Ventilated facade and energy efficiency

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Abstract

Buildings are listed as the biggest consumers of energy and therefore technology in the field of construction has been improved and oriented towards ecological, recyclable and energy efficient materials. One of the best findings in terms of energy efficiency is the use of ventilated facades in buildings.

The facade is one of the main technological, functional and protective elements for construction facilities. By itself it represents the outer covering or envelope of a building. Since there are different typologies of facades that are used, then a special attention should be paid to its appropriate selection for buildings in different regions.

Nowadays, climate change has become the biggest global concern, and one of the causes is the continuous use of exhaustible resources, therefore, ways are being sought to reduce the consumption of electricity and thus improve environmental conditions and we increase the quality of life. Based on the climatic conditions of a region, it is necessary to choose the right facade that protects the building from atmospheric agents, provides thermal comfort for the residents, is ecological and also has efficiency in energy efficiency.

Key words: *climate, building, ventilated facade, ecological materials, energy efficiency.*

1. Introduction

The increase in energy use has raised concerns about the depletion of energy resources and the negative impact on the environment. The largest consumers of energy on Earth are buildings, therefore there is a need to increase the efficiency of buildings to reduce consumption. This requires taking into account all influencing factors, where the climatic factor is one of the most important factors in the energy consumption of buildings. The most critical part of building design is considered the process of identifying and controlling the climatic influences of different parts of the building.

Climate design has the following main objectives:

- Reducing the energy cost of a building.
- Use of natural energy instead of mechanical energy.
- Providing a comfortable and healthy environment for people.

Design elements expressed in architectural language include:

- shape – surface-volume ratio, direction, height of the building.
- building materials – construction materials, thermal capacity, surface quality, control of darkness and light.
- windows – size, position and direction of windows, type of glass, appearance of internal and external elements.
- ventilation – air, indoor air, cross ventilation and natural ventilation.

Climatic parameters measured by meteorological stations are: temperature, humidity, air movement, precipitation, cloudiness, sunny days and solar radiation. Of all these parameters, four of them directly affect thermal comfort, namely: temperature, humidity, solar radiation and air movement. These are the main elements that must be considered in the design of the building. These parameters are closely related to:

- topography (height above sea level, hills, meadows, land surface conditions)
- flora (length, concentration of vegetation, shape, composition, place, most developed regions.
- building form (nearby buildings, surface conditions).

Facades of buildings make it possible to separate the internal environment from the external environment of the building and some of the functions of the facade:

- to have space to see outside.
- to be resistant to wind load.
- to bear its weight.
- provide as much natural stimulation as possible to minimize artificial stimulation.
- provide noise protection.
- provide protection from increased solar heat.
- to be resistant to the penetration of water and moisture.

The facade is one of the main contributors to energy conservation for buildings and various technologies are being used to help with energy efficiency. One of the types of facades that offers the most reduction in energy consumption is the sustainable facade. It should ensure minimal consumption of electricity and minimize the negative effects of the external environment on the building. To achieve energy efficiency, it is necessary to know the location of the building where the facade will be implemented and of course the climatic classification of the area, which are the main factors in determining the design of the facade.

The implementation of ventilated facades in buildings significantly enhances energy efficiency. It suggests that by utilizing appropriate facade technology, particularly in the context of various climatic conditions, buildings can reduce energy consumption, improve thermal comfort, and contribute positively to environmental sustainability. *Ventilated facades improve energy efficiency in buildings by reducing energy consumption and enhancing thermal comfort compared to traditional façade systems.* The article supports this by analyzing different façade typologies, emphasizing the role of climatic factors, and detailing the construction materials and methods necessary for optimizing energy performance.

2. Literature review

2.1. Climate

Urban areas are studied as a separate category because the climatic conditions are special, namely the temperature is higher than in suburban areas, weak winds (with low speed) and sunny days that depend on the level of pollution, urban density and concentration of constructions. From studies it has been noticed that for each degree increase in temperature, energy production increases by 2-4%, while smog increases by 4-10%.

The urban microclimate is complex in nature due to the content of several factors. External factors, for example temperature, wind conditions, solar radiation may vary based on topography and surrounding environment. Noise, air pollution and population density play an important role as well. During the winter season, the urban microclimate is milder than in rural areas, which is characterized by higher temperatures and light winds. The hottest areas of the city during the day are the streets with considerable width, areas without greenery and squares, while at night the narrow streets have a higher temperature than the rest of the city. In winter, green surfaces are more beneficial for the environment, especially during the late afternoon when tall buildings are very warm from the inside. The wind in the city is usually moderate due to the obstacles it encounters.

The characteristics of the surface in urban and rural areas are presented differently, as well as their thermal capacity varies greatly. Compared to rural areas, urban areas have a higher level of absorption (of solar and atmospheric heat), low reflectance, little evaporative heat loss, and rapid heat transmission. In urban areas the heat emission is higher than in rural areas. Air pollution in urban areas is very high, influencing the creation of the greenhouse effect. On hot summer days, the city feels the heat waves released by the dark-colored streets and buildings. Before night falls, the roads are still emitting heat, at a time when in the outskirts of the city, the rural areas are cooling down rapidly. Almost every city in the world nowadays is warmer than its surroundings. This temperature difference between urban and rural areas is called the "*urban heat*" effect. Urban heat is an effect that creates uncomfortable conditions, increases the need for air conditioning, creates great stress and what is most important negatively affects the environment, specifically urban smog (eg in metropolises).

2.2. Thermal comfort

Thermal comfort is considered the desirable or positive state that a person experiences in relation to how warm or cold that person feels. So it is very much related to the environment where the person is. Thermal comfort affects not only comfort, but also productivity, health and well-being.

Data on the human body:

a) Heat generated by the human body: 100W – by a person sitting; up to 1000W - from a person with maximum physical exercise.
b) Human body temperature is
c) A person will feel uncomfortable or sick if the body temperature is higher.

The body generates a certain amount of heat due to the oxidation process of food and this can be dissipated if the body temperature is not too high. Conversely, if a large amount of heat is lost to the environment, then the body temperature will drop. The clothes that people use play the role of thermal insulation. The amount of clothing used influences the amount of heat lost and this is reflected in the person feeling cold or warm.

The heat exchange between the body and the surrounding environment is represented by these quantities:

a) Evaporative loss (evaporation and sweating of the skin) and breathing.
b) Convection loss.
c) Radiation loss/gain.
d) Conductivity loss (usually negligible).
e) Gain from metabolic heat production.

The feeling of thermal comfort depends on a number of personal factors such as age, gender and body condition. However, for a group of people there are only two personal factors that have a relationship with comfort, and they are: physical activity and clothing size.

2.3. Thermal protection of the building

The thermal protection of the building includes the measures that must be taken, in order to reduce thermal losses from the inside/outside during the winter, while preventing excessive heat gains (from solar radiation) during the summer. In order for the heat losses to be as small as possible, i.e. to ensure a better heating with as little expenditure of thermal energy, namely electricity, it is necessary to take protective measures, first of all by the designers (architect and the constructor), associated with the corresponding relation.

Thermal protection of the building affects:

A) Improvement of comfort during the stay at work and in general during the stay in the residential premises.

The thermal comfort of a room presupposes the invariance of the temperature of the air and surrounding surfaces with time, as well as the non-existence of air currents. The design of the building must meet this requirement. Thermal comfort means that there is harmony between the person and the environment that surrounds him, which depends on age, race, gender, the work he performs, etc.; and which varies to some extent from the climate of the country where he lives: the conditions of comfort established for one people do not apply to another people. Man spends most of his life indoors. If we do not respond to the hygienic conditions of stay / comfort (residence), then people's health can be damaged.

B) Reduction of energy costs for heating (in winter) and cooling (in summer).

Energy resources in the world are decreasing, while with the development of society, thermal and electrical energy costs are increasing. Consequently, efforts are being made in the world to find and use new, renewable, alternative energy sources. In parallel with this, the costs of thermal energy for heating are increasing. In our country, a lot of electricity is used for heating, since it is useless from a thermodynamic point of view.

The thermal protection of the building greatly improves the economic use of thermal and electrical energy, bringing about its saving. So, with the improvement of the thermal protection of the building, the thermal energy required for heating the building, both hourly and yearly (during the winter period – converted into fuel), is greatly reduced. Meanwhile, the costs for cooling the premises in the summer period are significantly reduced (electricity). The addition of expenses for the thermal insulation of building structures, for the reduction of thermal transmission (winter/summer), in relation to the current state of constructions, is relatively low, compared to the benefits achieved through thermal insulation (saving thermal energy / fuel / electricity). (OFFICE, 2009)

C) Reduction of the power of the heating plant, related investments and maintenance expenses.

Investments for the installation and maintenance of the heating / cooling plant constitute an important element that enters into the overall construction cost and is related to the thermal protection of the building.

Since various constructive elements with high thermal conductivity (for structural or architectural reasons) are integrated into the building structures, such as columns, concrete, etc. - the so-called "thermal bridges" -, in these heat-insulated, high-conductivity, colder areas, water droplets can appear on the inner side of the surrounding structure. The consequence of this wetting will be not only the reduction of the thermal resistance of the constructive element (i.e. the increase of thermal losses / heat transmission), but also the gradual cooling of its surface, which leads to the occurrence of the phenomenon of condensation of steam indoor air (presence of moisture).

The existence of the thermal bridge is understood by the eye, by a pronounced blackening of the inner surface in the corresponding area, the appearance of the phenomenon of condensation, the formation of a thin layer of mold. This phenomenon, which is associated with the wetting of the external surface of the building structure on non-thermally insulated perimeter walls (Glaser phenomenon), causes the fall of external and internal plaster, the crumbling of bricks, the weakening of concrete, the corrosion of steel reinforcement, etc. While the thermal protection of the building does not create moisture, there is no deformation of the floor and other wooden constructions (placed on the walls), the color of the plaster is not removed, etc. The maintenance services of a thermally protected building are significantly lower and the life of the building longer.

2.4. Design requirements

The design requirements are presented in the necessary documentation of the building, in the plans and sections, orientation, height of the location where the construction takes place, construction structures, climatic conditions of the country, fuel to be used, etc. Architecturally (from a thermal point of view) more closed, compact forms should be preferred against open ones that have a larger external surface, thus greater thermal losses.

Calculations of the amount of heat are divided into two parts:

a) One concerns the transmission of heat from the various surrounding structures of the building, such as: walls, ceilings, floors, windows, doors and thermal bridges.
b) The other with the heat needed to warm the infiltrating outdoor air to room temperature.

Heat transmission is calculated from the known characteristics of the building materials, while air infiltration (the amount of air exchanged) is determined by experience. This amount of exchanged air constitutes natural ventilation, which is realized thanks to the change of internal and external conditions. The calculation of the necessary energy, either in a general way, in the first phase, or detailed, in the later stages of the design, requires the availability of climatic data for:

a) Calculation of cooling and heating requirements.
b) Design of heating, ventilation and air conditioning (HVAC) systems.
c) Energy assessment of buildings.

To calculate the energy needed for heating, you must:

- The internal temperature of the premises.
- External design temperature.
- Internal thermal sources (household appliances and solar radiation, which is generally favorable for heating, while unfavorable for cooling in summer).
- Phenomena that can cause cooling of the building, such as, for example, cold local wind.

The structure of the surrounding elements of the buildings must be calculated and dimensioned from the hygrothermal point of view, so that through the operation of the heating installations, the thermal comfort of the residence is achieved (in civil buildings), or the microclimate conditions in the case of technological processes (in industrial buildings).

For the surrounding elements of constructions, the following are defined in advance:

- The minimum thermal resistance is necessary to limit the thermal flow and to avoid the condensation of water vapor on the inner surface of each element.
- The thermal stability necessary to limit the internal surface temperature fluctuations of the structural elements.
- Resistance to the penetration of water vapors of constructive elements, which prevents the condensation of vapors inside the respective elements.
- Resistance to air infiltration.

With the orientation of the building from the south, the heat transmission has the most suitable values for heating the premises in winter and cooling them in the summer, where less heat is introduced by radiation, compared to the east / west orientation. The largest external surfaces of the premises should be oriented to the south; especially those environments where people stay more. Wind direction is also important, especially in winter. Strong winds (high speed) increase heat losses, especially in isolated buildings (open areas), or on the upper floors of taller buildings, compared to neighboring buildings. For this reason, the building should be placed so that it is as little exposed to the wind as possible, and preferably facing the wind are the parts of the building with fewer windows and good kissing (well kissing windows and full walls).

The rooms that are heated must be placed in the environment protected from negative external factors, i.e. in the interior of the building, while the rooms that are not heated, or secondary, such as the stairs (which, in multi-story buildings, in conditions of lack of electricity and to save it, it is good to provide windows, suitable for natural lighting).

Multi-story buildings consume less heat than single-story buildings, or with fewer floors, with the same usable area. As the number of floors increases, the percentage of thermal losses from the floor and terrace decreases, while that from walls and windows increases.

The constructive form of the building is important for thermal transmission (in thermal losses in winter and heat inputs in summer). For the same surface area, square and circular shapes have the smallest thermal losses (walls, windows). Buildings with large window surfaces, especially those with windows, are large consumers of heat in the winter, while their protection from radiation in the summer is quite difficult, and the consumption of cooling energy is high. Therefore, it is very important to insulate the walls as well as possible and to take measures to reduce the losses from the windows. The improvement of hygrothermal properties of perimeter walls, floors and terraces is achieved by increasing their thickness and thermal insulation, i.e. increasing thermal resistance, thermal stability, resistance to the penetration of water vapor and resistance to air infiltration. In this way, the value of the heat transmission coefficient "k" is reduced, the temperature difference in the different layers and on their inner surface is increased (thereby the temperature difference between the ambient air and the surrounding inner surfaces is reduced, thus improving sensitive thermal comfort), and at the same time the negative effects from the condensation of water vapor in the layers of the construction are avoided. We will thus have a higher internal surface temperature in winter and colder in summer. At the same time, some local measures should be taken; as, increasing the thermal resistance of the window parapet, where the radiator is placed, and the placement of heat reflective sheets there; increase in thermal resistance in thermal bridges in corners, etc. The most economically and thermally suitable material is cellular polystyrene.

Vertical building walls with 25 cm – 30 cm plastered on both sides have a heat transmission coefficient from 2.4 W/m^2K to 1.8 W/m^2K, which brings the heating need, referred to 1m2, from 100 – 120 W/m^2, and the amount needed for annual heating for $1m^2$ from 150-170 kWh/m^2. Whereas these loads today in European countries are respectively 30-40 W/m^2 and 50-70 kWh/m^2. These values correspond to an energetic building with thermally insulated walls with a coefficient of 0.35 – 0.45 W/m^2K (i.e. the thermal resistance of the walls should increase to values of 2.2 – 2.8 m^2K/W. Windows also play an important role. Therefore, the glass surface must be limited, within the values indicated by the thermal comfort; the thermal resistance of the glass must be increased to the values of 0.40 - 0.50 m2K/W, which can be achieved by using doppio insulating glass and in this way the overall heat losses are reduced by 20-40%. The windows must be large enough to provide sufficient natural lighting, as they have the lowest surface temperature and, therefore, create the greatest cooling of the human body through cold radiation in winter.

The indoor air in contact with the glass cools down a lot, increases its density and moves down towards the floor, creating a feeling of coldness at the feet. This effect is increased if the window is not well sealed. Another disadvantage of large windows is solar radiation in the summer, especially for windows facing east and west. External shutters greatly reduce the heat that enters the interior spaces through solar radiation. So, in an environment that is heated in winter, we have surfaces with different temperatures, some colder, such as external walls and windows, others warmer, such as stoves, radiators, etc. Thus, temperature differences appear in different points of the room, the size of which depends on the heating method. Through outdoor air and indoor air, we have temperature and humidity differences, which are accompanied by disturbing air currents. To avoid the occurrence of condensation, thermal protective measures should be taken in kitchens and bathrooms. For this reason, double-glazed windows should be provided, located so as not to cause the feeling of cold. The idea of building bathrooms without windows, with ventilation, is not recommended from a hygienic point of view.

Thermal comfort in moving air is particularly great, when all walls have an ambient air temperature of 20˚C. The term "walls of the environment" refers to all surfaces that give or receive radiant heat from the people staying in the building. The temperature of the walls of the building must be harmonized in such a way that heat losses, biologically necessary for the body, are not inhibited or increased (cooling).

3. Methodology

Facade typologies are different, but we broadly divide them into:

a) Opaque (complete) facades – are constructed of materials such as: masonry, stone, precast concrete panels, metal cladding, insulation, steel panels (cold formed).
b) Glass facades – are constructed of transparent glass materials and metal frames.

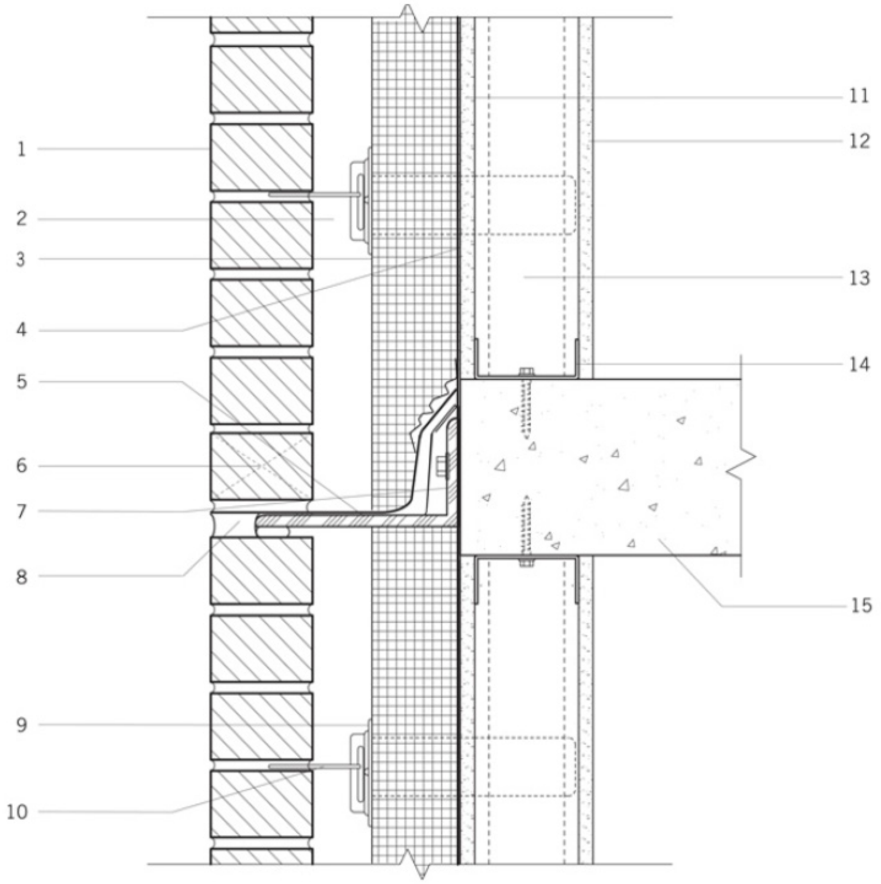
The physical behaviors of these facades are different and this is related to the components, materials and methods of their construction which are different.

In this article we will analyze only opaque facades and mainly its 3 main types. Below are their constituent elements and details of their installation in the elements of the supporting structures of the buildings.

3.1 Masonry facade

They consist of non-structural brick on the outside, supported by steel profiles (cold formed) or by a concrete masonry block (CMU). Between the outer layer of bricks and the internal support system there is an open space (cavity) which serves as a drainage area. The cavity makes it possible for water, which penetrates the outer layer, to drain at the bottom. Rigid insulation within the cavity or batt (glass wool) insulation between the steel frame members will improve the thermal performance of the wall. When the masonry cladding is supported by concrete masonry blocks (CMU), then insulation is placed on the outside of the CMU.

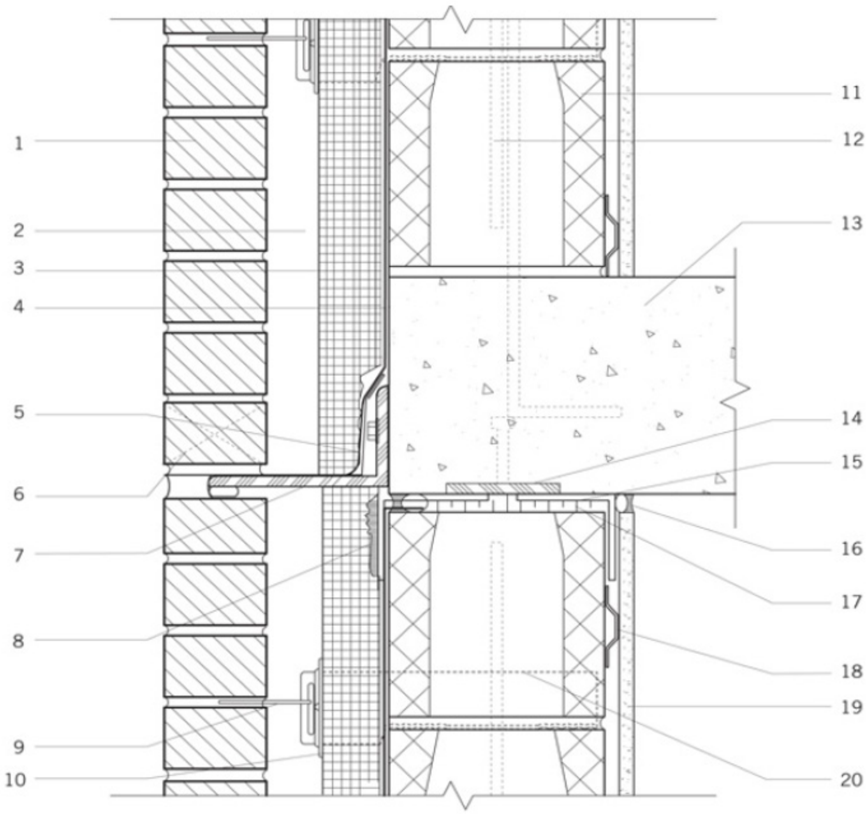
FIGURE 1 Masonry facade (Brick, hollow, frame, steel stud wall)



3.2. Facade with concrete panels

There are different types of concrete facades, such as: precast concrete panels used as a second structure cladding material, cast-in-place concrete walls, and insulated reinforced concrete panels. Other types of concrete facades include insulated concrete forms (ICF) and insulated concrete blocks (ICB). ICFs consist of pressed or expanded polystyrene panels that act as a frame for the concrete poured into the work; a final coat covers the polystyrene panels inside and out. These types of facades are typical for small-scale residential or commercial buildings. ICBs are CMUs that have expanded polystyrene sandwiched between the two faces of each block.

FIGURE 2 Masonry facade (Open brick wall with CMU support).



1 Brick
2 Air cavity
3 Rigid insulation
4 Continuous air barrier
5 Flexible continuous flashing adhered over metal flashing
6 Weep holes
7 Continuous steel shelf angle
8 Adhesive
9 Brick tie embedded in mortar joint
10 Insulation support
11 CMU
12 CMU reinforcement
13 Concrete slab
14 Steel weld plate
15 Steel channel clips
16 Backer rod and sealant
17 Semi-rigid insulation and firestopping
18 Supports
19 Interior gypsum board
20 Brick tie embedded in mortar joint

3.3. Rainscreen facade

They changed the traditional concept of protecting the interior space of the building from the penetration of rain and moisture. Most non-rainscreen facade systems rely on two protective layers. The first protective layer, the outermost surface of the facade, is the first protective barrier against air and moisture, designed to stop all air and water. The second layer of protection aims to stop small amounts of air and water vapor that can penetrate through the first layer of protection.

The rainscreen concept uses a variation of the outermost layer of the facade, which is not designed to be airtight and watertight. Instead, it acts as a rain barrier but relies on a weatherproof inner layer to block air and moisture penetration. Water penetration occurs because of air pressure changes that can be controlled by placing an air gap in the wall. Between the outer and inner layers there is a ventilation air space that moves water out. The void space (including the interior surface of the space) acts as the first layer of protection against air and water penetration. The clothing material is chosen first for its appearance. Cladding is usually panelized and can be made of a variety of materials, such as: stone, precast concrete, terra cotta (facade brick), cement composite, crystallized glass or metal. Because the inner layer is not visible in the finished construction, it is not designed for its visual qualities. Instead, it must be designed to withstand wind and seismic loads, to thermally and acoustically insulate the building, and to prevent air or water from entering the building.

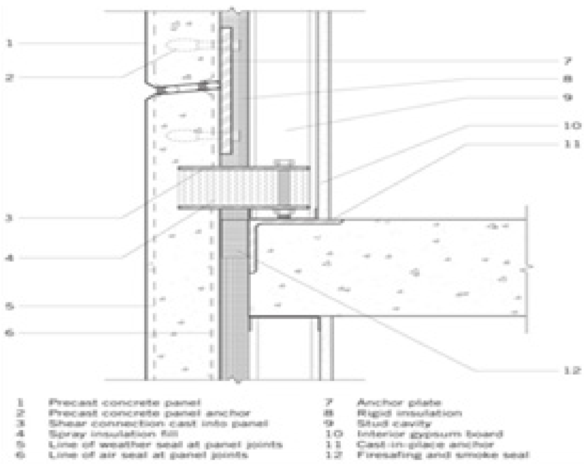


Figure 2 Precast concrete panel with steel

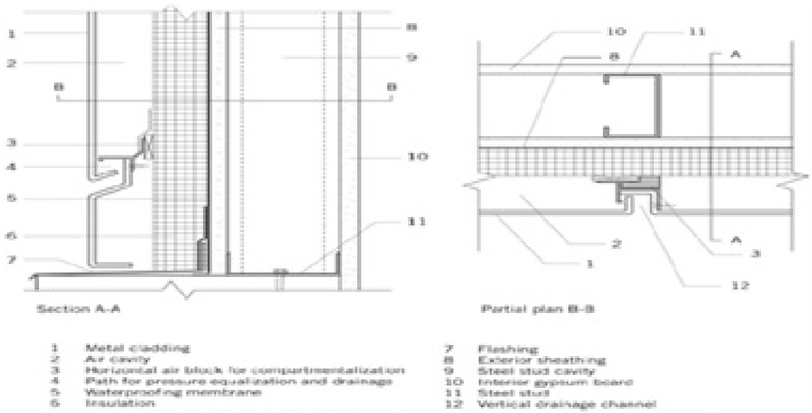


Figure 2 Rainscreen facade

4. Methods and analysis

4.1. Methods

Facade wrapping is very complex in itself and as such their calculation in terms of heat loss is a process that requires many influencing factors and parameters to be taken into consideration. Material selection is an important factor in designing sustainable facades. All materials have specific physical properties, such as density, thermal conductivity, thermal resistance and permeability.

R-values are most appropriate for determining the thermal performance of walls systems that consist of multiple layers of materials, each with its own R-value. Insulation materials are chosen for their thermal resistance and vapor barriers for their permeability. The nominal thermal resistance of a dark building facade can be calculated by adding the R-values of each layer of material, including air spaces. For each assembly, the overall R-value is calculated by adding the thermal resistance of the individual layers of material (determined by multiplying its R-values per unit thickness by the overall thickness of the material). Insulation materials for the three assemblies are rigid mineral insulation, spray polystyrene foam insulation, or mineral wool insulation.

4.2. Facade efficiency analysis

The components of the four facades taken into analysis are as follows:

A- ***Simple facade***: exterior plaster, thermal insulation, brick wall with holes, internal plaster.
B- ***Masonry facade***: masonry brick, air layer, thermal insulation; brick wall with holes, internal plaster.
C- ***Concrete facade***: coating foam-concrete panels, air layer, thermal insulation, brick wall with holes, internal plaster.
D- ***Rainscreen facade***: cladding aluminum panels, air layer, thermal insulation, brick wall with holes, internal plaster.

In summary, *Table 1* presents the part of the analysis of the facade decided for three of the types described above.

Table 1. Facade analysis

No.		Lsyers	δ (cm)	ρ (kg/m^3)	λ $(W/m\,K)$	$R = \delta/\lambda$ $(m^2\,K/W)$	$K = 1/R$ $(W/m^2\,K)$
1		Outside air				0.043	
2	*A*	*Simple facade with exterior plaster*	2	1800	0.90	0.022	45.00
	B	*Masonry facade*	*12*	*1800*	*0.60*	*0.200*	*5.00*
	C	*Coating foam-concrete panels*	*6*	*1600*	*0.70*	*0.086*	*11.67*
	D	*Cladding aluminum panels*	*1.4*	*2700*	*3.33*	*0.004*	*237.86*
3		Air layer	4	1.3		0.160	6.25
4		Thermal insulation layer	5	25	0.039	1.282	0.78
5		Brick wall with holes	20	1100	0.60	0.333	3.00
6		Internal plaster	2	1800	0.90	0.022	45.00
7		Indoor air				0.120	
		Total Value					
A		*Simple facade with exterior plaster*				***0.377***	***2.652***
B		*Masonry facade*				***1.998***	***0.501***
C		*Coating foam-concrete panels*				***1.883***	***0.531***
D		*Cladding aluminum panels*				***1.802***	***0.555***

5. Results

This article shows how the design of sustainable facades takes into account many factors, including environmental conditions, the orientation of the building, the design of the facade and the properties of its materials and components.

According to the analysis of different types of facades, it is noted that a ventilated facade has an energy efficiency of about 5 times more than a simple facade. While among the different types of ventilated facades taken in the study, we have similar values of thermal resistance, with a difference of 5% to 10%.

The physical behavior of the facade is a major contributor to the energy use of a building. Designers must consider the characteristics of materials and components, such as thermal and embodied energy, that go into the construction of a building's facade.

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