology and multi-layered modular systems. Using the CNC technology of the WikiHouse, a closed production, assembly and reusability of the construction system can be achieved. Also, by combining multiple layers with different properties, a component can be created that responds to specific climate conditions. While combining multiple components, a more complex but effective function for each component can be provided for a façade renovation. By taking the Ecuadorian existing construction standards, local climate characteristics, available solutions and technological opportunities, a prefabricated façade system can be designed to improve the indoor comfort of the existing building stock of Ecuadorian climate regions. Translating it to a customized prefabricated façade system built with modular elements that can be assembled and placed with different configurations, materials and functions, to guarantee its customization for climate and assembly constraints.

Sub-question: "How can a prefabricated façade system improve the indoor comfort of the existing building stock of Ecuadorian climate regions?"

The design of the façade system was tested multiple times with the Design Builder software. The final results of the proposed façade renovation system are based on these simulations. There was a constant loop between designing and testing, until the final results where reached, where the indoor comfort temperature of the two tested climates stayed inside the adaptive comfort parameters. The use of this software helps the designer very much to test constantly the design decisions. Although it was very helpful, a remark needs to be made, clarifying that this simulation software needs previous knowledge and a lot of previous research. This software could not be easily used by every designer or resident to test possible solutions for renovating a façade system.

Main research question: ¨How can a prefabricated façade system be mass customized, for Ecuadorian climate regions and its existing building stock, to upgrade the indoor comfort, while providing a circular workflow based on local production, the use of local resources and the reusability of the system? ¨

The aim of this project is to develop a façade system that can be mass customized to respond to the existing climate and building conditions across Ecuadorian regions, while guaranteeing its high quality by prefabrication processes and its reusability by a circular workflow. The fina product can be seen in Apendix 6 representing a commercial flyer, which can be distributed to designers and builders, as a guide to choose the appropriate components, depending on the location´s climate conditions. There, an overview of the functions and characteristics of the different components can be found. As well as the optimal facade functions responding to the orientation of the facades to the sun and predominant wind direction.

In the context of this research, the relation of climate and assembly adaptability is explored in depth. The results show that the final façade design is affected by both of these parameters. In effect, there are cases in which the arguments for climate adaptability and prefabrication were influencing the geometry development in apparently opposite directions and a middle ground had to be found. Additionally, CNC technology opened the possibility of complex-forms production and the fulfilment of the functional requirements.

The final product of this research is the result of a research-by-design approach. Its methodology started with the analysis of the target location on its climate characteristics and existing façade typologies. Then, design requirements for the façade system were defined, based on its functional requirements and the opportunity of CNC technology. In the next step, a design prototype was designed by taking into consideration not only the requirements and available references, but also the existing Ecuadorian context. Then, the performance of the design was tested according to the defined requirements under computational simulations on Design Builder software. Each test was carried out by simulating real Ecuadorian weather conditions on a three-dimensional building modelling of Ecuadorian existing façade typologies. The indoor comfort level was tested after applying different variations of the proposed façade system and resulted in the selection of the optimal variant for each climate type. The final design is the result of a constant loop between testing and design. With regards to the evaluation process, the physical prototyping of the design was not possible within the current COVID-19 circumstances, where further functional, assembly and aesthetic assessments could have been done. Nevertheless, computational prototyping was the key to evaluate the design under realistic and dynamic simulations, according to the defined design guidelines.

Furthermore, this work focused on the climate performance of the proposed façade system, instead of its detailed construction process. One consequence of this was that other aspects of the building process, such as CNC milling detailing and structural analysis, were not taken into consideration. Even though, general dimensioning of the system is presented in this document, determining the exact dimensions of each piece was not the main priority. The final product is a prefabricated façade system that is formed by one multi-layered modular component, with 9 different functional variations. These nine variations can be replicated with multiple combinations and directions to respond to different climate conditions, to allow mass customization of the system depending on each location. The final design allows the customization of the modules and sub-structure to guarantee its adaptability to the existing building sector in Ecuador.

The research showed that the combination of multiple layers, with different properties, provides the flexibility to develop one modular component with different functions. Finally, the use of CNC milling proves to be a promising solution for mass customization of complex forms that allows the interconnection of sheet-materials by using demountable dry connections. Also, this technology opens the possibility to use any type of sheet-material. This means that any type of raw material that can be transformed into a sheet can be manufactured. The opportunity to use this technology, which is currently available in Ecuador, opens the opportunity for local material production, components manufacture and façade assembly. This guarantees a circular workflow, minimising the use of resource inputs, the production of waste, pollution and carbon emissions.

During the design process, CNC milling showed to be a quick and effective tool for mass manufacture and customization. However, further research on milling detailing of the sheet materials needs to be done, taking into consideration tolerances, materials properties, processing time and costs.

10.2. FUTURE RESEARCH

This project is a primary stage of research on a climate customized façade system. The research process touched on several research subjects worthy of further exploration. More depth can be achieved on:

- Refine the connections detailing to achieve higher integration between all the elements.
- Refine the cladding connections to guarantee water tightness, accoustic insulation and fire proof performance.
- Structural evaluation and optimization of the system.
- Define corner details and roof principles.
- Experimentation with sheet materials and computational design to further reduce material usage.
- Research on the milling time and process to further reduce manufacturing time by design refinement and milling detailing.
- Structural computational and physical testing of the design, in order to assess the connection between the panels and the existing wall by the punctual connections.
- Evaluation of functionality and performance of the proposed design in real outdoor conditions, for further design refinement.

XI

11. REFLECTION

11.1. RESEARCH & DESIGN RELATIONSHIP

According to Christopher Frayliing (1993), there are two definitions of research. The first one involves care, and looking for something which is defined in advance, such as a criminal or a bed for the night. Here, professionalism, guidelines, or laboratories are not involved. The second definition is related with innovation, introduction, and improvement of products and processes (Frayling, 1993). He states that ´research´ has always been an important nourishment for the practice of teaching of art, craft and design.

Research, purely engineering-based, usually suffers from an exclusive confidence in numbers, while disregarding the design´s non-qualifiable reality layers (Ilkas & Ruby, 2010). This project embraces qualities as well as quantities. The research-by-design process can be described with the following steps:

- Study the specific case study location.
- Analyse the problem and its conection with different parameters, such as climate and availble reources.
- Size the available opportunities, to identify the capability to solve the problem.
- Set clear requirements.
- Study the existing solutions to identify potential resources and requirements.
- Propose a concept of investigation.
- Develop the design concept that respondes to previous steps.
- Prototype the product (computational).
- Test the design and state important feedback.
- Improve the proposed design to its final version.

11.2. RESEARCH PROCESS & APPROACH

Overall, the research and design process worked as intended, with the exception of a few points. The main research step that proved to be more time consuming than originally planned, was the computational prototyping and simulations. The software used for this was Design Builder, which provides a wide range of dynamic simulations for a very simple and schematic prototype. Finding the proper settings for each climate region and construction details was a time-consuming procedure. Based on the initial plan, the simulation results and conclusions should have been completed before P4 presentation. However, this goal was not achieved because of all the previous work that needed to be done for each 3d model and climate simulation. Adding to this, the physical prototyping was no longer an option due to the repercussions of the Covid-19 pandemic. Due to the nation-wide lockdown, TU Delft closed down all its faculties and facilities. Thankfully, the computational simulations allowed the prototyping phase of this work to continue.

Furthermore, a more detailed analysis on sheet materials available for CNC milling was meant to be done, parallel to the prototyping phase, by running different tests on sheet materials samples. This step was also no longer possible beacuase of the Covid-19 pandemic lockdown.

11.3. SOCIETAL RELEVANCE

The construction normative, in Ecuador, lacks Thermal Comfort Standards. This causes constructions to adopt generic building systems for the ease of optimizing construction time and lowering costs but disregarding the difference in the climate conditions between regions. A building´s façade is the main factor that influences the indoor comfort levels. This research aims to explore an alternative for the Ecuadorian context to improve the indoor comfort levels of the existing construction sector. The use of a prefabricated facade system that can be mass customized, allows to adapt one façade renovation design for extremely different weather characteristics

11.4. SCIENTIFIC RELEVANCE

This project explores the application of new computational design technologies by encouraging the use of CNC milling technology in the construction of façade components. The final product proposes an alternative solution, very different from the existing renovation systems in the Ecuadorian context, which have been proven to be rather expensive and unsustainable in the long term. From the first stages of design to the production of the final product, the entire process is automated and provides the advantages of an open source system, such as the WikiHouse project, which is based on the use of local resources, sharing information, lowering waste, designing for disassembly and including all types of labour.

XII

12. REFERENCES

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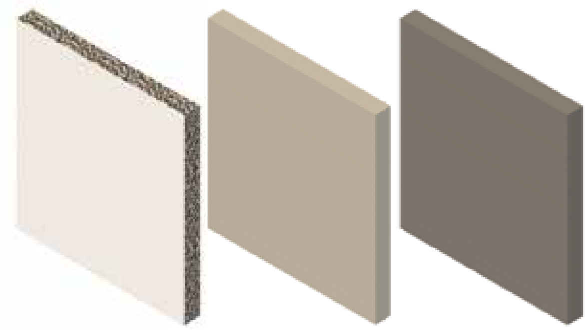
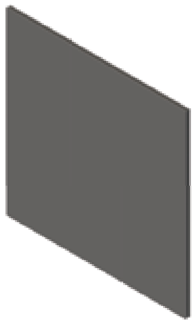
APPENDICES

CATEGORY	INSULATION			
CODE	1.1	1.2	1.3	
TYPE	RIGID	SEMIRIGID	LOOSE	UNITS
LENGTH	0.8	0.8	0.8	m
WIDTH	0.8	0.8	0.8	m
MATERIAL	RECYPANEL	ROCKWOOL	WOOL	-
THERMAL COND. λ	0.022	0.035	0.035	W/mK
THICKNESS	0.100	0.100	0.100	m
R-VALUE	4.464	2.857	2.857	m²K/W
DENSITY	100	22	31	kg/m^3
WEIGHT	6.4	1.41	1.98	kg
TOTAL R-VALUE	4.46	5.49	5.49	m²K/W
TOTAL U-VALUE	0.22	0.18	0.18	W/M²k



CATEGORY	WATER PROTECTION	
CODE	2.1	
TYPE	BARRIER	UNITS
LENGTH	0.8	m
WIDTH	0.8	m
MATERIAL	STOCKBORD	-
THERMAL COND. λ	0.100	W/mK
THICKNESS	0.020	m
R-VALUE	0.200	m²K/W
DENSITY	1520	kg/m^3
WEIGHT	19.456	kg
TOTAL R-VALUE	0.20	m²K/W
TOTAL U-VALUE	5.00	W/M²k

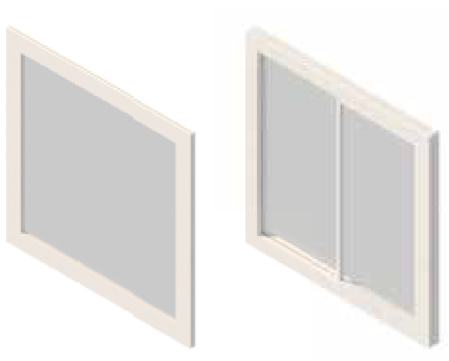


CATEGORY	HEAT/LIGHT COLLECTION	
CODE	3.1	3.2

TYPE	FIXED	OPERABLE	UNITS
LENGTH	0.8	0.8	m
WIDTH	0.8	0.8	m
MATERIAL	GLASS x2	GLASS x2	-
THERMAL COND. λ	0.780	0.780	W/mK
THICKNESS	0.004	0.004	m
R-VALUE	0.005	0.005	m²K/W
DENSITY	2500	2500	kg/m^3
WEIGHT	6.4	6.4	kg

TYPE	0.8	0.8	UNITS
LENGTH	0.8	0.8	m
WIDTH	CAVITY	CAVITY	m
MATERIAL	0.020	0.020	-
THERMAL COND. λ	0.020	0.020	W/mK
THICKNESS	0.990	0.990	m
R-VALUE	1.010	1.010	m²K/W
DENSITY	1.28	1.28	kg/m^3
WEIGHT	0.016	0.016	kg

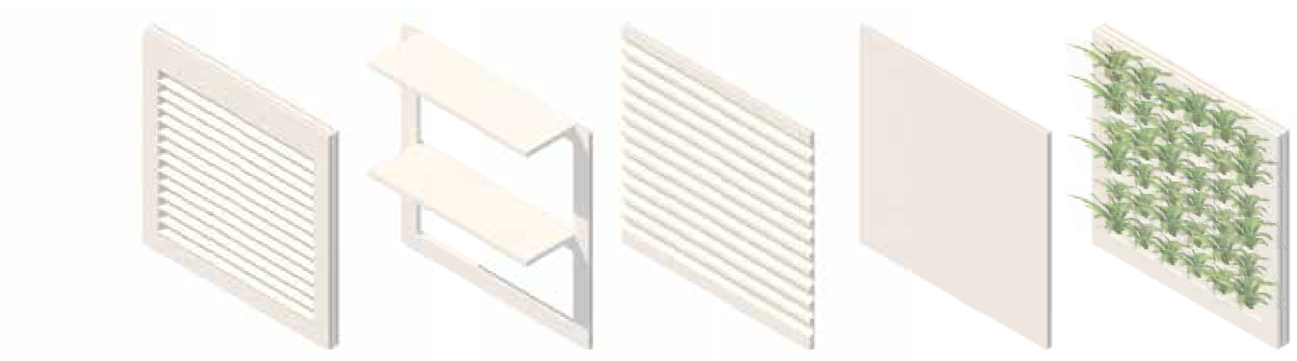
TOTAL R-VALUE	1.00	1.00	m²K/W
TOTAL U-VALUE	1.00	1.00	W/M²k



CATEGORY	SUN PROTECTION					
CODE	4.1	4.2	4.3	4.4	4.5	
TYPE	OPER. SHADE	FIXED SHADE	VENTILATED	AIRTIGHT	GREEN	UNITS
LENGTH	0.8	0.8	0.8	0.8	0.8	m
WIDTH	0.8	0.8	0.8	0.8	0.8	m
MATERIAL	EKOPLY	EKOPLY	ETERBOARD	STOCKBORD	ROCKWOOL	-
THERMAL COND. λ	0.108	0.108	0.000	0.100	0.035	W/mK
THICKNESS	0.020	0.000	0.020	0.040	0.1	m
R-VALUE	0.185	0.000	0.000	0.400	2.857	m²K/W
DENSITY	1000	1000	1850	1250	100	kg/m³
WEIGHT	12.8	0	23.68	32	6.4	kg

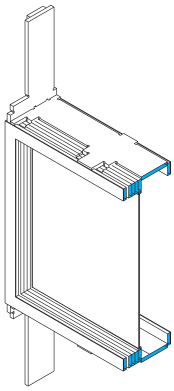
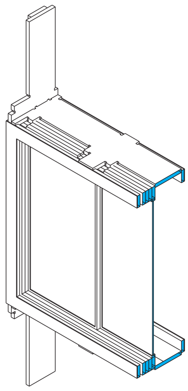
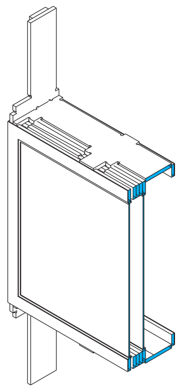
TYPE					0.8	UNITS
LENGTH					0.8	m
WIDTH					ECO-OH	m
MATERIAL					0.280	-
THERMAL COND. λ					0.040	W/mK
THICKNESS					0.143	m
R-VALUE					7.000	m²K/W
DENSITY					1000	kg/m³
WEIGHT					25.6	kg

TOTAL R-VALUE	0.19	0.00	0.00	0.40	2.86	m²K/W
TOTAL U-VALUE	5.40	0.00	0.00	2.50	0.35	W/M²k



CATEGORY	A. WINDOWS		
CODE	A1	A2	A2
FUNCTION	HEAT/LIGHT CAPTATION	HEAT/LIGHT CAPTATION + VENTILATION	HEAT/LIGHT CAPTATION + HEATING

ISOMETRIC SECTION

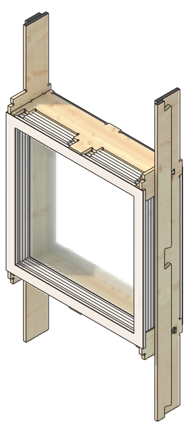
CHARACTERISTICS

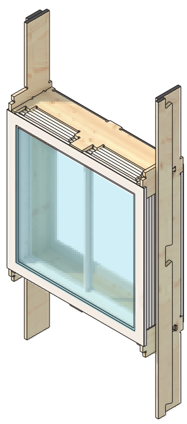
CODE	A1		
CATEGORY	TRANSPARENT		
FUNCTION	HEAT/LIGHT COLLECTION		
AMOUNT OF LAYERS	1		
LAYERS	CHARACTERISTICS		
	# layer	THICKNESS m	R-VALUE m2K/W
	3.1 fixed window	0.020	1.00
	-	-	-
	-	-	-
TOTAL U-VALUE W/M²K			1.00

CODE	A2		
CATEGORY	TRANSPARENT		
FUNCTION	HEAT/LIGHT COLLECTION + VENTILATION		
AMOUNT OF LAYERS	1		
LAYERS	CHARACTERISTICS		
	# layer	THICKNESS m	R-VALUE m2K/W
	3.2 operable window	0.045	1.00
	-	-	-
	-	-	-
TOTAL U-VALUE W/M²K			1.00

CODE	A3		
CATEGORY	TRANSPARENT		
FUNCTION	CAPTATION		
AMOUNT OF LAYERS	2		
LAYERS	CHARACTERISTICS		
	# layer	THICKNESS m	R-VALUE m2K/W
	3.2 operable window	0.045	1.00
	3.1 fixed window	0.020	1.00
	-	-	-
TOTAL U-VALUE W/M²K			0.50

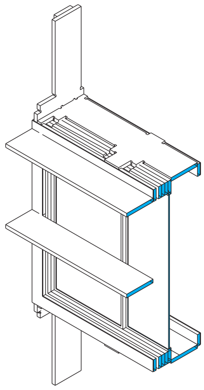
ISOMETRIC VIEW

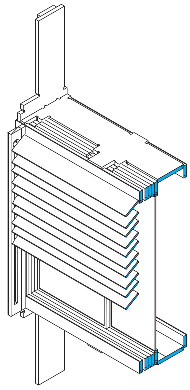




CATEGORY	B. SHADINGS	
CODE	B1	B2
FUNCTION	HEAT/LIGHT CAPTATION	HEAT/LIGHT CAPTATION + VENTILATION

ISOMETRIC SECTION



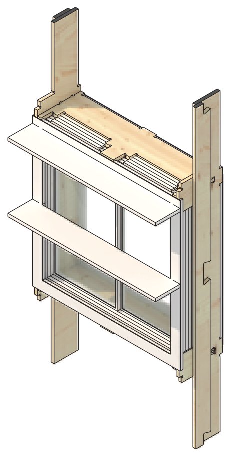


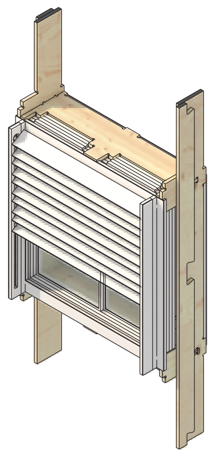
CHARACTERISTICS

B1		
SEMI TRANSPARENT		
SHADE		
2		
CHARACTERISTICS		
# layer	THICKNESS	R-VALUE
	m	m2K/W
3. fixed/operable window	0.020	1.00
4.1 fixed shade	0.045	0.00
	-	-
		1.00

B2		
SEMI TRANSPARENT		
SHADE + VENTILATION		
2		
CHARACTERISTICS		
# layer	THICKNESS	R-VALUE
	m	m2K/W
3. operable window	0.045	1.00
4.1 operable shade	0.045	0.19
-	-	-
		0.84

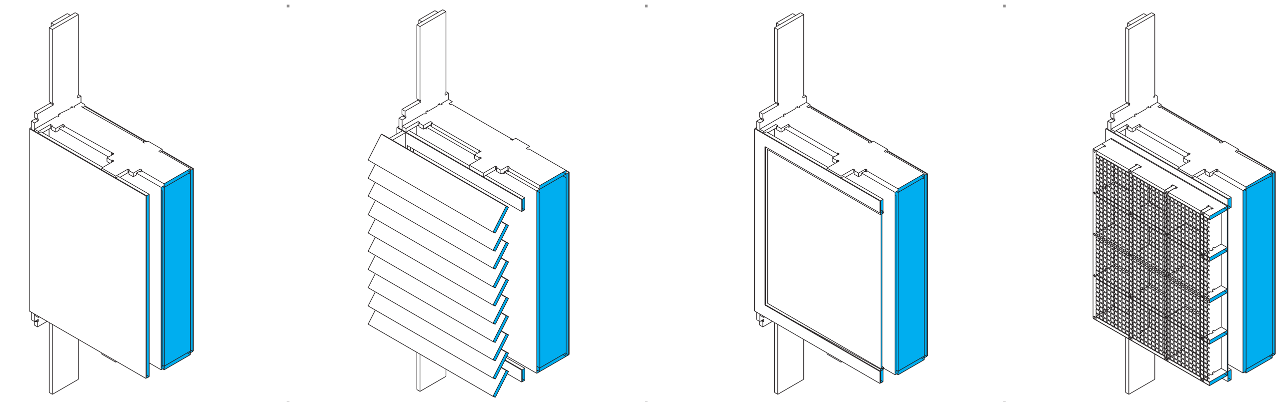
ISOMETRIC VIEW





C. CLADDINGS

C1	C2	C3	C4
SUN/RAIN PROTECTION	RADIATION PROTECTION + VENTILATION	PASSIVE HEATING +STORAGE	RADIATION PROTECTION

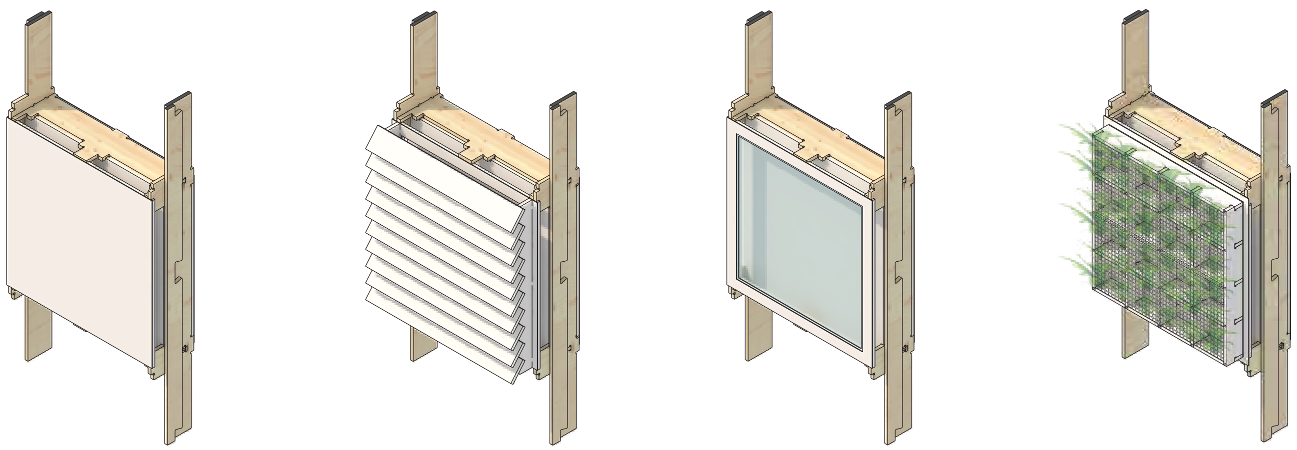


C1		
OPAQUE		
SHADING		
2		
CHARACTERISTICS		
# layer	THICKNESS	R-VALUE
	m	m2K/W
4.4 airtight cladding	0.040	0.40
1.1 insulation	0.040	4.46
3.1 moisture barrier	0.020	0.20
		0.20

C2		
OPAQUE		
SHADE		
2		
CHARACTERISTICS		
# layer	THICKNESS	R-VALUE
	m	m2K/W
4.3 vent cladding	0.020	0.00
1.2 insulation	0.135	5.49
3.1 moisture barrier	0.020	0.20
		0.18

C3		
OPAQUE		
HEATING		
3		
CHARACTERISTICS		
# layer	THICKNESS	R-VALUE
	m	m2K/W
2.1 fixed window	0.020	1.00
3.1 moisture barrier	0.020	0.20
1.3 loose insulation	0.135	5.49
		0.15

C4		
OPAQUE		
SHADE		
2		
CHARACTERISTICS		
# layer	THICKNESS	R-VALUE
	m	m2K/W
4.4 green fixed	0.045	2.86
3.1 moisture barrier	0.020	0.19
1.2 insulation	0.135	5.49
		0.33



**The cladding components can be used with or wothout insulation. As well as a ventilated or airtight cavity.*

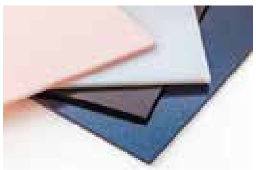
TRANSPARENT — OPAQUE

CLEAR GLASS
ECU

2 to 20mm

GLASKERAMIK
NL
glass compression
16, 20, 30mm

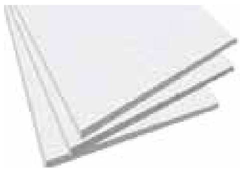
VIEWPAN-PET
DE
PET extrussion
9 to 18mm



VERSATO
NL
acrylic extrussion
3 to 20mm

EKOPLY
UK
plastic extrussion
10 to 21mm

STOKBORD
UK
plastic extrusion
3 to 18mm



ETERBOARD
ECU
glass fiber+cement
4 to 20mm

TECU BOND
FR
copper+plastic
4mm

EKOPAK
ECU
tetrapak compr.
5 to 40mm

***Materials marked with a blue rectangle are found in Ecuador today.**

OPAQUE

GLASKERAMIK
HK
palm fibers compr.
6 to 18mm

SCP
LT
pine + cement
25 to 35mm

RICHLITE
UK
paper compression
6 to 50mm

CEMPLAAT
NL
wood + cement
8 to 40mm

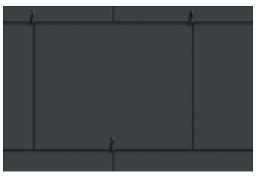
ECO-OH
BE
plastic extrusion
12 to 19mm

Al PLATE
DE
aluminium rolling
10 to 120mm

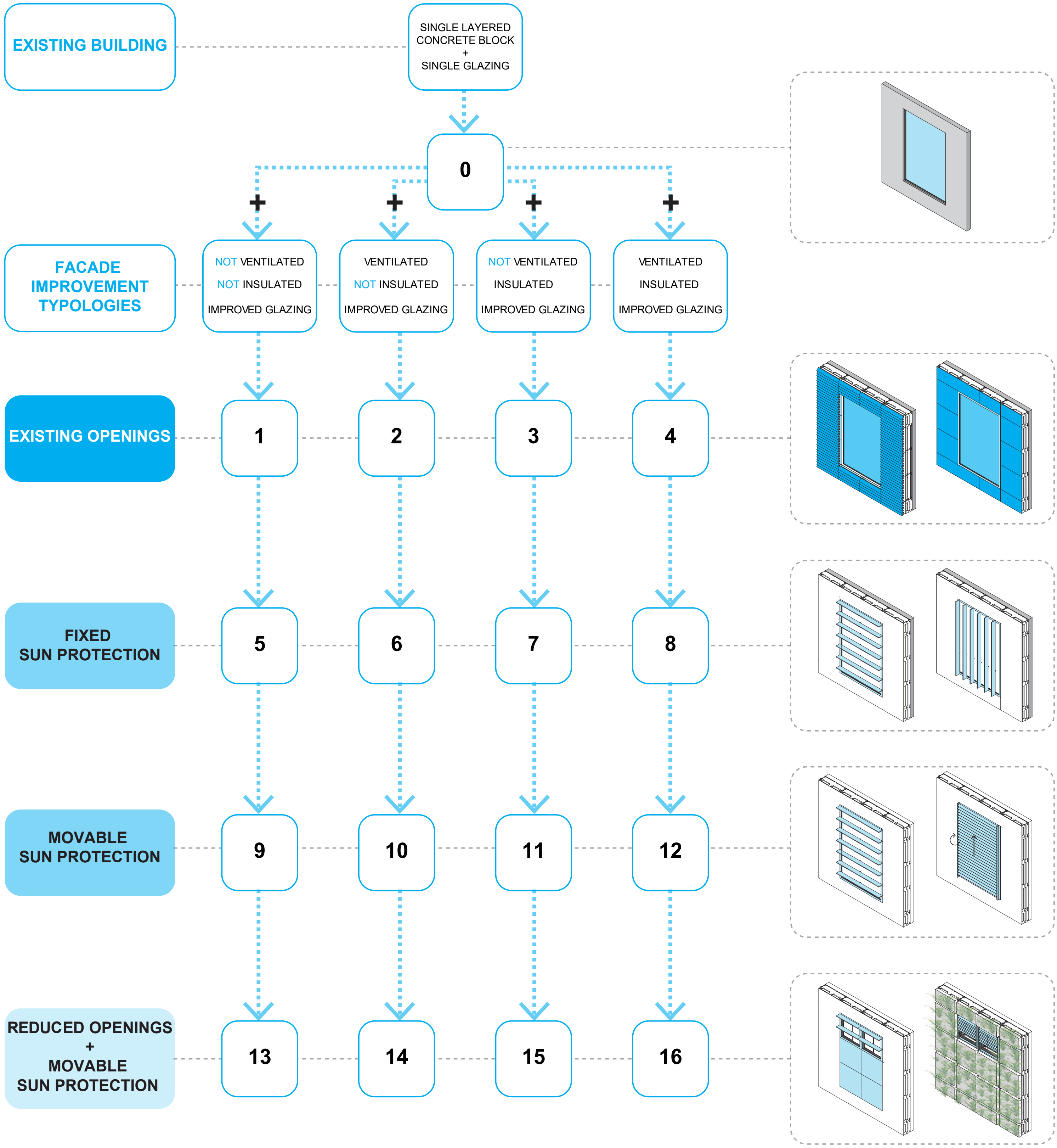
RECYPANEL
NL
polyurethane
10 to 35mm

VALCHROMAT
NL
colored mdf
2 to 30mm

ECO-C1
IT
rubber compression
20, 30, 40mm

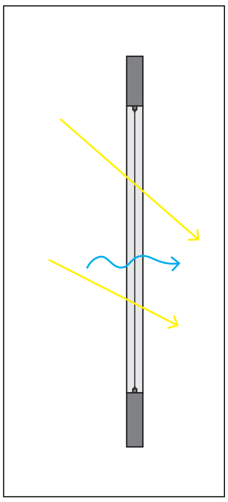


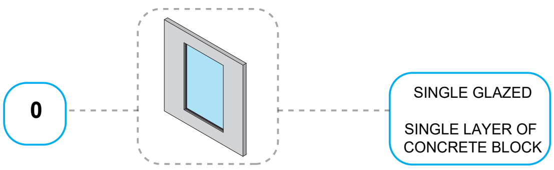
ETERNIT
NL
natural fiber+cement
4



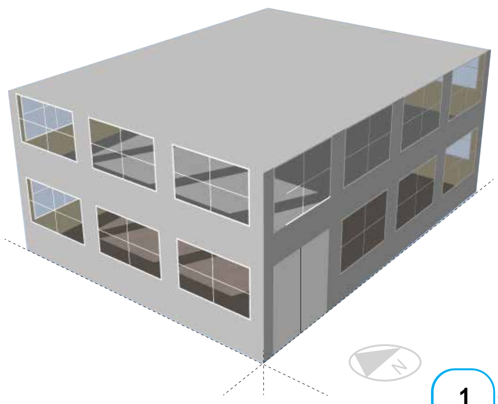
EXISTING BUILDING

CLIMATE DATA	PARAMETERS	UNITS	CASE 0
Tout.min. 16°C 6-July 3:00AM	T OPERATIVE	°C	28.68
	T RADIANT	°C	28.94
	GAINS WINDOW	kW	0
	LIGHTING	kW	0
Tout.max. 34°C 23-July 3:00PM	T OPERATIVE	°C	42.47
	T RADIANT	°C	42.36
	GAINS WINDOW	kW	19.48
	LIGHTING	kW	3.35

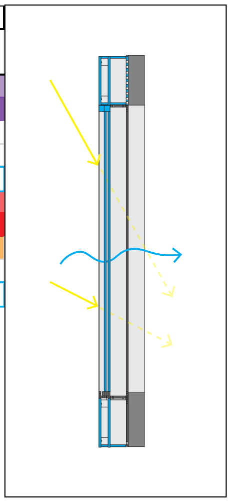


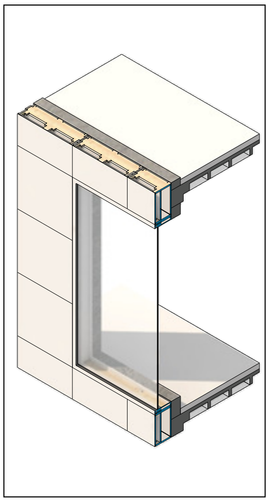


IMPROVED ENVELOPE / SAME OPENINGS

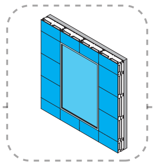


CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 1
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	24.19
	TRADIANT	°C	28.94	26.94
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-4.49°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	36.64
	TRADIANT	°C	42.36	37.27
	GAINS WINDOW	kW	19.48	11.64
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-5.83°C



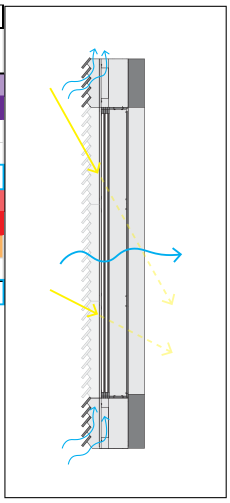


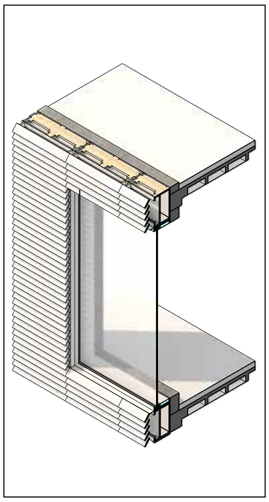
1



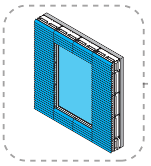
NOT VENTILATED
NOT INSULATED
IMPROVED GLAZING

CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 2
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	24.36
	TRADIANT	°C	28.94	27.17
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-4.32°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	36.47
	TRADIANT	°C	42.36	37.03
	GAINS WINDOW	kW	19.48	11.64
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-6°C



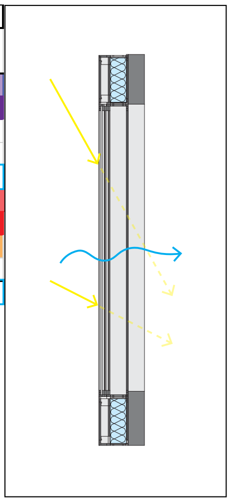


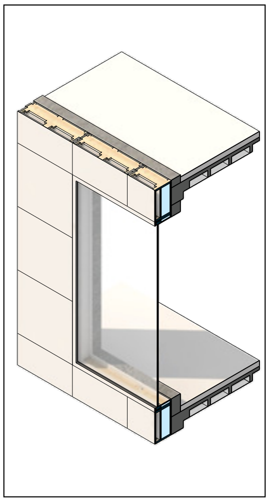
2



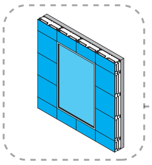
VENTILATED
NOT INSULATED
IMPROVED GLAZING

CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 3
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	24.24
	TRADIANT	°C	28.94	27.02
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-4.44°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	36.85
	TRADIANT	°C	42.36	37.57
	GAINS WINDOW	kW	19.48	11.64
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-5.62°C



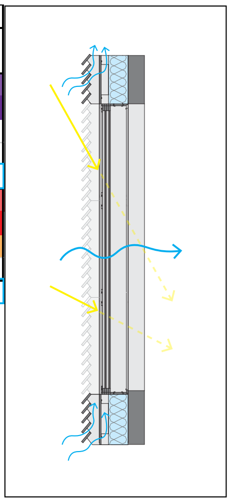


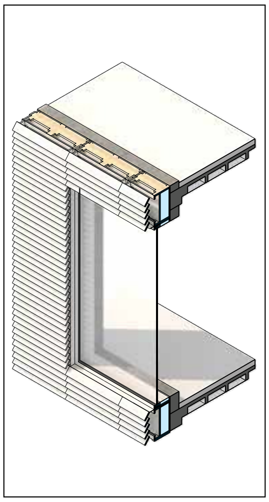
3



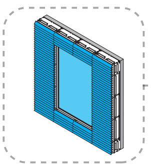
NOT VENTILATED
INSULATED
IMPROVED GLAZING

CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 4
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	25.48
	TRADIANT	°C	28.94	27.8
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-3.32°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	36.76
	TRADIANT	°C	42.36	37.44
	GAINS WINDOW	kW	19.48	11.64
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-5.71°C



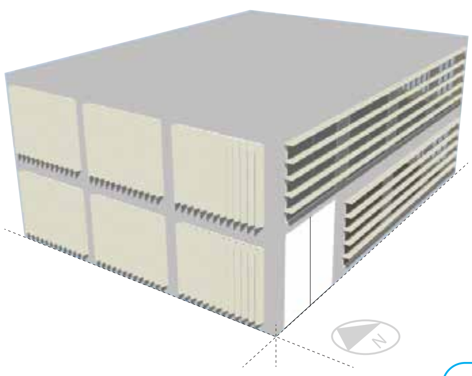


4



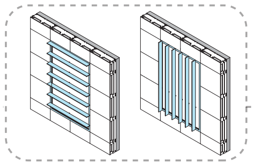
VENTILATED
INSULATED
IMPROVED GLAZING

FIXED SHADING / SAME OPENINGS



CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 5
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	23.51
	TRADIANT	°C	28.94	26.08
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-5.17°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	35.72
	TRADIANT	°C	42.36	35.97
	GAINS WINDOW	kW	19.48	10.77
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-6.75°C

5



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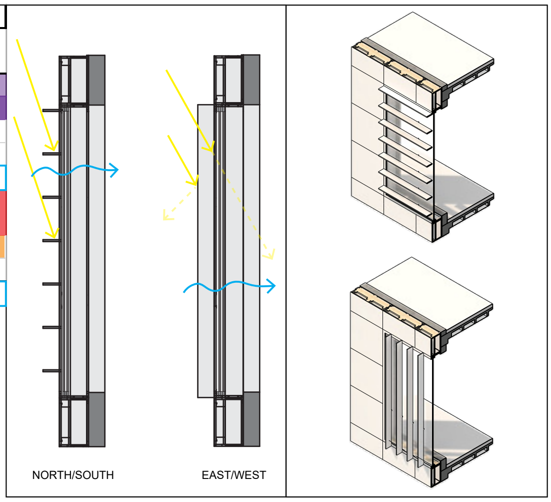
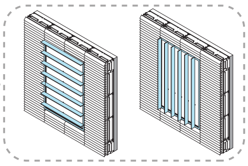
NOT INSULATED
IMPROVED GLAZING

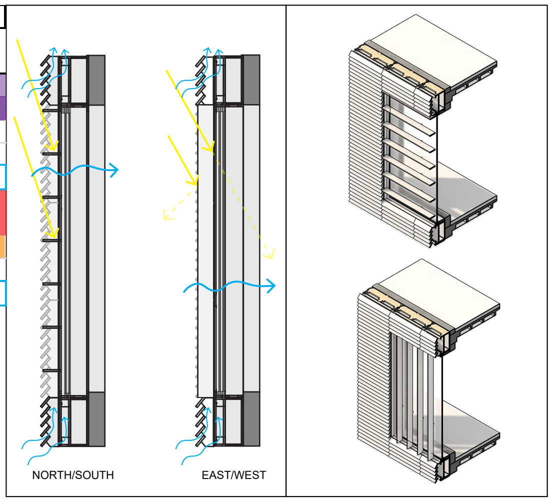


CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 6
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	23.65
	TRADIANT	°C	28.94	26.27
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-5.03°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	35.57
	TRADIANT	°C	42.36	35.76
	GAINS WINDOW	kW	19.48	10.77
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-6.9°C

6

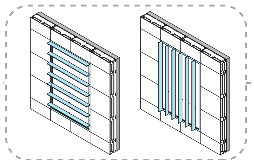


VENTILATED
NOT INSULATED
IMPROVED GLAZING

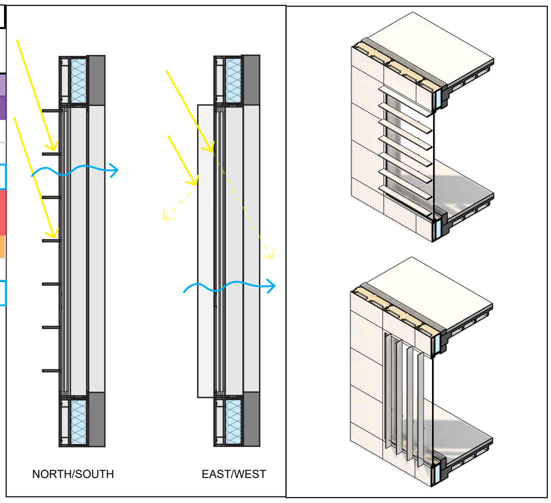


CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 7
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	23.49
	TRADIANT	°C	28.94	26.06
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-5.19°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	35.83
	TRADIANT	°C	42.36	36.14
	GAINS WINDOW	kW	19.48	10.77
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-6.64°C

7

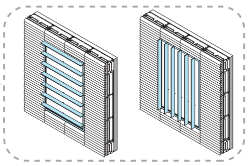


NOT VENTILATED
INSULATED
IMPROVED GLAZING

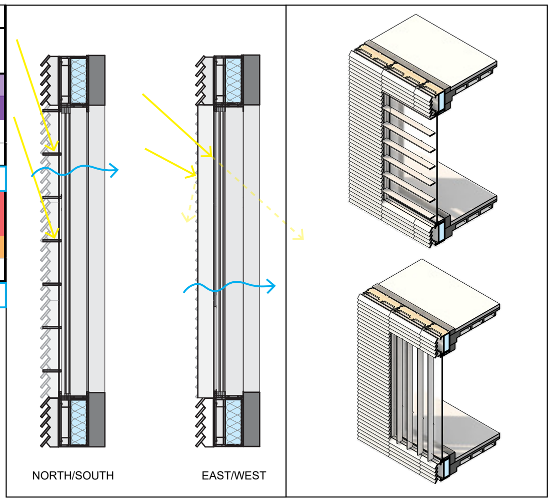


CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 8
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	23.6
	TRADIANT	°C	28.94	26.21
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-5.08°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	36.76
	TRADIANT	°C	42.36	36.04
	GAINS WINDOW	kW	19.48	10.77
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-5.71°C

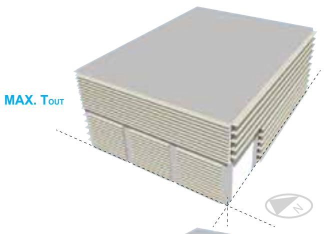
8

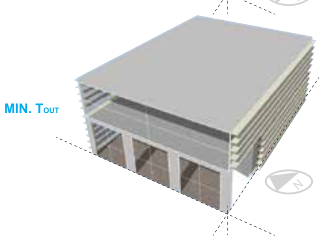


VENTILATED
INSULATED
IMPROVED GLAZING



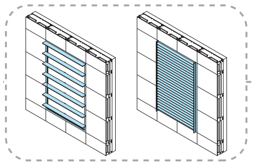
FIXED / MOVABLE SHADING SAME OPENINGS





CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 9
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	23.06
	TRADIANT	°C	28.94	25.5
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-5.62°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	34.48
	TRADIANT	°C	42.36	34.2
	GAINS WINDOW	kW	19.48	6.78
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-7.99°C

9



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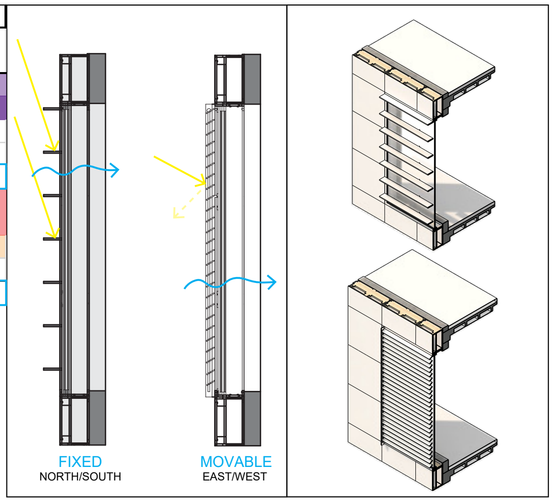
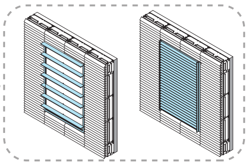
IMPROVED GLAZING

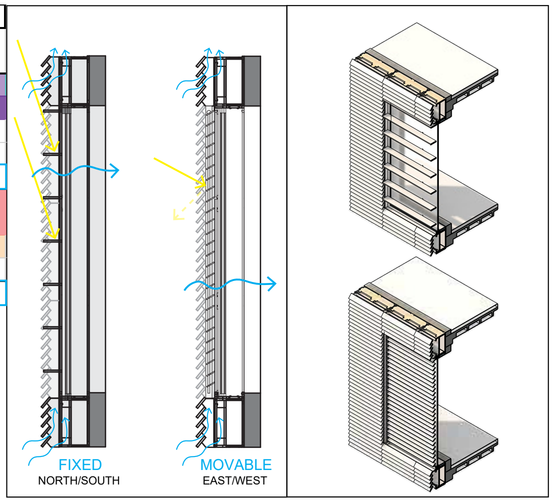


CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 10
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	23.18
	TRADIANT	°C	28.94	25.66
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-5.5°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	34.33
	TRADIANT	°C	42.36	34
	GAINS WINDOW	kW	19.48	6.78
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-8.14°C

10

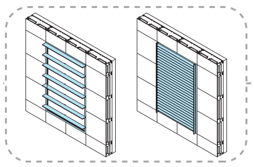


VENTILATED
NOT INSULATED
IMPROVED GLAZING



CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 11
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	22.91
	TRADIANT	°C	28.94	25.31
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-5.71°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	34.49
	TRADIANT	°C	42.36	34.22
	GAINS WINDOW	kW	19.48	6.78
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-7.98°C

11



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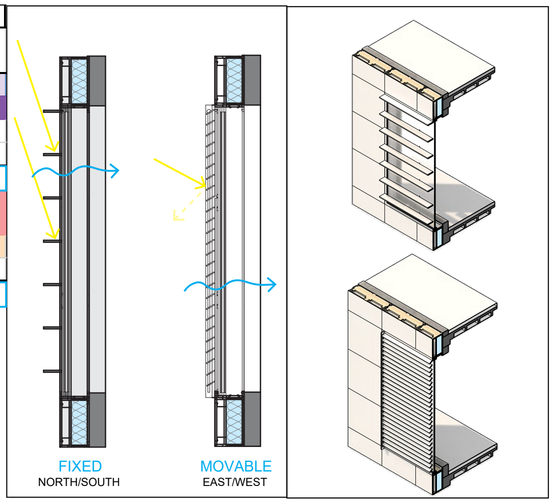
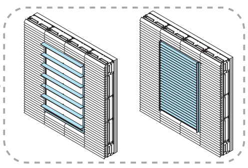
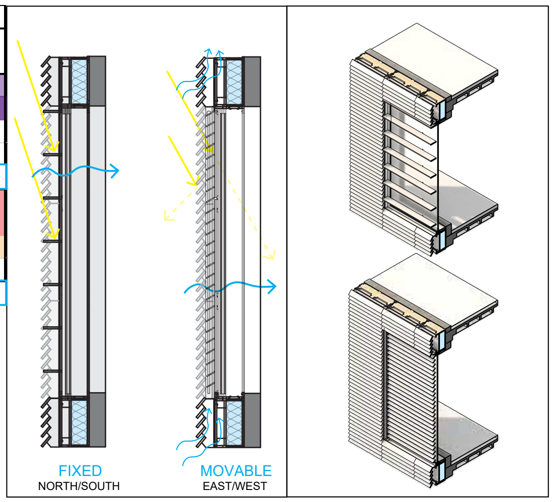


CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 12
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	23.02
	TRADIANT	°C	28.94	25.45
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-5.66°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	34.44
	TRADIANT	°C	42.36	34.15
	GAINS WINDOW	kW	19.48	6.78
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-8.03°C

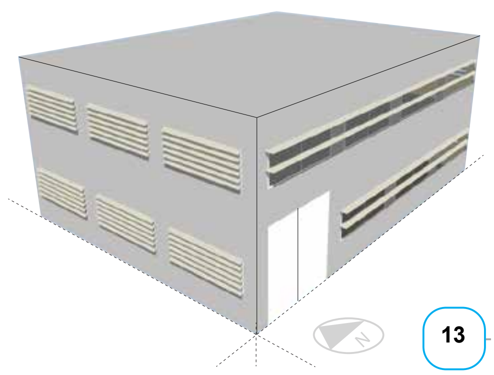
12



VENTILATED
INSULATED
IMPROVED GLAZING

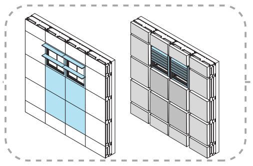


MOVABLE SHADING / IMPROVED GEOMETRY



CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 13
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	25.35
	TRADIANT	°C	28.94	25.85
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-3.33°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	32.5
	TRADIANT	°C	42.36	31.5
	GAINS WINDOW	kW	19.48	3.1
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-9.97°C

13



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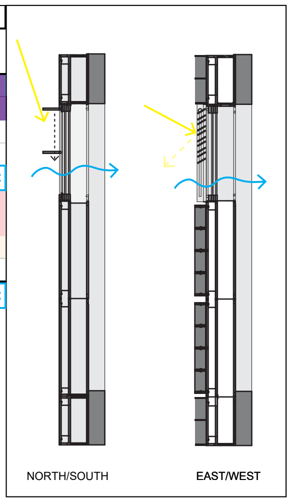
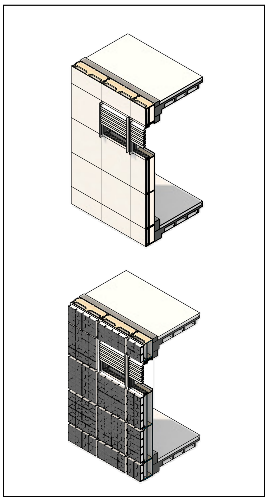
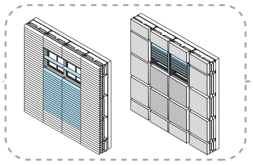
IMPROVED GLAZING



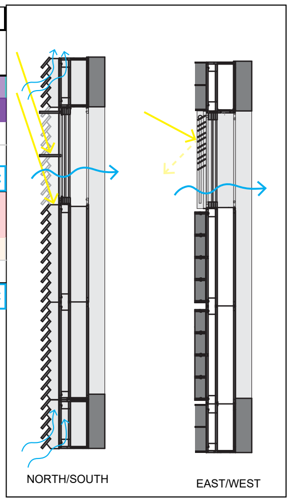


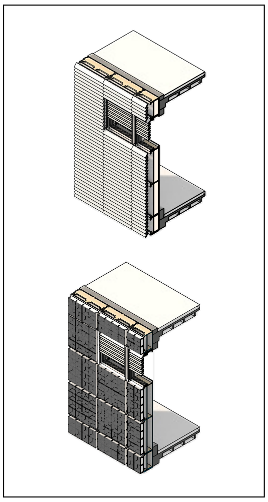
CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 14
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	23.42
	TRADIANT	°C	28.94	25.94
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-5.26°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	32.39
	TRADIANT	°C	42.36	31.36
	GAINS WINDOW	kW	19.48	3.1
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-10.08°C

14



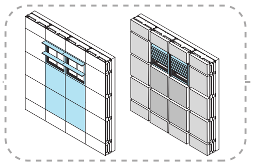
VENTILATED
NOT INSULATED
IMPROVED GLAZING



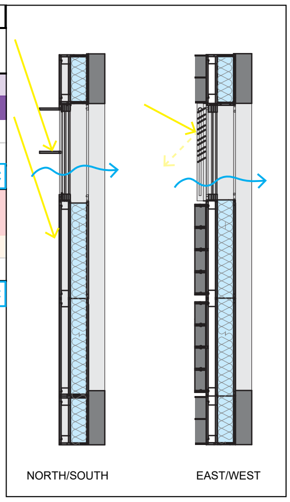


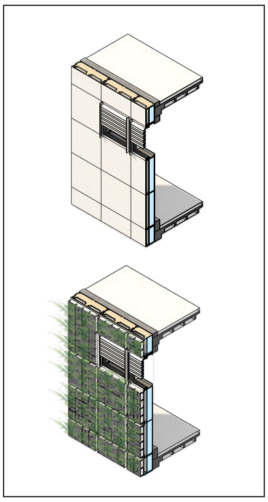
CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 15
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	22.8
	TRADIANT	°C	28.94	25.13
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-5.88°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	32.25
	TRADIANT	°C	42.36	31.17
	GAINS WINDOW	kW	19.48	3.1
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-10.22°C

15



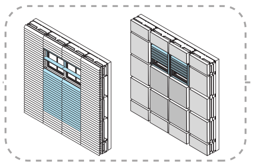
NOT VENTILATED
INSULATED
IMPROVED GLAZING



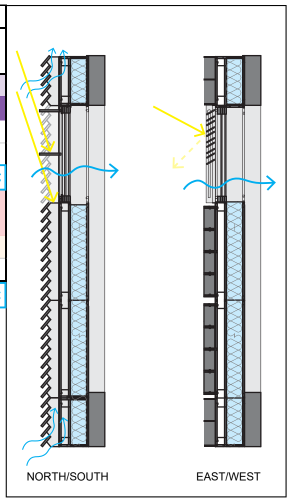


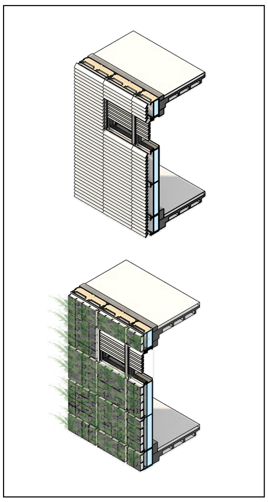
CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 16
Tout.min. 16°C 6-July 3:00AM	TOPERATIVE	°C	28.68	22.91
	TRADIANT	°C	28.94	25.28
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		-5.77°C
Tout.max. 34°C 23-July 3:00PM	TOPERATIVE	°C	42.47	32.22
	TRADIANT	°C	42.36	31.13
	GAINS WINDOW	kW	19.48	3.1
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-10.25°C

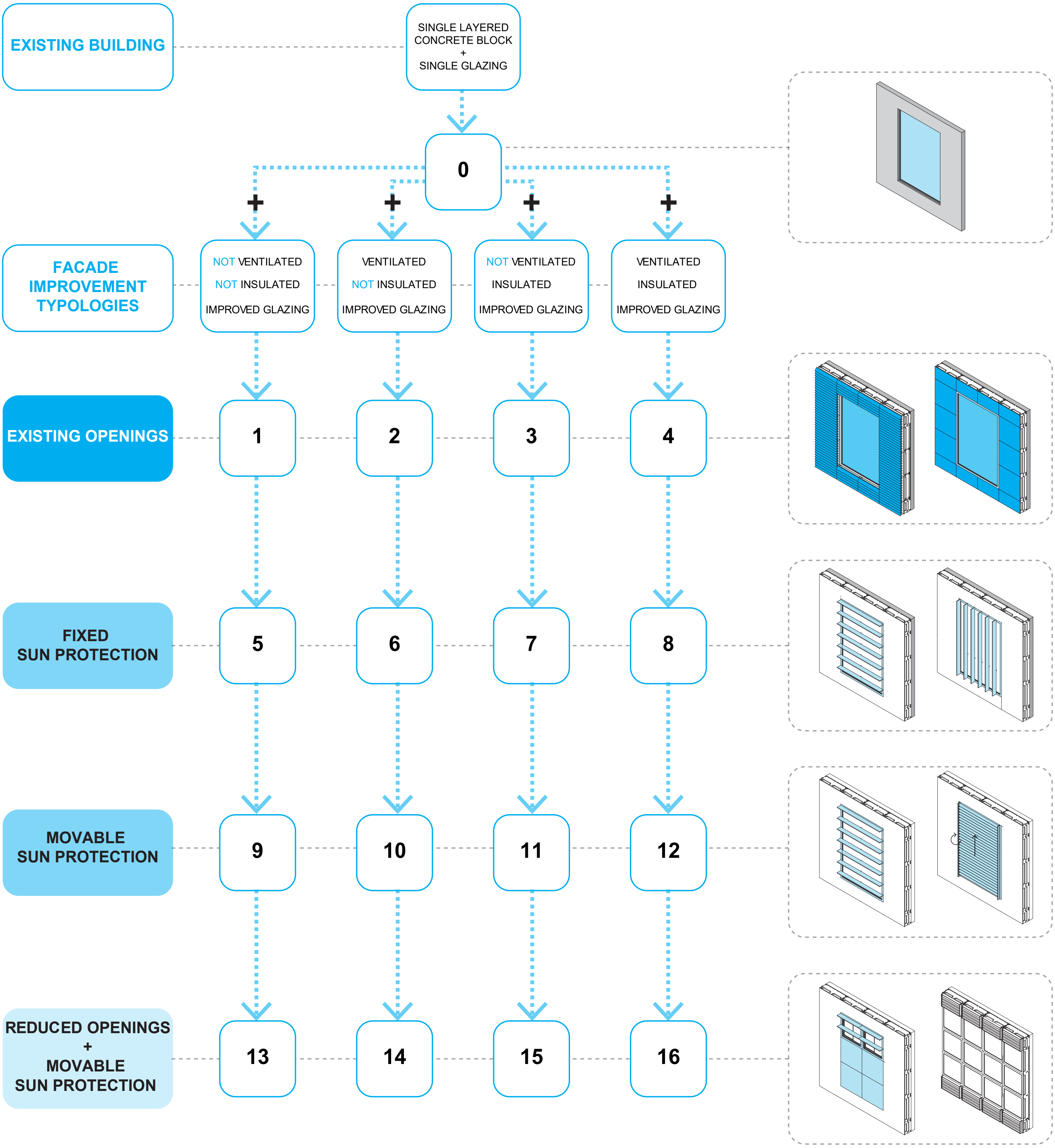
16



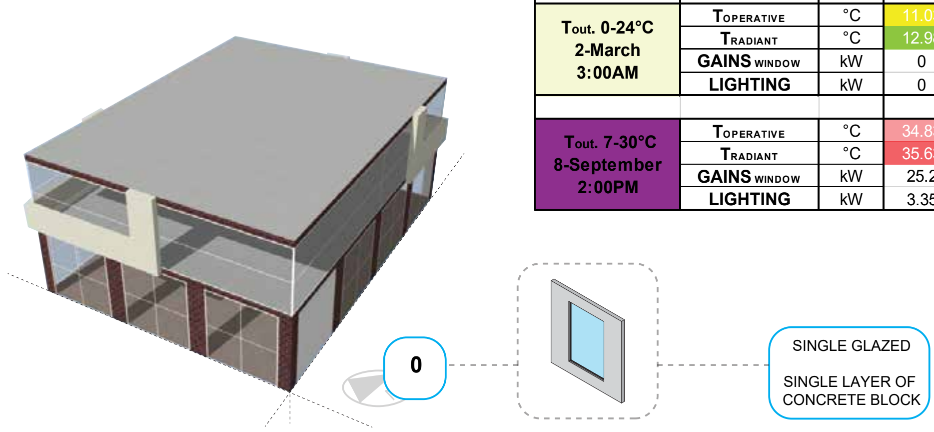
VENTILATED
INSULATED
IMPROVED GLAZING



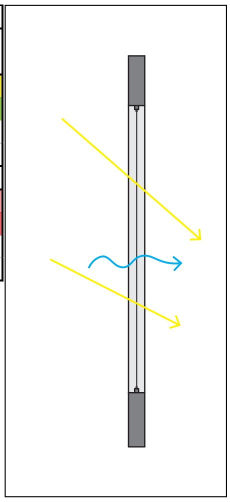


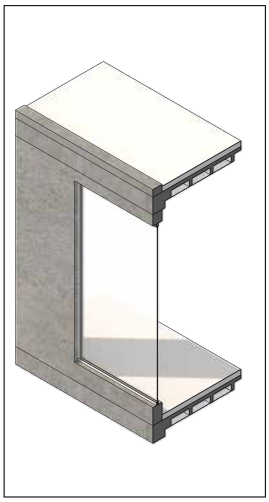


EXISTING BUILDING

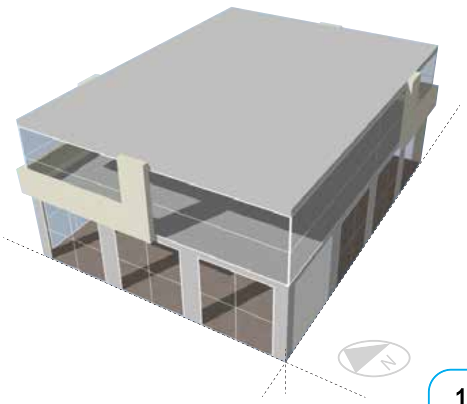


CLIMATE DATA	PARAMETERS	UNITS	CASE 0
Tout. 0-24°C 2-March 3:00AM	Toperative	°C	11.03
	Tradiant	°C	12.98
	GAINS window	kW	0
	LIGHTING	kW	0
Tout. 7-30°C 8-September 2:00PM	Toperative	°C	34.83
	Tradiant	°C	35.63
	GAINS window	kW	25.2
	LIGHTING	kW	3.35

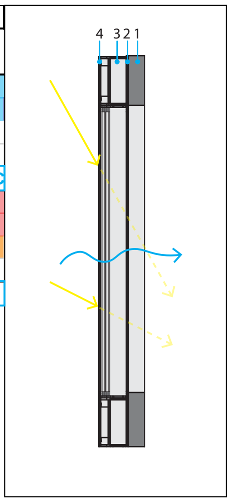


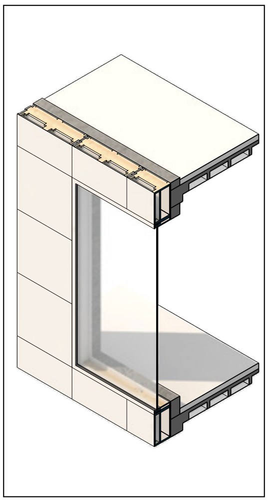


IMPROVED ENVELOPE / SAME GEOMETRY

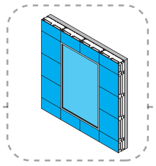


CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 1
Tout. 0-24°C 2-March 3:00AM	TOPERATIVE	°C	11.03	18.5
	TRADIANT	°C	12.98	18.69
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		+7.47°C
Tout. 7-30°C 8-September 2:00PM	TOPERATIVE	°C	34.83	34.13
	TRADIANT	°C	35.63	34.85
	GAINS WINDOW	kW	25.2	18.07
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-0.7°C



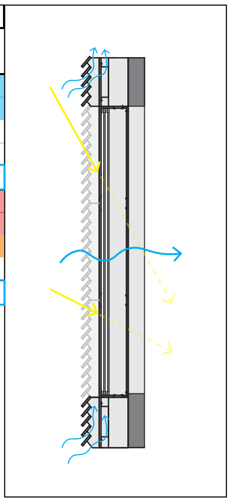


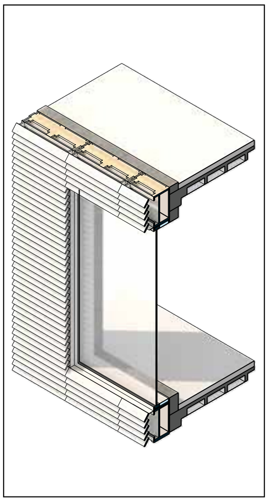
1



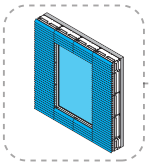
NOT VENTILATED
NOT INSULATED
IMPROVED GLAZING

CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 2
Tout. 0-24°C 2-March 3:00AM	TOPERATIVE	°C	11.03	17.6
	TRADIANT	°C	12.98	18.4
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		+6.57°C
Tout. 7-30°C 8-September 2:00PM	TOPERATIVE	°C	34.83	34.27
	TRADIANT	°C	35.63	34.89
	GAINS WINDOW	kW	25.2	18.07
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		



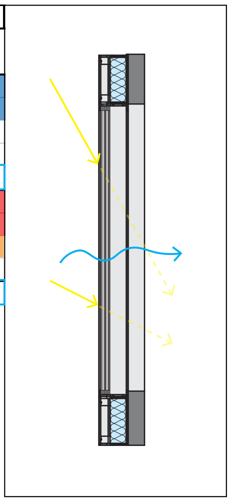


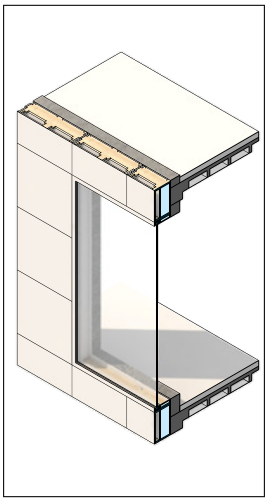
2



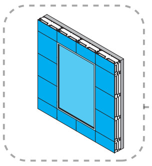
VENTILATED
NOT INSULATED
IMPROVED GLAZING

CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 3
Tout. 0-24°C 2-March 3:00AM	TOPERATIVE	°C	11.03	19.8
	TRADIANT	°C	12.98	20.73
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		+8.77°C
Tout. 7-30°C 8-September 2:00PM	TOPERATIVE	°C	34.83	35.06
	TRADIANT	°C	35.63	35.92
	GAINS WINDOW	kW	25.2	18.07
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		+0.23°C



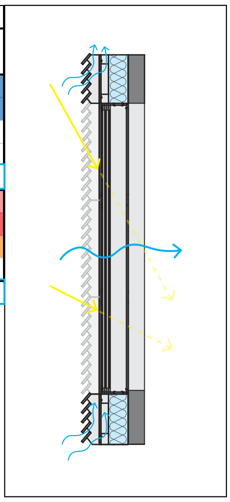


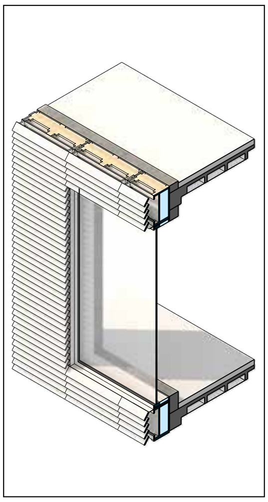
3



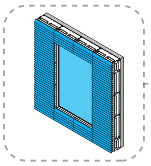
NOT VENTILATED
INSULATED
IMPROVED GLAZING

CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 4
Tout. 0-24°C 2-March 3:00AM	TOPERATIVE	°C	11.03	20.02
	TRADIANT	°C	12.98	20.95
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		+8.99°C
Tout. 7-30°C 8-September 2:00PM	TOPERATIVE	°C	34.83	34.98
	TRADIANT	°C	35.63	35.81
	GAINS WINDOW	kW	25.2	18.07
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		+0.15°C



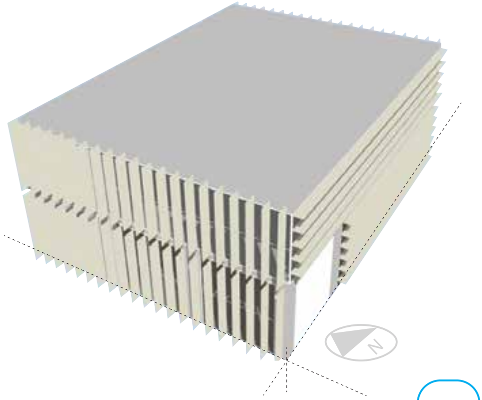


4



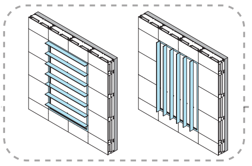
VENTILATED
INSULATED
IMPROVED GLAZING

FIXED SHADING / SAME GEOMETRY

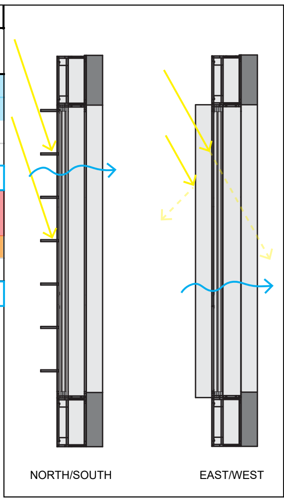


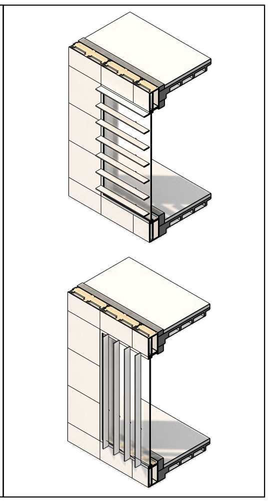
CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 5
Tout. 0-24°C 2-March 3:00AM	Toperative	°C	11.03	16.26
	Tradiant	°C	12.98	16.96
	GAINS window	kW	0	0
	LIGHTING	kW	0	0
	Tvariation	°C		+5.23°C
Tout. 7-30°C 8-September 2:00PM	Toperative	°C	34.83	33.42
	Tradiant	°C	35.63	33.78
	GAINS window	kW	25.2	13.59
	LIGHTING	kW	3.35	3.35
	Tvariation	°C		-1.41°C

5



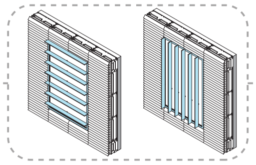
NOT VENTILATED
NOT INSULATED
IMPROVED GLAZING



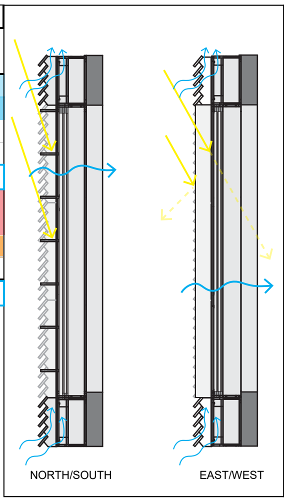


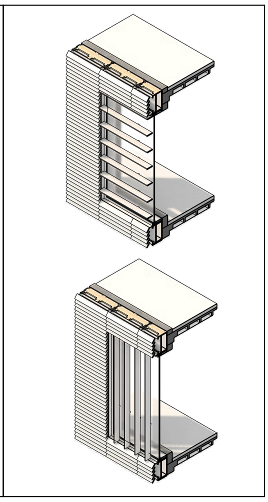
CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 6
Tout. 0-24°C 2-March 3:00AM	Toperative	°C	11.03	16.8
	Tradiant	°C	12.98	17.57
	GAINS window	kW	0	0
	LIGHTING	kW	0	0
	Tvariation	°C		+5.77°C
Tout. 7-30°C 8-September 2:00PM	Toperative	°C	34.83	33.34
	Tradiant	°C	35.63	33.67
	GAINS window	kW	25.2	13.59
	LIGHTING	kW	3.35	3.35
	Tvariation	°C		-0.79°C

6



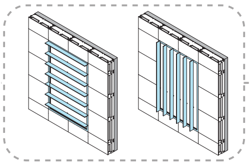
VENTILATED
NOT INSULATED
IMPROVED GLAZING



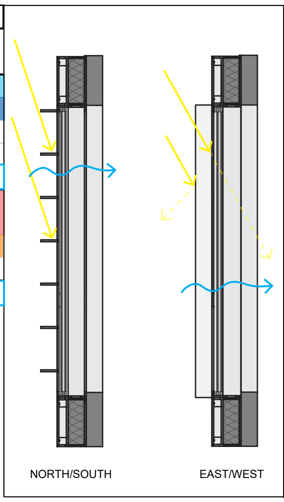


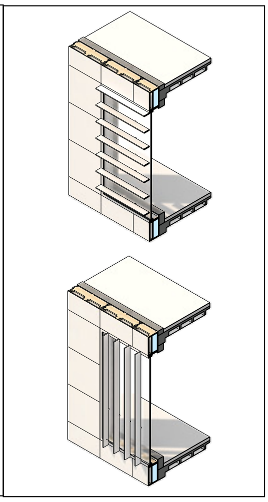
CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 7
Tout. 0-24°C 2-March 3:00AM	Toperative	°C	11.03	18.59
	Tradiant	°C	12.98	19.48
	GAINS window	kW	0	0
	LIGHTING	kW	0	0
	Tvariation	°C		+7.56°C
Tout. 7-30°C 8-September 2:00PM	Toperative	°C	34.83	34.04
	Tradiant	°C	35.63	34.6
	GAINS window	kW	25.2	13.59
	LIGHTING	kW	3.35	3.35
	Tvariation	°C		-0.79°C

7



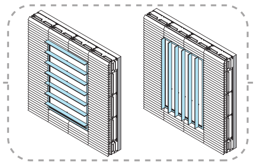
NOT VENTILATED
INSULATED
IMPROVED GLAZING



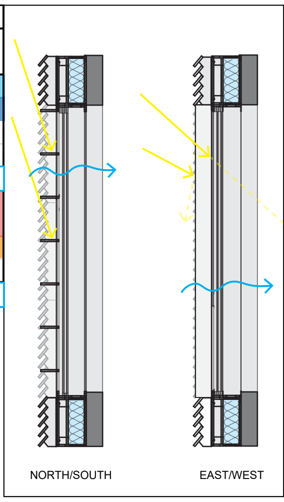


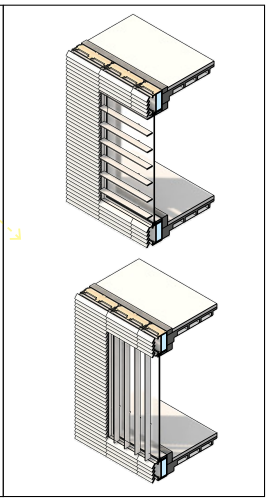
CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 8
Tout. 0-24°C 2-March 3:00AM	Toperative	°C	11.03	18.76
	Tradiant	°C	12.98	19.67
	GAINS window	kW	0	0
	LIGHTING	kW	0	0
	Tvariation	°C		+7.73°C
Tout. 7-30°C 8-September 2:00PM	Toperative	°C	34.83	33.98
	Tradiant	°C	35.63	34.52
	GAINS window	kW	25.2	13.59
	LIGHTING	kW	3.35	3.35
	Tvariation	°C		-0.85°C

8

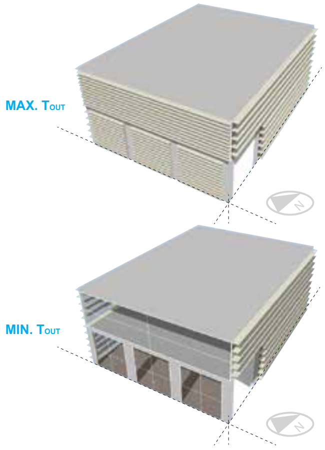


VENTILATED
INSULATED
IMPROVED GLAZING

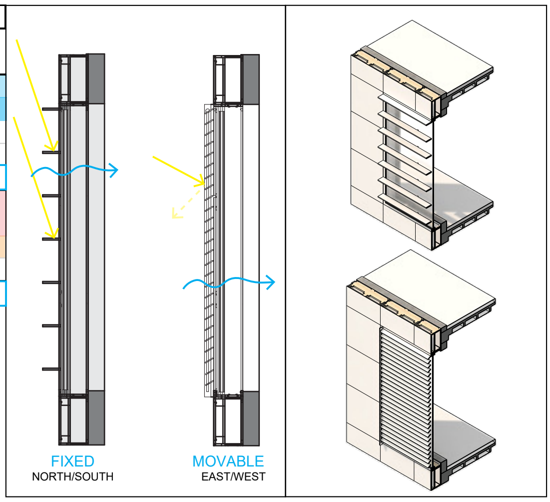




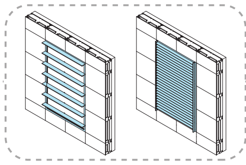
MOVABLE SHADING / SAME GEOMETRY



CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 9
Tout. 0-24°C 2-March 3:00AM	$T_{OPERATIVE}$	°C	11.03	16.75
	$T_{RADIANT}$	°C	12.98	17.47
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	$T_{VARIATION}$	°C		+5.72°C
Tout. 7-30°C 8-September 2:00PM	$T_{OPERATIVE}$	°C	34.83	31.38
	$T_{RADIANT}$	°C	35.63	31.07
	GAINS WINDOW	kW	25.2	10.5
	LIGHTING	kW	3.35	3.35
	$T_{VARIATION}$	°C		-3.45°C

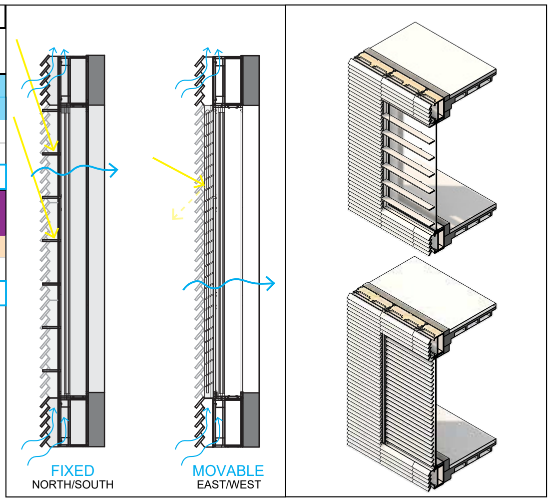


9

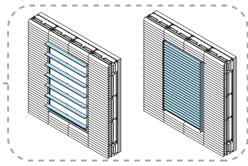


NOT VENTILATED
NOT INSULATED
IMPROVED GLAZING

CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 10
Tout. 0-24°C 2-March 3:00AM	$T_{OPERATIVE}$	°C	11.03	17.39
	$T_{RADIANT}$	°C	12.98	18.15
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	$T_{VARIATION}$	°C		+6.36°C
Tout. 7-30°C 8-September 2:00PM	$T_{OPERATIVE}$	°C	34.83	31.24
	$T_{RADIANT}$	°C	35.63	30.9
	GAINS WINDOW	kW	25.2	10.5
	LIGHTING	kW	3.35	3.35
	$T_{VARIATION}$	°C		-3.59°C

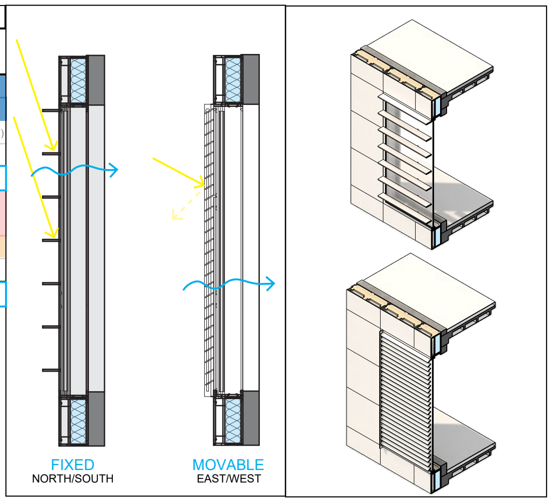


10

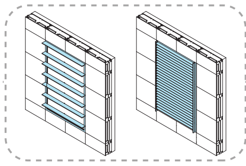


VENTILATED
NOT INSULATED
IMPROVED GLAZING

CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 11
Tout. 0-24°C 2-March 3:00AM	$T_{OPERATIVE}$	°C	11.03	19.4
	$T_{RADIANT}$	°C	12.98	20.34
	GAINS WINDOW	kW	0	10.2 (MIDDAY)
	LIGHTING	kW	0	0
	$T_{VARIATION}$	°C		+8.37°C
Tout. 7-30°C 8-September 2:00PM	$T_{OPERATIVE}$	°C	34.83	31.6
	$T_{RADIANT}$	°C	35.63	31.35
	GAINS WINDOW	kW	25.2	10.5
	LIGHTING	kW	3.35	3.35
	$T_{VARIATION}$	°C		-3.23°C

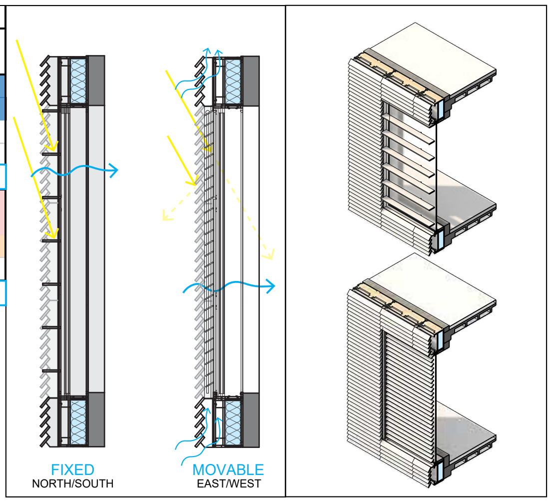


11

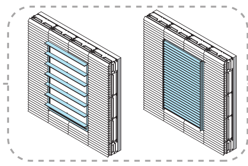


NOT VENTILATED
INSULATED
IMPROVED GLAZING

CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 12
Tout. 0-24°C 2-March 3:00AM	$T_{OPERATIVE}$	°C	11.03	19.6
	$T_{RADIANT}$	°C	12.98	20.55
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	$T_{VARIATION}$	°C		+8.57°C
Tout. 7-30°C 8-September 2:00PM	$T_{OPERATIVE}$	°C	34.83	31.56
	$T_{RADIANT}$	°C	35.63	31.3
	GAINS WINDOW	kW	25.2	10.5
	LIGHTING	kW	3.35	3.35
	$T_{VARIATION}$	°C		-3.27°C

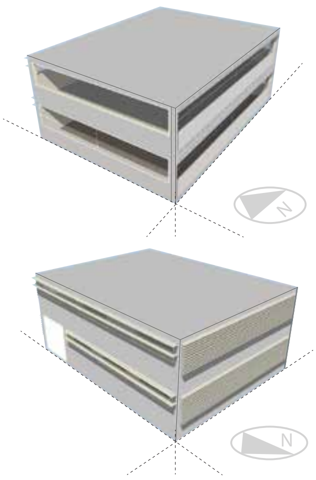


12



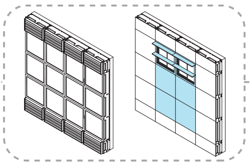
VENTILATED
INSULATED
IMPROVED GLAZING

MOVABLE SHADING / IMPROVED GEOMETRY

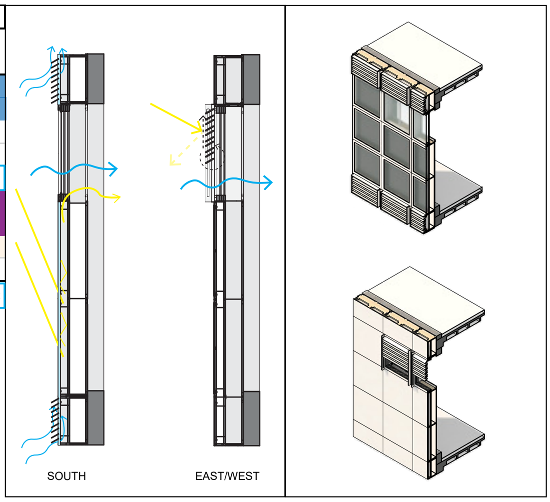


CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 13
Tout. 0-24°C 2-March 3:00AM	TOPERATIVE	°C	11.03	19.33
	TRADIANT	°C	12.98	20.2
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		+8.3°C
Tout. 7-30°C 8-September 2:00PM	TOPERATIVE	°C	34.83	29.8
	TRADIANT	°C	35.63	29.09
	GAINS WINDOW	kW	25.2	2.96
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-5.03°C

13

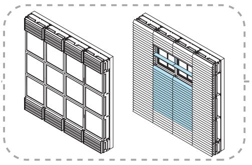


NOT VENTILATED
NOT INSULATED
IMPROVED GLAZING

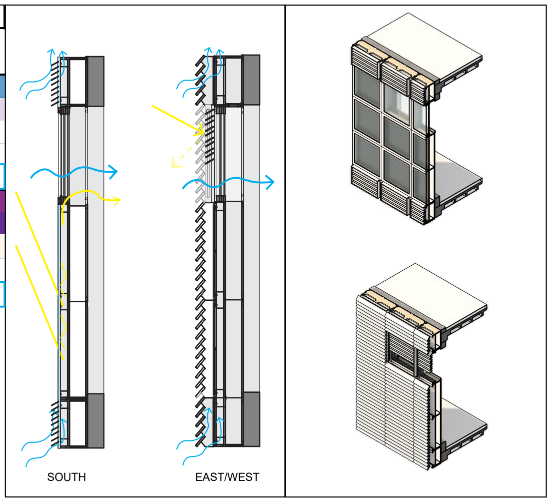


CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 14
Tout. 0-24°C 2-March 3:00AM	TOPERATIVE	°C	11.03	20.08
	TRADIANT	°C	12.98	21
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		+9.05°C
Tout. 7-30°C 8-September 2:00PM	TOPERATIVE	°C	34.83	29.61
	TRADIANT	°C	35.63	28.87
	GAINS WINDOW	kW	25.2	2.96
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-5.22°C

14

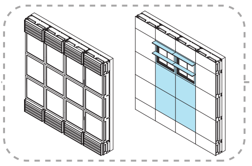


VENTILATED
NOT INSULATED
IMPROVED GLAZING

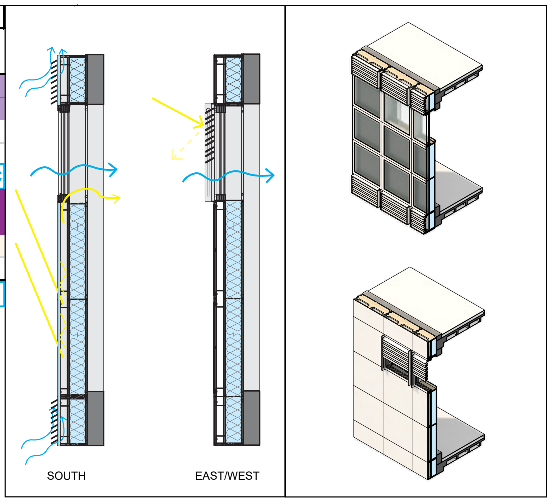


CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 15
Tout. 0-24°C 2-March 3:00AM	TOPERATIVE	°C	11.03	23.16
	TRADIANT	°C	12.98	24.25
	GAINS WINDOW	kW	0	0
	LIGHTING	kW	0	0
	TVARIATION	°C		+12.13°C
Tout. 7-30°C 8-September 2:00PM	TOPERATIVE	°C	34.83	29.92
	TRADIANT	°C	35.63	29.25
	GAINS WINDOW	kW	25.2	2.96
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-4.91°C

15

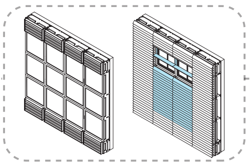


NOT VENTILATED
INSULATED
IMPROVED GLAZING

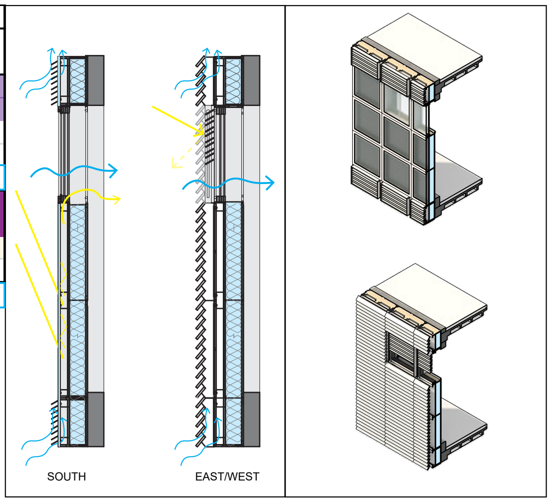


CLIMATE DATA	PARAMETERS	UNITS	CASE 0	CASE 16
Tout. 0-24°C 2-March 3:00AM	TOPERATIVE	°C	11.03	23.23
	TRADIANT	°C	12.98	24.31
	GAINS WINDOW	kW	0	
	LIGHTING	kW	0	0
	TVARIATION	°C		-5.77°C
Tout. 7-30°C 8-September 2:00PM	TOPERATIVE	°C	34.83	29.81
	TRADIANT	°C	35.63	29.13
	GAINS WINDOW	kW	25.2	2.96
	LIGHTING	kW	3.35	3.35
	TVARIATION	°C		-10.25°C

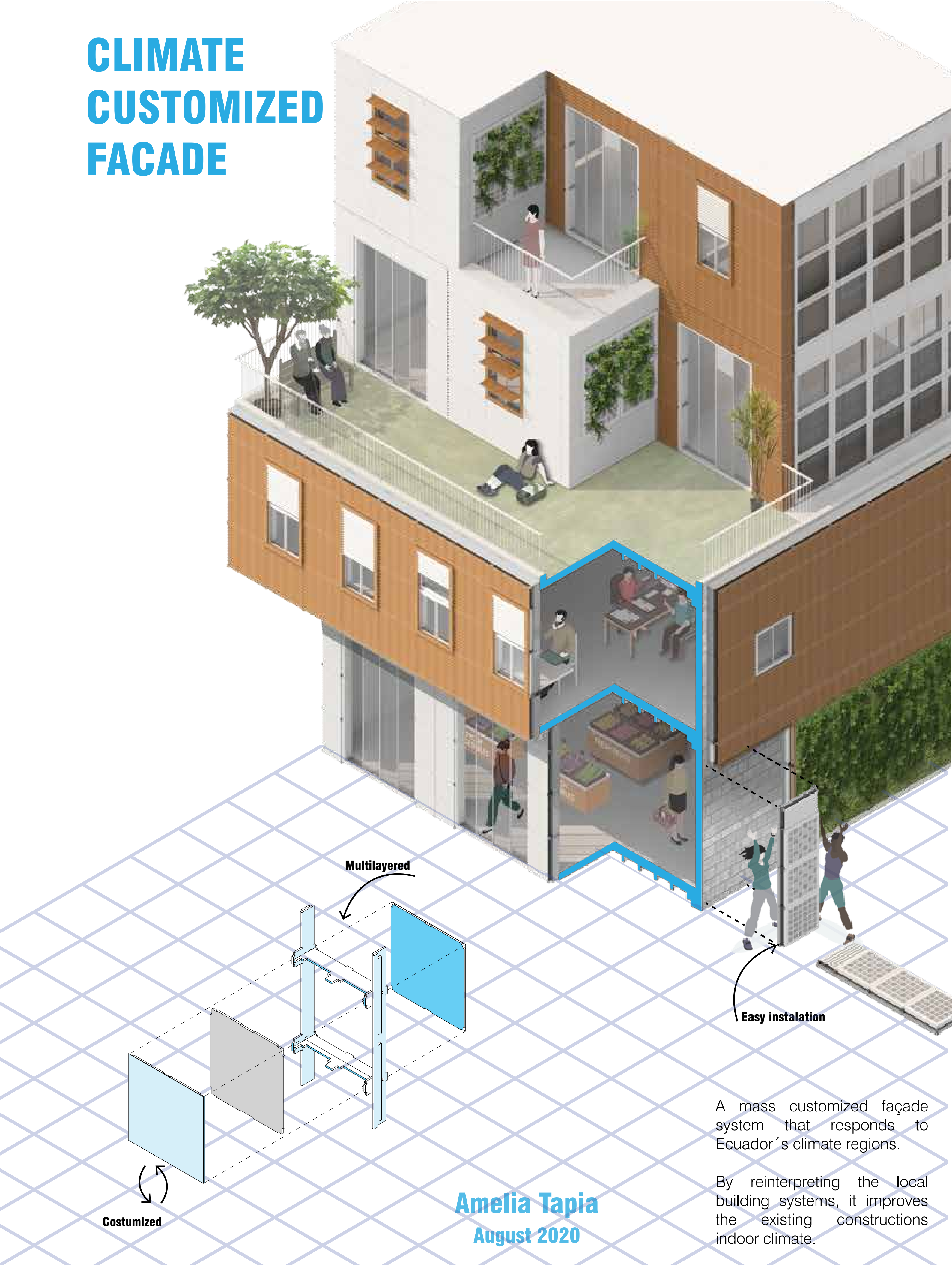
16



VENTILATED
INSULATED
IMPROVED GLAZING



CLIMATE CUSTOMIZED FACADE



A mass customized façade system that responds to Ecuador´s climate regions.

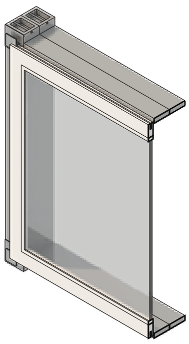
By reinterpreting the local building systems, it improves the existing constructions indoor climate.

Amelia Tapia
August 2020

Standard Products
modules

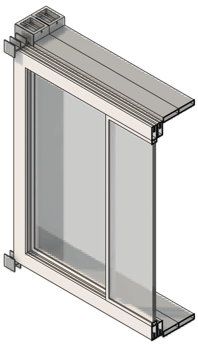
- SUN PROTECTION
- RAIN PROTECTION
- NOISE PROTECTION
- WIND PROTECTION

FIXED WINDOW



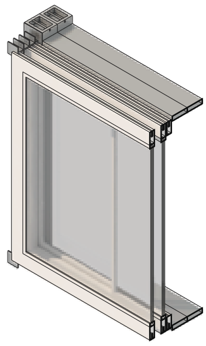
CODE	FUNCTION	U-VALUE
A1	COLLECTION + VIEWS	1.00 W/m2K

OPERABLE WINDOW



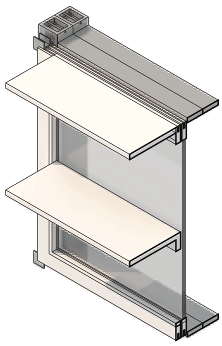
CODE	FUNCTION	U VALUE
A2	COLLECTION + VENTILATION	1.00 W/m2K

HEATING WINDOW



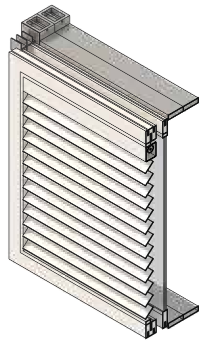
CODE	FUNCTION	U VALUE
A3	COLLECTION + HEATING	0.98 W/m2K

FIXED SHADING



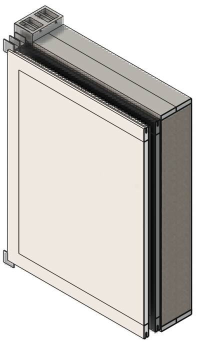
CODE	FUNCTION	U VALUE
B1	COLLECTION	1.00 W/m2K

OPERABLE SHADING



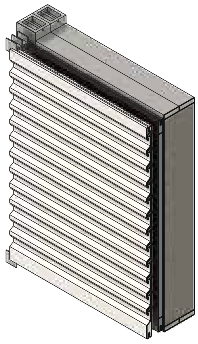
CODE	FUNCTION	U VALUE
B2	SHADE + VIEWS	0.84 W/m2K

AIRTIGHT CLADDING



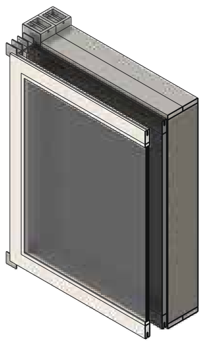
CODE	FUNCTION	U VALUE
C1	SHADE	0.22 W/m2K

VENTILATED CLADDING



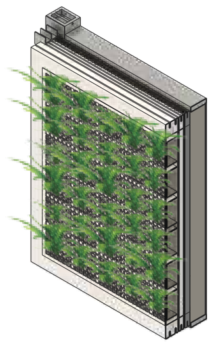
CODE	FUNCTION	U VALUE
C2	SHADE	0.18 W/m2K

PASSIVE HEATING



CODE	FUNCTION	U-VALUE
C3	SHADE + HEATING	0.15 W/m2K

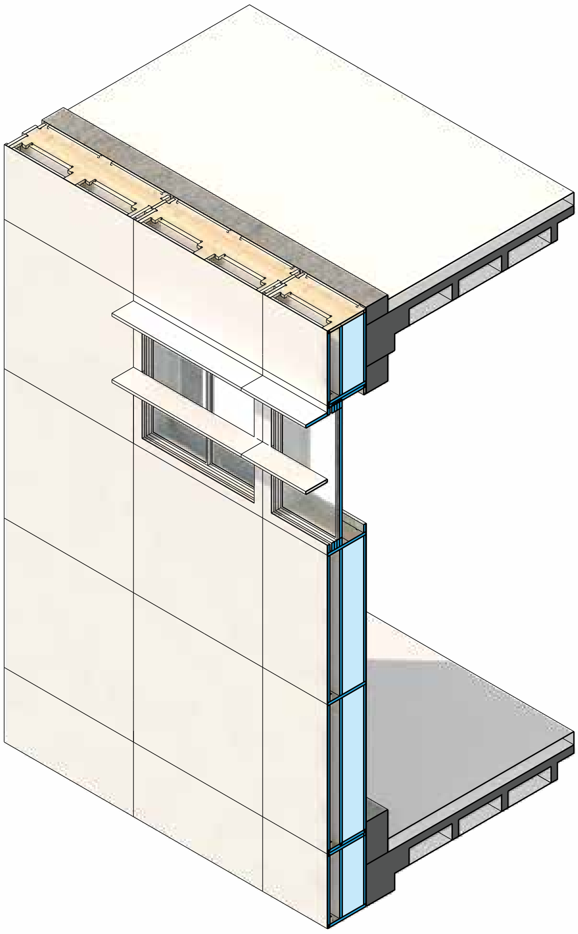
GREEN



CODE	FUNCTION	U VALUE
C4	SHADE + AIR PURIFICATION	0.33 W/m2K

Standard system
TEMPERATE climate

TOUT
0-30°

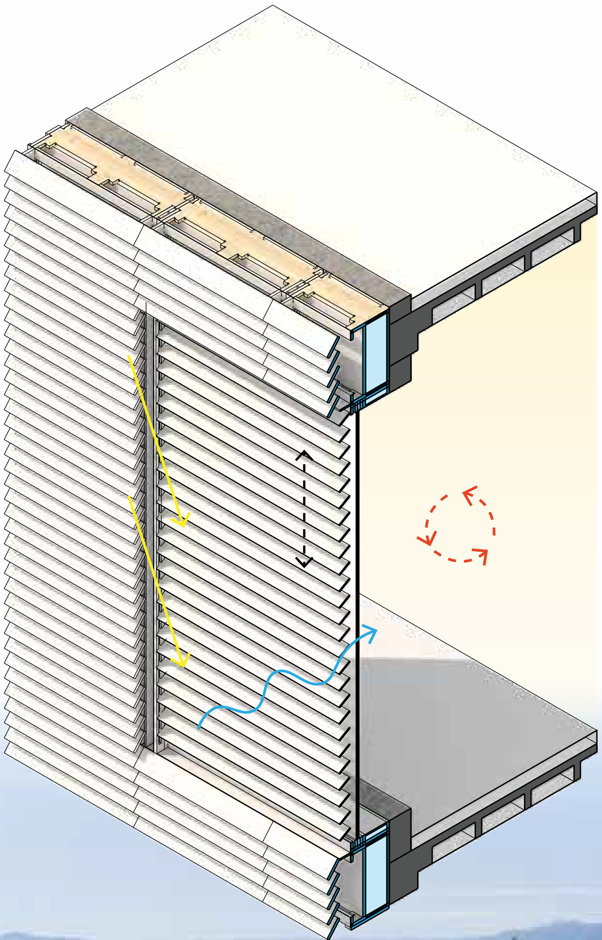


OPTIMAL NORTH FACADE

CODE	FUNCTION	U VALUE
B1	SHADING+ VENTILATION	1.00 W/m2K
C1	SHADE	0.22 W/m2K

TIN
16-25°

- INDIRECT SUN LIGHT
- RAIN PROTECTION
- NOISE PROTECTION
- NATURAL VENTILATION
- HEAT STORAGE



OPTIMAL WEST FACADE

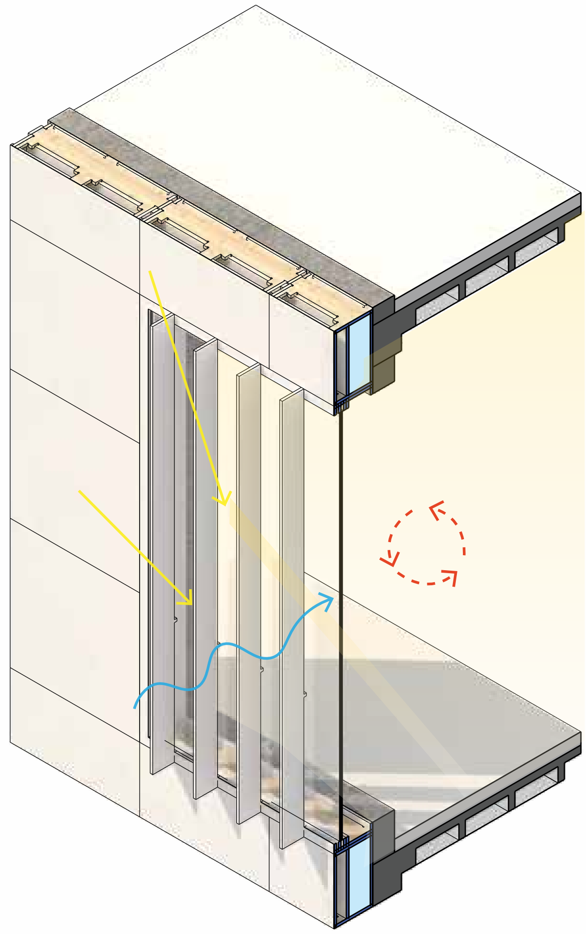
CODE	FUNCTION	U VALUE
B2	OPERABLE SHADING	0.84 W/m2K
C2	SHADE	0.18 W/m2K

TIN
16-25°

- HEAT GAIN / PROTECTION
- RAIN PROTECTION
- NOISE PROTECTION
- NATURAL VENTILATION
- HEAT STORAGE

Standard system
TEMPERATE climate

TOUT
0-30°

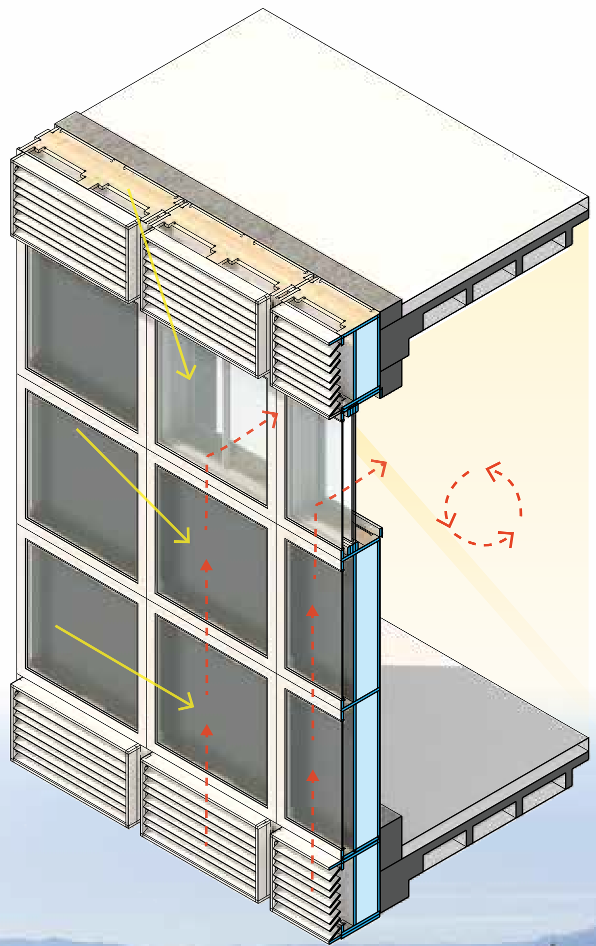


OPTIMAL EAST FACADE

CODE	FUNCTION	U VALUE
B1	SHADE + VIEWS	1.00 W/m2K
C1	SHADE	0.22 W/m2K

TIN
16-25°

- SUN PROTECTION
- RAIN PROTECTION
- NOISE PROTECTION
- NATURAL VENTILATION
- HEAT PROTECTION



OPTIMAL SOUTH FACADE

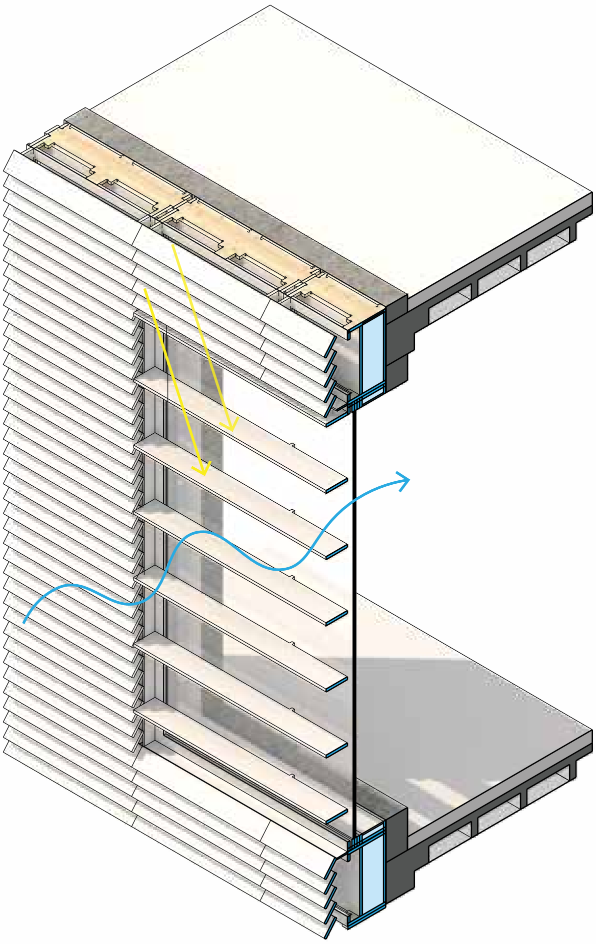
CODE	FUNCTION	U VALUE
A2	COLLECTION + VENTILATION	1.00 W/m2K
C3	SHADE + HEATING	0.15 W/m2K
C2	SHADE	0.18 W/m2K

TIN
16-25°

- INDIRECT SUN LIGHT
- RAIN PROTECTION
- NOISE PROTECTION
- NATURAL VENTILATION
- HEAT STORAGE / RELEASE

Standard systems
TROPICAL climate

TOUT
16-34°

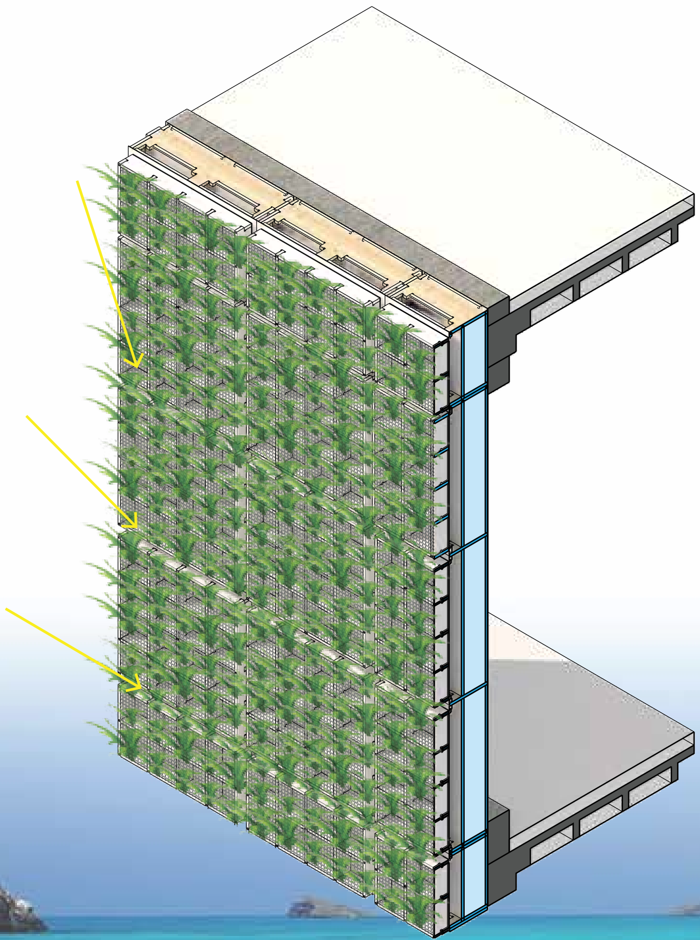


OPTIMAL SOUTH FACADE

CODE	FUNCTION	U VALUE
B1	SHADE + VIEWS	1.00 W/m2K
C2	SHADE	0.18 W/m2K

TIN
25-32°

- SUN PROTECTION
- RAIN PROTECTION
- NOISE PROTECTION
- NATURAL VENTILATION
- HEAT PROTECTION



OPTIMAL WEST FACADE

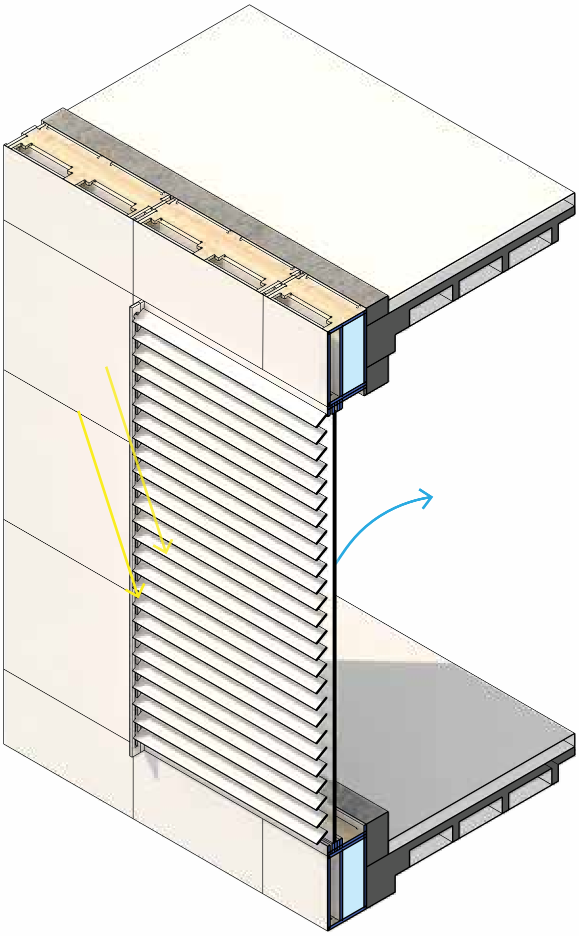
CODE	FUNCTION	U VALUE
C4	SHADE + AIR PURIFICATION	0.33 W/m2K

TIN
25-32°

- SUN BLOCKING
- RAIN PROTECTION
- NOISE PROTECTION
- SEALED CONSTRUCTION
- INSULATION

Standard systems
TROPICAL climate

TOUT
16-34°

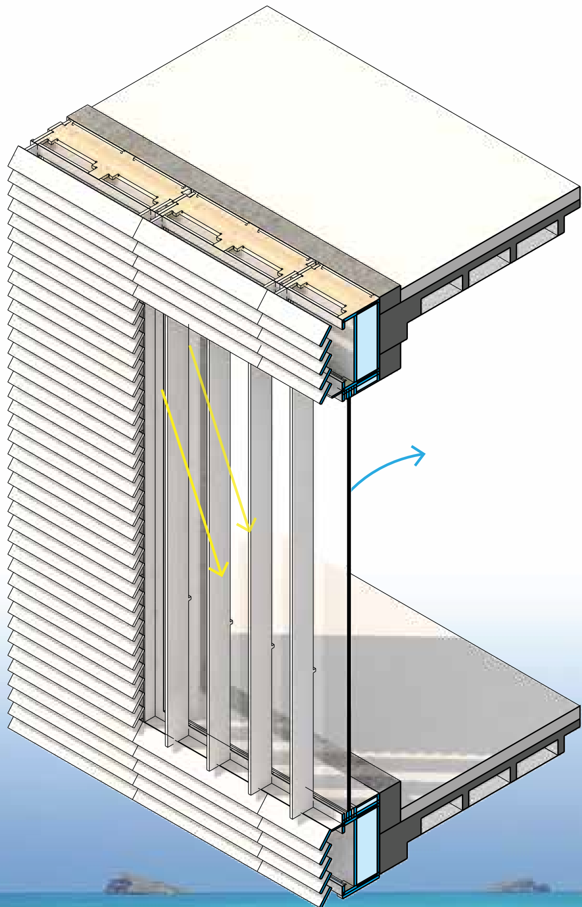


OPTIMAL EAST FACADE

CODE	FUNCTION	U VALUE
B2	SHADE + VIEWS	1.00 W/m2K
C1	SHADE	0.22 W/m2K

TIN
25-32°

- SUN PROTECTION
- RAIN PROTECTION
- NOISE PROTECTION
- NATURAL VENTILATION
- HEAT PROTECTION



OPTIMAL NORTH FACADE

CODE	FUNCTION	U VALUE
B1	SHADE + VIEWS	1.00 W/m2K
C2	SHADE	0.22 W/m2K

TIN
25-32°

- SUN BLOCKING
- RAIN PROTECTION
- NOISE PROTECTION
- SEALED CONSTRUCTION
- INSULATION

TU Delft
BK Bouwkunde

AMELIA TAPIA