ABSTRACT

The envelop is one of the most important elements when one analyzes the operation of the building in terms of sustainability. Taking this into consideration, this research focuses on developing a classification system of the envelopes opaque systems, crossing the knowledge and parameters of construction systems with requirements in terms of sustainability that they may have. To have a better understanding of how these systems work with respect to their sustainable contribution to the building. Therefore in this paper it evaluates the importance of the envelope design on the building sustainability, it analyses the parameters that make the construction systems behave differently in terms of sustainability. At the same time it explains the classification process generated from this analysis that results in a classification where all opaque vertical envelope construction systems enter.

KEYWORDS: Sustainable, exterior walls, envelope, facades, construction systems, energy efficiency.

I. INTRODUCTION

This research rises from the need to cross parameters and requirements of construction systems with the applications they may have on a sustainable level over the building. The vertical envelop systems are one of the elements that most contributes with the quantity of energy exchange and comfort parameter of a building. This is evident when analyzing the life cycle of a building, the envelop represents 15% of the total CO2 emissions and 17% of the energy consumed of the total of the cycle; Cuchi et al (2009).

Therefore, a good design of these elements can mean a big change in the building sustainable level. The façade is one of the components that most contribute to the amount of energy exchange and comfort parameters of a building. Energy consumption is clearly related to the design of the façade. Energy demand can be reduced by applying materials with thermal inertia, thermal insulation, optimizing the glass surface, and applying passive and active measures to the layers of materials that compose the envelope construction system; Knaack (2007).

Taking all of these concerns and parameters into consideration, a classification system of the vertical opaque envelope arises.

II. SUSTAINABILITY AND ARCHITECTURE

The concept of sustainable architecture is based on the principle of sustainable development proposed by the United Nations; United Nations (1987), which is a term that describes environmentally conscious managed by architecture design techniques. Being this defined, sustainable architecture is what allows that the design of any urban or architectural element respects the needs of future generations, minimizing the waste, energy and water consumption generated by buildings or cities; Edwards (2009).

Having said that, nowadays, not only we should be concerned about being more sustainable, but also we must contribute with researches of new construction systems and their reuse or recycling. Moreover, we have to pay close attention to climate change and how the society is being evolving. Taking this as premise, this research focuses on the possibility of being able to understand what the sustainable requirements of the façade are, without neglecting the comfort and satisfaction user needs; Olgay (2010).

Considering from the construction stage to demolition; taking into account the embodied energy in the material production, the development of the construction, use, demolition and reuse of materials. Not forgetting the location, the climate conditions, orientation, materials and technical resources. You cannot talk about sustainability as an abstract, it has to be situated on a context to suit all variables or indeed sustainable. Taking into consideration that "[…] the buildings adaptation to climate change requires respect three principles: the envelop and the area occupied by the building are critical to their long-term survival, adaptability and energy efficiency; the average construction quality must be higher (better insulation, high quality materials, etc.) means should be provided to improve the conditioning of buildings, especially in cooling and consumption of renewable energy"; Edwards (2009).

III. THE ARCHITECTURAL ENVELOPE

It is understood as building envelope as the construction system that separates the interior space with the outside, delimiting the living area. The envelope includes the four main facades of the building, the cover, and the surface in contact with the ground. Which not only limit the space they occupy but are an integral part of the building, influencing both, the interior and exterior and relating to the design, use, structure, function and construction services; Knaack (2007).

The vertical envelope "[…] is the architectural enclosure for excellence, as in addition to basically defines the interior spaces, constitutes the most apparent envelope of the architectural work, through which it can be express the
building functionality and defines the sculptural-architectural value thereof with all historical, creative and social aspects that this entails”; Monjo (2003).

No doubt that the facade is what gives the character, shape and image we perceive at first glance of the building; Sanchez (2011).

It is the only part we observe from the outside, which makes it one of the elements that people pay more attention of building design. This special focuses in details should include their performance and requirements as "controlling humidity, natural light and noise; in addition to the geometric definition (volumetric) of spaces and separation and external independence”; Monjo (2003).

One of the most important features that building envelopes must to have is the ability to act like a membrane skin which adapt to local climate; this will contribute to the sustainable performance of the building. Rodriguez-Mora (2007). This attributes allowed to have more relationship between the interior space and the outside environment, because the more tightness and rigid it is, the less ability to adapt to extreme behaviors that may have the local weather “Fig 01”.

A. Function and composition of vertical envelope:

The envelope design should take into account the technical requirements that this element needs to respond. These aspects can be defined considering the following parameters:

- Weather data: The composition and design of the facade must consider the weather data of the location where the building is located. These weather data would be: outside air temperature, the insolation, prevailing winds direction, etc."

- Thermal and energy consumption requirements to reach the level of comfort: Thermal comfort in a building is controlled by avoiding the energy exchanges between the interior and exterior environment, in this, the composition and design of the facades plays a very important role; Knaack (2007). These requirements will be better explained in the next chapter."

- Requirements of visual comfort: This requirement is satisfies by the glazed facade. The aim is to relate the user with the external environment. This helps with the entry of natural light into the interior spaces of buildings; Knaack (2007)."

- Resistance and stability: "the facade may be structural or not structural but both cases must meet the mechanical strength and stability to the vertical and horizontal gravitational, wind and eventually seismic loads”, Schmitt et al (2009)."

- Hygiene requirements/ natural ventilation: The air quality of the indoor environment plays a significant role in terms of comfort and hygiene. This hygiene can be ensured by renewing the indoor air introducing fresh air through openings in the facade to allow natural ventilation of the space; Knaack (2007)."

- Acoustic comfort requirements: The acoustic comfort in a room is influenced by the sounds transferred from outside to inside space. The building envelope has to filter these sounds from the outside to avoid the level of comfort comes down; Knaack (2007)."

- Water and air tightness: The facade acts as a screen that prevents the rainwater and outdoor air from entering into the building; Desplazes (2010)."

- Safety requirements: The facade systems must ensure the minimum requirements in the regulations for safety and fire resistance; Herzog (2004)."

To speak about the performance from a sustainable point of view that an envelope type has, we must take into account that the design have to response to the local weather and orientation of the building in which this facades is located.

The envelope of the building works as a filter between the interior and exterior environment. This element will act as an interface through which air and heat can be acquired and be dissipated. That element helps to provide comfort as discussed in the previous section.

Figure 1. The envelope as a membrane vs. as a sealed

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In order to provide the user with this environmental comfort, the facade should be a flexible membrane that adapts the local climate and minimizes the energy exchange between the interior and the outside environment. If the envelope is not malleable enough, this flexibility can be supported with passive and active systems that are incorporated into the design of the façade; Knaack (2007). To analyze the sustainability performance of a building system, we must consider the active and passive physical processes that the envelope has that help it to be more efficient.

B. The envelope and sustainability

Taking into consideration all the features that were just describe, this research focus on the sustainable requirements of the envelopments systems (thermal comfort, natural lighting, minimize the energy exchange, reduce the CO2 emissions, etc.). The main parameters to be taken into account when designing the envelope as a sustainable tool to improve the building performance are as follows "Fig 02":

- Site requirements: energy exchange, visual connection, adaptability to local climate, etc.
- User comfort requirements/ climate conditioning: natural light and ventilation, solar radiation, humidity, views and hygiene requirements, etc.
- Construction requirements: water and air tightness, embodied energy of materials, durability, life cycle, etc.

![Figure 2. Sustainable envelope functions](image)

C. Difference between the opaque and glazed envelope

There are two main differences between the types of envelopes that can be found in buildings, one is opaque envelope and another is glazed envelope.

The major difference is that the glazed envelope is characterized by being located in the holes or openings of the façade of a building by means of which the visual connections between the external environment and the internal spaces are generated.

At the same time it is identified with glass that is its main material that is translucent and allows the visual connection, the heat input and natural lighting. Therefore, it is one of the materials that allow more energy exchange. This type of envelope is composed of different layers of glazing material (different glass types), gases or fibers in the air gap as a thermal insulation, and sun protection application.

By contrast the opaque envelope is composed of materials not translucent, usually contains the structural part of the building, and supports the glazed façade. This type may be composed of one or more materials, and can accommodate various physical processes at a time, as the insulation and thermal inertia. In this research we focus on the opaque envelope as it is the least studied form a sustainable level in the academic world.

IV. CLASSIFICATION SYSTEM OF OPAQUE VERTICAL ENVELOPE

The classification process consists in crossing the typologies of construction systems worldwide with physical processes (discussed above) that affects the sustainable performance of a building. Taking this into account, we may have on one side the construction systems, with the Mono-layer and Multi-layer as principal systems, and crossing this information with the possibility of having materials with thermal inertia or insulation if available, and the location of an air gap. In this way, we have the crossing of construction field of expertise with sustainable field or the environmental impact that buildings produce.

A. Classification of construction systems

The first step of the classification is to enunciate the two main types of construction systems. Having the vertical opaque envelope system of Mono-layer and Multi-Layer "Fig 03".

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The Mono-layer consists of a single material which has to respond to the requirements of comfort, energy exchange and structural support.

Usually, they are vertical envelopes of materials origin from stone, which base their performance in terms of energy exchange in the capacity of thermal inertia that this material may or may not have. Considering the mass, thickness and thermal transmittance of the same (e.g.: factory walls, mud, stone, etc.) "Fig 03". The average U value of these types of materials is between 2.8 to 2 W/m²-K, since stone materials fail to have low thermal transmittance (U value); BRE, (2007).

The Multi-layer system consists of several specialized layers of different materials; each material have a specific function on the performance of the opaque façade, this function can be structural, aesthetic or sustainable.

The materials that compose the Multi-layer construction systems can be quite varied, but usually we can find at least one layer that is structural supports and the layer that complies with the aesthetic functions. Then, having other possible layer that comply with thermal insulation, thermal inertia, heat dissipation, control of solar rational, etc., depending on which configuration is been design "Fig 03".

Having U values that varied depending on the materials that form the façade, the rages are from 3.7 to 0.35 W/m²-K; Anderson (2006).

The thermal inertia usually occurs in heavy materials (e.g: brick, mud, stone derivatives, etc.), and on lightweight materials is almost nonexistent.

This happens because the inertia depends on the mass, specific heat and thermal conductivity coefficient of the material.

The benefit of this type of envelope is that amortized heat, absorbing the heat generated by the energy exchange that occurs during the day, and giving this heat back overnight. This works very well in varying weathers, where daytime has high temperatures and at night there is a significant decrease in temperature.

In this type of façade it can have variety U values, presenting ranges from 2.5 to 0.25 W/m²-K for the types of envelope without thermal inertia and ranges between 2.8 to 0.28 W/m²-K for the type of façades with thermal inertia; Anderson (2006).

These ranges were calculated taking into consideration the material type and thicknesses that usually participates in each classification composition. Taking into account all of these parameters the construction systems are classified considering whether they have a layer with or without thermal inertia "Fig 04".
C. The incorporation of Thermal insulation

The third step of the classification is the existence or not, and location of a thermal insulation layer on the composition of the opaque facade.

The importance from a sustainable point of view depends on the type of weather in which the building is located, the presence of thermal insulation materials can achieve significantly reduce the energy flow of the exchange with ranges of few centimeters of material.

What characterizes a thermal insulating material in terms of energy exchange is the level of thermal transmittance which it has, as this is what controls the exchange of heat between the interior and the outside, which is the relationship between material thickness and thermal conductivity.

When we talk about thermal insulation materials we refer to materials with low thermal conductivity of the order of 0.04 W/m2-K or lower. These types of materials are very important to counteract energy exchanges in cold climates.

This is because during the winter the contribution of these materials is to stop the energy exchange, making the heat of the inner layer decanted into the environment slower.

In this type of facades, we can have various U values, presenting ranges from 2.5 to 1.0 W/m2-K for the types of envelope without thermal insulation; ranges between 0.7 to 0.1 W/m2-K for types of facades with central thermal insulation; ranges between 0.6 to 0.2 W/m2-K for the classification with central thermal insulation; and ranges between 0.7 to 0.2 W/m2-K for types of envelope with external thermal insulation; BRE (2006).

These ranges were calculated taking into consideration the types of materials and thicknesses normally involved in the composition of each classification.

Taking all these parameters into account the construction systems are classified considering whether it is composed of a layer with thermal insulation material and the location will be identified within the constitution of the system. Having as possible locations: to the central system, and to the exterior of the system "Fig 05".

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D. The incorporation of Air Chamber

The fourth step of the classification is to identify the existence of an air gap or chamber within the composition of the construction system, which is one of the possible layers of an opaque façade.

The presence of the air gaps helps to reduce the effects of the solar radiation, throwing shadow to the system, and ventilating the outer layer, causing the outdoor air to which the system is exposed to have lower temperature than the environmental weather.

This effect helps very much when you are working with very warm weather or with temperature fluctuations that in summer times have high temperatures. Within the classification scheme the presence or absence of the air gap in the system is identified. Also identifies whether this air chamber is ventilated or unventilated "Fig 06".

This difference exists because there are construction systems that only use the air gap to minimize the effects of solar radiation without venting the air inside the chamber.

In this type of envelope we can have various U values, presenting ranges from 3.7 to 0.2 W/m²-K for types of envelopes without an air gaps, ranges between 2.5 to 0.2 W/m²-K for classifications with ventilated air gap, and ranges between 2.5 to 0.2 W/m²-K for types of facades with non-ventilated air chamber; Anderson (2006).

These ranges were calculated taking into consideration the types of materials and thicknesses normally involved in the composition of each classification. After having cleared this classification scheme, it is contrast with another chart where it has been studied all types of construction systems of vertical opaque envelopments, and these types are located in the final classification scheme.

In this way, the accuracy of the classification is verified and the parameters are identified.

E. Classification of envelope system and the adaptability to the local climate

Having studied this classification we can realize significant parameters. These parameters speak about the behavior of each vertical opaque envelope system to the local climate and ability to adapt to it, as well as ranges of values of transmittance (U value) that each type has, taking into consideration the materials that compose it, night temperatures, but is not so recommended for cold weathers.

On the other hand, including thermal insulation on buildings envelope improves the performance of the buildings that are located in cold and temperate climates, especially cold weathers where you have lower temperatures most of the year, because buildings needs to be protected against the cold, blocking the energy exchange.

We can also deduce that including an air gap helps the buildings located in warm weathers, especially tropical and
desert climate, where we find high temperatures throughout the year. At the same time supports building located on temperate or seasonal climates where we can find high temperatures during the summer time.

This happens because Regarding the adaptability of the façade to the climate, it can be noted that the Multi-layer construction systems are more versatile than the Mono-layer, because they are composed of various materials allowing reacting to changes in the local weather; this makes more sustainable.

At the same time, we can conclude that the incorporation of the thermal inertia supports the sustainable performance of the building when located in temperate and warm climates, especially if it has noticeable differences between day and night. The air chamber helps to lower the temperature of the air inside the building, ventilated the façade, renewing the air in the chamber, lowering the difference between the temperatures outside and inside and the energy exchange.

Taking in to consideration all the parameters discuss above we can make another table of classification viewing which façade works better and more sustainable in which climate. For this we are using Koppen climate classification system; EoEarth (2011) "Fig 07".

<table>
<thead>
<tr>
<th>Classification scheme/ incorporation of the air gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without air gap: B1.1.1, B1.2.1, B1.3.1, B1.4.1, B2.1.1, B2.2.1, B2.3.1, B2.4.1</td>
</tr>
<tr>
<td>With ventilated air gap: B1.1.2, B1.2.2, B1.3.2, B1.4.2, B2.1.2, B2.2.2, B2.2.3, B2.4.2</td>
</tr>
</tbody>
</table>

**Figure 6.** Classification scheme/ incorporation of the air gap (Caption. Without air gap: B1.1.1, B1.2.1, B1.3.1, B1.4.1, B2.1.1, B2.2.1, B2.3.1, B2.4.1. With ventilated air gap: B1.1.2, B1.2.2, B1.3.2, B1.4.2, B2.1.2, B2.2.2, B2.2.3, B2.4.2. With non-ventilated air gap: B1.1.3, B1.2.3, B1.3.3, B1.4.3, B2.1.3, B2.2.3, B2.3.3, B2.4.3)

<table>
<thead>
<tr>
<th>A- Tropical</th>
<th>B- Dry</th>
<th>C- Temperate</th>
<th>D- Continental</th>
<th>E- Polar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Af- Tropical Rainforest</td>
<td>BSk- Subtropical Dry Subtropical</td>
<td>Cfa- Humid Coastal Mediterranean</td>
<td>Dfa- Humid Continental Hot Summer, Wet All Year</td>
<td>Dwa- Humid Continental Hot Summer, Wet All Year</td>
</tr>
<tr>
<td>Af- Tropical Rainforest</td>
<td>BSk- Subtropical Dry Subtropical</td>
<td>Cfa- Humid Coastal Mediterranean</td>
<td>Dfa- Humid Continental Hot Summer, Wet All Year</td>
<td>Dwa- Humid Continental Hot Summer, Wet All Year</td>
</tr>
<tr>
<td>Am- Tropical Monsoon</td>
<td>BSk- Mid-latitude Dry Subtropical (Steppe)</td>
<td>Cfb- Marine-Mild Winter</td>
<td>Dfb- Humid Continental Mild Summer, Wet All Year</td>
<td>Dwb- Humid Continental Mild Summer, Dry Winter</td>
</tr>
<tr>
<td>Am- Tropical Monsoon</td>
<td>BSk- Mid-latitude Dry Subtropical (Steppe)</td>
<td>Cfb- Marine-Mild Winter</td>
<td>Dfb- Humid Continental Mild Summer, Wet All Year</td>
<td>Dwb- Humid Continental Mild Summer, Dry Winter</td>
</tr>
<tr>
<td>Aw- Tropical Wet and Dry</td>
<td>BWh- Subtropical Dry Arid (Desert)</td>
<td>Csa- Cool Semi-arid</td>
<td>Dsa- Subtropical With Cool Summer, Wet All Year</td>
<td>H- Highland Climate</td>
</tr>
<tr>
<td>Aw- Tropical Wet and Dry</td>
<td>BWh- Subtropical Dry Arid (Desert)</td>
<td>Csa- Cool Semi-arid</td>
<td>Dsa- Subtropical With Cool Summer, Wet All Year</td>
<td>H- Highland Climate</td>
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World map of Köppen-Geiger climate classification

Figure 8. Köppen climate classification system. University of Melbourne. EoEarth

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V. CONCLUSION

The description of envelopes classification according to their behavior in terms of sustainability completes an overall view of all these systems and their implications in the sustainable behavior of the building. This produces a new view towards the choice and design of these envelopes, since the understanding of these systems is based in the classification of the construction systems or covering materials. This classification, allows architects to choose the most appropriate envelope systems relating to the location, climate and environmental parameters that they are working with.

It also confirms the significance that the envelope has regarding the sustainable performance of the building and how a good design of this architectural element may be used as a strategic tool to produce a proper performance of the building through its life cycle. Since this is the element which controls the energy exchanges of interior and exterior area. Because of this, its proper functioning is essential to generate the comfort of building users, and also support the search for reducing energy demands, water use and production of CO2 emissions in buildings.

At the same time, unifying the criteria as it is doing in this research, a better understanding of sustainable operation level is provided, taking into consideration that the information of the traditional construction system merged with the innovative systems. And in turn the concepts on active and passive sustainable architecture, with building systems and their implications on sustainable building operation are unified.

In turn, there should be taken into consideration that after the selection through this typology classification system of opaque envelope to be applied to a project, there should take into account that the material selection to arrange this system shall also vary the sustainable level of the building.

Therefore, the recommendation is that after using this classification method for the selection of the construction system, the decision should be support with an analysis of the complete life cycle of the building. The major contribution of this research is that a well understanding of each typology and, making clear their performance on the latitudes and type of climate they do better and their different applications, the architects shall use these concepts to design in a better way their future projects, taking into consideration the relevance of the envelope proper functioning and the implications of their designs on the buildings performance.

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