POLITECNICO DI TORINO

MASTER THESIS

Master's degree in building engineering

MODELLING AND SIMULATION OF DOUBLE SKIN FAÇADE USING “TRNSYS”

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ABSTRACT

The buildings sector of Europe, requires more than 40% from the total energy consumption. In the last few decades, different strategies and technologies have been taken to increase energy efficiency in buildings. However, in Europe is estimated that the 80% of the potential for energy savings in buildings is still untapped. One of the building components with a great potential are windows that significantly affect some of the main features of the energy demand, such as space heating and cooling, lighting and ventilation. The research project of "REINVENT" on which this thesis is grounded; is focused on the development of DSF system that aims to achieve three main objectives:

(i) Develop DSF solutions that contribute to reduce total energy consumption of the buildings.

(ii) Model and simulate a suitable DSF system with the support of building performance simulation (BPS) tools.

(iii) Validate their effect through the comparison between experiment data and simulation data.

The study of the thesis is focused on two different DSF system: "box window" and "multistory façades", by analysing their behaviour with mechanical ventilation, with the use of BPS tool such as TRNSYS (V17).

The results obtained with the model are compared and validated with experimental data. Some of the data that have been investigated during thesis work are:

- The temperatures distribution along the air cavity and the surface of the glass;
- The thermal airflow between the cavity and the indoor zone;
- The components of solar radiation, which are absorbed and transmitted by the internal and external;

In conclusion, this study supports that the increasing capabilities of dynamic simulation tools are enabling designers with performance-based knowledge to understand the complex characters of DSF systems. Hence, BPS tools became very important as support to verify and validate technical solutions to achieve energy efficient and comfortable buildings, during the entire project's development.

1 INTRODUCTION

At the base of the desire to build or preserve buildings, there is the conviction that using terrestrial resources sparingly and carefully considering the consequences of personal actions are a better way to achieve the well-being of human settlements.

1.1 OVERVIEW OF ENERGY CONSUMPTION

Nowadays, unfortunately, man has put a strain on the earth, exploiting and consuming a large part of its heritage. One of the main factors that have contributed to destroying the environment is the disproportionate consumption of energy by man. To get a detailed overview of this phenomenon on a territorial scale, the "BURN" energy journal provides an estimation on the energy consumption from person deriving by each country in the world *[1w]*.

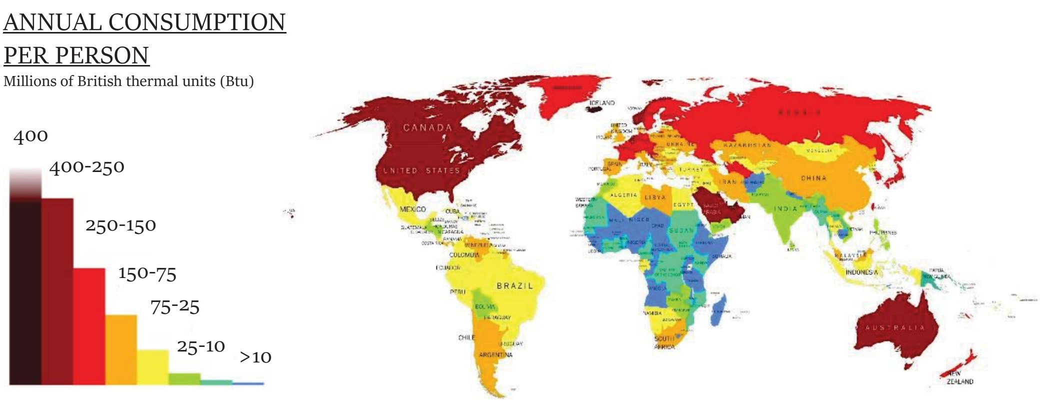


Figure 1: The Energy Consumption of the world [1w]

From the data emerged from the graph and from the considerations made on the statistics of the International Energy Agency (IEA), the countries with the highest energy consumption are:

1 USA, CANADA, Australia and United Arab Emirates;

2 European countries and Russia;

3 Asian countries;

4 Central America and Latin America;

5 Africa and India;

A big part of human life has been spent inside buildings, houses or offices. The energy used by commercial and residential edifices represents a significant value on the total consumption of energy on the planet. It was estimated that buildings are the main primary energy consumers in all sectors, surpassing the transport and industrial sectors by 40% percent. In fact, according to the data previously reported, countries with a higher energy consumption of buildings are certainly the most industrialized *[2w]*.

Specifically, from a study carried out by the IEA in 2013, percentages have been reported regarding the individual aspects of the building that influence the consumption of primary energy, both for commercial and residential buildings *[3w]*.

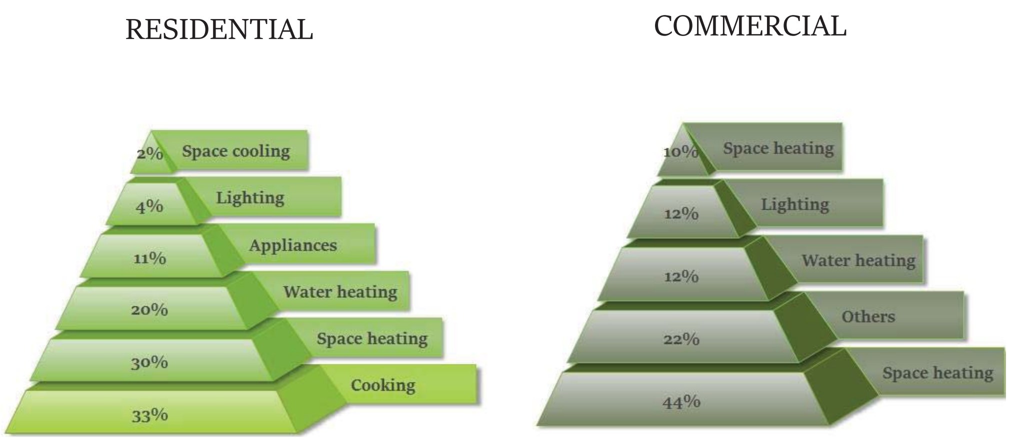


Figure 2: The consumption of residential and commercial building

These data make it imperative that buildings are primary targets for reducing global demand for energy and fossil fuels. In order to meet these needs, precautionary measures have been implemented from the late 1990, to lower the concentration of carbon dioxide, reduce energy consumption and exploit renewable energy sources *[2w,3w]*.

One of the most important environmental protection measures is the Kyoto protocol, signed in 1997 by over 167 countries.

This procedure is an important step in the fight against global warming because it contains binding targets for the limitation and reduction of six greenhouse gases (CO_2 carbon dioxide, CH_4 methane, N_2O nitrogen oxide, HFC hydrofluorocarbons, PFC perfluorocarbons, hexafluoro sulphur SF_6).
In particular, it aimed at reducing, in the 2008-2012 period, the total emissions of developed countries. With the Doha agreement, the extension of the protocol was extended from 2012 to 2020, with further targets for cutting greenhouse emissions *[1]*.
The pressure of global political institutions, has allowed a develop of strategies for sustainable construction through the stipulation of energy and environmental regulations and protocols. Among the different theories applied since the 90s there are: Passivhaus (in Germany), Zero Energy Home (in the United States), Autonomous Maison en énergie (in France) or Green Building (in England, United States, Canada). These theories differ in the socio-economic and cultural contexts that have constituted the reasons for the different reference climates and for the different constructive habits, but they have a single concept, Zero Energy Building (ZEB). ZEB is a building which tends to obtain a balance between the imported and the exported energy, trying to have a very low impact on the environment *[4w]*.
The application of this concept was possible thanks to the discovery and evolution of new horticultural technologies, which facilitates the integration of the building with the environment, by reducing consumption and pollution. One categorization of this technologies is responsive building elements, including façade systems, roof systems, underground systems, energy storages and passive solar systems.

1.2 PROBLEM STATEMENT, OBJECTIVES AND RESERCH QUESTION

One of the processes of sustainable construction that characterizes the building envelope is the design or refurbishment of the fenestration. The components used for this process have suffered a notable change over time, where the facades have become an extremely important element for controlling the thermal and lighting comfort of the building. Among the new systems of windows used there are the "Double skin façade". The development of this façade was aimed for years to obtain dynamic solutions, for the integration with the building envelope. To give an answer of this study, the research has experimented with mathematical models and constructions, in order to analyze and improve the performance. One of the innovative tools, which focus the features of this component is the use of the Building performance simulation software "BPS". This software through calculation units, let model the geometry and simulate their operation, by assessing their behaviour. The use of these tools is important for the interoperability between users and building and to speeds up the design and the development process of the new technological components.

The thesis is based on physical mathematical modelling and on the thermo-energetic simulation of double skin facades, through a BPS called TRNSYS. The purpose of this activity is to enhance the understanding of the functioning and performance of DSF, by analysing fluid dynamics problems and energy comfort implications. Furthermore, the results of the work will support the design of the innovative façade system and the definition of strategies for the control of the intelligent component.

2 LITTERATURE REVIEW

In this chapter, it will be introduced the theme of the energy efficiency of the building, by describing the evolution of sustainable construction and the reduction of consumption. It will be also analyzed a hi-tech technological component called Double Skin Facade, in its structural and performance characteristics.

2.1 THE NEW BUILDING ENVELOPE

The building envelope - represents the boundary that divides the building internal environment from the outside. This shell is made up of numerous components and materials, which aim to achieve an optimal indoor comfort, in terms of thermal, hygrometric and light, without being influenced by external climatic conditions *[2]*.

Figure 3: The energy efficiency [5w]

In the last 150 years, the envelope had a substantial evolution in his form and functions, both in the use of the materials and the performance of the components. This need was made to achieve the two main objectives: 1 develop architectural and functional aspects and 2 improve energy performance. The former change according to the architectural mood of the years and the technological progress. On the other hand, the latter, aims to enhance the quality of life in the space in which the human being lives, connecting to the first two aspects and obtaining materials and technological components with better efficiencies and with design *[2,3]*.

As previously reported in the introductory chapter, the primary energy consumption by the buildings, is one of the main problems in terms of pollution and overheating of the planet. To overcome this problem, many several world institutions have been formulated preventive forms and protocols to reduce consumption and to improve the quality of buildings *[2,3]*. The main aspects, which concerned these solutions, are the use of alternative energy sources, by promoting "Green Building", and the use of materials or components with a low impact on the environment, but also with very high efficiency, which can call "High-Tec" solutions *[4]*.

2.1.1 Sustainable construction

Nowadays, the terms "hi-tech" and "green building" can be contained in one word that is: sustainable construction. In fact, both terms focus on the same social, ecological and economic goals. The sustainable construction is based on five main aspects: 1. Sustainable site development, 2. Water conservation and savings, 3. Energy efficiency, 4. Resource Efficient Materials, 5. Healthy Indoor environmental quality *[4]*. The research has aimed to achieve this result by improving and developing three components of the building envelope: Wall, Roof, Fenestration.

The "**walls"** are a main part for the building; these are important for maintaining the thermal and acoustic comfort, within a building without damaging the architectural and aesthetic part of the building. One of the most influential parameters on the performance of the walls is certainly the thermal resistance, which expresses the ability of a wall to retain heat and therefore to be a function of energy consumption of the building. The dual function of this character is thermal insulation, which according to the materials and their thickness, defines the thermal resistance of a wall *[5]*. To date, numerous techniques and different types of materials have been developed to thermally insulate the building envelope, such as passive solar wall, lightweight concrete (LWC) walls or ventilated or double skin walls *[3]*. The first typology is used in cold climates, and has the important function to absorbed solar energy and transmit it to the building. This function is made possible thanks to the use of photovoltaic cells, phase change materials or heat transfer fluids. On the other hand, the second type, aims to reduce thermal resistance using concrete with a density of less than 2000 Kg/m3., mixed with additional aggregates coming from natural materials (such as pumice, diatomite, expanded clay or expanded shale, etc.), treated by-products (such as foamy slag, sintered powdered fuel ash), unprocessed materials or aggregates with low conductivity like polystyrene beads, vermiculite and leca *[3,6W]*. Finally, the third type exploits the air inside a cavity between two layers of the wall, with the purpose of generating a forced or natural flow ventilation, to reduce thermal effects or to passively heat and cool the building *[3]*.

The “**roof**” is a critical part of the building, exposed to solar radiation and external weather conditions. Even the roof interacts with the quality of the internal environment through transmittance; in fact, the main researches have been aimed at reducing this parameter. As in the walls, the most important innovations concern the use of high performance materials, combinations with photovoltaic surfaces and the design of integrated ventilation systems. Furthermore, there have been two important innovations of building integration with green and water *[3]*.
The roof garden is a roof completely covered with vegetation, it can be of two types, intensive and extensive.

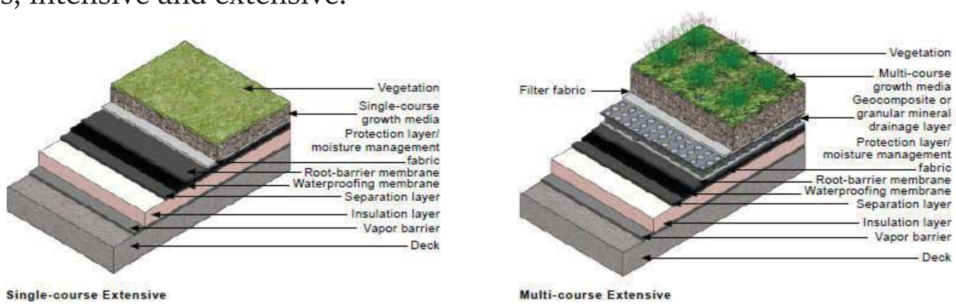


Figure 4: Extensive and intensive roof garden [7w]

The intensive, is characterized by a deeper soil substrate which allows to cultivate deep root plants like shrubs and trees.
On the contrary, the extensive is composed by a thinner substratum that let cultivate low-level seedlings such as lawn or sedum. Green roofs are not useful for reflecting solar radiation, but they also serve as additional thermal insulation *[3,7w]*.
Finally, another particular high-performance roof is the evaporative roof cooling; this technology provides for the construction of an artificial lake on the roof surface with the ability to be covered automatically according to the seasons and phases of the day. The pool of water, bases its operation on the evaporation of latent heat, with the aim of keeping the roof cold. This component is in fact very popular in hot or tropical climates *[2b,8w]*.

The last group of innovative solutions for sustainable building is the fenestration. The term "**fenestration"** indicates all glazed components that separate the internal environment from the outside. The façade has an important role in the balance of the thermal comfort and the level of interior lighting, but is also an object of design and decoration of new buildings.
The research to improve the facades has developed following 4 main aspects: the glass, the frame, the shade and the ventilation *[3]*.
Nowadays, regarding glass, there are different new solutions such as low-rise emissivity coatings (low-e), performance materials like aerogel and polycarbonates or special gases to fill the cavities. Low emission coatings filter the visible light of the solar spectrum allowing to block the light beam responsible for the solar heat gains. Polycarbonates and aerogel, on the other hand, are transparent polymers with a very low density, but with an excellent thermal resistance, allowing to increase the performance of the facade.
On the same principle the use of gases such as argon or krypton is based, but they have some difference with the polymers, for example they need a cavity, by increasing the total thickness and they improve the acoustic capacities of the component *[9w]*.

The second aspect regards the components used for the frame; in fact, these also try to reduce the performance gap, but above all they aim to obtain a lighter and more easily composable composition, in order to create buildings in modules, with strange shapes and big sizes. The main variable to regulate the daily lighting is represented using shades. These applications today are completely automated systems and can be found inside or outside the façades. The types are varied, ranging from roller, curtain or lamina systems, up to complex systems of sun breakers. One of the feature of this component is the material, which is lightest, efficient and compatible with the system *[3]*.
Finally, we have the integration of the facades with the ventilation; to find out this system, it is necessary to create a cavity with two glass layers. This new structure allows to minimize the dispersions and to dampen the external thermal effects. It can also be useful to recover the air inside the cavity and use it as a support to the cooling and heating system of the building.
The 4 characteristics described, thanks to the technology have been integrated into a single component called DOUBLE SKIN FAÇADE *[6]*.
This window represents one of the most important hi-tech components of eco-sustainable building and is also the object of the thesis, in fact it will be analyzed and described in the chapters later.

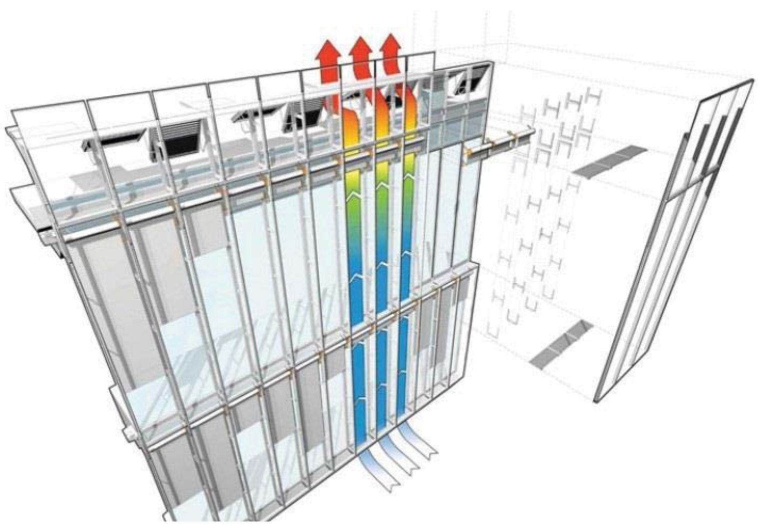


Figure 5: The Double skin façade [7]

2.2 THE “DOUBLE SKIN FAÇADE”

After the exhibition of the different technologies and new ideas of building develop, the study focuses on a new technological component: an active transparent façade, called “double skin façade” (DSF).

These types of façades have a different structure in terms of construction and ventilation, with the ability to adapt to environmental conditions, to achieve good energy performance and internal comfort. The double skin façade is an architectural pattern used mostly for the aesthetic desire for an all glass façade that makes the building more transparent, for improve indoor environment, for improve the acoustics in places whit a lot of noise polluted areas and for reduce the energy use in the buildings *[8,9]*.

In 2002 the Belgian Building Research Institute [BBRI], in a source book described the structure of this the DSF. The façade is made up of an exterior glazing, which can be made of glass or other material, and an interior double-glazing unit (usually made of translucent fixtures). Between the two panes there is an air cavity, with a width between 200 mm to more than 2m, that allow the passage of the air flow, the maintenance interventions and the positioning of device. Also, they can have automatically controlled solar shading integrated inside the air cavity or with component to outside.

<u>COMPONENTS</u>

1. Exterior glazing.
2. Interior glazing.
3. Structural frame.
4. Operable sun shade.
5. Sun shade canopy.
6. Upper operable ventilation.
7. Maintenance catwalks.

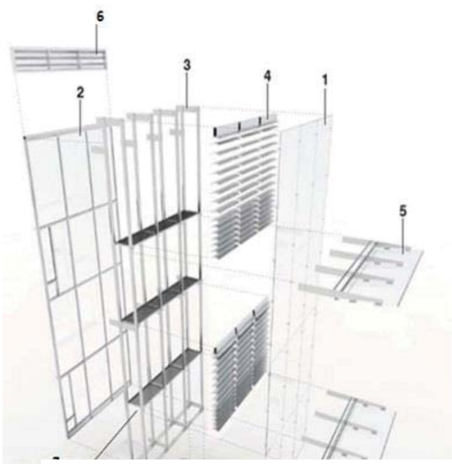


Figure 6: The composition of DSF [11w]

The airflow ventilation in this space can be totally natural or mechanically ventilated with the fan supported. The cavity is also open at some points to the outside of the building, to ensure the natural ventilation from the bottom to the top, this passage allow advantages both in summer and in winter: in summer there is the lowering of the surface temperature, in winter it avoids the presence of humidity and condensation (only the inner skin can be opened to guarantee the natural ventilation of the rooms), *[8,10,11w]*.

2.2.1 The evolution of DSF

From the end of the XIX century, the purpose of the architects was to adopt large glazed surfaces, to confer to the building an image linked to an aesthetic transparency, with a pleasant visual appearance both from the inside and outside. However right away there was a lot of problem related to the poor internal thermal comfort and to the high-energy consumption. The first description of an early version of a mechanically ventilated skin façade is from the 1849 by Jean-Baptiste Jobard, which mentions how in winter hot hair should be circulated in the cavity between the two glazing, while in summer it should be cold air. In fact, since the beginning of 900 up to half century, the architects focused their search to achieve the solution of these problems led to the creation of the double-skin façade (DSF), *[8,10]*.

In this century, one of the most important supporter of this component was the famous architect Le Corbusier. He tried to achieve comfort building through the combination between energetic building design and active system. The idea of Le Corbusier was to insert cool or cold hair between two large layers of glass; this type of component was called “Mur neutralisant” and it was used to build the “Villa Schwob (La Chaux-de-Fonds, Switzerland, 1916), which represent the first concrete example of DSF*, [12w]*.

Based on the past studies, in the coming years, various characteristics regarding the DSF have been deepened and perfected; particularly was analyzed the adaptation capacity of these components according to climatic conditions. In the places whit cold climate, the adequate temperature was ensured with the realization of a window system with two glass panels, separated with an air gap of a dimensions of the order of the ten centimetres, the box-type windows. In winter season, the air in the gap it is like a thermal buffer, decreasing the thermal conductivity, in summer season the panel can be open and the outer one removed. Indeed, in the places with a hot climate, instead the presence of a double skin was linked to the necessity to reduce the problem of overheating and glare for the sun. For this reason, the maintenance of the comfort condition in summer was more difficult than in the cold season. *[8,10]*.

To solve this problem, have been adopted two solutions.

The first, regarded the use of an inside shielding, that removed the glare of the sun, but not the solar radiation because of the absorption and then re-emission through the shielding, which implied an overheating of the ambient. Instead the Second, concerned an outside shielding (atmospheric agents proof), but with maintenance problems due to the uppermost position. During the next few years, the architects need included another layer of glass in the outside, protection of the shielding, that create a typical configuration of a transparent façade with a double skin and a shielding, with the increase of this technology, found out the potentiality of an air gap in the inside. This progress is made during the 80's when this type of façade started gaining boost. From the 90's most of the façade are designed using both environmental concerns as an argument and aesthetic effect of the multiple layers of glass, this because of the new image of "green buildings". *[8,9,10]*

Figure 7: Villa Schwob[12w]

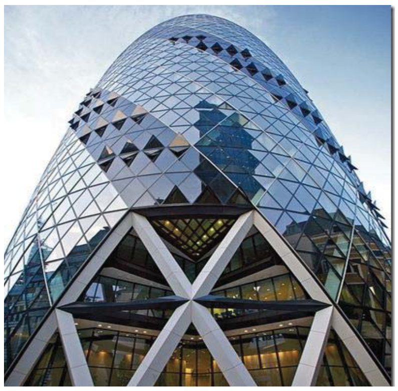


Figure 8: Swiss Re tower [11]

2.3 CLASSIFICATION CRITERIA

The complexities and design variations of Double-Skin are large, but there is not a specific terminology adopt to identify those. This because of the various configurations and aspects that the type considering. Usually there are different classification criteria depending on the type of double skin system, type of construction and type of ventilation system, *[6]*.

2.3.1 Types of double skin system

There are 4 basic types of double skin system: Buffer Façade, Extract-Air Façade, Twin-Face Façade and Hybrid Façade.

- The Buffer Façade was invented to maintain the daylight into buildings while increasing insulating and sound properties of the wall system. The technology use two layers of glazing, without any type of opening to inner and outer environment. Thus, this system work as a closed box to increase the performance features of thermal comfort, moreover the hot or fresh air produced to box can be introduced in the environment through a separate HVAC system. A modern example is the Occidental Chemical/Hooker Building in Niagara Falls*, [9,11,4]*.

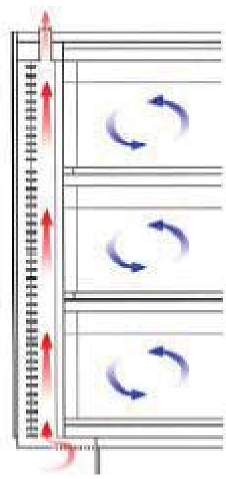


Figure 8: Thermal Buffer [11]

Figure 9: Occidental Chemical, Niagara Falls [11]

- The Extract-Air Façade is a system used with HVAC when natural ventilation is not possible. In this type of double skin, the air between the two glasses is mixed with the air extracted from the building and sent through a fan to the HVAC system. In fact, this technology balances cavity temperature and optimizes energy consumption for heating or cooling the environment. One of the most important example of this technology is the Helicon Building, Finsbury Pavement, London *[11,12]*.

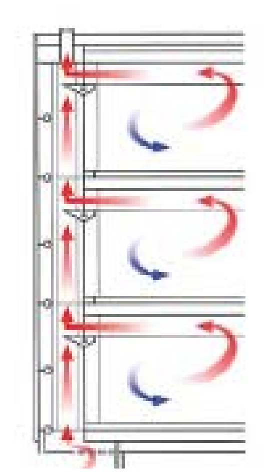


Figure 10: Extract air [11]

Figure 11: Helicon Building [11]

- Twin-Face Façade consists of a curtain wall system inside a single glazed building skin; the outer glazing usually is laminates or insulating glass. The distinction from the other types is the inclusion of openings in the skin to allow the natural ventilation. The internal skin has insulating properties in order to minimize heat loss. RWE Tower in Germany is a classic Twin-Face building, *[11,12]*.

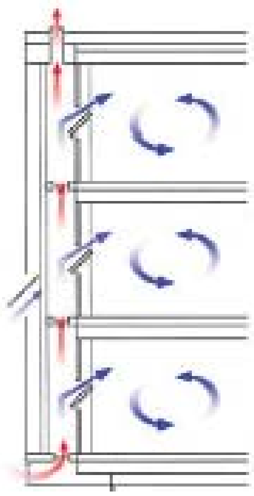


Figure 12: Twin façade [11]

Figure 13: Germany, Rwe Tower [11]

- The Hybrid Façade is a system that combine one or more of the precedent typologies, to create a different system. This façade is made of two glazed layers separated by a naturally or mechanically ventilated cavity, also is possible to insert in the cavity a system of shade. The main example is the of Renzo Piano, in New Caledonia *[11,12,13]*.

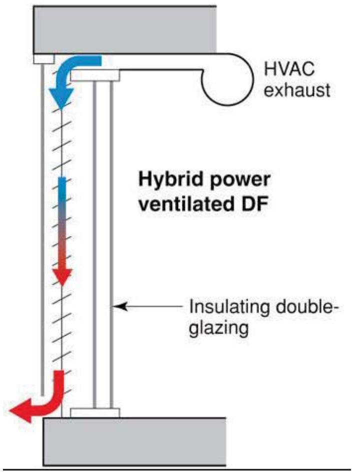


Figure 13: Hybrid Façade [13]

Figure 14: Build in new Caledonia [11]

2.3.2 *Types of construction*

In the general overview of double skin façade can be categorized four groups of DSF according to the type of cavity and the constituent modules *[14w]*.

1.BOX WINDOW

2.CORRIDOR

3.SHAFT BOX

4.MULTISTORY

This concept of DSF is probably the oldest one adopts on the building façades. "**Bow Windows"** are double-skin façades divided by structural bay widths or on a room-by-room basis, so the façade can be divided in different cells, all independent from the other.

The vertical height of the glass that composed the box it's the same of the entire plan, this creates stronger uplift forces, due to increase the stack effect, however in the upper parts of the façade the glass chimney can become appreciably hot, lending to increased heat gains and thermal discomfort. Instead, the width of the box depends on the structure of the building. This type of DSF can start in the cavity a wind-induced ventilation with two openings: one on the bottom for the extraction of the fresh air and another one in upper zone for the release of the "old air".

The cavity is also closed horizontally and vertically at each floor to prevent the transmission of noise and smells from room to room and from the outside.

The Box-Window Façade can be summarized in a system with a cavity closed horizontally and vertically at each floor. It is good to prevent the sounds and smells transmission from room to room *[6,11,14]*.

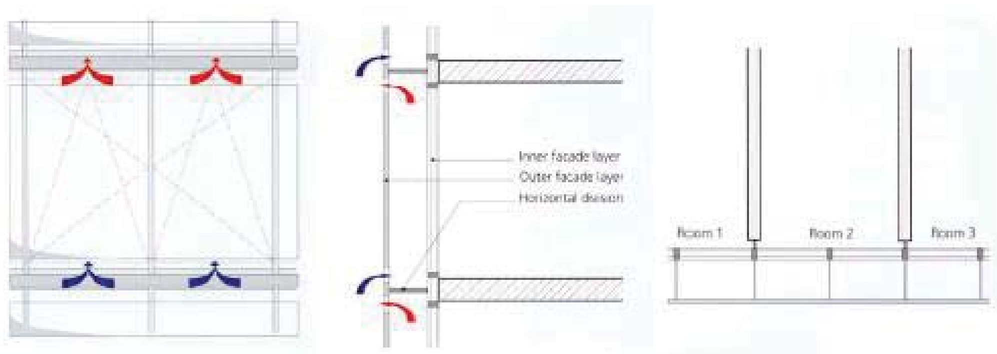


Figure 5: Box Window [11]

"Corridor Façades" is a type of DSF is based on a cavity that is separated horizontally at each floor, the division along the horizontal length of the corridor are only where this is necessary for acoustic, fire-protection or ventilation reasons (for example in different side of the building there could be pressure difference based on the different direction of the wind).

This system allows good natural ventilation in the cavity, but it could cause sound transmission problems from room to room. This cavity is called corridor because it has a very large space, which is also walkable. The air is intake at the level of the floor and extract at the ceiling with openings on the skin. In final Corridor Façade System can be summarized in a type of DSF with a cavity separated horizontally at each floor *[6,11,14]*.

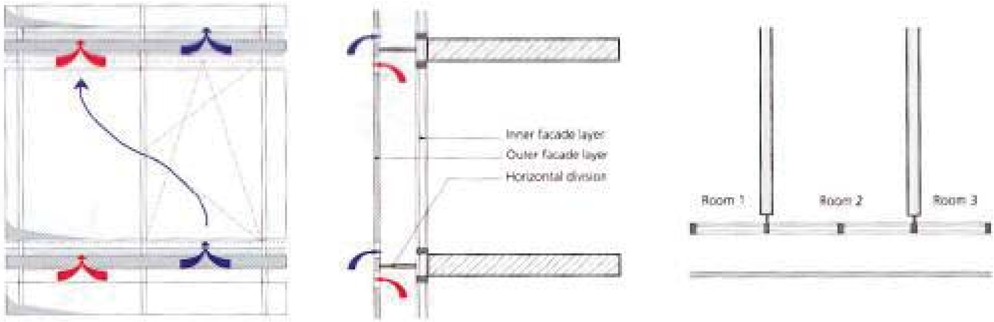


Figure 16: Corridor facades [11]

"Shaft-Box Façades" is a box window façade. This box window systems are connected with a continuous vertical shaft (with a stronger thermal uplift) which improves the ventilation of the façade. Ultimately it consists of an alternation of boxes and shaft. Also, it Provides a better sound insulation and it has less openings on the external skin.

The air in the cavity of the modules arrive from the adjacent cavity through the openings placed in the upper part of those modules of all the floors.

In addiction the air within the cavity, is expelled at the summit, thanks to the chimney effect. It has maximum performance in lower rise buildings, moreover, the cavities are connected to each other on the floors, in the hot season the air could be reach high temperatures in the upper floors.

The natural ventilation is guaranteed by a thermal effect, which increased by the presence of the vertical shaft. If this is not enough, it is necessary a mechanic ventilation, placed in the upper part of the cavities. The Shaft-Box Façade System can be summarized in a type of DSF with several box window systems connected with a vertical shaft and cavity with less openings on the external skin. This system improves the ventilation of the façades and better sound insulation *[6,11,14]*.

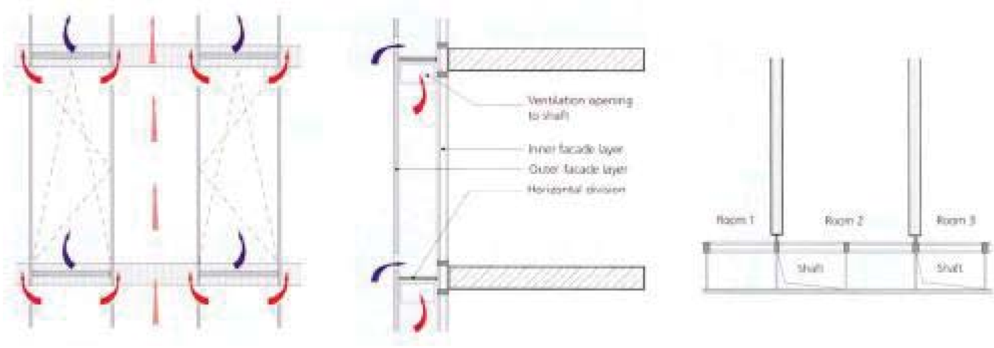


Figure 17: Shaft BOX [11]

The "**Multi-storey Façades System"**, provides a cavity not divided on all the surface of the building, that is adjoined vertically and horizontally according to the number of rooms. The cavity is large as is necessary to make the maintenance of the façade (also for the openings on the internal layer) and is usually ventilated mechanically.

The aeration inside the cavity is also guaranteed by the pressure difference of the wind and the fireplace effect.

The intake of air is at the bottom of the façade, the release on the top. In cold season, the openings can be closed to create a thermal buffer for increase the thermal insulation. In hot season, due to the large size of the façade, can be a massive rise of the temperature e inside the cavity, so is necessary an appropriate HVAC design system. Also, this system is necessary for avoid potential condensation in the air space and on elements/surfaces within that space.

The rooms are not ventilated by the cavity air, but whit a mechanical system, this because the air, in cold season, is very poor for a use in the rooms, and for the acoustic insulation (without partition in the cavity, the noise is free to pass in the adjacent ambient but the multi-story façade is also suitable for remove the acoustic pollution).

In final, the Multi-Storey Façade can be summarized in a system with a cavity that is not divided and has openings only at the top and at the bottom of the façade, mechanically ventilated

The properties are the good insulation and strong thermal insulation and openings on the internal layer used just for maintenance and cleaning purposes *[6,11,14]*.

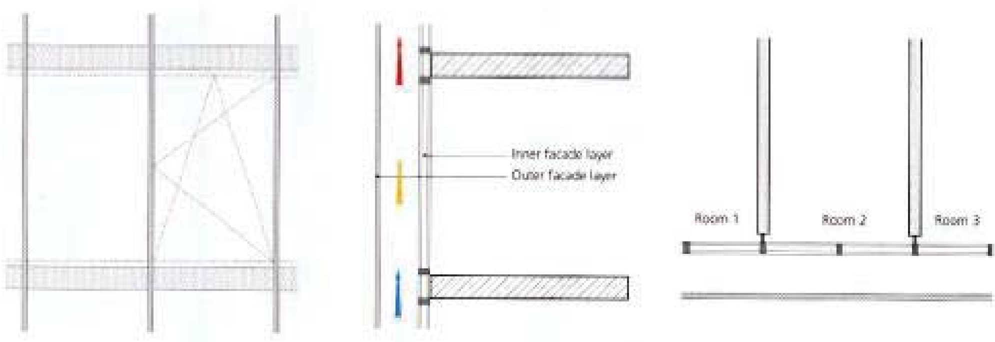


Figure 18: Multistory façade [11]

2.3.3 *Types of ventilation*

The extensive use of DSF has developed a large group of systems that can visually be similar but they are completely different in performance, especially different depending on the type of ventilation of the cavity. The type of ventilation be due to the force that generates the flow of the air inside the cavity between the two layers. The air cavity can be categorized in:

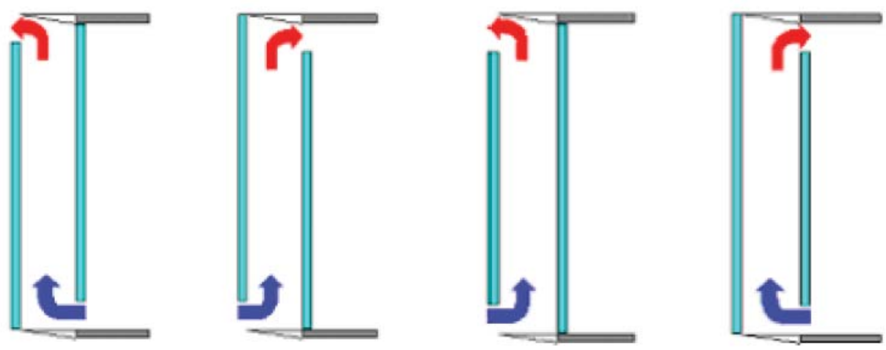
- Mechanically ventilated cavity: the cavity works as sound insulation and controls dynamically the thermal performance of the façade. We can call this type of ventilation, active.
- Natural ventilated cavity: the force of the airflow is based on the pressure difference of the wind. This type of ventilation is also called passive.
- Hybrid ventilated cavity: the cavity used the two previous typologies, depending on the user needs about ventilation and climate conditions. The hybrid type, represents an interactive system.

In addition, the width of the cavity influences the function of the concept and it can be between 10cm to more than 2m, and it influences the way the façade is maintained too *[9,15]*.

In the DSF the different types of ventilation refer to the destination and the origin of the air circulating into the cavity, but the air flow is independent from these typologies, not all the façades can adopt all the ventilation modes, in fact, at a given moment a façade is characterised by a single ventilation mode. However, a façade can adopt several ventilation modes at different moments, depending by the components integrated into the façade (for example operable openings). There are different schemes of ventilation, they depend on the integration of the façade with the building, the energy interchange and eventually control system of the HVAC (heating, ventilation and air conditioning system) *[9]*.

The different type of airflow of the cavity can be categorized in:

- EA (Exhaust Air)
- SA (Supply Air)
- OAC (Outdoor Air Curtain)
- IAC (Indoor Air Curtain



a) EA **b)** SA **c)** OAC **d)** IAC

Figure 19: type of ventilation [9]

a) EA – Exhaust Air

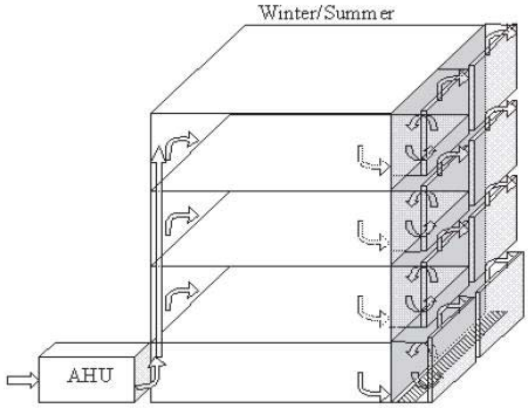


Figure 20: DSF System with Exhaust Air [15]

The air comes inside and it is expelled outside, this is possible through the cavity with the ventilation of the façade. The cavity of this type is open to the interior spaces at the bottom and open to the outside on the top of the façade *[15,16]*.

b) SA – Supply Air

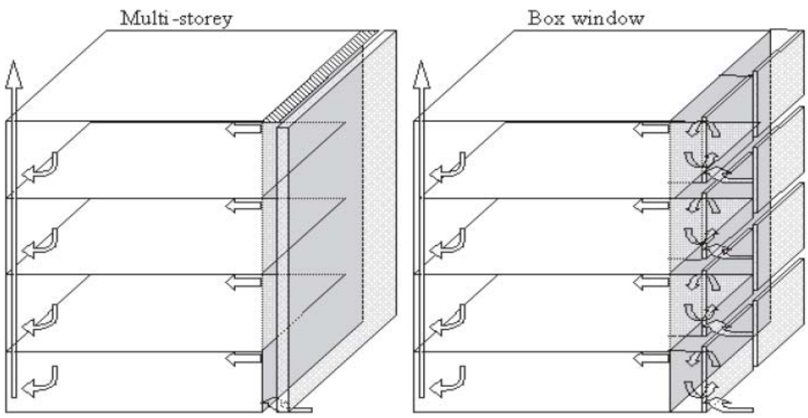


Figure 21: DSF System with Supply Air System [15]

In this type, the ventilation of the façade is take place through outdoor air, that comes inside the cavity and then in the interior spaces, or into the ventilation system. So, the provider of the outer air is suitable for the ventilation of the building. The cavity has an opening to the interior spaces on the top and an opening to the outside on the bottom of the façade *[15,16]*.

c) OAC – Outdoor Air Curtain

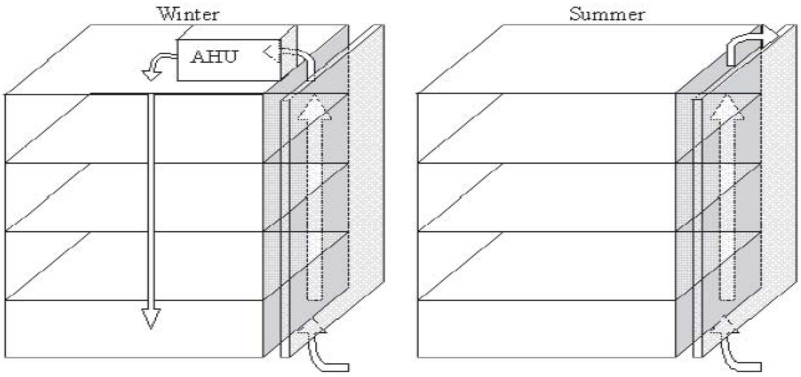


Figure 22: DSF System with OAC [15]

The air cavity of this type of ventilation is ventilated only by external air, that circulate inside the cavity, without connections with the internal air, and it is immediately rejected in towards the outside. Therefore, the cavity can form an air curtain enveloping the outer façade *[15,16]*.

d) IAC – Indoor Air Curtain

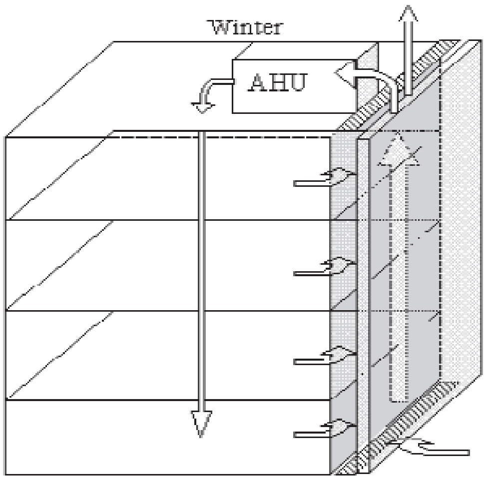


Figure 23: DSF System with OAC [15]

In this type, the air comes from the interior spaces and it is returned to the interior space through the cavity, sometimes by a ventilation system. There is no connection with the outside air *[15,16]*.

2.4 PERFOMANCE CRITERIA

The dynamic envelopes have an energy performance that depend on different factors, such as type of ventilation, airflow, position of the solar shield. The energetic performance of the façade can't be asses only by usual indicators like thermal transmittance (U) and solar factor (g), because the temperature and the air flow are conditioned by a lot of thermal performance as: fluid dynamics, optical process that are related to geometric, thermos-physical, optic and aerodynamics components. The determination of this parameter is crucial to define a control strategy that provides acceptable thermal comfort conditions during the year and allows the use of solar gains during the hot season. In the summers months the risk of overheating in the internal ambient is high when the design of the DSF in not coupled properly with the strategy of the HVAC system *[10,12]*.

The behaviour of dynamic skins is analysed taking into consideration the performance criteria that can be measured by mathematic simulation or experimental campaign:

- Thermal Comfort
- Energy Performance
- Daylight Performance

2.4.1 *Thermal Comfort*

The thermal comfort of DSF has a typical performance parameter that is the internal glazing temperature. This aspect has a large effect on the thermal comfort of the occupants in the perimeter zone, in fact, the position of the occupant in room have a big impact on the perceived temperature.

The most important equation of this aspect is the calculation of "**Top**", to solve this operation, there is need to know two important parameters, the medium radiant temperature, "**Tmr**", which depend to geometrical design, the indoor air temperature, "**Tair**" and finally the, **"h_c"**,

"h_r", which are the convective heat exchange coefficient and the radiant heat exchange coefficient for a person.

$$t_o = \frac{(h_c \cdot t_a + h_r \cdot t_r)}{(h_c + h_r)}$$

But in most case when the airflow is below 0.2 m/s and the difference between **Tair** and **Tmr** is below <4°C, the **Top** can be considered the average of air and medium radiant temperature in a specific position [1,13].

$$t_o = \frac{(t_a + t_r)}{2}$$

The percentage of dissatisfied people (PPD and PMV) are another performance parameter can be used to evaluate the thermal comfort. They establish three classes of comfort depending on the value of PMV (Predicted Mean Vote), calculated according to the theories of Fanger.
The regulations regarding thermal comfort and therefore the evaluation of indoor air quality is different for each European state according to their climatic characteristics. In general, in temperate climates, it can be said that the use of the double skin facade, balancing the surface tempering of the internal glass, contributes to reducing a local discomfort *[8,10]*.

2.4.2 *Energy Performance*

According to a study of energy performance of 2003, only few combination of Multi Storey Façade – modelling and building energy simulation are available. The study gives a complete survey of double skin façades and of the behaviour of supply air windows, it is focused on the energy saving objecting of three multi-storey façades typologies used in a single office. To simulate the energy demand of the office, the Multistory facade model is coupled with TRNSYS. The results are compared and confronted with the objectives taken. The most commonly mentioned energy advantages are the reduction of the transmission loss, the possibility of recovering the transmission losses by the airflow, the position of the shading device sheltered from climatic conditions and the ability to remove the absorbed solar heat. It is shown in the study that is possible to improve the building's energy efficiency by using DSF, but only by combining typologies or changing the system settings according to the particular situation *[10]*.

In addition, to correctly evaluate the energy efficiency an annual simulation focusing on both heating and cooling load is necessary. The way the cavity air is used strongly change the energy performance. For this reason, is obligatory not only to study the transmission loss and gain but also the enthalpy change of the cavity air, this to perform a whole building energy analysis.

Another strategy that can be used is the Kyoto pyramid, supported by Sankey diagrams in a preliminary decision process. The Kyoto pyramid is based on the principle of the Trias Energetica approach; it provides a framework of priorities based on the reduce-reuse-recycle principia. These priorities are carried on in successive steps, first the passive demand reduction measures, then an application of renewable technologies and at last an efficient use of fossil fuels *[18, 7w, 8w]*.

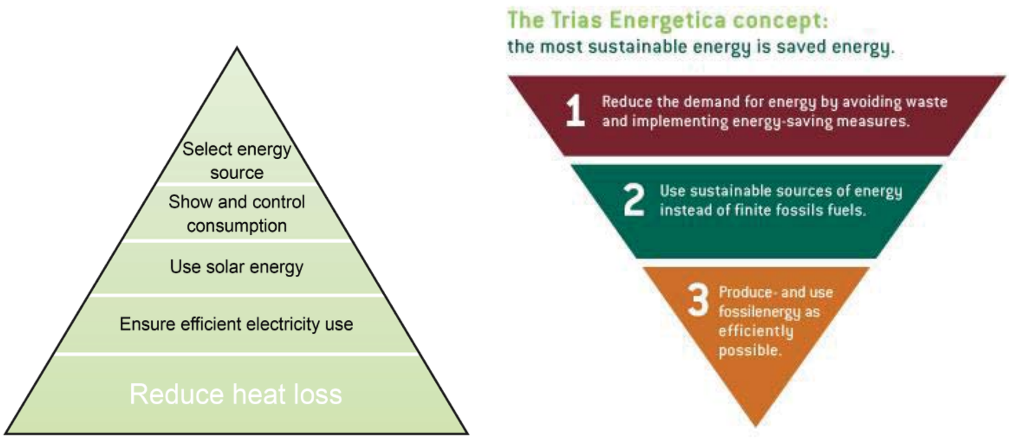


Figure 24: the Kyoto pyramid and the Trias Energetica concept [8w]

This method is used in the preliminary performance and it is important to identify the interrelationships between energy flows within the building, because as an attempt to reduce energy demand, it will affect the whole energy use distribution of the building. Can be achieved maximum energy savings and costs effectiveness by comparing performance of different retrofitting solutions on buildings components and system level. In fact, the integrated design solution has the potential of producing synergy effects *[7w, 8w]*.

2.4.3 *Daylight Performance*

The daylighting is one of the most important parameters to make the build very performant, it is important for two main aspect: 1 it has the ability to reduce the amount of electrical lighting required, 2 the quality of light from daylight is preferential to electrical lighting.
In one paper, which discuss this performance criteria it's report a description of daylighting:

> "Good lighting of the workplace is one of the main factors of indoor comfort that can positively influence health and productivity of office personnel. Natural light, its variations and its spectral composition are of great importance for well-being and mental health. Natural light is a fundamental component of our life, helping our body to produce vitamin "D", an important anticancer element." *[12]*.

Following these words, today, the control of this criterion is fundamental, in fact the science seek to develop new systems to improve the capabilities of this criteria. Naturally one of the new applications to increase the performance of daylighting is the glazed façades, which aim to improve 5 main aspects *[8]:*

- the reduction of the quantity of light entering the rooms as a result of the additional external skin
- the additional effective room depth caused by the façade projection
- the compensatory effect of larger areas of glazing and
- the scope of installing light reflecting elements in the façade intermediate space where they are protected against the weather

Also, is important the position of shading devices inside the DSF cavity. These devices are recommended to be placed inside the intermediate cavity, as result this will be divided into two sub cavities. Therefore, the position of the shading has a major role in the distribution of the heat gains in the cavity. If the shield is right in front of the internal façade and the space between the two elements is not optimal ventilated, the air in the front part can heat up considerably – an unsatisfactory phenomenon. The ideal position of the shield is inside the outer half of the intermediate space, precisely in a third of the façade cavity, with good ventilation towards the space above and under the shadow of the sun (the absorbance of the shading device should do not exceed 40%). *[8,12]*

Figure 25: Difference between dsf with shade e no shade [12]

2.5 INNOVATION AND RESEARCH

The research on contemporary architecture are more connected to the object to propose new models of dynamic envelope that have the purpose of reduce the energy needs of the building. In fact, they are made by tool that can change conformation in relation to the necessity of adjust the energy thermal, light and acoustic flows. The activity of research develops a standardized procedure of experimental analysis, which can elaborate the knowledge of the behaviour and performance of the façade, optimizing the current systems or developing new components more efficient. The developing of the concept of a dynamic façade can be summary in these research themes: definition of new solution of active envelope with less environmental impact, architectural integration of an advanced screen building envelope system, development of a modular system, possibility to integrate different technologies, ability to guarantee variable thermo-hygrometric performances in relation to the external climate. *[19]*

Computer modelling and simulation are currently some of the more used techniques by engineers and designers (the various building simulation tools are: ESP-r, IDA ICE, TRNSYS) and the experimental data for the validation was gathered in a full-scale outdoor test facility. The empirical data sets comprise the key-functioning modes of DSF: thermal buffer mode with closed DSF cavity, and external air curtain mode with naturally ventilated DSF cavity with the top and bottom openings. For studying the DSF are used experimental and numerical models that can predict and analysing the façade system, also including analytical and lumped models, dimensional analysis, network models, control-volume models and "Computational Fluid Dynamics" (CFD) *[20]*.

Since the 2000, more and more sophisticated modelling and simulation techniques have been developed to analyze detailed aspects of the double skin façade. In 2002 was developed a simulation algorithm for temperature and flow characteristics of DSF to assist energy consultant to make decision without using CFD system. To describe the energy performance of natural ventilated façade was proposed in 2004 a non-dimensional analysis involving energy and thermal properties that were validated with experimental and CFD simulation results. Other studies in 2009 started to model and simulate the air flow network, by assessing the effect of chimney on the DSF *[21]*.

Many other studies and updates have supported these tools in these last years, allow to arrive at the point of supporting users with a software of analysis and simulation, capable of replacing the management and the control on site.

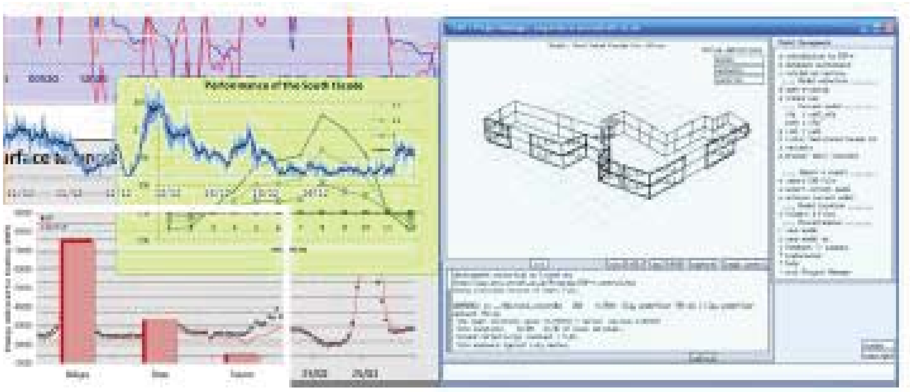


Figure 26: BPS tool [22]

The research has come to define different innovations, which make a better contribution to the construction of the DSF. An example is the study refers to the wind pressure on the façade. Wind pressure is one of the most important thing that affect the glass because the double-skin façade has three surfaces subjected to wind pressure. Due to the airflow between the double façades, those are the outside and inside surfaces of the external skin façade and the outside surfaces of the internal one. The wind creates differences of pressures that make the airflow move in the buildings and depend on the direction of the wind, shape and height of the building.

Moreover, the integration of photovoltaic panels is an important new application for this technology. These components are used not only to generate electricity, but also to give a contribution in the solar control to achieve a better thermal comfort.

In an article of end another application, which is developed in the last years of the research, is the availment of shading device.

As has been shown in the paragraph 2.4.3, this component is helpful for the control of daylighting, but furthermore this device is crucial to reduce the total heat transfer through the cavity *[21]*.

In the article of Miro Bugarin, dedicated to the advanced systems facades, it highlights a series of components that today can be fully integrated with the basic structure, which give a contribution both in terms of thermal and energy *[7]*.

The façade includes:

- Double-glazed with two façades of layers, ventilated through ventilation ducts with movable flaps;
- Photo-voltage solar panels, thermal solar panels for hot water or solar air panels whose warm air can be integrated in the heating and cooling system;
- Bio-reactive collectors;
- Wind turbines, which can provide enough power for the independent functioning of the executive dynamic elements of the AIF facades.

Figure 27: New DSF [7]

3 METHOD & MATERIALS

The previous chapters described an overview of the need to reduce consumption, defining new strategies to improve the energy efficiency of the building envelope. In particular, one of the key components of this process has been described; the “DOUBLE SKIN FAÇADE”. Today, these technologies lead to a process of building dynamism, which becomes increasingly complex and difficult to control. For this reason, the thermal energy design of the building needs simulation tools that can facilitate the analysis of the behavior of these components.

In this chapter we will try to investigate the validity of the use of simulation software to conduct an experimental energy analysis of two mechanically ventilated facades, focusing on the software chosen to conduct the research (TRNSYS).

4.1 CASE STUDY: THE MOCK-UP

To test the effectiveness of a new technology and its simulation through BPS tool, it is necessary to perform a validation and comparison with real experimental study. The thesis has been used as a reference for experimental research carried out on two different types of facades: a BOX WINDOW and a MULTISTORY facade.

The first double skin facade is called “**NSRP**” (nuova sede Unica della Regione Piemonte); the façade has been designed to be used in the building of a new association of the regional agency, located in Italy in Turin.

The second type of façade concerns a study conducted by the TRBR group of the Turin Polytechnic on the buildings of the company operating in the naval sector and building envelope "SOMEC". The building is located in Zoppè di San Vendemiano in the province of Treviso *[23]*.

3.1.1 BOX WINDOW, **NSRP**

The mock-up is an environment of 20m2, oriented with the transparent facade towards South- West. Indoor air conditioning is carried out by a system air that maintains the internal temperature following a reference schedule. The opaque structure is made of pre-insulated multilayer metal panels with high density mineral fibre insulation and can be used both for walls and for covers. The radiant panels that release a controlled temperature are installed on the ceiling *[23]*.

Figure 28: NSRP [23]

The transparent facade is divided into two equal portions from the point of view dimensional (150 x 427cm). To test different types of double-skin façade, in the two cells (A and B) different glazed windows are mounted *[23]*.

The façade, consisted of a high performance outer skin, a roller screen in the ventilated cavity and an inner transparent skin. In particular, two glass composition are:

	MODULE A	**MODULE B**
➢ External skin	Double glazed unit with a selective external glass, 20/16/10 mm	
➢ Shading	Reflective roller screen	
➢ Inner skin	Single extra-clear glass pane of 10 mm	Double glazed unit with clear glass, argon cavity and low_e coating glass 10/16/10 mm

More over the ventilated façade, is characterized by ventilated cavity of 20cm through an Exhaust air system, the cavity receives the air of the internal environment and uses it to be ventilated. In order to control the flow, are used for the whole time of the analysis two fans with an air flow of 20 m3/h. One in input located inside the cell and one in output located on the upper part of the façade *[24]*.

3.1.1 MULTISTORY, ***SOMEC***

The mock-up concerns in a transparent façade with mechanized ventilation, extended on two floors up to a height of 17 m and exposed to the South-West. In this case the building is not a test cell but a real building, in fact the mock-up of analysis, will be modeled by the software with dimensions relative to a single strip of facade. The internal temperature is set by a schedule, also the superficial wall surface temperatures [1,3].

Figure 19: SOMEC [23]

The layer structure of the façade module was:

1. An external single glazing of 12 mm;
2. A ventilated air gap of 714 mm;
3. Reflective roller blind, positioned at 112 mm from the outer glazing;

4. An internal double extra clear glazing (5+5/15/8 mm) filled with argon, with a low-e coating.

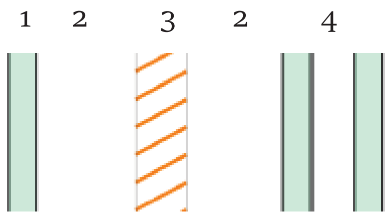


Figure 30: The composition of the glass

The ventilation scheme is "air extraction"; in this case the air extracted from the indoor environment can be sent to a heat recovery unit (which, in winter, it allows pre-heating the intake air and pre-cooling it in summer). In addition, the façade is equipped with two fans with a capacity of 100 l / s operated according to the phases of the day. The intake fan is also useful for controlling the temperature inside the cavity *[23]*.

3.2 PROJECT SOURCE: "BPS" TOOL

Building performance simulation (BPS) are increasingly indispensable to run dynamic analysis, in order to assess energy performance and thermal comfort of building envelope. Their interoperability, allows to support engineers and architects in their decisions during the whole design process.

3.2.1 BPS tool selection criteria

However, one of the challenge concerning the application of the BPS is that they are usually used to evaluate after decision-making, rather than applied to address implant design and energy decision, already in the early design phases *[25]*. This bonnier implies a no clear methodology to assess specific and criteria of these tools for developers, practitioners and educators. Shady Attia in this regard, research conducted by identified a set of 5 criteria to consider in the choice of BPS tool *[26]*:

- Usability and Information Management (UIM) of interface.
- Integration of Intelligent Design Knowledge-Base (IIKB).
- Accuracy of tools and Ability to simulate Detailed and Complex building components (AADCC).
- Interoperability of Building Modelling (IBM).
- Integration with Building Design Process (IBDP).

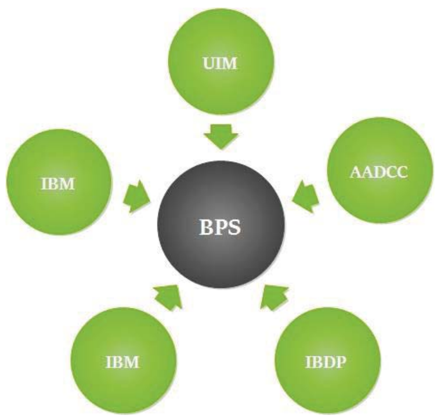
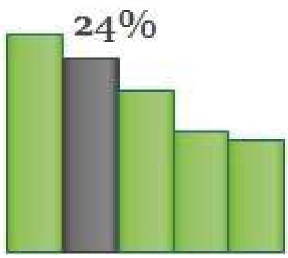


Figure 30: The five selection criteria modified from [26].

Also in this quest Shady Attia evaluated through a survey, the perception of 5 criteria from users. The survey was conducted on base and skilled users as architects and engineers, that deal with sustainable construction in the United States. The results obtained from the questionnaires have allowed to quantify the percentage of importance of various characteristics *[27]*.

The "**UIM**" is a criterion based on two main features, "usability" and "information management". The first aspect describes the operation of the software through the methodology, techniques of representation and documentation of research, used to achieve the goals set. The second aspect focuses on the comparison of the project with predefined templates to assess quality of inputs in order to customize and facilitate the data entry and user interface *[26]*.

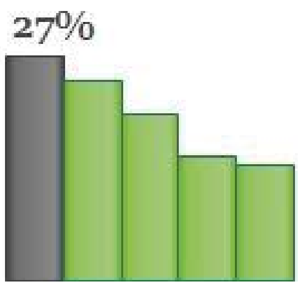
From the data in the graphs of the article, we see that this policy is one of the most important, with 24% of satisfaction. The responses of users agree, both architects and engineers evaluate these features with the same degree of appreciation *[27]*.



Graph 1: ***UIM***

The criterion "**IIKB**" analyses the "Knowledge-Base" and the "intelligence" of the tool. The Knowledge Base is a qualitative and quantitative support to influence decision-making of planning and design optimization, through the application with procedural methods and building codes. The intelligence component represents a useful tool to find strategies for optimizing design solutions, by analysing energetic, structural and economic phenomena *[26]*.

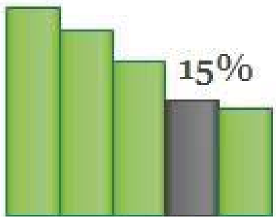
This survey is the one with the higher rating, with an estimated 27% of the votes. Also in this category, the two different types of users expressed the same opinion, by appreciating the integration and intelligence of knowledge-base and design process support *[27]*.



Graph 2: **IIKB**

“**AADCC**”; under this criterion are focused two aspects regarding the “Accuracy” and the “Ability” to resolve simulation models. The first feature Accuracy consists on analytical verification of the level of quality assurance, based on comparative testing of simulation. The other feature ability, is concerned with capacity to model and simulate complex building systems, such as (performance of passive design strategies, renewable energy systems, HVAC systems, energy associated emissions, cost analysis and life cycle cost analysis “LCCA”) and building components, such as (green roofs, double skin facades “DSF”, chilled beams, atria, concrete core conditioning, etc.) *[26]*.

The evaluation expressed by users for this criterion is different. In fact, the architects express a low rating, instead the engineers consider it one of the key parts for choice *[27]*. Then following the number of responses from both users, it was decided to report an average of 15% *[28]*.

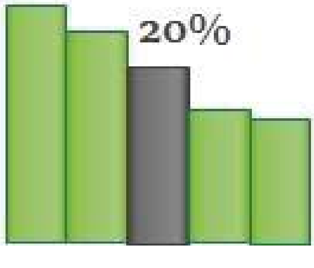


Graph 3: **AACDD**

“IBM” concerns “the Interoperability of Building Modelling”. This criterion allows to manage and share building data and information with a virtual representation. In the last years, this feature has been very developed, in order to create a direct link between design software and dynamic or static simulation software.

The representative model of this application today is “BIM” (building information modelling) that have the aim to connect a technological model to a project information database, by allowing interoperability with other support tools *[27]*.

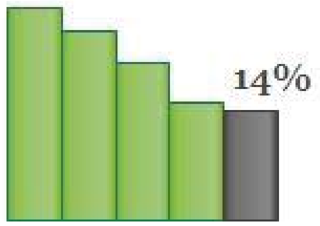
Also in this feature there isn’t a unique thinking, indeed the interoperability with other systems is grateful for architects and not for engineering *[27]*. Even in this case it proceeded to calculate the average between the two opinions, with a result of 20% *[28]*.



Graph 4: **IBM**

The **“IBDP”,** “Integration of tools in Building Design Process” is another criterion that became very important for BPS tools selection and evaluation. This aspect helps in choosing of the BPS tools, by verifying the ability for adaptive use, by different users and design stages, and underlining the importance to integrate BPS as elements of the whole design process *[26]*.

About the last criterion there is a problem in the assessment, because in the analysis of the survey there isn’t an explicit question to achieve information data. However, thanks by another research connect to the survey of Attia, was possible to assess the value of 14% *[28]*.



Graph 5 : **IBDP**

The criteria “UIM” and “IKB” were very important for a first selection of BPS tool suitable for modelling and simulating of dynamic component “DSF”. In particular, they provided the guidelines for comparison with established research models and to value the main characteristics for the representation of the component. Also, they were very important to assess the adaptability between BPS tools and users, thanks to the considerations about the Interoperability of building modelling and the integration of tools in building design process.

3.2.2 BPS design assistant tool

The guidelines provided by selection criteria were allowed to get to the choice of 5 software suitable for topics that are related to the thesis and in particular to the modeling and simulation of “DSF”:

Figure 31 : The 5 software

In this chapter was conducted a careful analysis of the five BPS tool, with the aim to choose the most suitable to model and simulate the technological component related to the thesis. Every software has been rated with three main aspects: 1. the type of system, 2.the unit of calculation that processes the data and 3.the interoperability of users *[25,26,28]*.

Energy Plus

- The main purpose of this software is to organize the whole systems in different modules, in order to work together or separately *[25,28]*.
- This tool exploits two systems of energy simulation, BLAST and DOE-2, representing the first unit of calculation in the thermal balance, by allowing to solve the thermodynamics equations of the system *[25,26]*.
- Although in Energy Plus, the parameters can be inserted only through text file and without user interface. Thus, this aspect represents one of the limits of the tool, however exist visual interface able to concept the building model such as, (Open Studio and Design Builder) *[25,22]*.

IDA ICE (Indoor Climate Energy)

- This is an innovative software, based on open source model *[25,28]*.
- The IDA calculation engine can solve a complex system of dynamic equations calculating, with extreme precision, the real thermophysical behaviour of a building model *[25,26,28]*.
- The IDA ICE user interface is designed to model and simulate build through simple and advanced cases. It has the great ability to represent the real- time 3D behaviour in combination with comprehensive tables *[25,22]*.

ESP-r, acronym of Environmental System Performance

- This software represents one of the reference software to assess energy performance of building environment and to have a detailed control over its different parts *[27]*.
- The calculation code has a deterministic character that exploits the finite volume method to calculate the mass balance and the thermodynamic equations *[25,22]*.
- Esp-r is very flexible for the users' needs and allows to analyse several particular aspects of the building. However due to this ability it requires specific knowledge and experience of the users *[25,22]*.

IES- VE (Integrated Environmental Solutions - Virtual Environment)

- One of the best features of the software is the compatibility with different software of 3d modelling as, Revit or Sketch Up, that allow to make up an easy geometric representation *[25,26]*.
- The calculator system is based on the instrument "Apache sim", which asses the dynamic thermal simulation for natural ventilation and HVAC. In addition, this tool is forefront in the analysis of air leak, natural lighting and shading. The overall of these features makes it one of the most comprehensive in its field [25,26].

- IES-VE is a versatile software dedicated to the energetic and environmental analysis of buildings. The tool is able to satisfy the several needs in the phases of drawing for architects and engineers *[25,28]*.

TRNSYS, Transient System Simulation Tool

- One of the best features is that it has an expansible environment on to the transient simulation of thermal systems including multi-zone buildings *[25,26,28]*.
- The process unit of this software calculates thermophysical properties, through the linear regression and interpolation of external data files *[25,28]*.
- It is used mostly by engineers and researchers around the world to validate design and simulation of different models such as wind turbines, pumps, HVAC equipment, multizone buildings *[25, 26]*.

This presentation was very important to highlight the main features and the calculation process of the 5-software considered. However, to reach in this thesis the conclusion of one software for modelling and processing the "DSF", have chosen to compare tools through 3 main categories:

1- CREATION OF BUILDING
2- BUILDING SIMULATION
3- ANALISYS OF RESULTS

These three main categories contain all the specific characteristics of each software. Indeed, the first parameter analyzes all aspects of component modelling and interoperability with other software. The second one focuses on the technical aspects related to simulations such as processing times, the equations used in the calculation and management of variables. Finally, the third value the quality of software analysis, going to assess the ability to simulate different types of energy systems *[28]*.

SOFTWARE	ENERGY PLUS	IDEA ICE	ESP-r	IES-VE	TRNSYS
1. CREATION BUILDING					
- Walls, roofs and floors	✓	✓	✓	✓	✓
- Windows, skylights, doors and external coatings	✓	✓	✓	✓	✓
- Polygons with my faces	✓	✓	✓	✓	
- Imports of building from CAD	✓	✓	✓	✓	✓
- Export geometry of buildings for CAD software	✓	✓	✓		
- Import/Export of simulation models of program	✓	✓	✓	✓	
- Calculation of thermal balance	✓	✓	✓	✓	✓
- Absorption / Release of moisture from the building materials	✓	✓		✓	✓
- Internal thermal mass	✓	✓	✓	✓	✓
- Human thermal comfort	✓	✓	✓	✓	✓
- Solar analysis	✓				✓
- Analysis of isolation	✓	✓	✓	✓	✓
- Advance fenestration	✓	✓	✓	✓	✓
- Calculation of the building in general	✓		✓	✓	✓
- Surface temperatures of zones	✓	✓	✓	✓	✓
- Airflow through the windows	✓		✓	✓	✓
- Driving surfaces	✓	✓	✓	✓	✓
- Heat transfer from the soil	✓	✓	✓	✓	✓
- Thermophysical variables		✓			
- Daylighitng and lighting controls	✓	✓	✓	✓	
- Infiltration of a zone	✓	✓	✓	✓	✓
- Automatic calculation of coefficients of wind pressure				✓	
- Natural ventilation	✓	✓	✓		✓
- Natural and Mechanical ventilation				✓	✓
- Control open of windows for ventilation	✓	✓	✓		✓
- Air leaks in multiple zones	✓	✓	✓		✓
2. BUILDING SIMULATION					
- Simulation of loads, system and solutions	✓	✓	✓	✓	✓
- Iterative solution of non linear system	✓	✓	✓	✓	✓
- Variable time intervals per zone	✓		✓		
- Simultaneous selection of building system and user		✓	✓	✓	✓
- Dynamic variables based in transient simulation	✓	✓	✓		

3. ANALYSIS OF RESULTS FROM DIFFERENT SYSTEM					
- Solar energy	✓		✓	✓	✓
- Trombe wall	✓	✓	✓	✓	✓
- Photovoltaic panels	✓		✓	✓	✓
- Hydrogen systems			✓		✓
- Wind energy			✓		✓
- Distribution and management of power loads	✓		✓		✓
- Eletricity generators	✓				✓
- Network connection	✓		✓		✓
- Hvac idealized	✓	✓	✓	✓	✓
- Possible configuration of HVAC systems	✓	✓	✓	✓	✓
- Repetitions cycle air	✓	✓	✓	✓	✓
- distribution systems	✓	✓	✓	✓	✓
- Modelling CO 2		✓		✓	✓
- Each distribution of air per area	✓	✓	✓	✓	✓
- Forced air Unit per zone	✓	✓	✓	✓	✓
- Equipment Unit	✓		✓	✓	✓

Figure 33: Comparison of Features of Various Simulation Software tools, modified from [26].

From the Comparison between software, highlights that Energy plus and TRNSYS are the two most complete software, especially to assess “Removable energy systems” and “Electrical systems”. An important aspect concerns the geometry and interoperability of software with CAD programs, about this TRNYS is not operative. However, the aim of the thesis is to model and simulate technological components “DSF”, by analysing the ventilation system (natural and mechanical), without delving into geometric aspect.

The table shows very clear data regarding the latter aspect, by defining TRNSYS one of the best software to reproduce and analyse the ventilation.

Thanks to this selection, for this thesis was chosen TRNSYS as BPS software tool *[25,28]*.

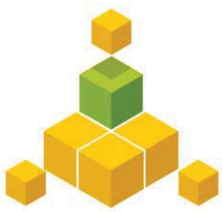
3.3 TRNSYS METHODOLOGY

TRNSYS is developed by the Solar Energy Lab of the University of Wisconsin-Madison, the Solar Energy Application Lab at the university of Colorado and today is developed by the German software Lab “TRNSOLAR”.

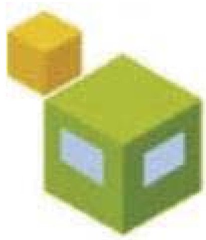
3.3.1 *The structure of TRNSYS*

TRNSYS is a software with a modular structure, based on one unit called (kennel) that performs mathematical operations and another unit relating a library of components. In particular the software is made-up of a main interface “SIMULATION STUDIO”, where is possible to connect different components of output and input called “TYPE N°”, to generate and analyse the base-model. In addition, TRSYS include many other applications, for pre- or post-processing:

- Solar systems (solar thermal and photovoltaic “PV”);
- Low energy buildings and HVAC systems with advanced design features;
- Renewable energy systems and cogeneration, fuel cells;
- Control and setting of the 3D geometry of the building (Sketch Up Zones and user interface TRNBUILD);
- Control and setting of the ventilation of model (user interface TRNFLOW);



SIMULATION STUDIO



TRNBUILD

TRNFLOW

- ***SIMULATION STUDIO***

Simulation studio is the main virtual control and management system.

The structure is based on a basically component, called type; these units are important to simulate the building, analyzing and evaluating in detail the different components or the thermophysical characteristics *[29]*.

The structure of a TYPE is very similar for all the different types, it has an interface where you can set: parameters, inputs, outputs, derivatives, special cards; furthermore, to gather information from outside with the external file application *[29]*.

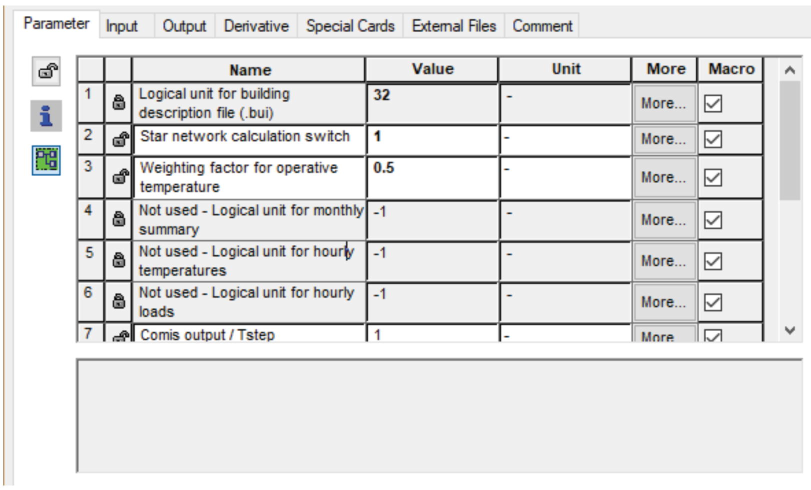


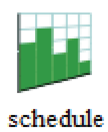
Figure 33: The main interface of type [29]

The software has a very large type library, which is based on five main aspects:

1. Control

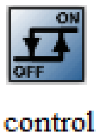
The function elements of this feature are very important for the management and monitoring of data; but also, to represent and plot data under time profiles *[29]*.

<u>TYPE NUMBER 14</u>



This component allows to report the values of the inputs under a time profile. The program has a simple structure, at each moment of time corresponds a value, which can have a unit of measure that varies between s and hr *[29]*.

TYPE NUMBER 2



This component is an on / off control that evaluates a 0/1 function. The reasoning of the system is based on the analysis of 1 reference values, which must be between a maximum and a minimum value *[29]*.

2. Thermal energy structures

The 2 category contains the most important components of all software. In fact, these types are considered the heart of the system, allowing the modelling and analysis of the main elements of the system designed.

The software allows the design of five main systems:

Electric, hydronic, HVAC, thermal, solar; they can be used in coupling or individually *[29]*.

TYPE NUMBER 56

It is the main unit in the analysis of multizone building; he is made up of all the components by the building and through his calculation system he is able to analyze them on all the thermo-energetic aspects. The editing phase of this type leads to interface directly with the building and with the different thermal zones, which have been modelled in the visual interface TRNBUILD *[29]*.

Regarding the other structures, no other component of this category is reported on the thesis because the thesis was focused on multizone building.

3. Boundary conditions

Another very important aspect for the analysis of a system is to impose the boundary conditions in the most appropriate way, to facilitate this operation.

TYPE NUMBER 15

This unit, represent the beginning of the whole system. It allows to insert the weather data files; which transfer information concerning the environment and the associated climatic conditions, such as: t environment, solar irradiance, humidity t soil, characteristics related to the wind, etc *[29]*.

TYPE NUMBER 9

This component is very important to make TRNSYS interoperable in exchanging data with other software, allowing to receive data type information and apply it to the system. One of the most common applications concerns the exchange of text or excel information *[29]*.

TYPE NUMBER 33

This component, controls the psychometric data, receives as input temperature and pressure, and a percentage of humidity of the wet bulb, is able to evaluate any psychometric data, from enthalpy to dew temperature *[29]*.

4. Output

As a last feature, we analyze the category of outputs. These types are essential for the representation and extrapolation of data.

TYPE NUMBER 65

This tool performs the important task of processing data received from inputs and plotting them through scatterplots *[29]*.

TYPE NUMBER 65d

This component can be considered a plus of the first because in addition to the plot function it offers the possibility to print the graphs obtained and to transform the outputs into readable files to other software *[29]*.

Up to now we have illustrated all the different components of the interface SIMULATION STUDIO; but to complete the scheme and define the logic of the project, we need to link the individual units. The software makes this action possible through the switch "LINK" *[29]*.

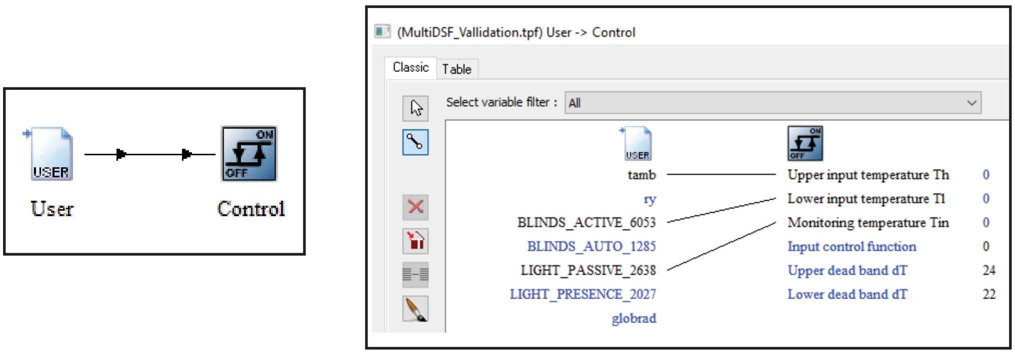


Figure 34: The use of link [29]

After defining the system design scheme, you need to set up and parameterize the generic variables that affect the process.

The simulation studio interface offers a very detailed toolbar and in particular to the switch, two very important functions are, control, cards and output manager.

The first is a setting unit of the calculation system, where it is possible to impose the time limits and the steps of the analysis, the maximum and mini values of iterations, and other values that affect the calculation method. Instead, from the second it is possible to manage all the output units inserted in the system, going to decide the labels of the graphs and the units of measurement *[29]*.

Finally, always from the simulation study toolbar you can insert a scientific and statistical calculation unit called "EQUA"[34].

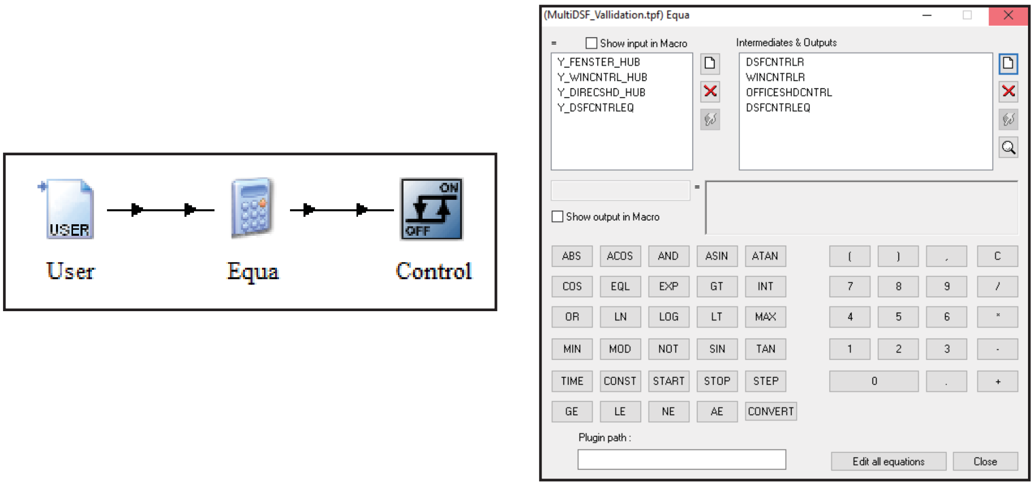


Figure 35: The interface of EQUA [29]

Going into detail, the aim of the thesis is to model and analyze a technological component applied to the building. The reference type used to analyze the thermophysical behaviour of the component was TRNBUILD.

- **<u>TRNBUILD</u>**

TRNBUILD, can be considered as the main interface of TRNSYS for the management of the building envelope. To get a file with type building you need to create a new multizone building model, to get this system, you need to create an IDF file. Produced by Sketchup.

The Sketchup 3d modelling software returns this type of file thanks to a particular design made possible by the appropriate plug for TRNSYS.

This plugin implements the Sketchup drawing tool bar with tools that allow saving the creation of thermal zones and shaded areas.

Specifically, it is possible to create editable areas that can be converted into thermal zones. These areas are implemented with the definition of the features and the position of the materials that compose it *[29]*.

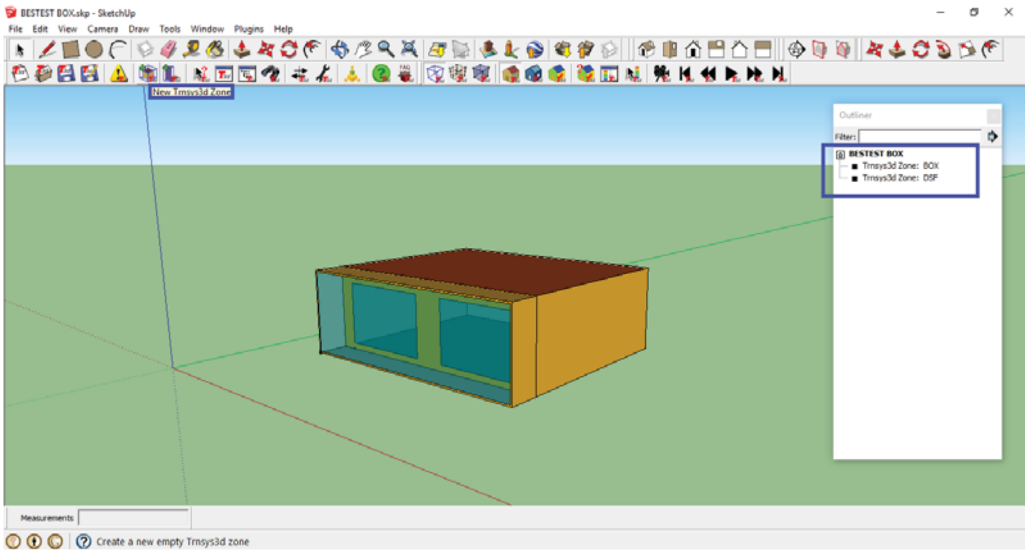


Figure 36: The modelling in sketchup

After having designed the model, we move on to the management of the thermophysical details in the type 56 "TRNBUILD".

The general screen of this interface, presents the model in the form of thermal zones, specifically the multizone building of the TRNSYS 17 version, allows to divide the thermal zones in the air node. The TRNBUILD Toolbar is based on 6 blocks.

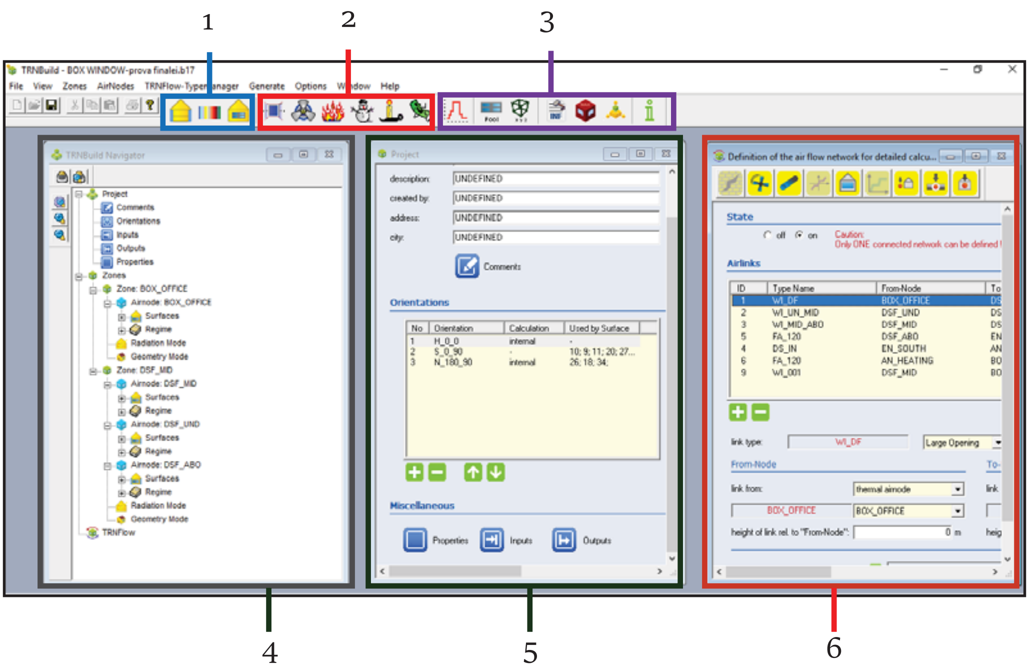


Figure 37: The main interface of TRNBUILD

In the first block there are tools suitable for the composition and management of opaque and transparent components; you can create new layers or new opaque and visual components. These commands are useful for setting the parameters of glazed components such as (shade, frame, thermo-optical features) or in the case of opaque components to modify (transmittance or absorption factors of solar radiation).

The second group of Swatch, allows you to set the design values related to heating, cooling, ventilation, infiltration, loads and building comfort.

The third block is characterized by a command with which to enter and program time schedules, another to evaluate the geometry of the building and its spatial coordinates and commands for supporting or exporting data.

To parameterize the trend of the characteristics, these components use 3 types of CONSTANT, INPUT, SCHEDULE values.

The management part of the components is carried out inside the "TRNBUILD Navigator", in this window you can see the subdivision scheme of the various thermal zones and the relative airnode. The Airnode is divided into 2 categories one that establishes the conditions of REGIME (heating, cooling, ventilation, infiltration) and one dedicated to the SURFACES, where it is possible to change the type and the surface temperature, the orientation and the shade conditions. The other two components that complete the thermal zone section, are the task that deals with setting the radiation distribution and the long wave and the one dedicated to the geometry analysis *[29]*.

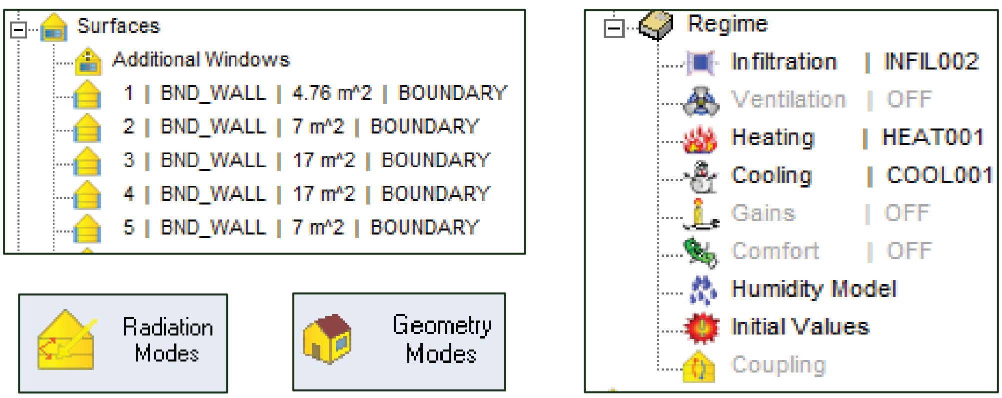


Figure 38: Surface & Regime

Instead in the project section, it is possible to define project credentials, inputs, outputs and calculation variables.
The inputs are often used to define conditions that this unit is not able to calculate and which therefore come from the calculation o, reading of type extents. The outputs, on the other hand, present a very large library, subdivided according to the following groups: thermal, auxiliary, external nodes and type dedicated to: surfaces, thermal balance and mass flow *[29]*.

The multizone building has two particular types of TYPE 56, a basic version and an integrated version with ventilation modelling, called "TRNFLOW.
This function allows to treat the ventilation of the rooms and to design the main scheme of the Airflow.

- **TRNFLOW**

TRNFLOW is the integration of the multizone airflow model COMIS (Conjunction of Multizone Infiltration Specialists) in the thermal construction module of TRNSYS (type 56). COMIS is a calculation method, created by an international collaboration within the framework of the IEA Annex 23.
TRNFLOW bases the building ventilation design on a network of connected nodes. The nodes, called "AIRNODES", represent the rooms and the surrounding building. While "AIRLINKS", perform the function of connection between the previous units and can model: openings, doors, cracks, window joints and shafts as well as ventilation components such as crack, ducts or fan *[29]*.

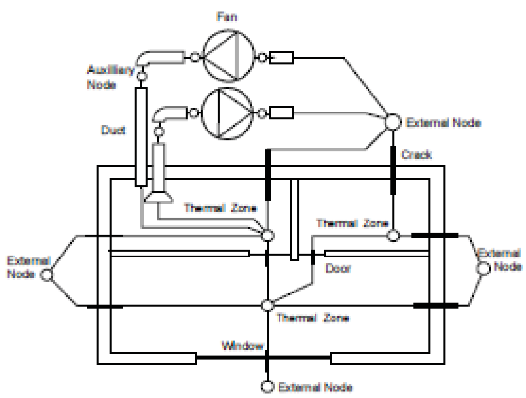
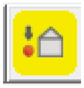


Figure 38: The general structure of TRNFLOW [33]

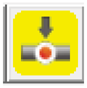
The **AIRLIKN**, are divided in three categories:

- ➢ EXTERNAL NODE



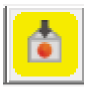
It represents a source external to the building, which is often expressed in thermal functions of the climatic file or of the surrounding environment where the building is simulated. The External node is characterized by the wind speed and direction coefficients, since they interact significantly in ventilation *[29]*.

- ➢ AUXILIARY NODE



This unit is useful for introducing air flows with controlled temperatures or humidity or from different sources. It is often associated with schedules or input values controlled by other external types *[29]*.

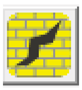
- ➢ THERMAL AIR NODE



The latter component is the main part of ventilation, since it connects the air flow model to the building. in fact, this unit represents the individual parts of the geometric design, such as thermal zones or rooms *[29]*.

The **AIRLIKN**, are divided in five categories:

- CRACK

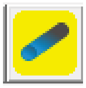


This component shapes a slot, which allows the flow of a portion of air between two different thermal zones, often can be considered to analyze the dispersions *[29]*.

- FAN

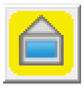
It is one of the most important functions of mechanized ventilation; it controls the air flow and pressure parameters, which can be entered or extracted from the rooms *[29]*.

- STRAIGHT DUCT



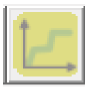
This parameter, model a physical connection of environments, and offers the possibility to select different shapes and geometries to contain the air *[29]*.

- LARGE OPENING



This tool is a useful to define the spaces of the thermal zones, enabling to model the different types of ventilation. It carries out the important task of integration between the building and ventilated facades *[29]*.

- TEST DATA



This air link is helpful to monitor the flows and to use as a basis for an external control, with the aim of operating other system. Moreover, it shows the trend of the air flow design *[29]*.

The final goal of TRNFLOW is to schematize the entire ventilation process by composing a single detailed structure. The scheme will be composed of nodes that outline the areas of air to be treated and their position *[29]*.

3.3.2. <u>Modelling and setting of DSF in TRNSYS</u>

The simulation is "The creation of a model of reality that allows to evaluate and predict the evolution of a series of events or processes, characterized by outline conditions chosen by the analyst " *[23]*.

Therefore, to achieve this, it is important, that there is a particular focus on the creation of the model, trying to describe reality in the best way.

The purpose of this section is to explain the various modelling and setting phases of the analyzed DSFs. Finally, to evaluate the validity of this process, a comparison will be made with the experimental data of the models of the thesis.

- **GENERAL ASPECT**

The behaviour of the double skin facade was analyzed in 2 different periods of the year, one in winter and one in summer, for a period of two weeks. The modelling of these two temporal phases was very important for the control of the input parameters that make up the façades. In fact, TRNSYS has been set up with a very precise scheme to obtain a model suitable for simulating all the boundary conditions. The scheme provides an identical structure for both the SOMEC and the NSRP, where the input data and the parameters that store each of the two components will be varied.

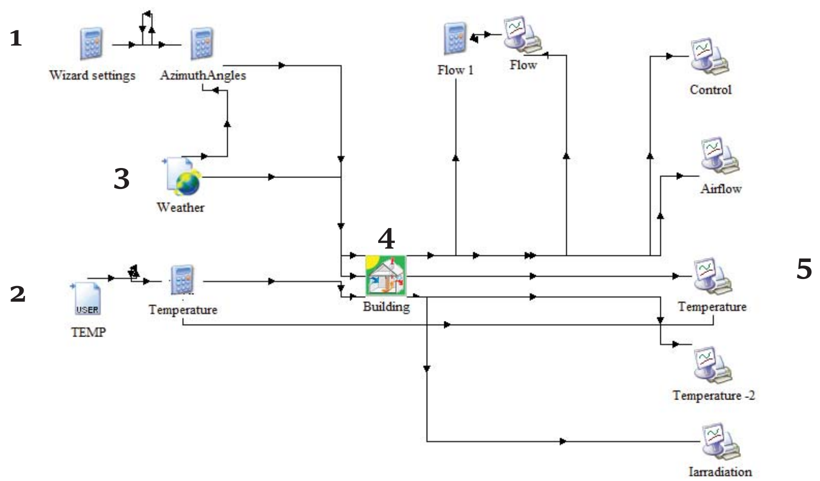


Figure 39: Structure of the modelling

1. Wizard system, this control allowed to perform a rotation of the orientation of building, with set of the azimuth angle (7° Sud-West Treviso, 15° Sud-West Torino).

2. The second block consists of TYPE 9, where all the input temperatures that regulate the two sides are inserted. Going in the detail on the NSRP, we have as input data:

   - ✓ Different surface temperatures of walls, ceiling, floor;
   - ✓ Indoor and outdoor air temperature;
   - ✓ Temperature of the sky;

   While on the SOMEC the data vary and are:

   - ✓ One temperature for all internal components;
   - ✓ indoor and outdoor temperature;
   - ✓ Temperature of the sky;
   - ✓ Temperature introduced into the cavity.

3. The third component that constitutes the final element of the input data group is dedicated to the reading of the climate file. This tool allows to read an external file of origin. epw, referred to the so-called Type Year (TRY: Test Reference Year). In Italy, the construction of the Type Year has been addressed by the IFA (Institute of CNR Atmosphere Physics).
   The Type Year is constructed through a statistical procedure, starting from data of a weather station collected in continuous mode for 20 years. The procedure calculated mean value and variance of the air temperature for each month of the year. The type of multiple month is selected representative of the mean value and variance of the air temperature closer to the values calculated for that month on the entire population.
   However, for an empirical validation, of primary importance is the coincidence of the various input data between the model and the experimental module. Thus, it was necessary to create a climate file,

containing the real measurements of the models in analysis. In fact, in order to finalize this operation, the data relative to the solar radiation of the experimental analysis hour by hour, have been parameterized according to the climatic file. The temperatures have not been evaluated, because the system is based on pre-set temperatures.

4. The fourth component is the heart of the system and represents the data processor. In fact, it receives the input data just illustrated and by performing calculations it converts them to output. Of course, all processes concerning the setting of the components of the models will be explained later.

5. The fifth and last block of the system regards the outputs, these present an online plotter function that returns the calculation performed by the type 56. Outputs can be managed by setting the labels and the units of measurement. We chose to plot 6 main output categories:

- ✓ Temperatures of the components;
- ✓ Temperatures of set point and of the different thermal zone;
- ✓ Mass airflow;
- ✓ Solar radiation;
- ✓ Shade component control;

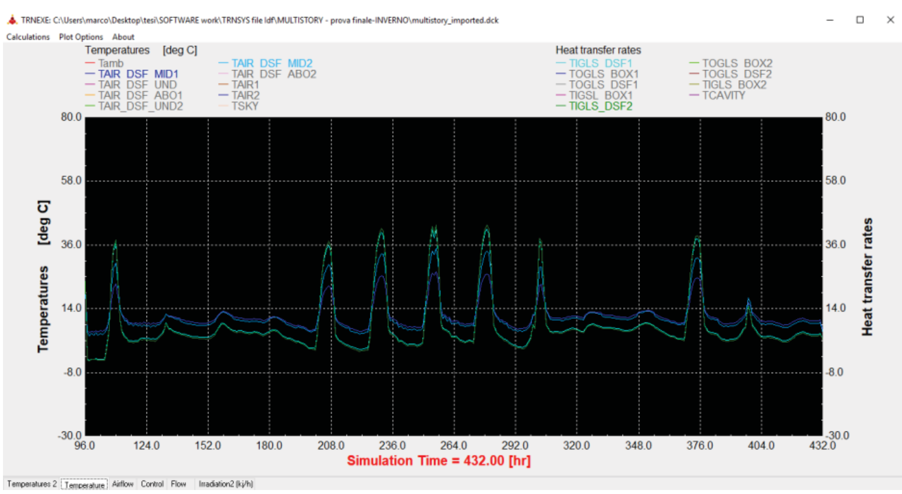


Figure 40: Online plotter output TRNSYS

Trnsys processes all the energetic quantities in (kj/h), while the experimental data are reported in (w/m^2), to execute the conversion are inserted calculators, which perform the following operation:

$$(kj/h) \rightarrow (w/m^2) = A/3{,}6/S$$

- A = number of split
- S = m^2 of surface

Finally, to make a direct comparison with experimental data, Trnsys offers the possibility to export data in formats readable by Excel to make a comparison through scatterplots.

- **GEOMETRY**

The second aspect of the analysis concerns the geometric modelling, this phase was performed using the TRNSYS plug for the 3D Sketchup design software, where the different thermal zones and the internal space were designed. In detail, the NSRP building has the following characteristics:

- ✓ BOX length 5m
- ✓ BOX width 1.4 m
- ✓ BOX height 3.4 m
- ✓ DSF length 1,4 m
- ✓ DSF width 0,20 m
- ✓ DSF height under 0,20m
- ✓ DSF middle 3,0 m
- ✓ DSF height above 0.20 m

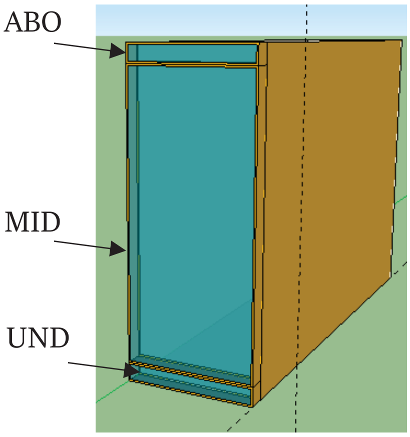


Figure 41: The box window in Sketchup

On the other hand, about the double skin facade SOMEC; it is divided into two equal blocks, corresponding to a DSF 1, DSF2 and a BOX 1, BOX 2.
To explain the geometric features of the building more easily, only one form is analyzed.

- ✓ BOX length 5m
- ✓ BOX width 1.4 m
- ✓ BOX height 3.5 m
- ✓ DSF length 1,4 m
- ✓ DSF width 0,30 m
- ✓ DSF height under 0,7m
- ✓ DSF middle 2,9 m
- ✓ DSF height above 0.30 m
- ✓ Total height 7,0 m

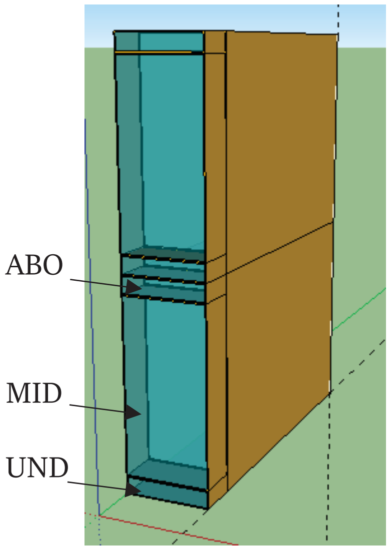


Figure 42: The multistory in Sketchup

The surfaces of the components are also parameterized within the geometric modelling. as shown by the figures to create a stratification of thermal areas and therefore airnodes useful for ventilation, it was necessary to create different parts for a single dsf, which are divided by virtual surfaces that will be considered even open for the ventilation of the air flow. Furthermore, the system defines the opaque components as external and adjacent to the building. last fundamental condition for the development of a correct analysis is to parameterize the walls with boundary conditions, allowing TRNSYS to edit their features.

- **OPAQUE & TRASPARENT COMPONENTS**

This section focuses on the configuration of the main components found in type 56, windows and walls. These two units are very important for the detailed analysis, because TRNSYS, does not allow to modify too many cards, but often relies on pre-set components from libraries.

One of the main objectives of the modeling was to make our walls, adiabatic to the outside and to have surface temperatures set by setting.

TRNSYS, fails to set an internal surface temperature of the walls but only external. To solve this problem, a mass layer was created, isolated from the outside but with a low thermal resistance, by allowing to create a starter with a setting temperature. In this editing, it has been important to study the equations of the thermal convective heat transfer, which expresses the exchange of heat between zone and component.

From the TRNSYS manual the values of:

- inside: 11 kJ / h m^2 K
- outside: 64 kJ / h m^2 K

At the exterior facade layer, total heat transfer is considered as the sum of radiative and convective heat transfer. In-between surfaces, walls are modelled according to a transient method that consider thermal behaviour from surface to surface in time series to characterize the resistant heat flows into and out of the surface. The number of time series tell if the wall is thermally heavy. While windows are thermally considered as an external wall without thermal mass in the heat balance (two node resistance), a detailed window model is integrated into the thermal model calculation procedure. The optical properties of windows are calculated using the

data derived from WINDOW 5 (LBNL). By regard to the windows and its light balance it is important to set the parameters by the shade, to have the correct performance we followed the study done by a previous thesis that simulated a similar type of double skin facade and that shows the following table of calculations *[30]*.

SHADING DEVICE DESCRIPTION	INPUT PARAMETER	
Opaque fraction of shading	ISHADE	$1-\tau$
Internal blind (base case)	0.70	$\tau = 30\%$
DSF-shading device	0.80	$\tau = 20\%$
Reflection coeff. towards window	REFLISHADE	$\rho/1-\tau$
Internal blind (base case)	0.38	$\rho = 27\%$
DSF-shading device	0.50	$\rho = 40\%$
Reflection coeff. towards zone	REFLOSHADE	$refl_{sh,\rho}$
Internal blind (base case)	0.50	-
DSF-shading device	0.10	-
Convection to air-node	CCISHADE	$c_{conv,sh}$
Internal blind (base case)	0.33	-
DSF-shading device	0.50	-

Figure 43: The setting of shade in TRNSYS [30]

- **SOLAR RADIATION**

One of the factors, which influence our calculation is the solar radiation, in TRNSYS 17, this property is based on a system of analysis of shortwave, diffuse and longwave of a detailed type, which treats the three components separated by applying wave-length dependent view- factors called Gebhardt factors. The original solution of this software, on the other hand, was based on factors that did not hold certain optical properties, simplifying the process. This standardized methodology allows a less refined calculation but in the case of DSF, detailed calculation is preferred. To get a specific idea of the decomposition by the software of solar radiation, we report an image of the manual of TRNSYS, which analyzes a situation with the presence of the shade *[29]*.

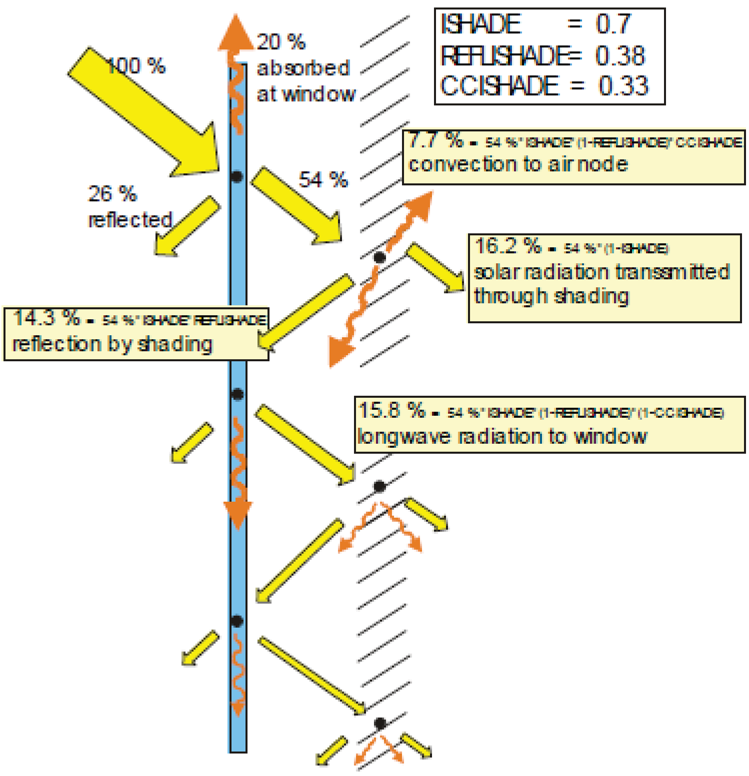


Figure 44: The solar radiation [29]

The solar radiation balance for thermal zones show the magnitude of incident sun on the solar apertures of the envelope (windows including frames) and the respective distribution of how much solar radiation is blocked, how much is entering the zone and how much is exchanged with other zones *[29,30]*.

$$Q_{BAL} = Q_{S,ext} + Q_{S,adj} - Q_{B,refglz} - Q_{B,absglz} - Q_{B,r\,frm} - Q_{B,exshd} - Q_{I,loss} - Q_{G,win} - Q_{B,refshd} - Q_{G,ishdc} - Q_{G,sgwall} - Q_{G,solatr}$$

	POSSIBLE GAINS		ZONAL LOSSES
$Q_{S,ext}$	total incident	$Q_{I,sloss}$	Int. rad. loss
$Q_{S,adj}$	zone exchange	$Q_{B,refshd}$	Reflected out int. shd.
	BLOCKED GAINS		ZONAL GAINS
$Q_{B,refglz}$	reflected, ext. glass	$Q_{G,win}$	Absorbed int. glass
$Q_{B,absglz}$	absorbed, ext. glass	$Q_{G,ishdc}$	Convection int. shd
$Q_{B,r\,frm}$	blocked, frame	$Q_{G,sgwall}$	Absorbed int. walls
$Q_{B,exshd}$	blocked, ext. shd.	$Q_{G,solatr}$	Concvect. solar fraction

- **VENTILATION**

The airflow network in TRNFLOW, is different from the other BPS-tools; in this software there is a complete integration with the thermal domain. In fact, how explain a paper of Flamant, it is based on an onion approach, where airflow rates are passed from the ventilation model to the thermal model, which calculates new air temperatures and pass them to the ventilation model, which calculates new airflow rates *[29]*.

As already mentioned, the thermal nodes of our building that are realized in the 3D design, make up the nodes of the airflow model's structure.

The two fundamental figures for the ventilation of the two façades are the large opening and the fan.

By regarding the first component, these are parameterized with a top closing system, and depending on their position, they can be vertical or horizontal the horizontal are considered as a virtual surface always open, with the aim to create a whole system o facade.

In our study, SOMEC presents only closed vertical large opening and separate the flow indoor and the flow in DSF, while in NSRP, there is an under large opening with a factor of 1, which symbolize, even open, so we have an exchange of flow between box and DSF.

The second component is the fan, it is very important to balance the quantity of mass air flow which the environments exchange. This tool is characterized by a fan curve, function of the air pressure; the manual of TRNFLOW reports the graph of 5 main fan *[29]*.

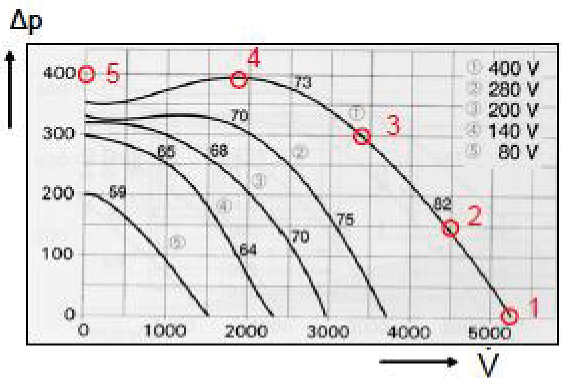


Figure 45: The fan curve [29]

From the analysis of the graph we note that considering our flow rates in volume we can describe our curve on the parameters of 0,150,300 Pa.

The ventilation in our project is divided in two models.

The NSRP, provides an airflow, which characterize the whole building, box and DSF. The scheme is based on this structure:

- FAN IN (BOX) -> DSF (UND) -> DSF (MID) -> DSF (ABO) ->FAN EX (DSF)

The structure of the SOMEC, opposite the previously system, airflow design is focus only in the cavity and it is made up in this way:

- FAN IN (DSF1) -> DSF (UND1) -> DSF (MID1) -> DSF (ABO1) -> DSF (UND2) -> DSF (MID2) -> DSF (ABO2) ->FAN EX (DSF2)

4 RESULTS & DISCUSSION

This chapter presented the result of the simulations on the two double skin facade models. To investigate the reliability of the model, they are compared with the measurements acquired during the monitoring.
The outputs that are evaluated are divided into 5 main categories:

- ✓ Temperature of the air cavity;
- ✓ Surface temperatures of internal and external glass;
- ✓ Thermal flow longwave and convective;
- ✓ Solar radiation;

These values have been collected in practice thanks to measuring instruments such as "Thermocouple", a sensor that allows to measure temperature of surface and air; "Thermofluometer", sensor for analyzing the thermal flux exchanged between two surfaces; "Solarimeter", a tool used for the measurement of solar radiation titled on the surface. These sensors were positioned on different levels of the facades. To make a correct comparison of the data, it would be necessary to have the same heights relative to the air nodes of the simulated model. But due to a geometric characterization this was not possible, in fact the models of TRNSYS, provide a structure with altitudes of air nodes different from experimental data. To overcome this problem, it was decided to interpolate the experimental data and bring them back to the heights of the various air nodes. Below are the height levels of the dude façades of both experimental sensors and airnodes.

	NSRP experimental	**NSRP Trnsys**
Level 0	+1,00 m	+0,10 m
Level 1	+2,00 m	+1,70 m
Level 2	+3,00 m	+3,30 m

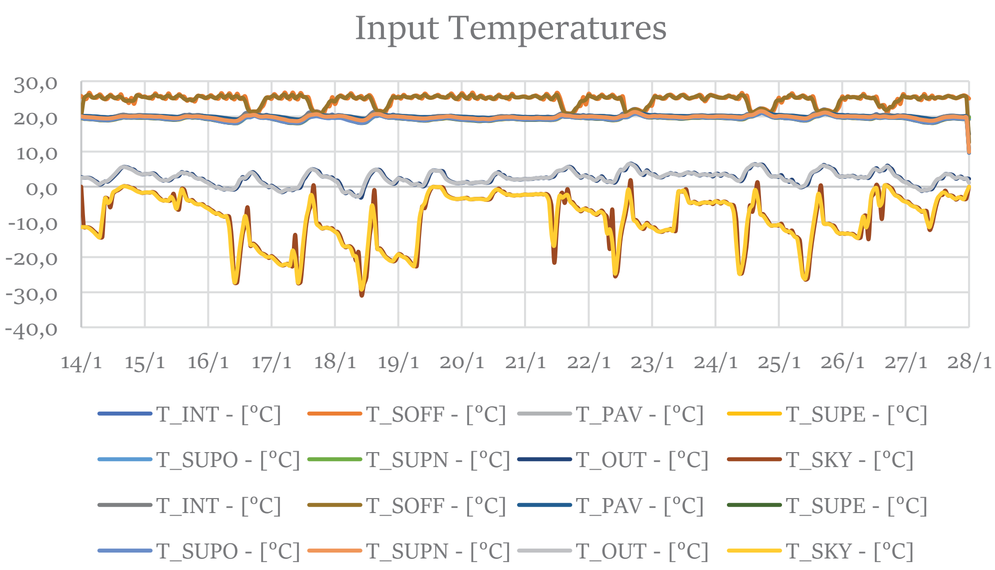
	SOMEC experimental	SOMEC Trnsys
Level 0	+0,90 m	+0,15 m
Level 1	+2,70 m	+1,75 m
Level 2	+4,25 m	+3,35 m
Level 3	+5,65 m	+3,65 m
Level 4	+5,65 m	+5,25 m
Level 5	+7,00 m	+6,85 m

For the box window mock-up, the data of comparison are taken in two periods of the year one in winter and one in summer.

TYME	winter	summer
NSRP	14/01/2013 - 28/01/2013	29/07/2013 - 12/08/2013

4.1.1. *Data monitoring winter season*

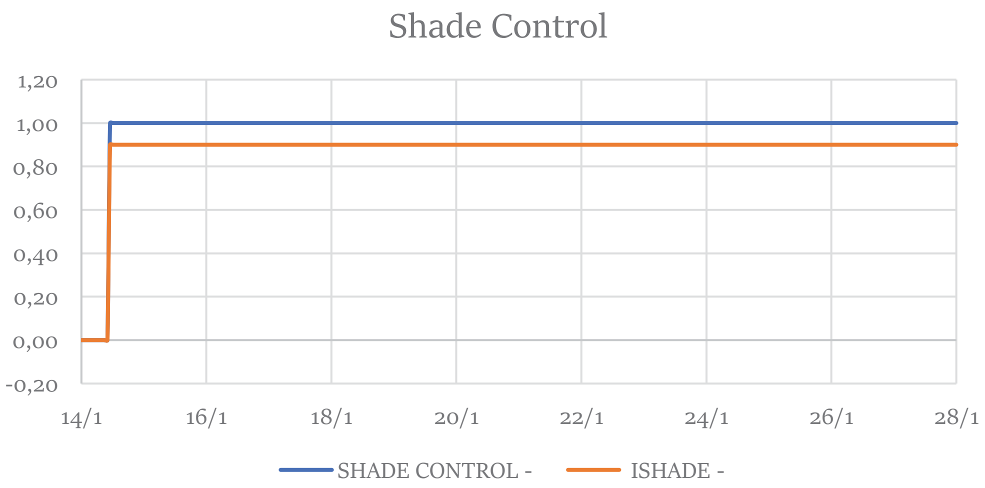
The data are presented for the winter case, corresponding to the period of monitoring 14/01 - 28/01: lowered solar shading, external glass with slab double, with selective external glass. To perform the experimentation, have been evaluated the responses of our model, which receives this following input temperatures.



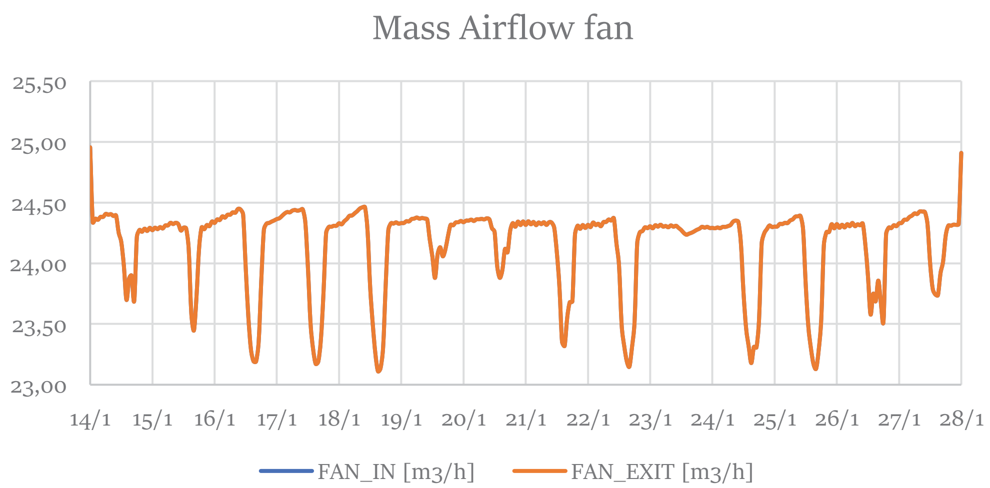
As can be seen from the graph, the software reads as input the settings regarding the internal and surface temperatures. There is a constant pattern of surface temperatures of the walls and of the floor temperature, which falls around 20°C, while the ceiling temperature is slightly higher, because suffer the influence of a radiant ceiling,

Instead, the last two profiles, simulate the Texternal and Tsky trend.

To obtain a more correct answer to our datum, it was fundamental to work on the values of the shade, because the balance of enter solar radiation is not easy to analyze. The final control of the winter season is reproduced with a shade always closed, with a solar absorption value which is 0.85.

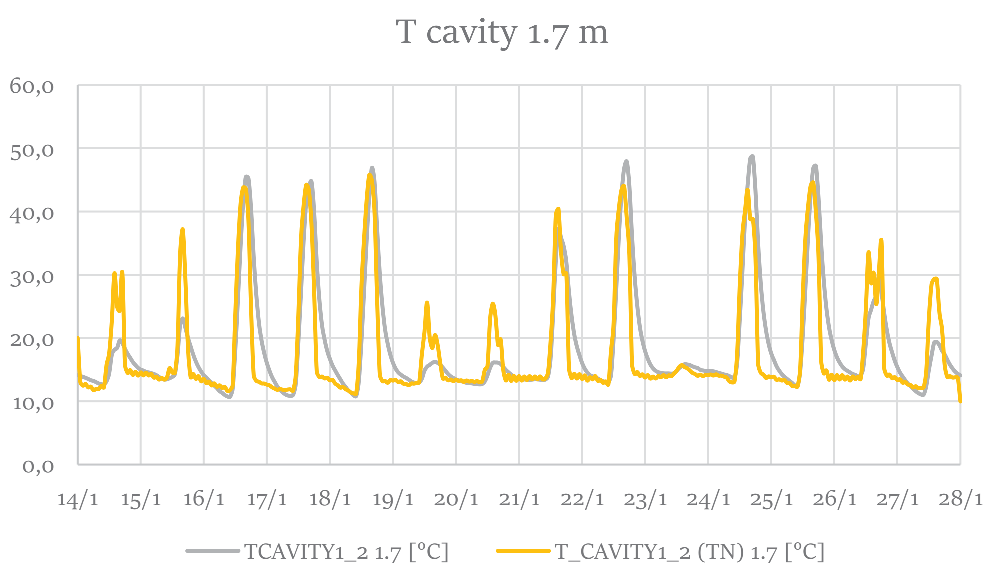


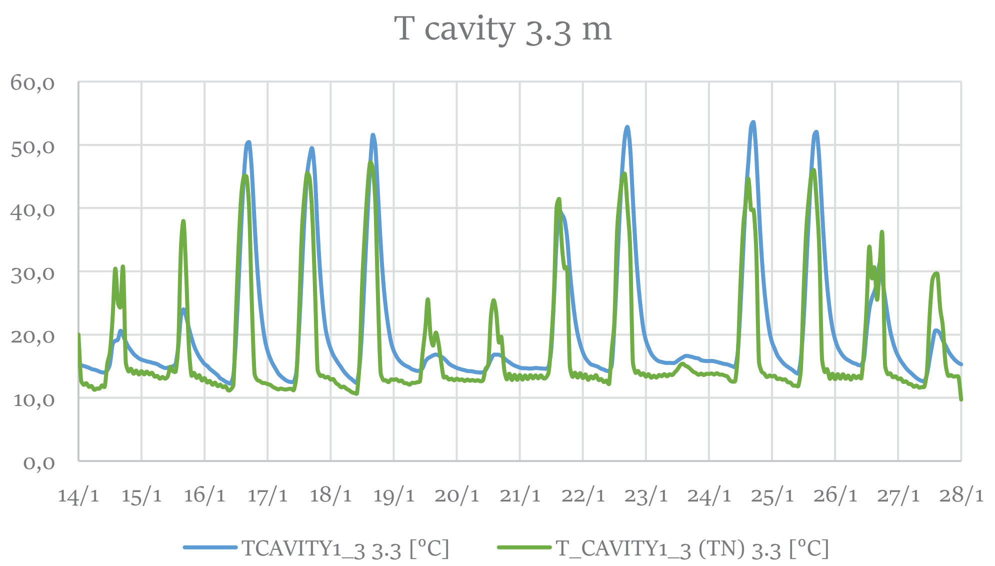
The last parameter that allows standard programming is the control of the fan's mass airflow, where you can see a sinusoidal pattern, balanced according to the fan setting curves, the value is in the range between 23 m^3/h and 24, 50 m^3/h.



- **Temperature of the air cavity**

The first experimental result that is compared is the temperature of the air cavity, to make this comparison an interpolation of the experimental data was performed, providing the value on the relative airnodes of TRNSYS. The most significant data are at the height of 1, 7 m and 3.3m, respectively MID DSF and ABO DSF.

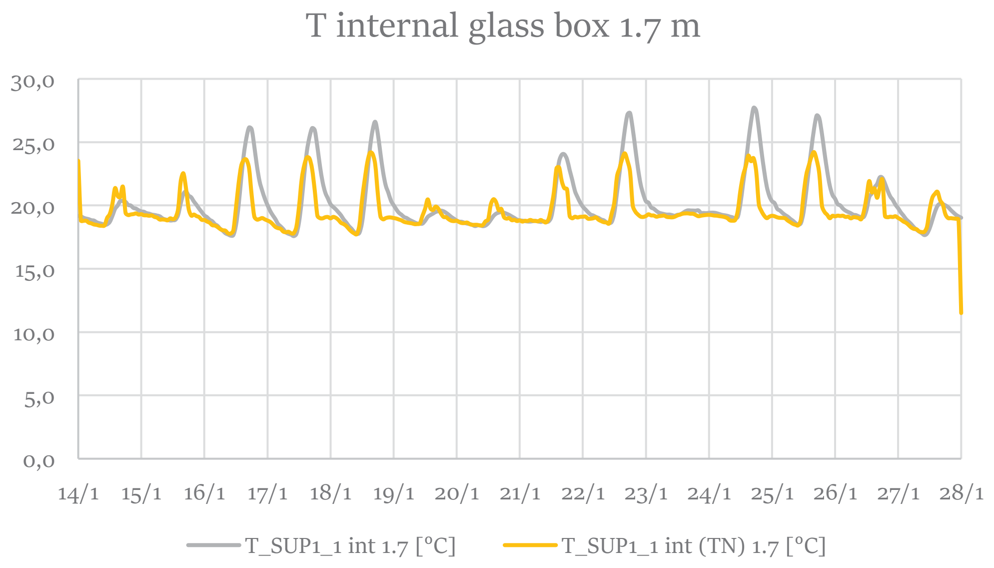




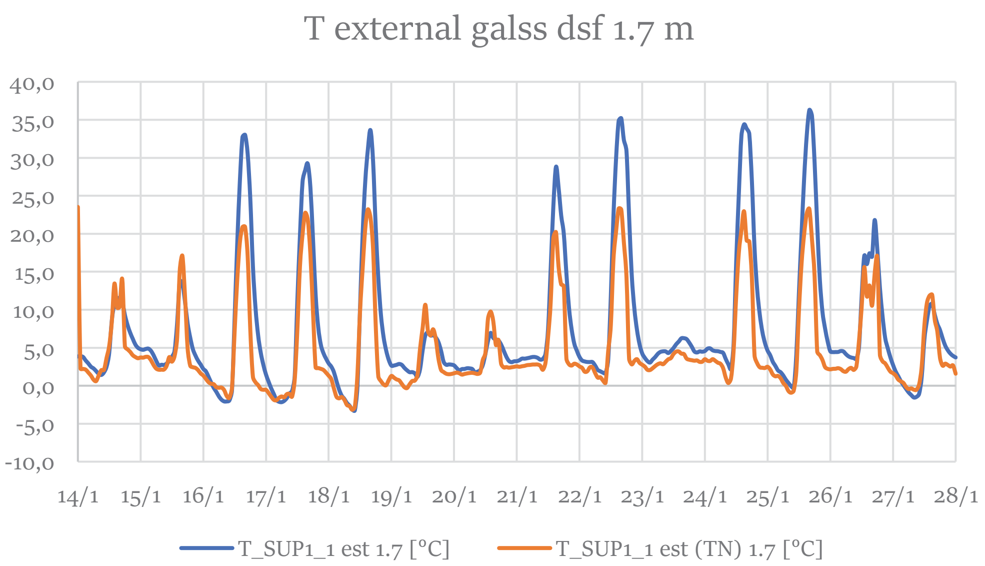
From the comparison of the data we can see how the simulated datum is close to the experimental datum, except for values on the peaks, which could be traced back to the temperature variation between the different thermal zones. Moreover, a slight offset of the temperatures can be noticed, this is a factor known to the simulation with BPS-tool, as these processors fail to take into account the thermal inertia given by the slabs constituting the façade. This is due to an immediate response of the process that offsets the profiles of surface temperatures, also of the cavity.

- **Temperature of external and internal glass**

Following the reasons mentioned, an even more evident effect on the superficial glass temperatures can be seen. Even in these data, interpolation for comparison was performed. The most significant datum of the simulation on TRNSYS, has been obtained at the height of 1.7 m.

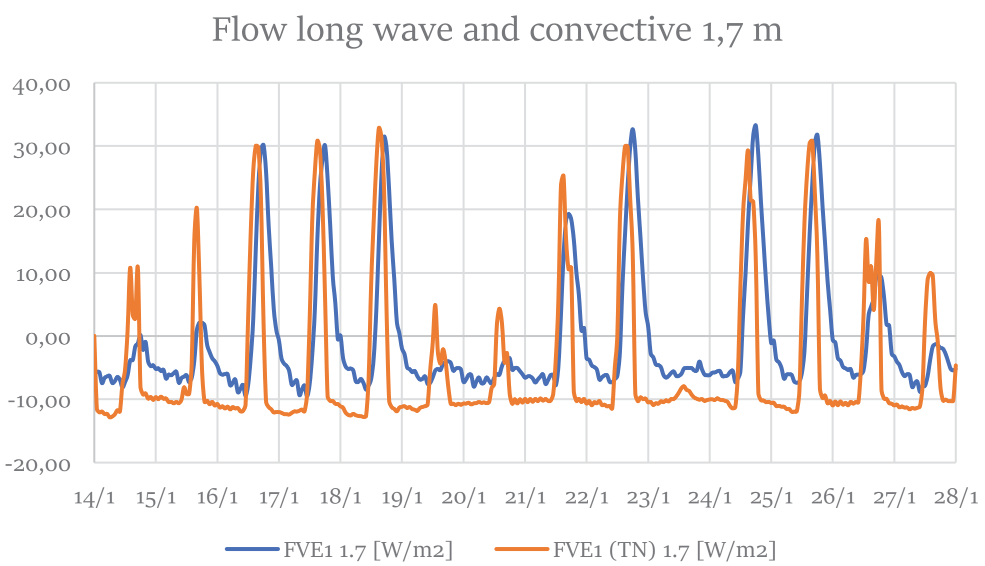


In this data there is not a large variation of the temperatures on the peaks and can be traced back to the previous considerations. While the next graph relative to the temperature on the external surface, there is a evident difference in the peaks near the 20 %, between 35 °C and 25°C. One possible reason could certainly be the composition of glass. The model uses glass components calculated with the WIS system, which try to replicate the experimental data in the best way, but in this case the characteristics of the glass could be too high and therefore reduce its thermal impact.



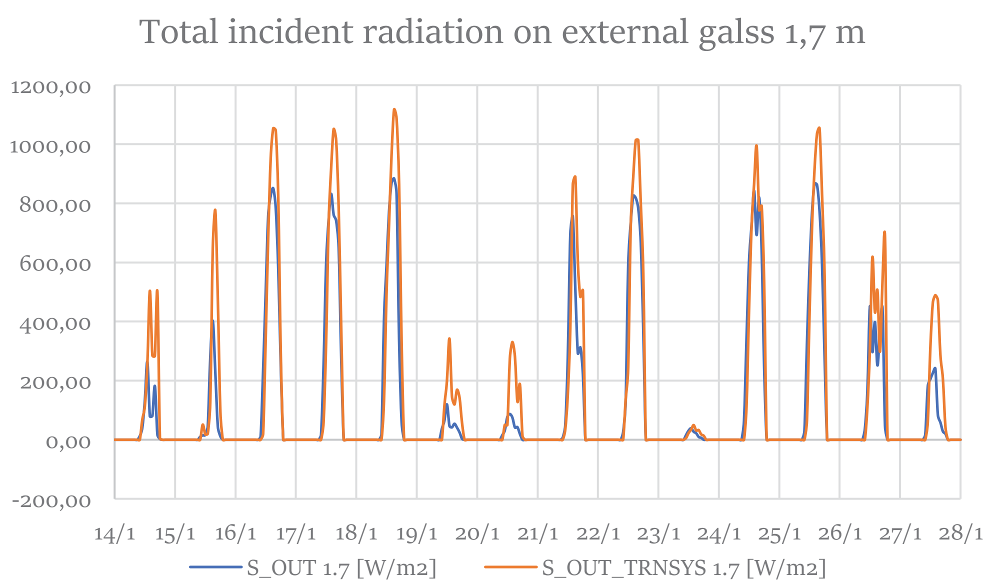
- **Thermal flow longwave and convective of internal glass**

Regard the flow, there is a greater staggering, especially in the lower part of the graph, the reason may be due to the hypothesized fan curve, which in these points increases the air flow. Another reason, is the deviation is certainly a function of the software's ability to calculate long wave radiation.



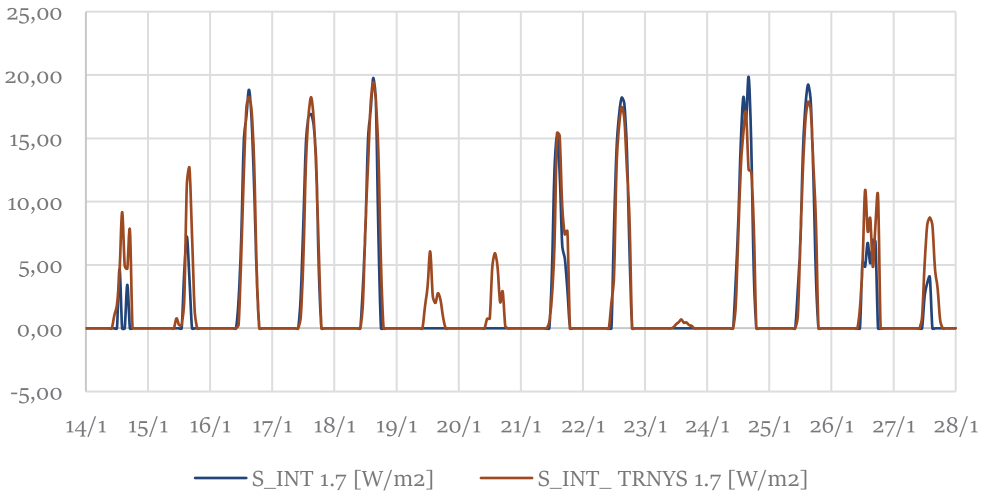
- **Solar radiation**

As the last data analyzed for the experimental comparison, there are the solar radiations incident on the external façade and that transmitted from the internal glass to the environment. The values of total radiation on the vertical, have been provided by experimental data, but the software through the climate file, requires radiation on the horizontal. To carry out this transformation, the ZEB department of Trondheim studied the transformation and decomposition of radiation into its three components, beam, diffuse and reflect. By modifying the climate file with these radiations, the software should re-establish the experiment conditions, but on the reading in the case of the Turin climate file, there are problems.
It is estimated that the total radiation incident on the external surface is not correct but has a phase shift of about 100 w / m2; this can be evidenced by the fact that the software processes the radiation with an internal calculation, which is difficult to reproduce and therefore evaluates a component that increases the profile.



One thing that still allows to evaluate the experiment is that the trend is similar, so it is thought to lower this component inside through a higher yield of shade. This means that the solar radiation transmitted by the inner glass is close to the experimental one.

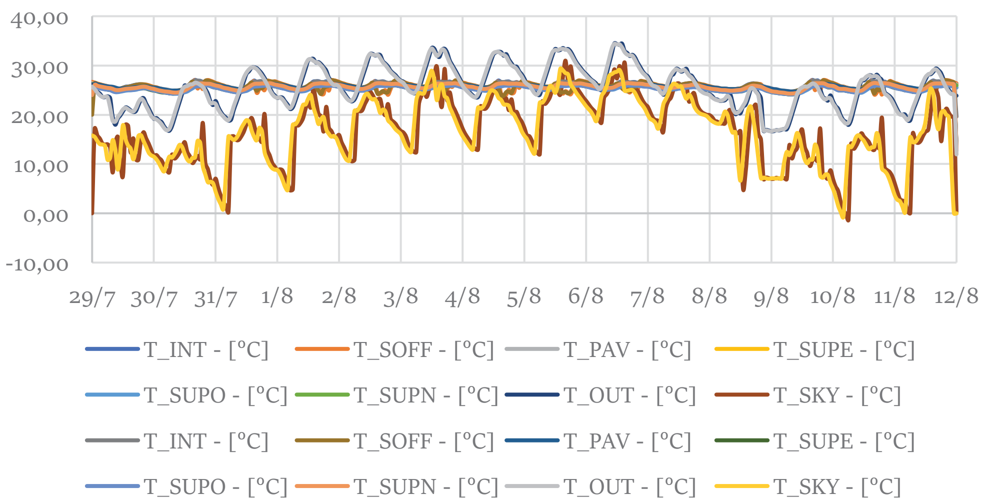
Total trasmitted radiation of internal glass 1,7 m



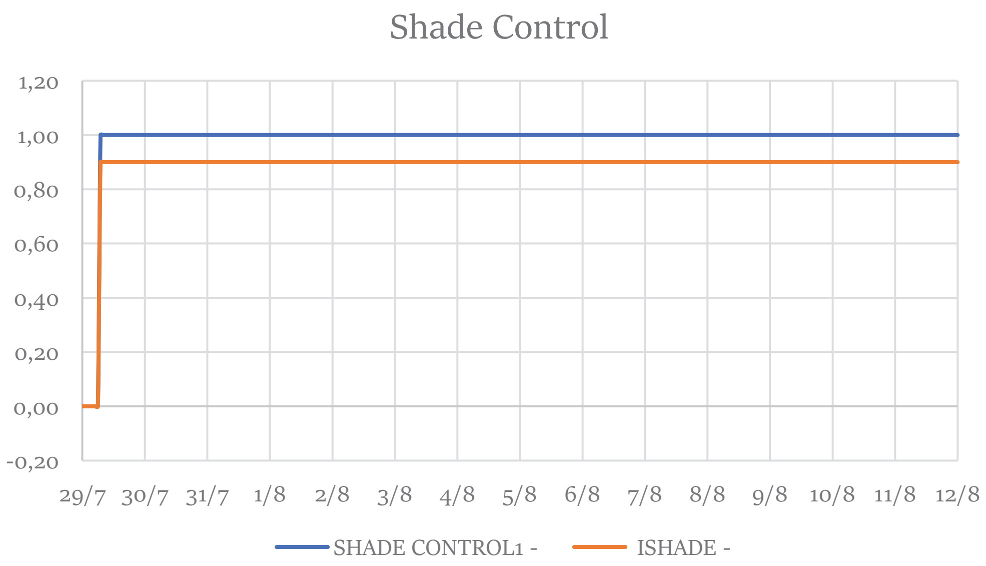
4.1.2. Data monitoring summer season

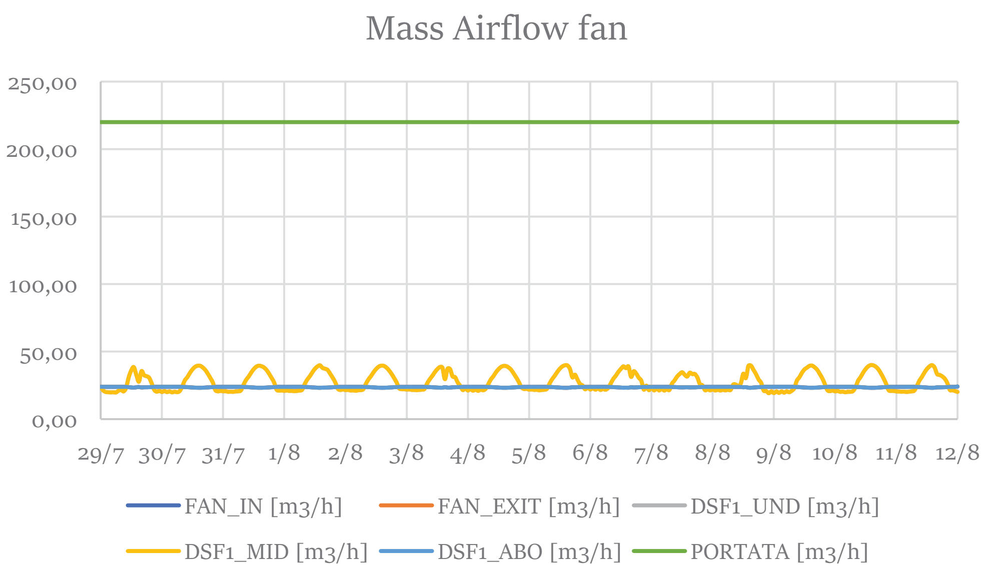
In this case the data are presented for the summer season, corresponding to the period of monitoring 29/07 - 12/08: lowered solar shading, external glass with slab double, with selective external glass. To perform the experimentation, have been evaluated the responses of our model, which unlike the previous simulation, is set with different temperatures and solar radiation values.

Input Temperatures



The fan and shade settings remain constant to the winter simulation.

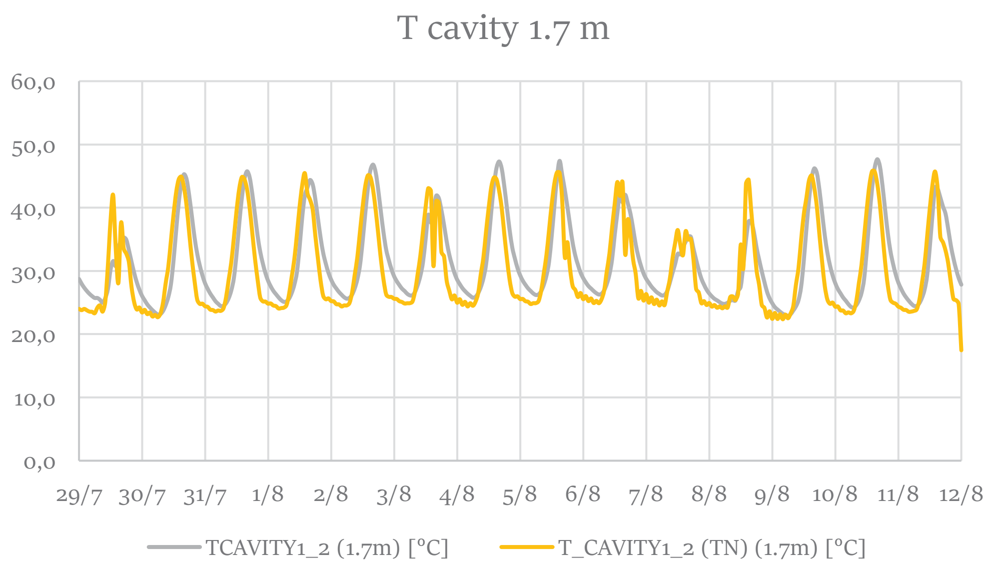


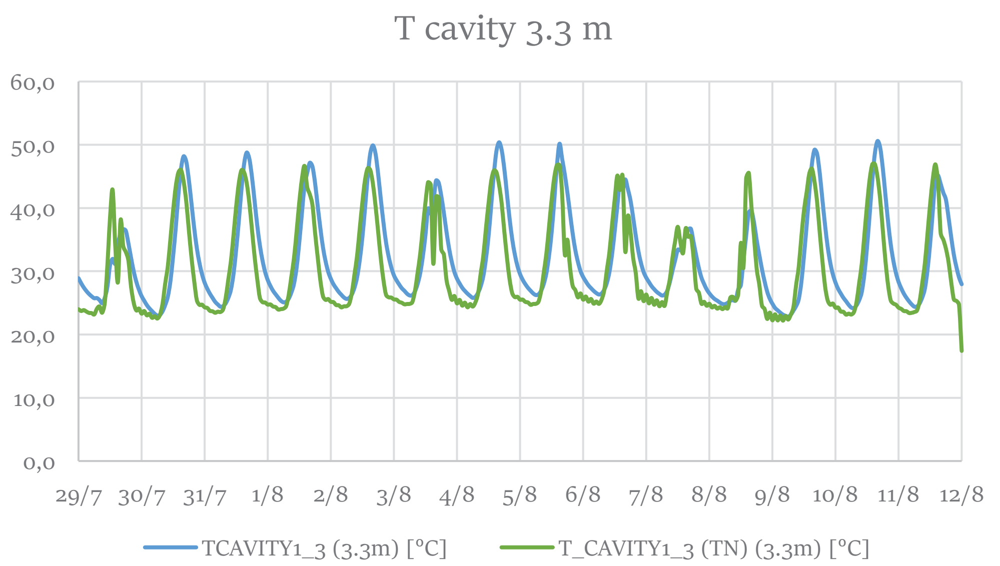


The comparison with the experimental summer data, presents the same problems as the previous chapter, because it is clear, that the problem is always caused by the anomalous reading of the climate file.

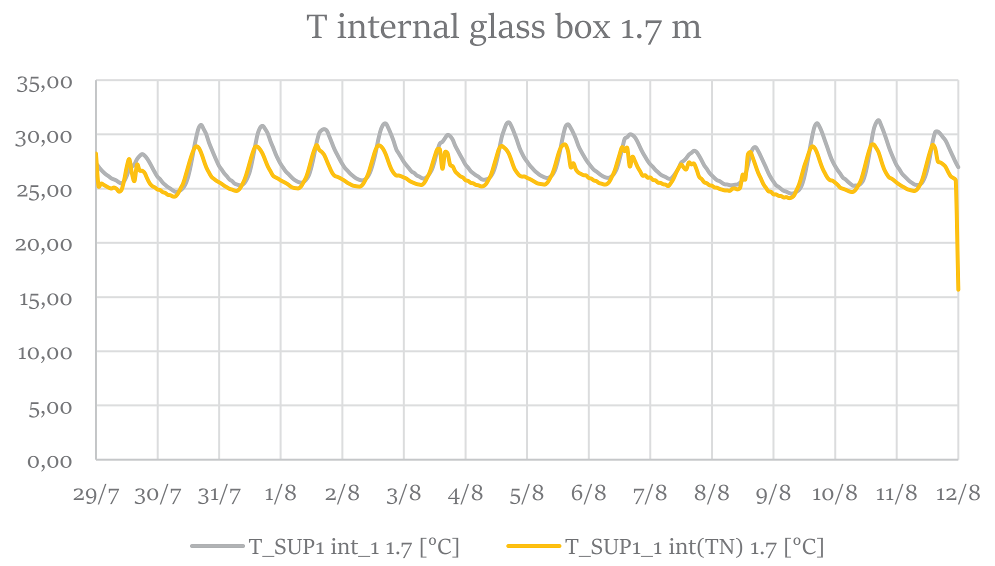
It was chosen to insert the graphs without comments as they will have the same inconsistencies of the winter simulation, naturally with different values of temperatures and flows.

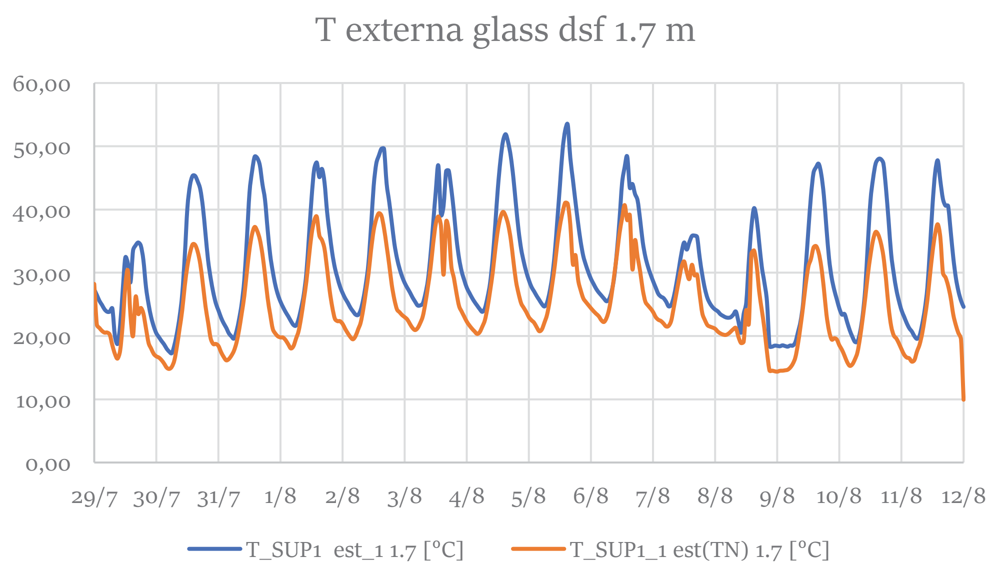
- **Temperature of the air cavity**



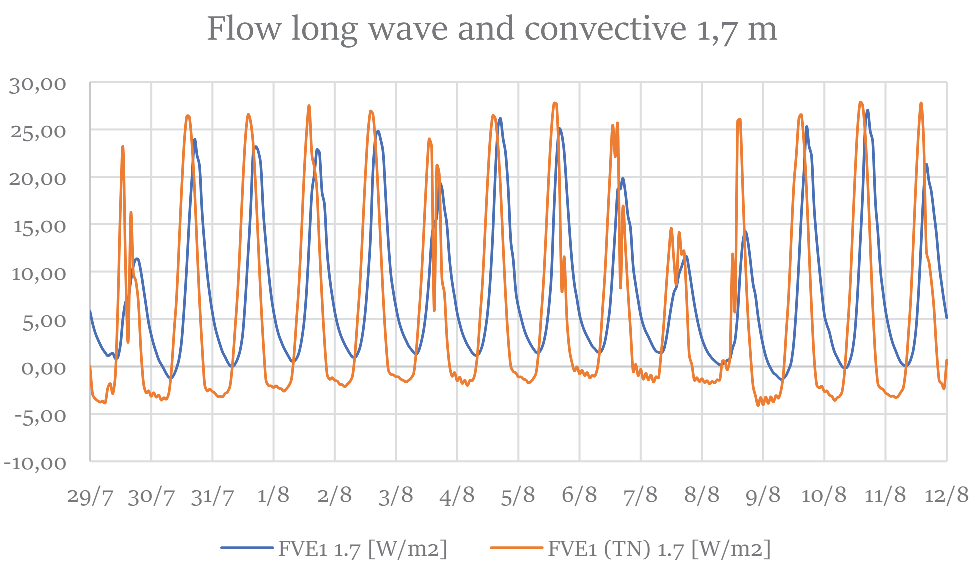


- **Surface temperature of internal and external glass**

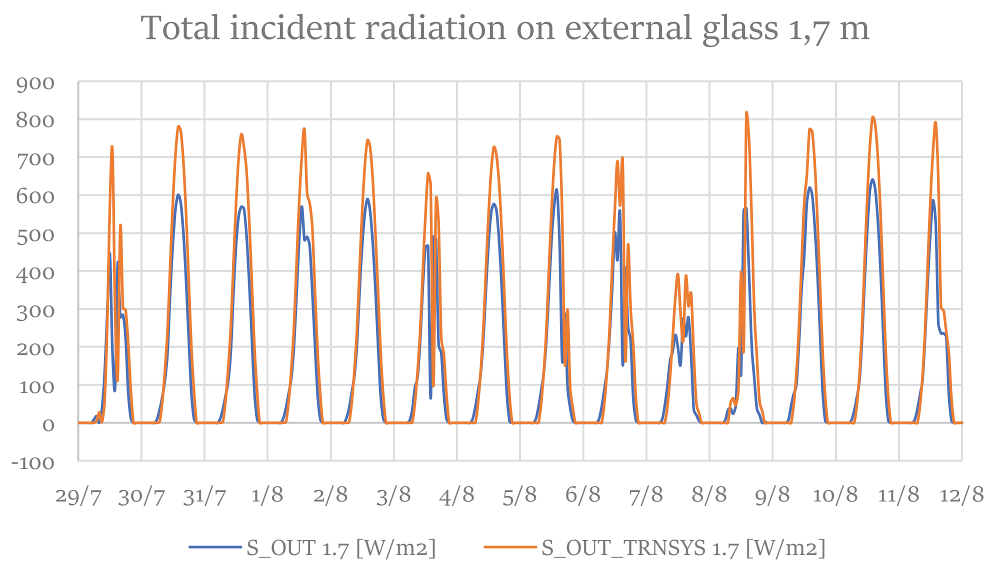


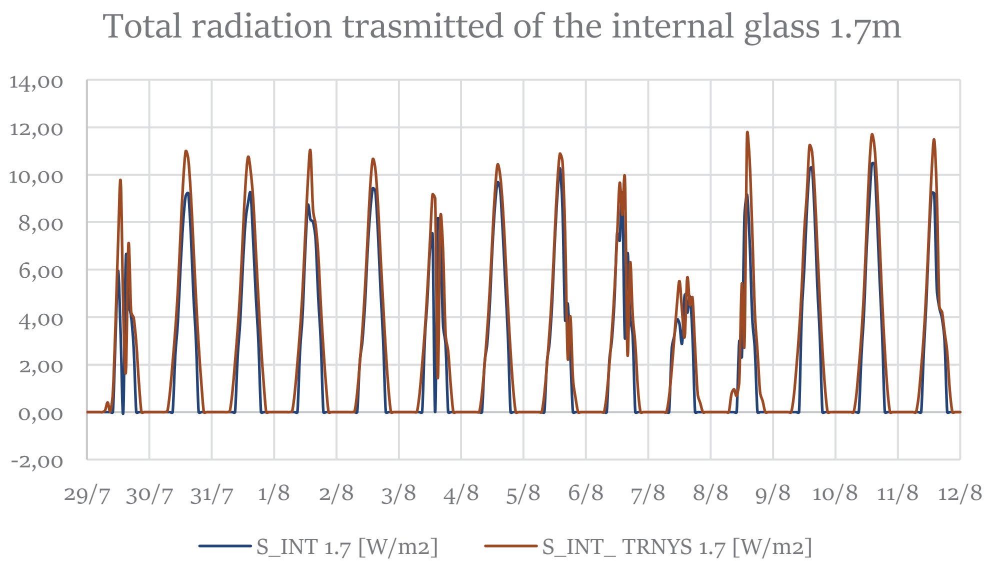


- **Thermal flow longwave and convective of internal glass**



- **Solar radiation**





Total radiation trasmitted of the internal glass 1.7m
14,00
12,00
10,00
8,00
6,00
4,00
2,00
0,00
-2,00
29/7
30/7
31/7
1/8
2/8
3/8
4/8
5/8
6/8
7/8
8/8
9/8
10/8
11/8
12/8
S_INT 1.7 [W/m2]
S_INT_ TRNYS 1.7 [W/m2]

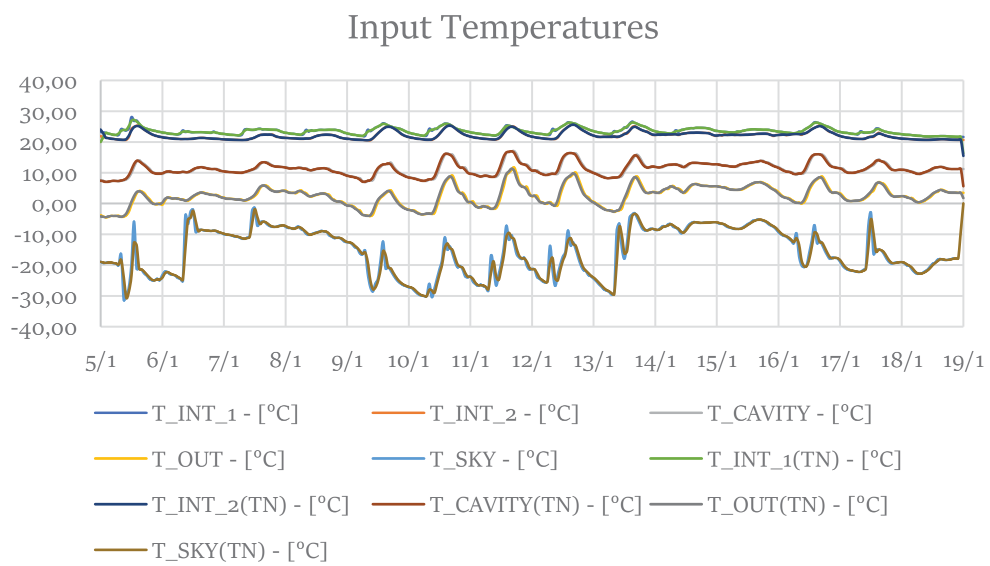
4.2 MULTISTORY: **SOMEC**

Even for the multistory mock-up, the data of comparison are taken in two periods of the year one in winter and one in summer.

TYME	winter	summer
SOMEC	**05/01/2009 - 19/01/2009**	**19/07/2009 - 02/08/2009**

4.2.1. Data monitoring winter season

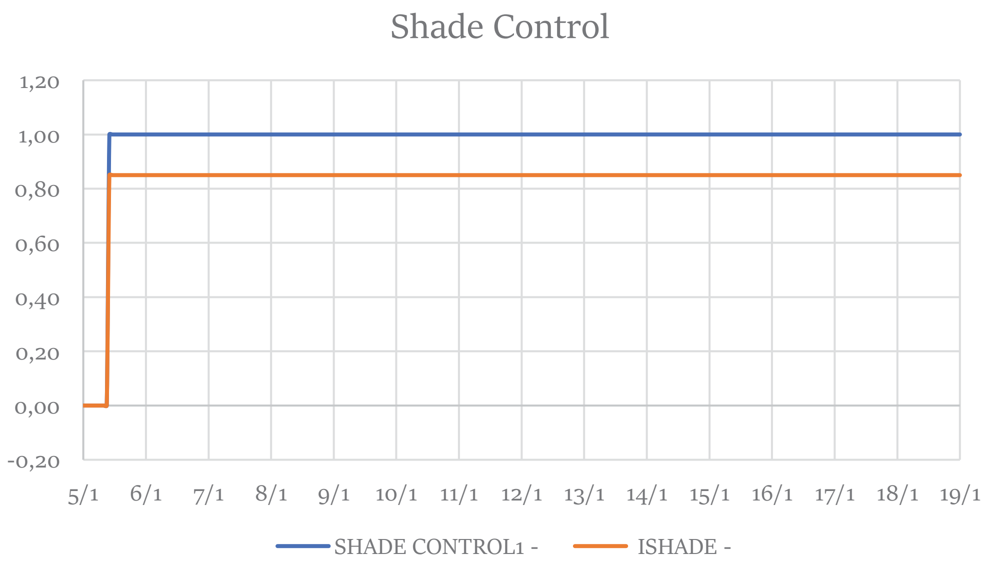
The data are presented for the winter case, corresponding to the period of monitoring 05/01 - 19/01: lowered solar shading, external glass with slab double, with selective external glass. To perform the experimentation, have been evaluated the responses of our model, which receives this following input temperatures.



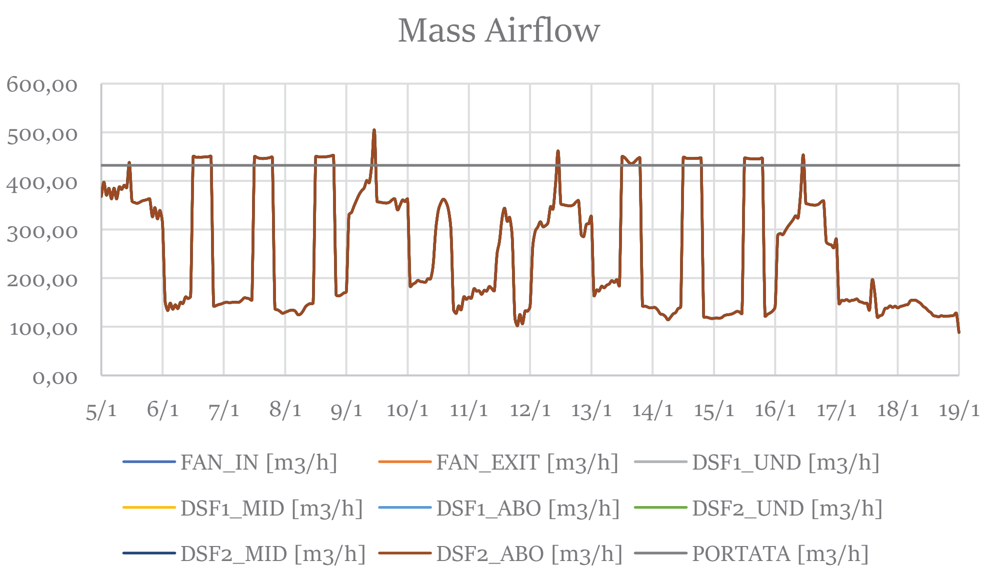
As can be seen from the graph, in this type of façade we find less components that affect the surface temperature of the internal walls set with a single value equal to that of the temperature inside the rooms. But we find an extra value, which characterizes the cavity, this temperature is an input data that regulates the thermal balance of the cavity.

In winter This value varies between 15 ° C and 10 ° C.

Solar shading for this study concerned in a roller shade is also active here for the duration of the simulation with a solar absorption of 0.8.

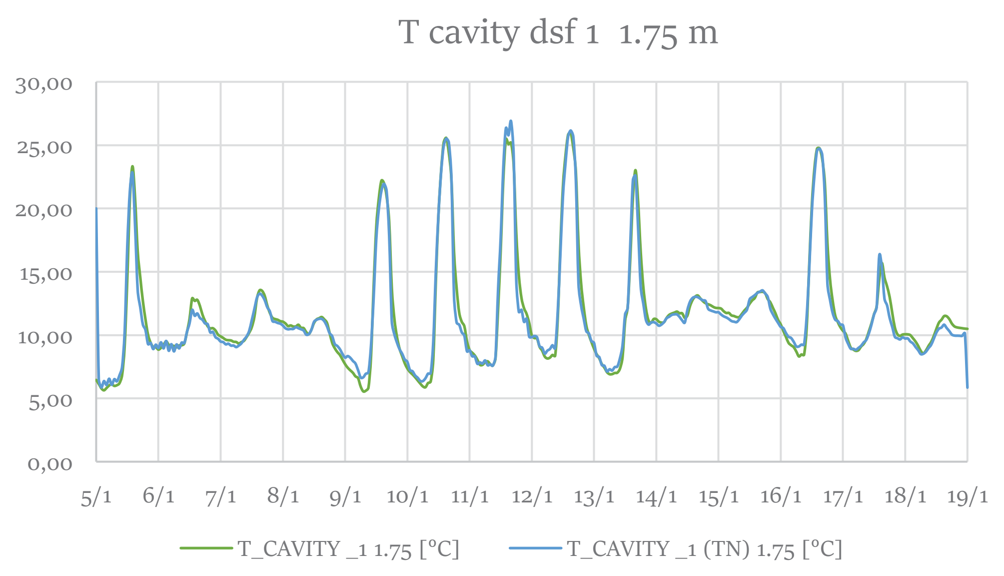


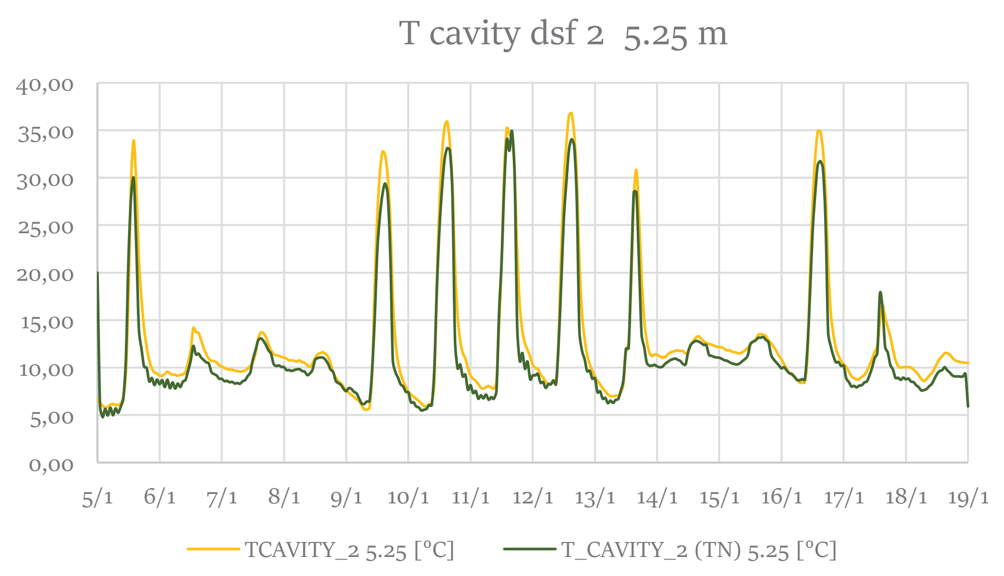
Finally, we analyze the use of the fan, which for this facade, concerns the forced ventilation of the only double skin facade. In particular, to balance the superheating effect caused by solar radiation, a specific control of fan speed is tended to be defined. This schedule is parameterized with values that during the daily work phases are high while during the night are lower; moreover, there is a slight decrease during the weekend.



- **Temperature of the air cavity**

Also in this type of façade, the experimental measurements do not coincide with the heights relative to the TRNSYS airnodes. Therefore, interpolations of the experimental data were carried out and, through a trend evaluation, the measurements relating to the software data were eliminated. Specifically, the most used heights coincide with the centre of gravity of the two DSF modules 1.75 m and 5.25 m.

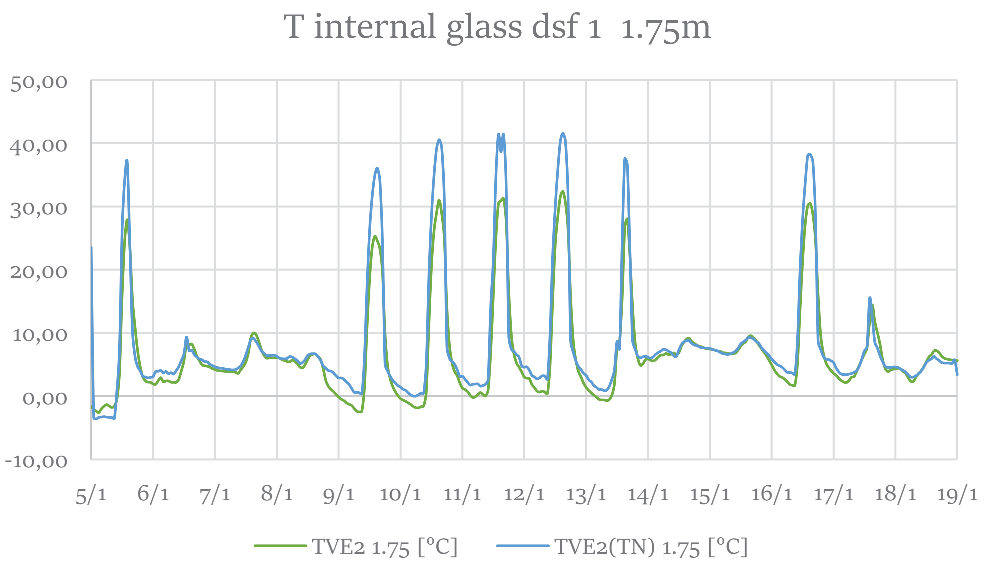


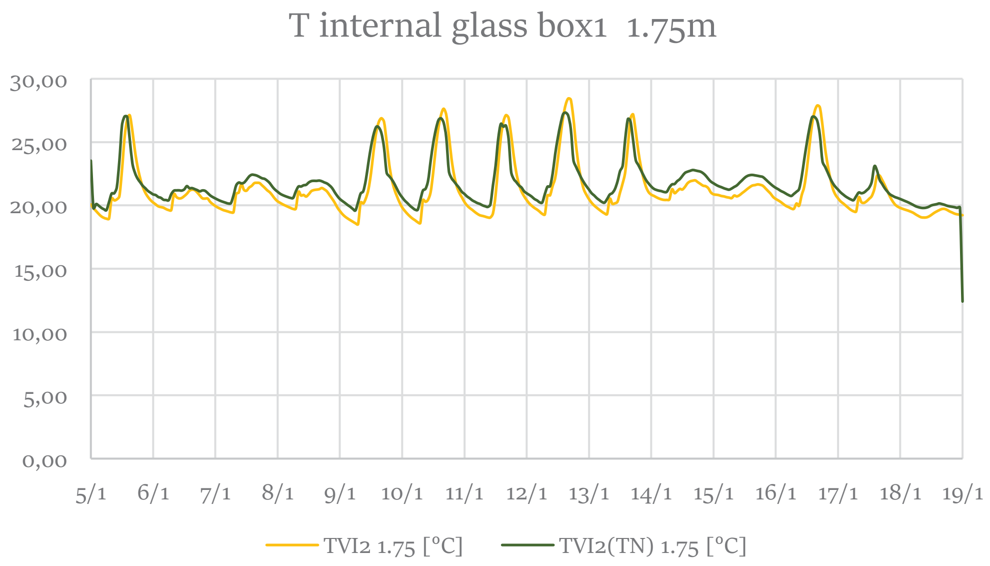


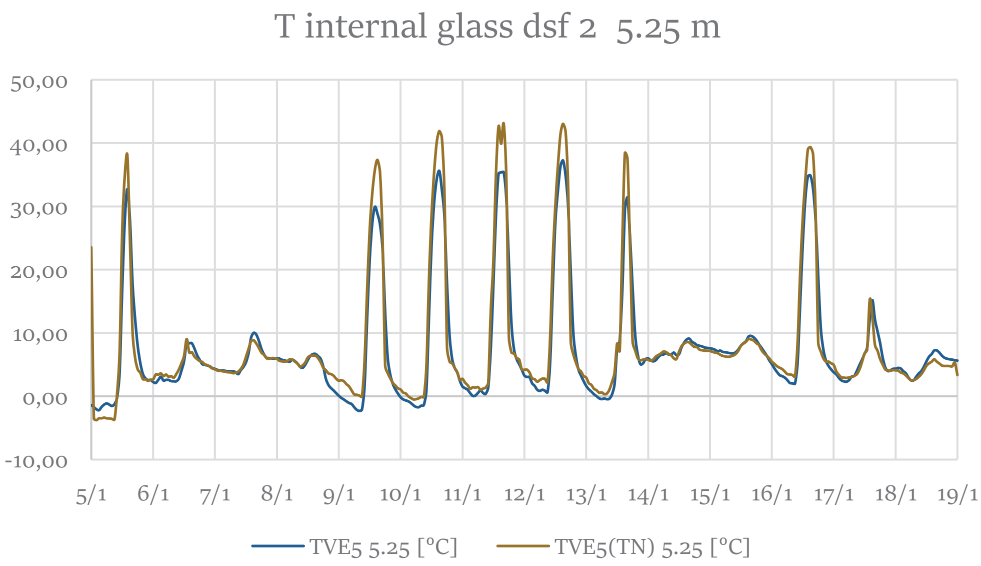
In this analysis there is a good reading of the software of the incident solar radiation, this characterizes the results extremely close to the experimental data. The only differences that can occur are the usual effects related to the thermal inertia of transparent components that offset the graph of the simulated data.

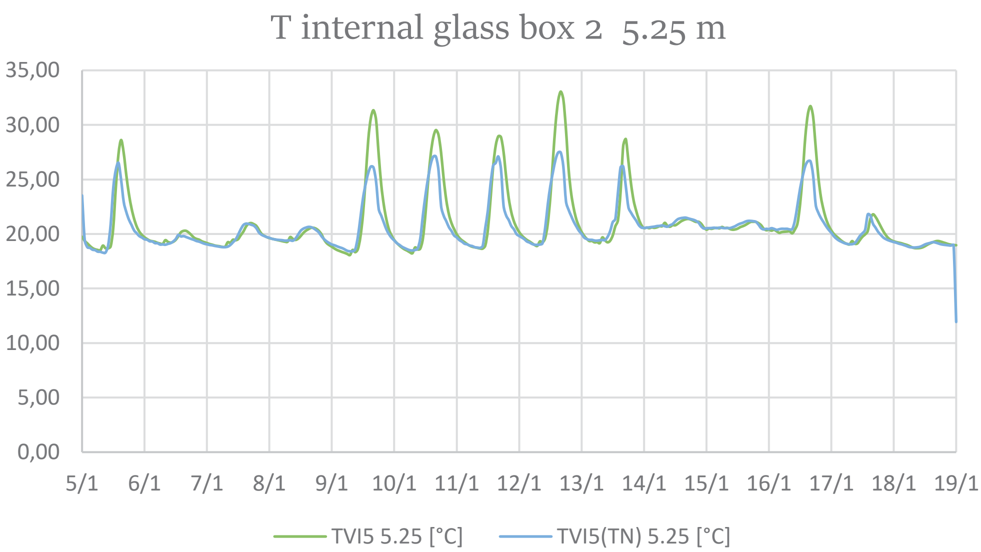
- **Surface temperature of internal and external glass**

Another small problem that is evident in the analysis of surface temperatures is that of not reaching peaks on certain days, this could be characterized to the not perfectly correct interpolation, and the other due to the composition of the glass.





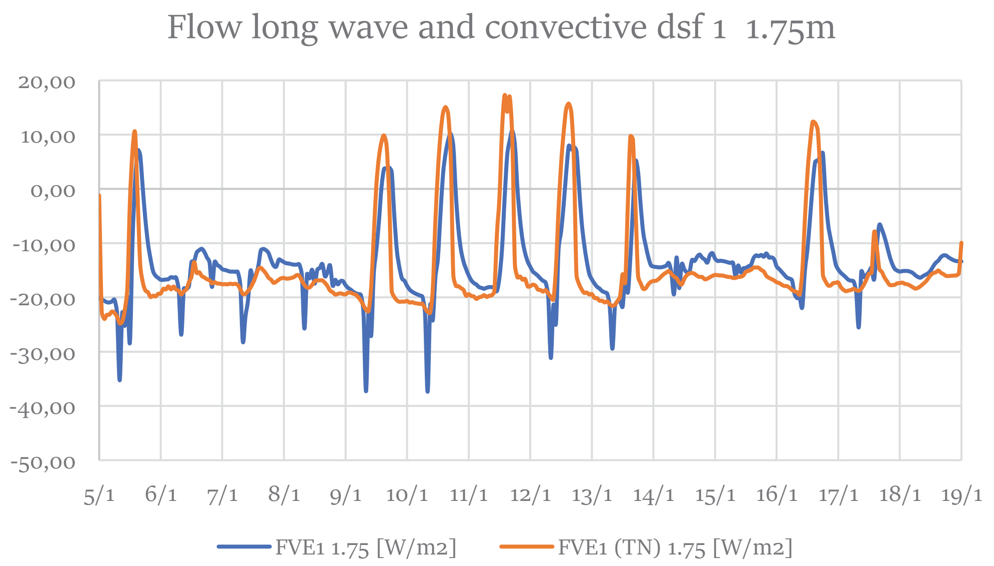


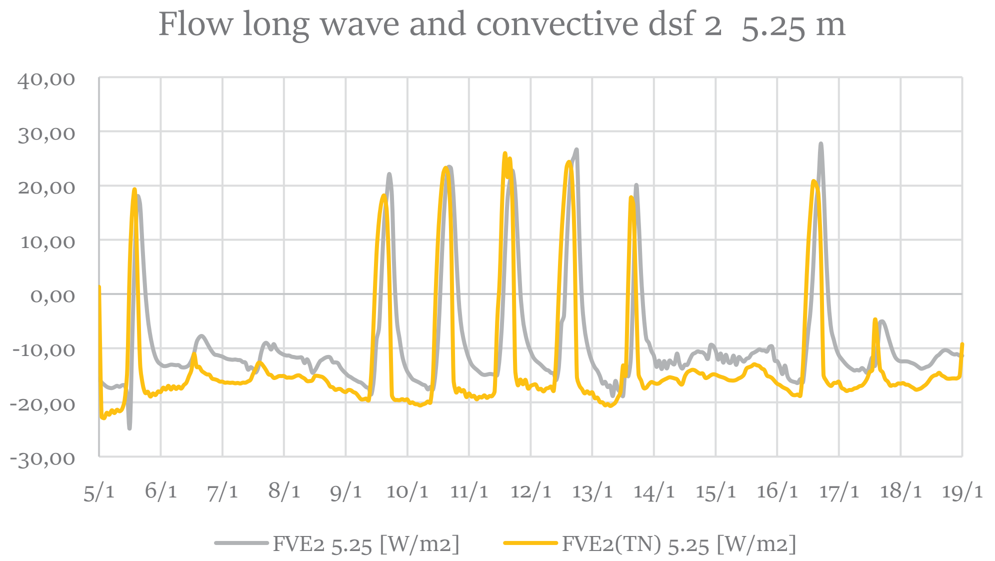


From this comparison we can deduce that another influential factor is certainly the height in fact the software will be more sensible to the source of air introduced, accentuating the peaks in the first part of cavities and reducing them in the second.

- **Thermal flow longwave and convective of internal glass**

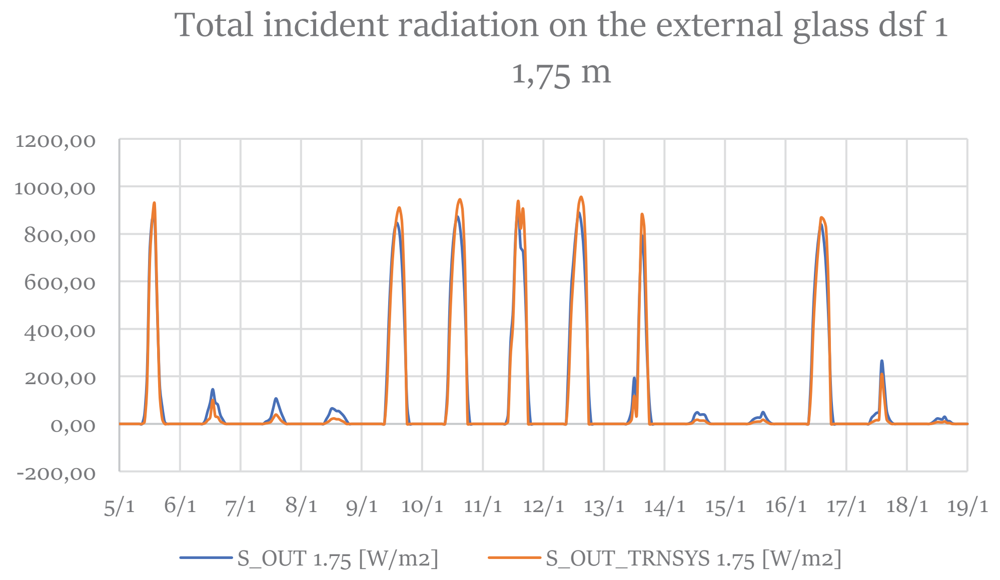
Keeping in mind the considerations made in the previous point, we find confirmation in the data in front of the flow, where the dsf 2 presents a smaller gap from the experimental data that highlights a mile balancing of convective exchange. The phase shift continues to be the problem related to thermal inertia.

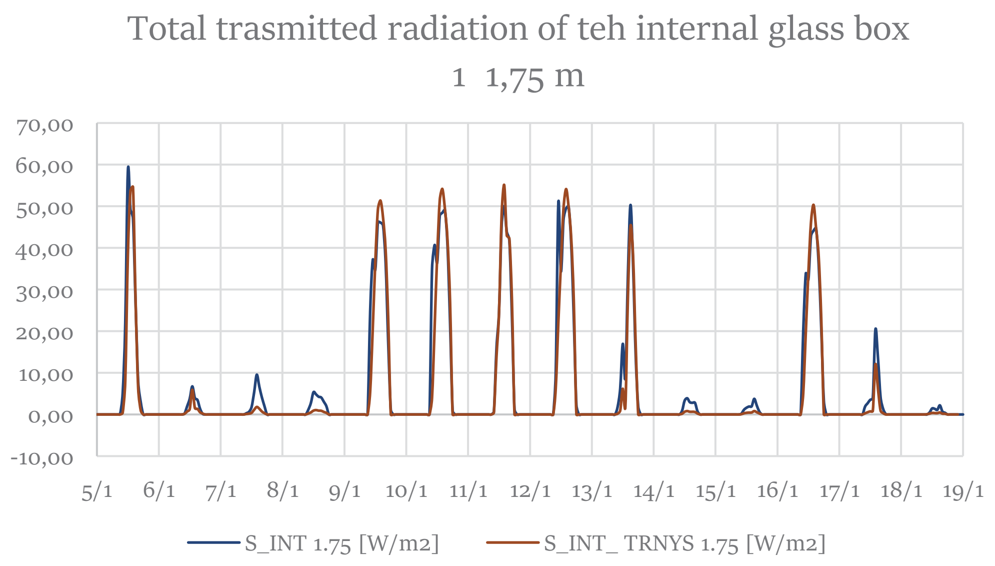




- **Solar radiation**

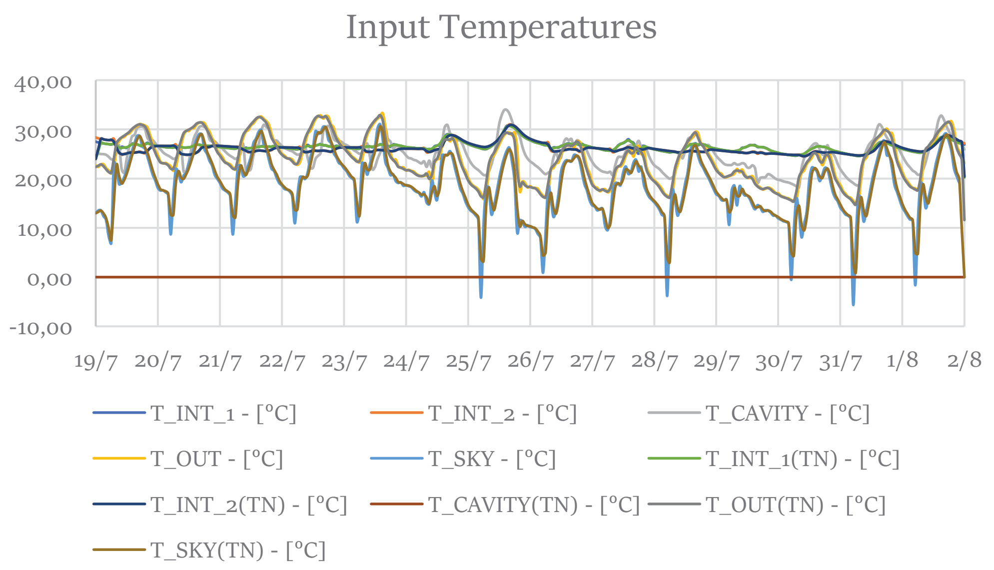
Finally, we find the solar radiation, this feature, as already reported is better than the previous study in fact the values on the vertex are correctly read from the climate file. This procedure allows to have a better data and therefore to have to balance the characteristics of the glass to obtain a good result.
Thus, I do not support variations on the shade.



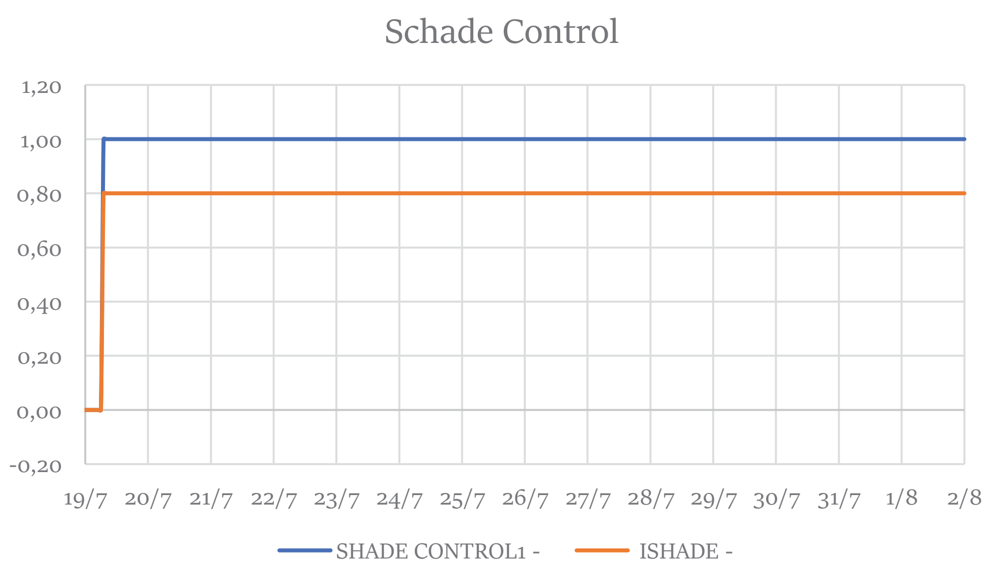


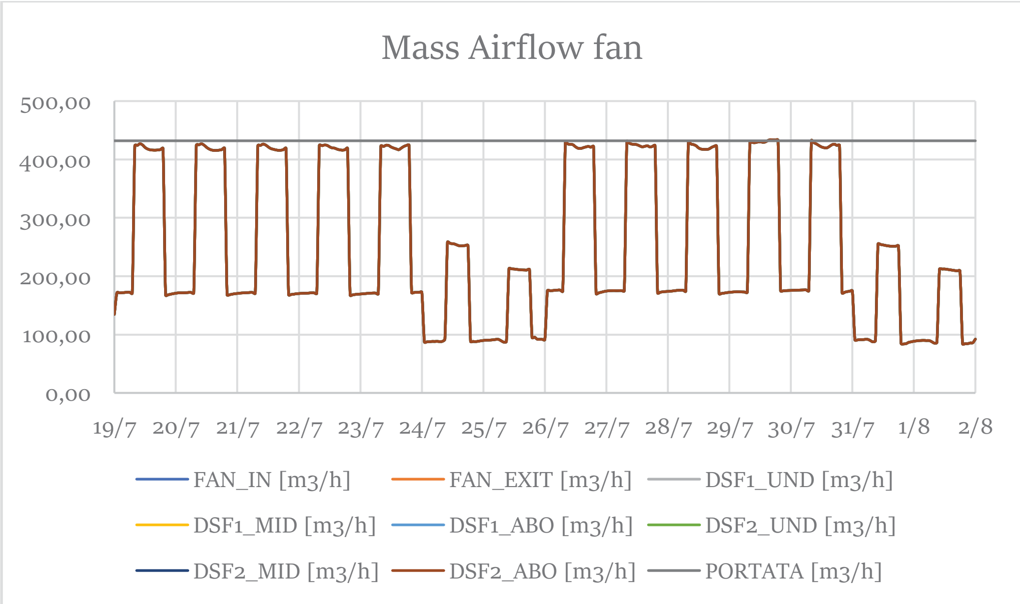
4.2.2. Data monitoring summer season

The data are presented for the winter case, corresponding to the period of monitoring 19/07 - 02/08: lowered solar shading, external glass with slab double, with selective external glass. To perform the experimentation, have been evaluated the responses of our model, which receives this following input temperatures.



The fan and shade settings remain constant to the winter simulation.

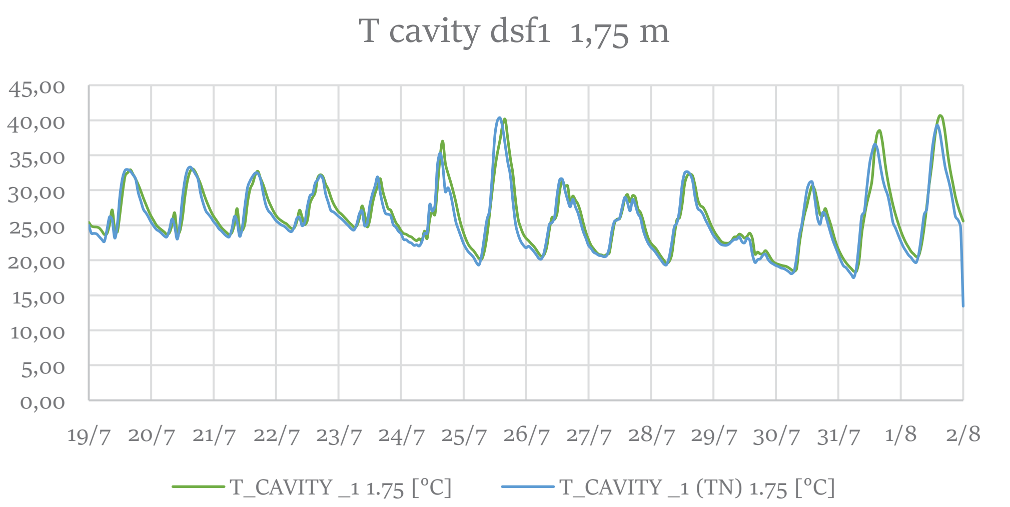


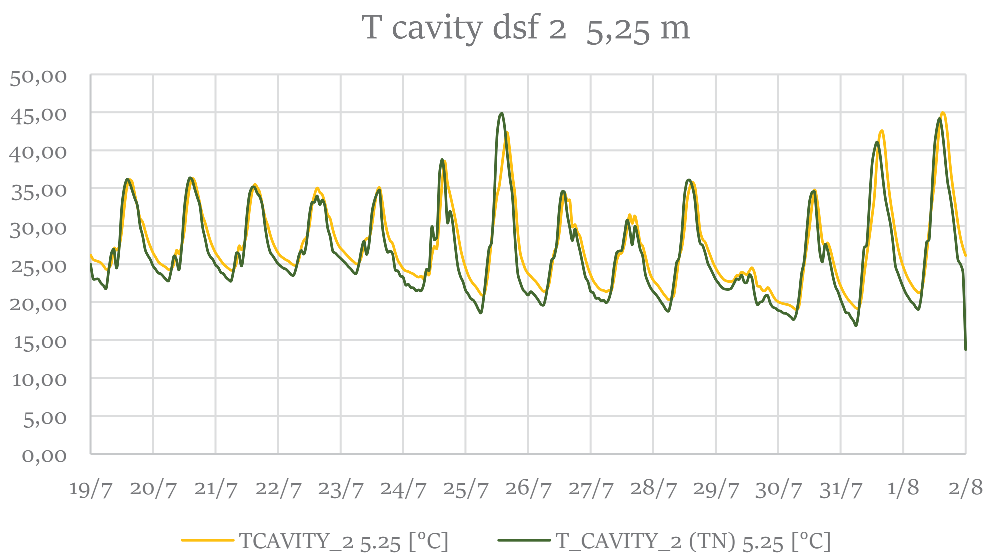


Also in this modelling the double skin facade in summer experiment the same errors related to winter data. However, the evaluations remain quite positive as solar radiation is also parameterized in the corrected form.

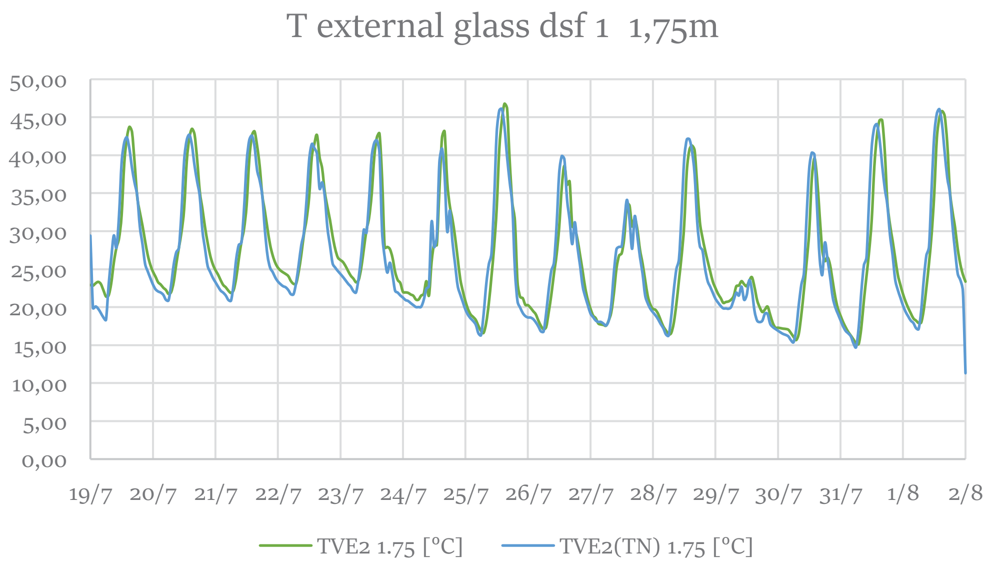
It was chosen to insert the graphs without comments as they will have the same inconsistencies of the winter simulation, naturally with different values of temperatures and flows.

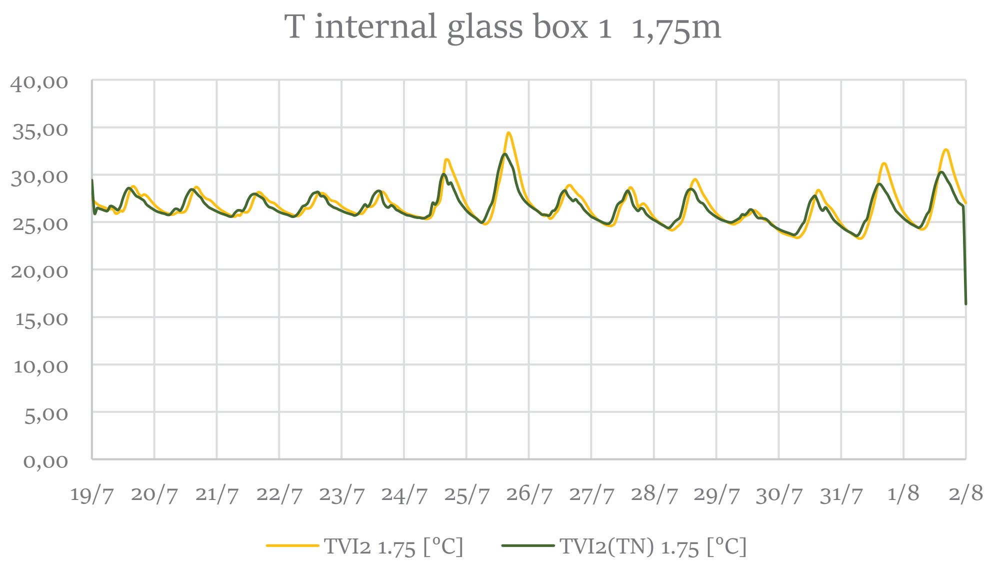
- **Temperature of the air cavity**



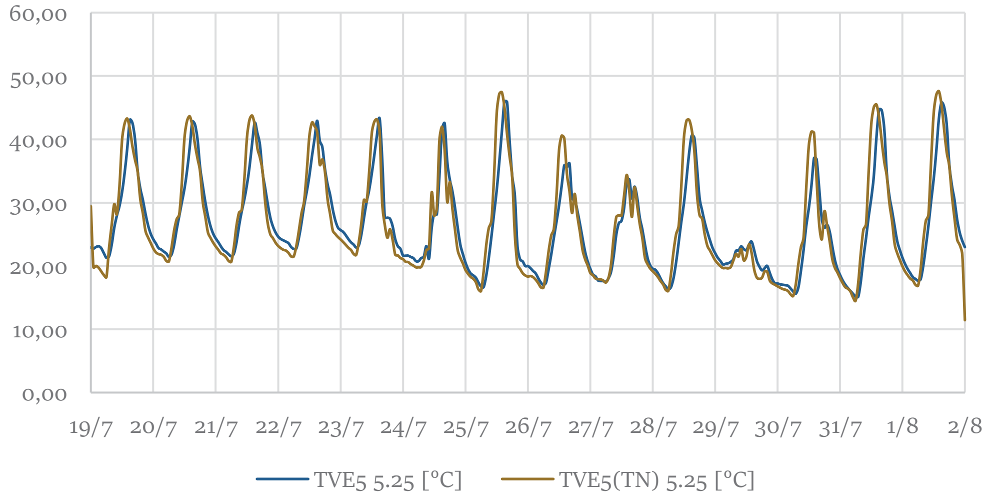


- **Surface temperature of internal and external glass**

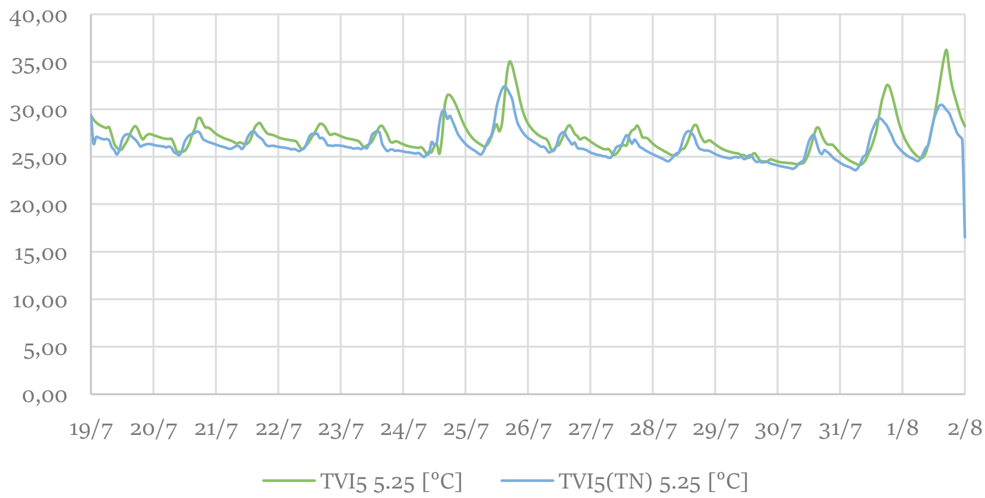




T external glass dsf2 5,25m

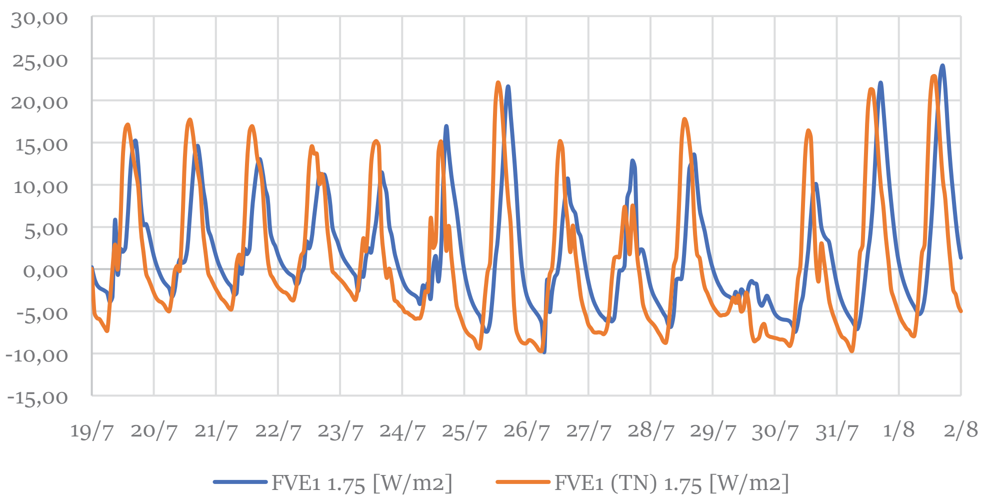


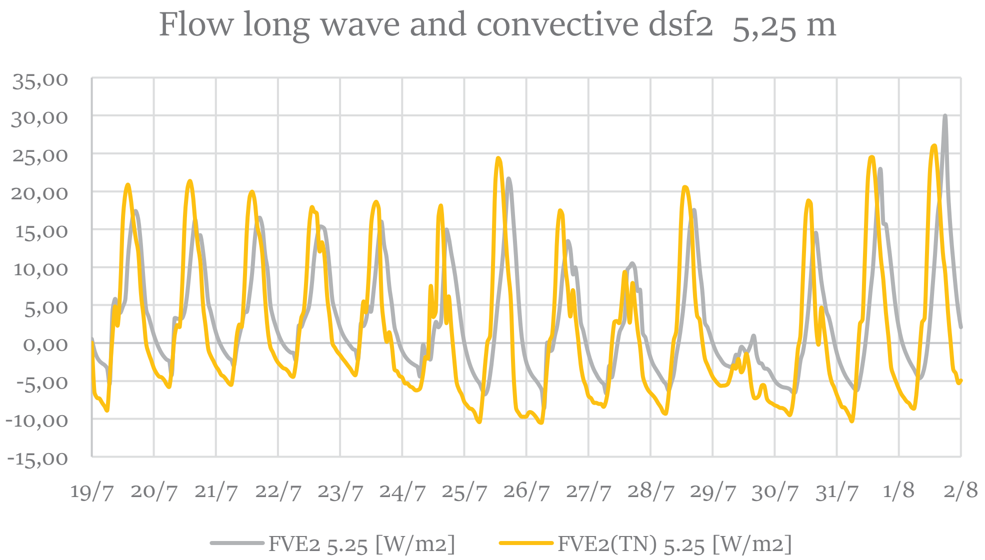
T internal galss box 2 5,25m



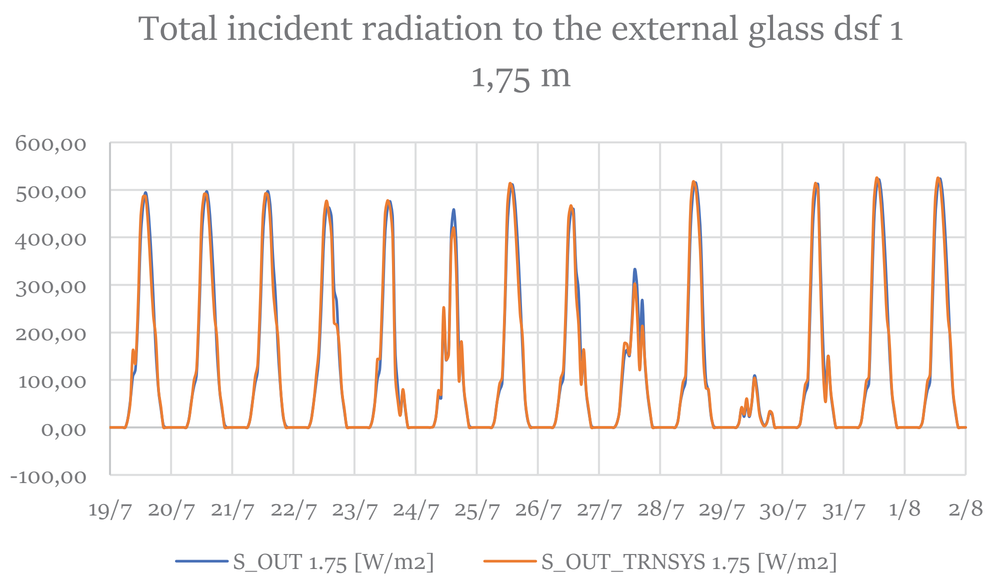
- **Thermal flow longwave and convective of internal glass**

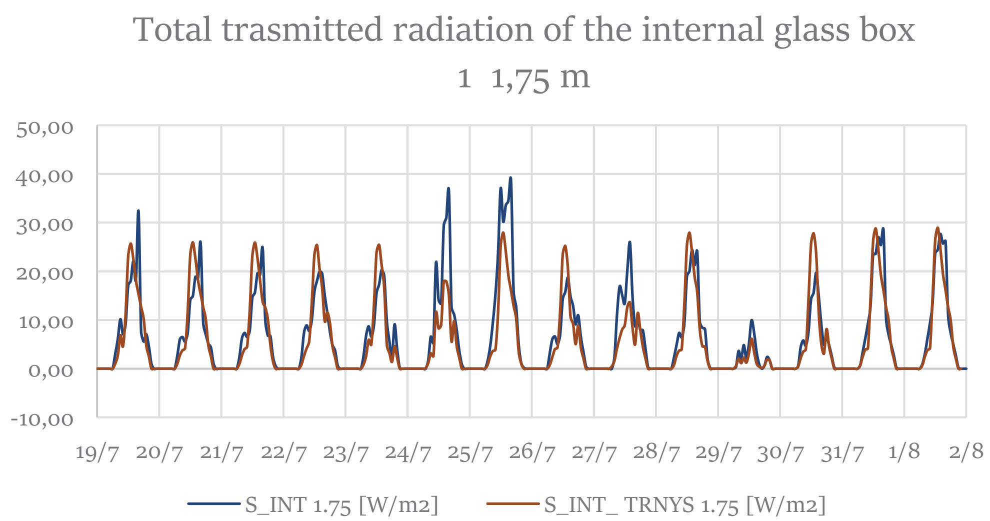
Flow long wave and convective dsf 1 1,75 m





- **Solar radiation**





4.2.3. Observations

In conclusion, it is possible observe how in both simulations, one of the fundamental aspects is certainly represented by the control of solar radiation. In the first case, this capacity was poor, but by simulating a profile with the same trend it was possible to evaluate the hypothetical reaction that it had on the component. Surely the simulation of SOMEC, offers a more precise evaluation; in fact, where the results of the solar radiation are read correctly, certainly the setting and control of the shade are satisfied in both fundamental models. In fact, from the first simulation, there was a serious problem, because the glazed components could not even simulate 50% of the actual peaks ; then , from the software analysis , it was realized that the problem was induced by the shade capacities set by TRNSYS. This device is considered with a thermal resistance of default which is not explicit, but certainly can be increased.

As soon as a minimum value has been added to this component, the parameters have started to take shape. This means that the shade begins to store solar radiation and convert it into heat, making surfaces and cavities warmer. As far as the displacement of the profiles is concerned, it has been made known, that these software are not able to reproduce the effect of thermal inertia of the glazed components.

Finally, as can be seen from the comparisons, the TRNSYS software has a good calculation operator with re-investigated requisites, but fails in receiving data and transformations of solar radiation, being implemented on its own non-modifiable calculation bases.

5 CONCLUSION

The study of the thesis was focused on the technological component double skin facade, which is one of the most advanced hi-tech solutions in terms of energy efficiency. Double skin façade is part of a series of technological innovations that tend to revolutionize the concept of building envelopes, from static element to a dynamic element. This necessity derives from the fact that in recent decades the energy consumption of the building both at the European and the world level emerges as a main culprit of the overheating of the earth and the exploitation of natural resources.

To overcome this phenomenon, the institutions have induced new protocols and precautionary measures aimed to reduce CO_2 emissions and consumption of primary energy. Regarding the building, sustainable design is the fundamental basis of the energy development of the building envelope.

This function uses advanced technologies that can reduce consumption and improves the aesthetic and performance quality of the envelope.

The DSF that are part of this category, are presented with a structure composed by two layers of glass, with a cavity inside, which can have different widths. A function that characterizes the façade is the ventilation of the air, which makes it possible to provide a thermal and energetic comfort to the building. The thesis shows an overview of the main types of façades that can be used in the fenestration design. The dynamism of the façade, involves a change in the configuration of the ventilation which makes it suitable for various climates. The application of the double skin facade today is constantly evolving, but there are no guarantees on their functionality for any type of external condition. Experimental evaluation systems are used to evaluate the functioning and the actual gains that this component can provide to the building's total energies. The processes developed over the last decades have undergone an important evolution, which has given a wider choice of tools

for detailed analysis. In fact, new automated calculation models called BPS-tools have been developed.
This topic has been studied in detail, because the study of the thesis, aims at the simulation and modelling of two DSFs through the BPS Tool TRNSYS.
The BPS, are instruments characterized by very complex structures, based on high performance computing units. Through a series of selection criteria, it was possible define a choice that could have good results on the application to the two models under examination; the software chosen was TRNSYS.
This software is useful for ventilation; it has the ability to define a detailed airflow diagram through the specific TRNFLOW component.
The initial phase of geometric modeling in TRNSYS was a very simple process; the software uses a Sketchup plugin that allows you to create thermal zones and impose boundary conditions to the components used for the construction. Successively TRNSYS, must be set through the realization of a scheme made up of units specialized in the calculation or reading of determinate parameters, called "Type". This phase was one of the most complex to be developed, due to the multi-disciplinarily of the software, which has an infinite library of "Type". To solve this problem and obtain a valid scheme for the experimental analysis, it was necessary to analyze all the software descriptive profiles and to interface with people from the ZEB department of Trondheim specialized in the use of BPS-tools.
Furthermore, even the phase of parameter setting was not easy. In fact, after having defined the main structure, all the parameters relating to the building components must be set, through a unit dedicated to the building multizone called Type 56, This section has an interface quite user-friendly, but difficult to edit, because it is based on calculation models and pre-established functions. An experimental analysis means evaluating the responses of a component subjected to pre-established values; to replicate this condition, the BPS, aim to obtain flexible systems capable of developing and interacting with the input conditions, excluding the random variables. Getting this result into

practice is a complex job and even today, there are several contrasting points to finalize this goal in the best possible way.

One example is the parametrization of the glass in TRNSYS. These components cannot be modified, but are chosen from a default library. In order to parameterize with the characteristics of the experimental analysis glasses, an additional software was used to evaluate the thermal parameters of the glasses starting from the composition. This process demonstrates one of the unfavorable points of the software in terms of completeness and versatility of the system.

Continuing the interoperability of TRNSYS, another factor that influenced the outcome of the test was certainly the assessment of the shade. the software imposes, a default thermal resistance value, which characterizes the passage of solar radiation and the dual absorption of the component. To evaluate the behavior of this device, several tests have been performed.

In the end, it has been concluded that the thermal default resistance of the shade must be increased by a value not established to obtain a response in terms of heat exchange inside the cavity and on the surfaces of the components. Finally, regarding the setting; another parameter that has been of most interest in the various tests of the modeling is solar radiation. the software calculates this component through 2 possible configurations, detailed and standard.

The standard model requires a great number of specific values and parameters that needs a very detailed description of the radioactive process.

While, in the detail model the system has an intelligent calculation unit based on optical factors, which automatically performs the decomposition of the solar radiation received from the climate file. From the experimental analysis treated, the standard model is complex and unreliable, as it is incapable of transforming and reading the radiation incident on the surfaces. On the other hand, about the detailed procedure, the calculation is certainly valid but it is not possible to define the quantity of the component decomposed by the software.

The facades of the thesis are: a double skin, box-window located in Turin, used as an experimental mock-up for the building (NSRP) and a double skin multistory, based on two floors located in Treviso in the SOMEC building.
The two facades are characterized by a mechanical ventilation, for this reason, TRNSYS was very useful for defining the design of ventilation.
The first, was made up of a selective double glass on the outside and a low emission glass inside, while the other has a single glass outside and a low- e glass inside. As previously explained, the optical properties of the glass affect the analysis, it is noted that going to modify the parameters of reflection and absorption it is possible to obtain a response close to the experimental data.
The two fundamental parameters that regulate the trends are solar radiation and shade. In particular, from the final evaluations it has been deduced that the NSRP façade does not report a reading of the solar radiation of the climatic file more correctly, a trend like the experimental one is obtained, but with a larger quantity of 100 w / m^2.
To obtain comparable values, it was decided to balance the incoming radiation through a greater amount of shade absorption. These conclusions led to obtaining acceptable flow and temperature values. The only problem we encounter is the thermo-phase displacements due to the lack of software capacity to reproduce correctly the thermal inertia phenomena of the components. this phenomenon is accentuated on the calculation of long wave thermal flows that are a function of solar radiation and convective flow.
In the SOMEC modeling, the software can read the solar radiation measurements of the climate file and accurately report the results. The comparison does not show the particular difference, except the usual interference due to thermal inertia, which divides the profiles and does not reach the peaks.
Finally, the results obtained from the use of the SOMEC model, are quite representative of the real conditions of the mock-up also in view of the uncertainties related to the speed of the fans and the characteristics of shade and glass. To improve the results achieved so far, further future studies will

have to evaluate the influence of these parameters. About solar radiation, the software is not very reliable, so you will have to find suitable tools model the characteristics that were neglected in this preliminary study or simplified.

In conclusion, it can be said, that the BPS tool as TRNSYS are useful software to simulate experimental analyzes and to support research, but not completely to replace direct measurement and therefore become a single processor of qualitative and quantitative energy evaluation.

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