# ENERGY EFFICIENT BUILDING

Building And Architectural Engineering
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Case study : Home For Life
Team 14

POLITECNICO
MILANO 1863

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2019-2020

# CHAPTER 1

## BUILDING GENERAL INFORMATION

## Study case n°2: Home for Life


FIGURE 1.1

**Architects:** AART Architects
**Partners:** VELFAC, VELUX Group, Aart Architects and Esbensen Consulting Engineers, Engineering College of Aarhus, Alexandra Institute, Aarhus School of Architecture, Danish Building Research Institute, Municipality of Aarhus
**Contractor:** KFS-Boligbyg
**Developer:** VKR Holding
**Type of project:** New construction
**Building type:** Detached house
**Project Year:** 2008
**House Address:** Lille Elstedvej 5, 8520, Lystrup,Denmark
**Area:** 200.0 m2

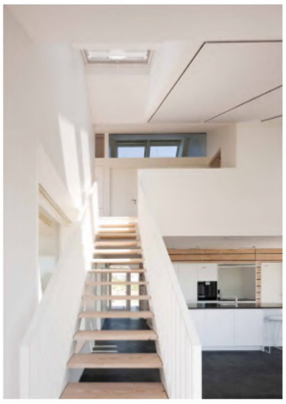
**Number of units:** 1 housing

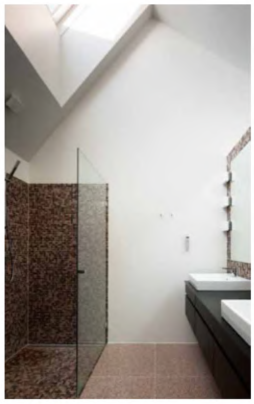
## General concept introduction

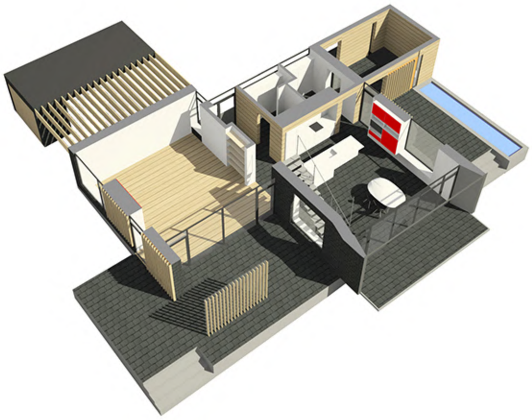
Home for Life represents in many ways the aspirations of homeowners in the early 21st century. It is home to the Simonsens,a family of five, with a large, undivided living space on the ground floor and individual rooms above. Home for Lifeis the first of six buildings in Europe to be constructed as part of the Model Address Home 2020 experiment. Home for Life is an active house producing more energy than it conumes. With an expected energy surplus of 9 kWh/m2/year, it takes Home for Life approx. 35 years to produce the same amount of energy that was used to produce its materials, and by that time, the house will have returned more to nature than it has consumed. Over the long-term, therefore, the house will be an asset for rather than a burden on the environment.

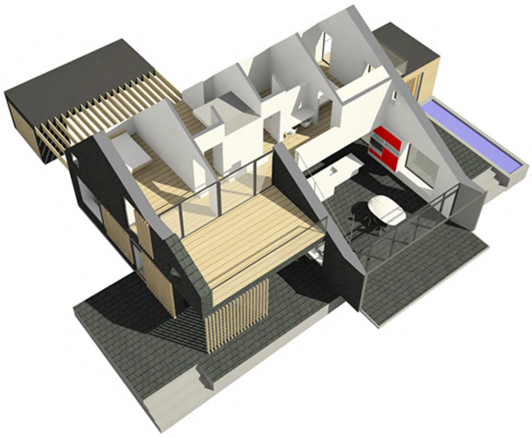
FIGURE 1.2

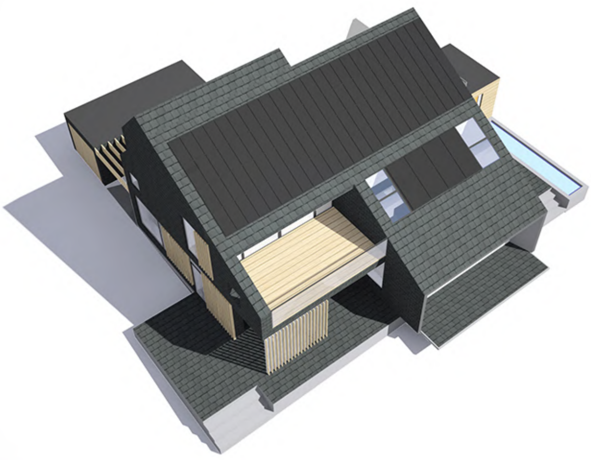
Home for Life was developed by the VELUX Group and VELFAC in cooperation with aart arkitekter and bensen Consulting Engineers. The house is the result of an interdisciplinary project to incorporate the issues of energy, comfort and visual appeal into a holistic entity in which these parameters supplement each other and give the best possible quality of life in the home and its surroundings. the idea was to creat a carbon-neutral building that would benefit from solar energy, both actively by producing electricity and solar heat and passively by benefitting from the heat of the sun.





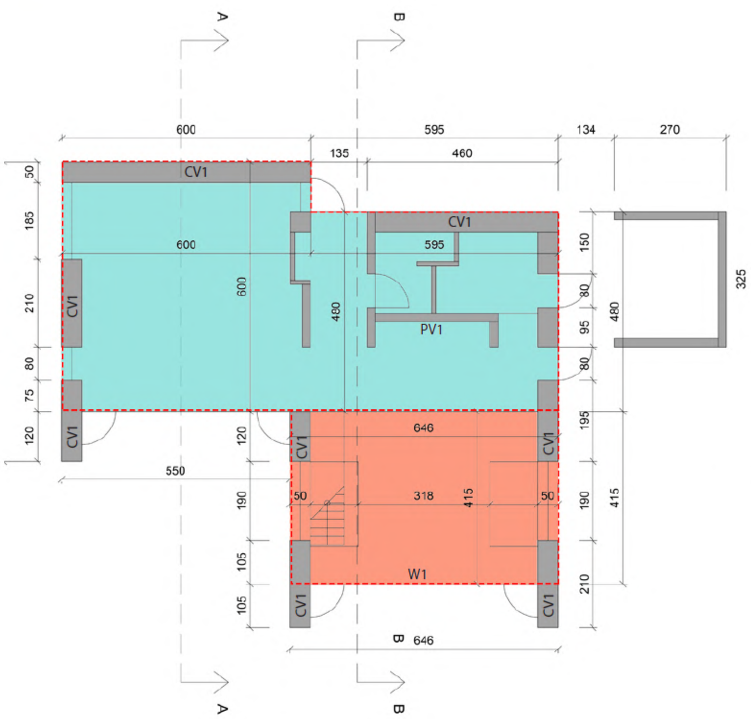




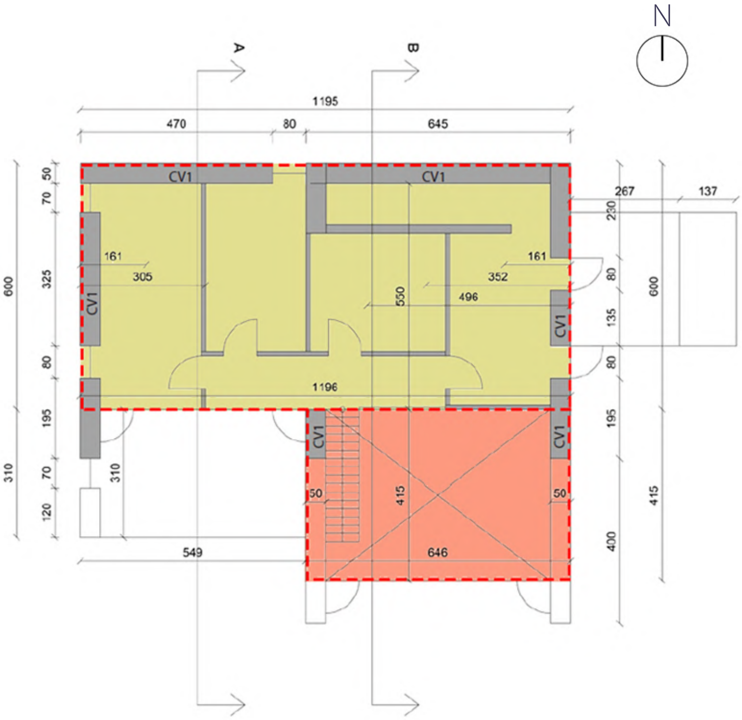


## HOME FOR LIFE CONSISTS THREE THERMAL ZONES:

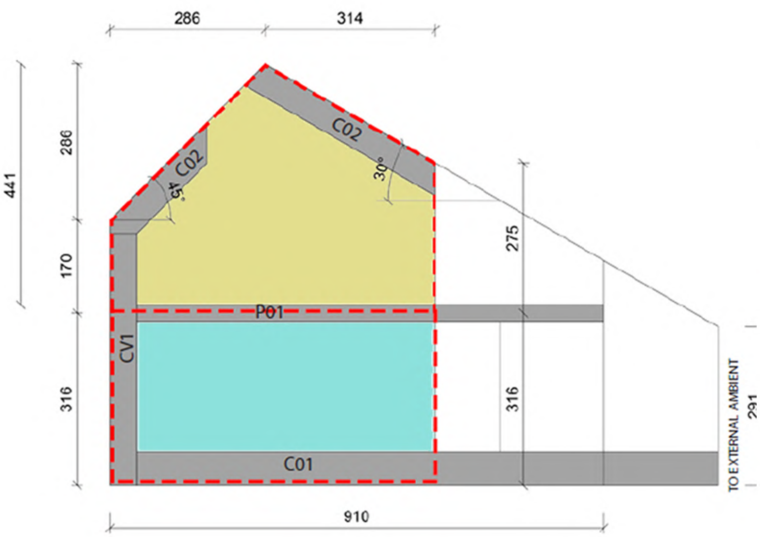
- **ZONE 1** IS LOCATED ON THE GROUND FLOOR WITH A TOTAL AREA OF 65m2
- **ZONE 2** IS LOCATED ON GROUND FLOOR AS A DOUBLE HEIGHT SPACE COVERING A SURFACE OF 27m2
- **ZONE 3** IS LOCATED ON FIRST FLOOR (ON TOP OF ZONE 1) THAT COVERS 72m2



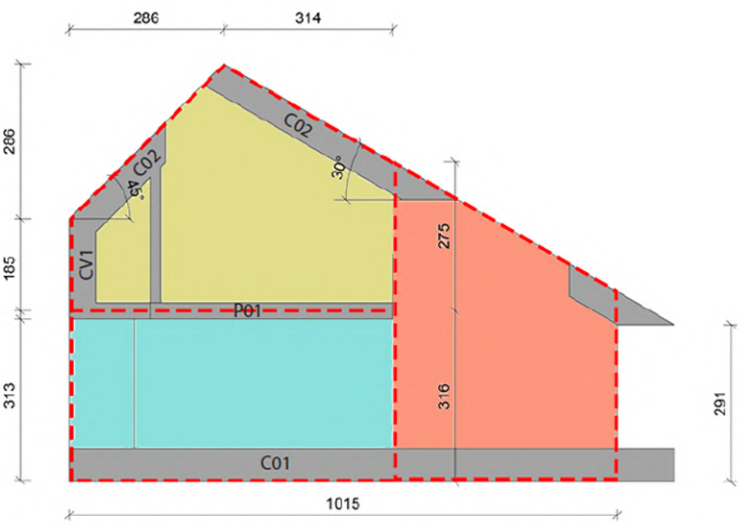

**GROUND FLOOR PLAN**
FIGURE 1.3




**FIRST FLOOR PLAN**
FIGURE 1.4




**SECTION A.A**
FIGURE 1.5




**SECTION B.B**
FIGURE 1.6

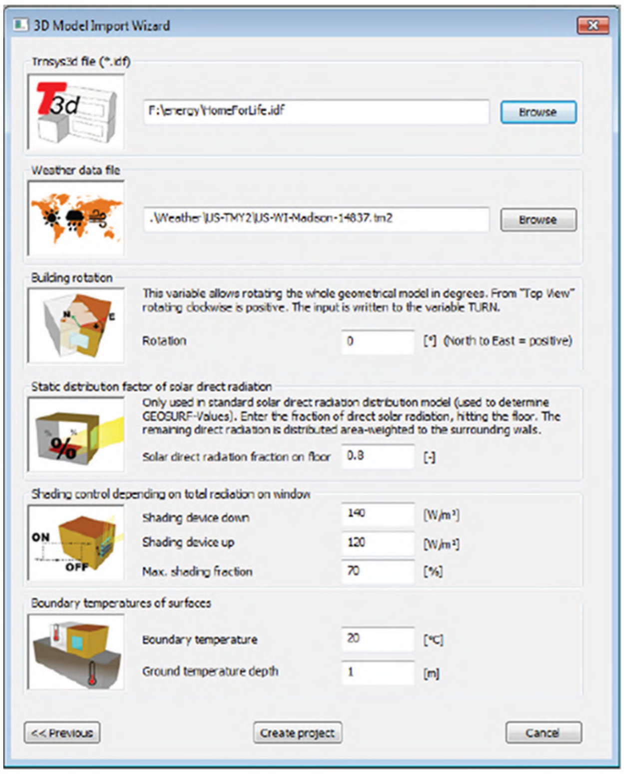
The modelling phase is the first one in the simulation process and is important that the 3D building has a good precision,to have reliable results. While modeling the building a lot of checks were made to avoid errors. For this reason the model has been exported several times in "Simulation Studio", verifying it was free of faults.

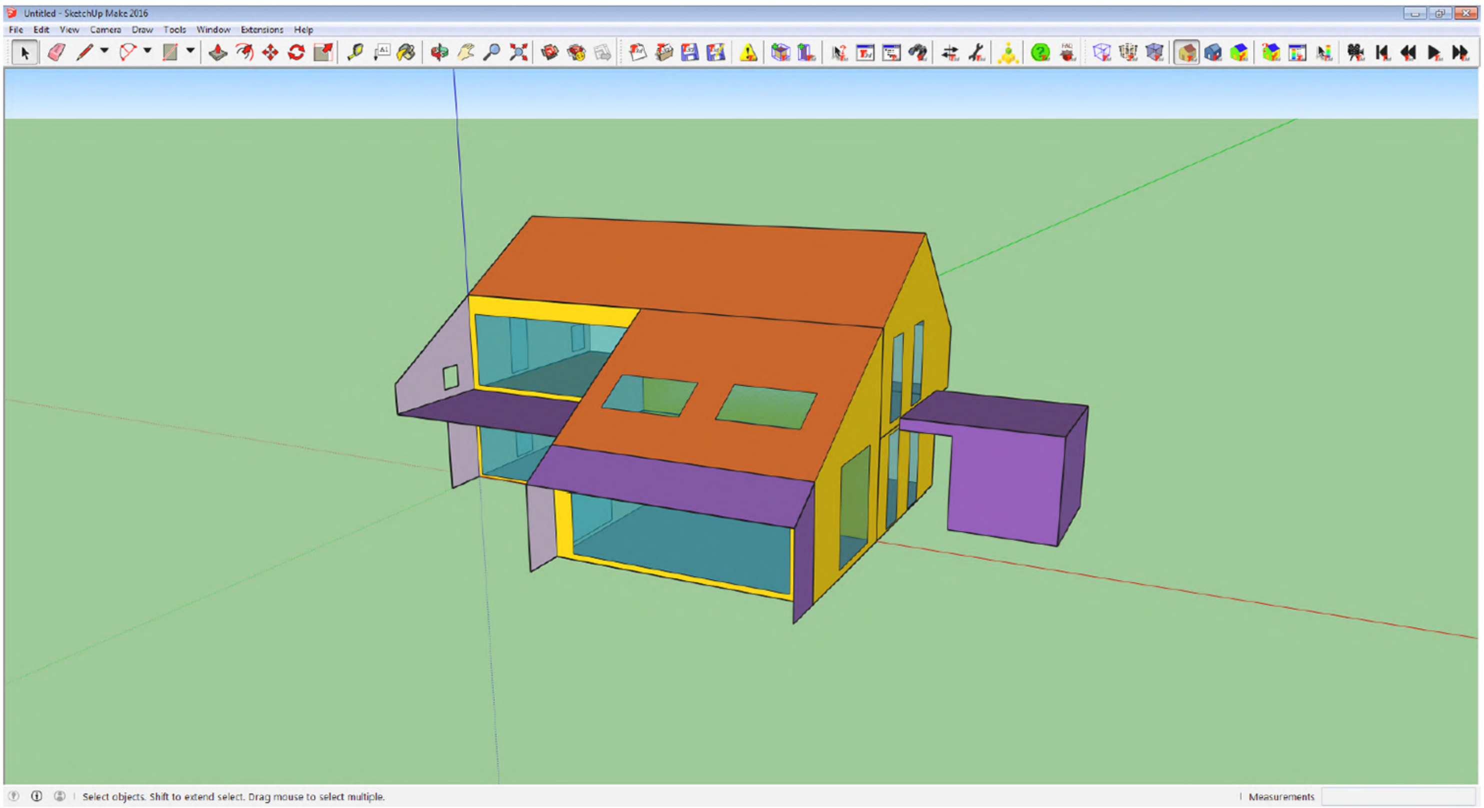
To explain the modelling process are here reported by screenshot.
The first step is to use the Trnsys3D plugin for Sketchup.

In this screeshot is possible to see the building completely modeled. Thanks to the plugin it was possible to assign specific informations of the building to each technical element, walls, roofs, floors and windows, created in Sketchup as a simple surface.

The model was divided in three different Thermal zones, as specified in the building informations. Every thermal zone has similar thermal features.
For each surface of the different thermal zones it has been set up the boundary conditions, if adjacent with other surfaces,or in contact with exterior. This allows to the program to understand the behaviour of the different zones relating to external temperature.

The TRNSYS Simulation Studio is a part of the whole software, in which is possible to set the different simulation parameters.
Importing the .idf file as "3D building project", setting the orientation and position, the weather file and the boundary temperature.



The envelope technologies in this study are divided into constant technologies (less effective on performance) and varied technologies. The three elements that are constant in this study are: Partition Wall and horizontal slabs, since they perform only as a division between two internal zones. Ground floor slab, since it performs between an internal zone and ground which has a roughly constant temperature throughout the year.

## Partition Wall

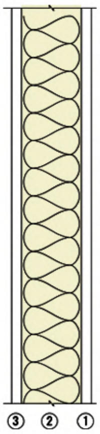



FIGURE 1.7

| N | Layers | Thickness [ma] | λ [W/mK] | C [J/kgK] | ρ [kg/m3] |
|---|---|---|---|---|---|
| 1 | Plasterboard (1+1) | 0.025 | 0.210 | 840 | 900 |
| 2 | Mineral wool | 0.150 | 0.045 | 1000 | 115 |
| 1 | Plasterboard (1+1) | 0.025 | 0.210 | 840 | 900 |

*RESULTS*

| fd [-] | φ [h] | Ms [kg/m2] | U [W/m2K] |
|---|---|---|---|
| 0.799 | 5.03 | 62.25 | 0.2610 |

TABLE 1.1

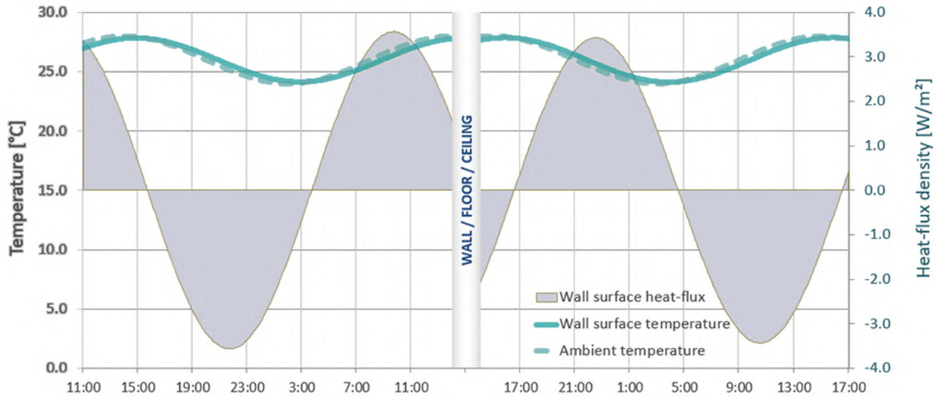



FIGURE 1.8

## Horizontal Slab

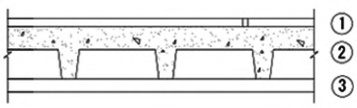



FIGURE 1.9

| N | Layers | Thickness [m] | λ [W/mK] | C [J/kgK] | ρ [kg/m3] |
|---|---|---|---|---|---|
| 1 | Wooden flooring | 0.015 | 0.2 | 1800 | 1300 |
| 2 | Concrete | 0.10 | 0.16 | 880 | 500 |
| 3 | Plasterboard (1+1) | 0.025 | 0.21 | 840 | 900 |

*RESULTS*

| fd [-] | φ [h] | Ms [kg/m2] | U [W/m2K] |
|---|---|---|---|
| 0.759 | 4.65 | 92.00 | 0.9267 |

TABLE 1.2

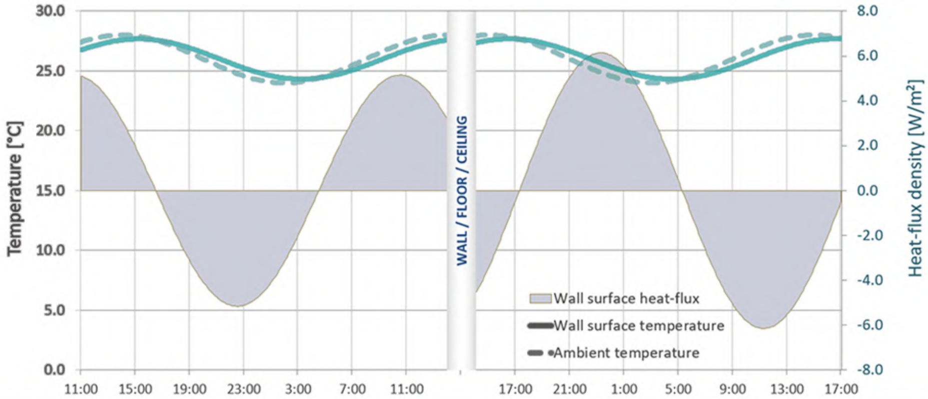



FIGURE 1.10

## Ground Slab base

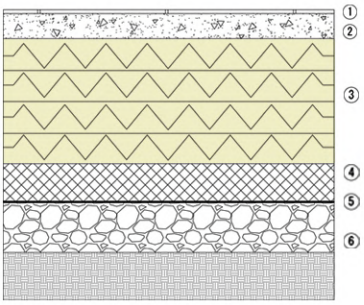



FIGURE 1.11

| N | Layers | Thickness [m] | λ [W/mK] | C [J/kgK] | ρ [kg/m3] |
|---|---|---|---|---|---|
| 1 | Wooden flooring | 0.015 | 0.200 | 1800 | 1300 |
| 2 | Lightweight concrete | 0.100 | 0.160 | 880 | 500 |
| 3 | Polystyrene | 0.500 | 0.034 | 670 | 100 |
| 4 | Concrete | 0.150 | 0.910 | 880 | 2500 |
| 5 | Waterproof membrane | - | - | - | - |
| 6 | Gravel | 0.200 | 2.000 | 1000 | 1800 |

**RESULTS**

| fd [-] | φ [h] | Ms [kg/m2] | U [W/m2K] |
|---|---|---|---|
| 0.006 | 6.57 | 854.50 | 0.0629 |

TABLE 1.3

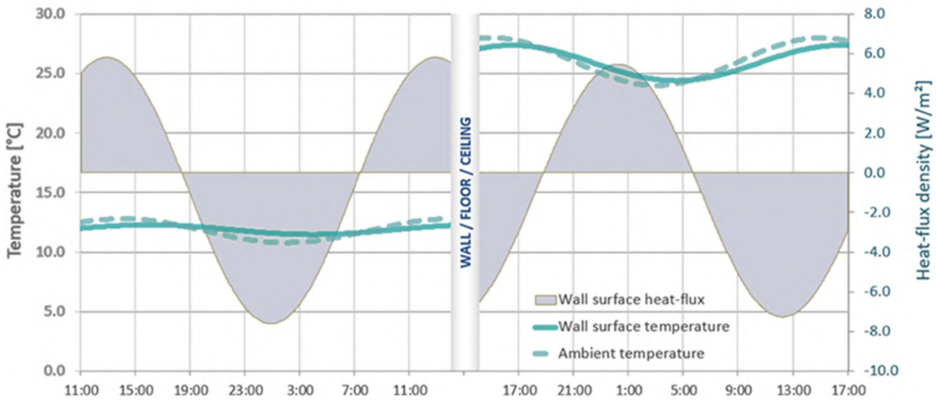



FIGURE 1.12

In the following pages three main strategies will be implement onto two most affecting parts of the envelope, External Wall and Roof technologies. the three technologies are default basecase, light case and massive case. in all three the thermal transmission has been tried to be kept constant so the other variables could be compared and the best performing technology in terms of attenuation, time shift, decrement factor, and finally Periodic Thermal Transmittance (Yie) could be recognized.

## BASECASE PROPERTIES

### External wall

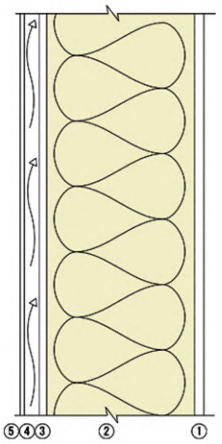



FIGURE 1.13

| N | Layers | Thickness [m] | λ [W/mK] | C [J/kgK] | ρ [kg/m3] |
|---|---|---|---|---|---|
| 1 | Plasterboard (1+1) | 0.025 | 0.210 | 840 | 900 |
| 2 | Mineral wool | 0.395 | 0.045 | 1000 | 115 |
| 3 | OSB | 0.020 | 0.150 | 1600 | 1000 |
| 4 | Ventilated cavity | 0.04 | - | - | - |
| 5 | Finishing | 0.011 | - | - | - |

*RESULTS*

| fd [-] | φ [h] | Ms [kg/m2] | U [W/m2K] |
|---|---|---|---|
| 0.195 | 13.95 | 87.93 | 0.1087 |

TABLE 1.4

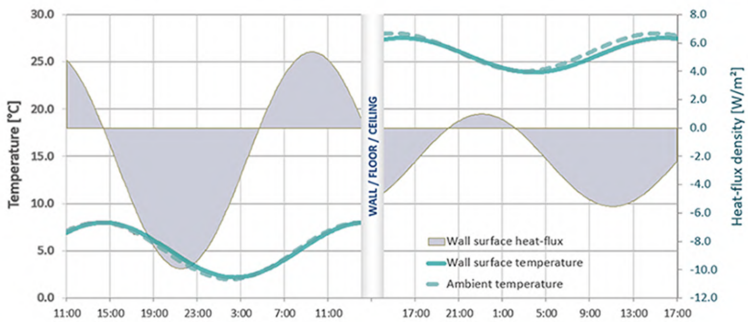



FIGURE 1.14

### Roof

| N | Layers | Thickness [m] | λ [W/mK] | C [J/kgK] | ρ [kg/m3] |
|---|---|---|---|---|---|
| 1 | Plasterboard | 0.0125 | 0.210 | 840 | 900 |
| 2 | Mineral wool | 0.540 | 0.045 | 1000 | 115 |
| 3 | OSB | 0.020 | 0.150 | 1600 | 1000 |
| 4 | Ventilated cavity | 0.04 | - | - | - |
| 5 | Finishing | 0.011 | - | - | - |

*RESULTS*

| fd [-] | φ [h] | Ms [kg/m2] | U [W/m2K] |
|---|---|---|---|
| 0.068 | 18.71 | 93.35 | 0.0809 |

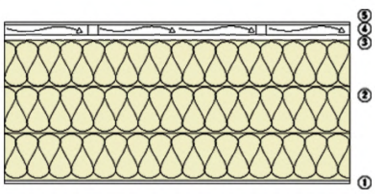


FIGURE 1.15

TABLE 1.5

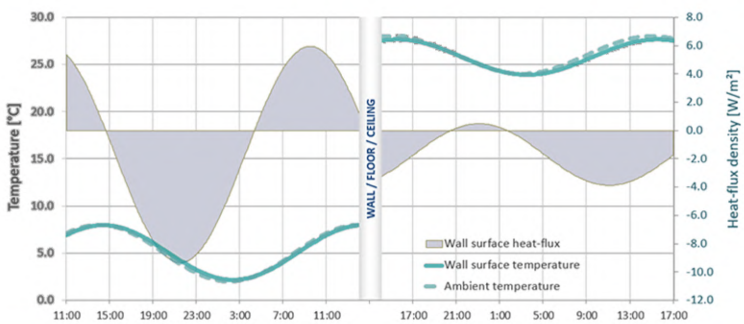



FIGURE 1.16

## LIGHT PROPERTIES

### External wall

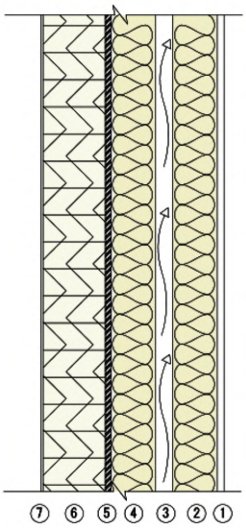



FIGURE 1.17

| N | Layers | Thickness [m] | λ [W/mK] | C [J/kgK] | ρ [kg/m3] |
|---|---|---|---|---|---|
| 1 | Gypsum plasterboard | 0.015 | 0.25 | 1000 | 900 |
| 2 | Rock wool | 0.10 | 0.034 | 1030 | 60 |
| 3 | air cavity | 0.040 | - | - | - |
| 4 | Rock wool | 0.10 | 0.034 | 1030 | 60 |
| 5 | Cement lime plaster | 0.0125 | 0.7 | 1100 | 1600 |
| 6 | EPS 041 | 0.14 | 0.041 | 1450 | 20 |
| 7 | rain screen cladding Aluminum alloy | 0.005 | 160 | 880 | 2800 |

*RESULTS*

| fd [-] | φ [h] | Ms [kg/m2] | U [W/m2K] |
|---|---|---|---|
| 0.186 | 9.75 | 62.30 | 0.1048 |

TABLE 1.6

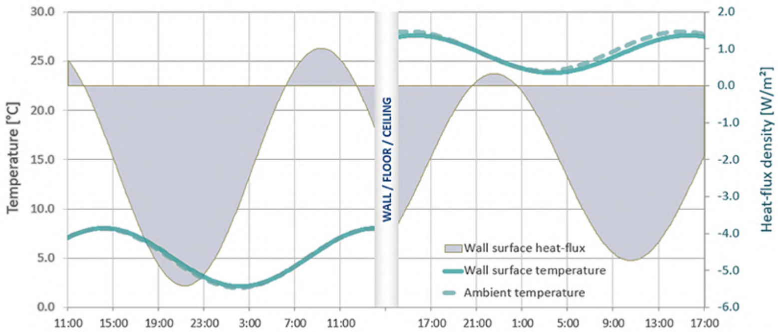



FIGURE 1.18

### Roof

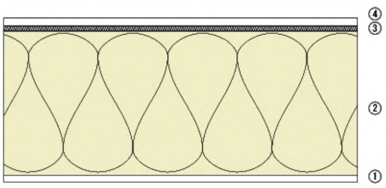



FIGURE 1.19

| N | Layers | Thickness [m] | λ [W/mK] | C [J/kgK] | ρ [kg/m3] |
|---|---|---|---|---|---|
| 1 | Plasterboard (1+1) | 0.025 | 0.210 | 840 | 900 |
| 2 | Mineral wool | 0.54 | 0.045 | 1000 | 115 |
| 3 | Wood fiber insulation board | 0.02 | 0.045 | 2500 | 150 |
| 4 | terracotta | 0.03 | 1.00 | 800 | 2000 |

*RESULTS*

| fd [-] | φ [h] | Ms [kg/m2] | U [W/m2K] |
|---|---|---|---|
| 0.057 | 20.05 | 147.60 | 0.0783 |

TABLE 1.7

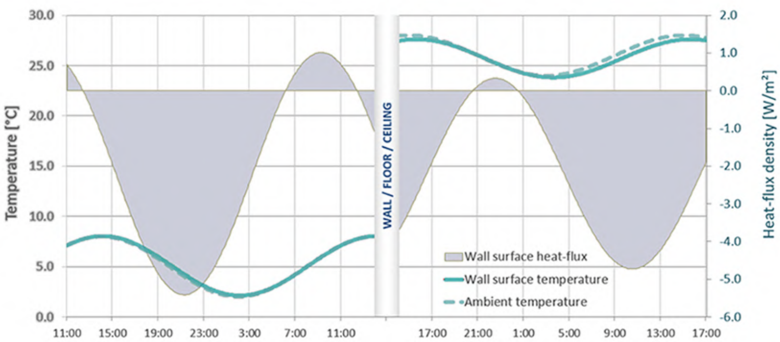



FIGURE 1.20

## MASSIVE PROPERTIES

### External wall

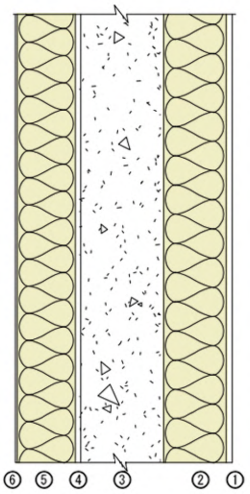



FIGURE 1.21

| N | Layers | Thickness [m] | λ [W/mK] | C [J/kgK] | ρ [kg/m3] |
|---|---|---|---|---|---|
| 1 | Gypsum plasterboard | 0.015 | 0.25 | 1000 | 900 |
| 2 | Rock wool | 0.15 | 0.034 | 1030 | 60 |
| 3 | concrete | 0.20 | 0.39 | 1060 | 1200 |
| 4 | Cement lime plaster | 0.0125 | 0.7 | 1100 | 1600 |
| 5 | Mineral wool | 0.140 | 0.045 | 1000 | 115 |
| 6 | Façade cladding Aluminum alloy | 0.005 | 160 | 880 | 2800 |

*RESULTS*

| fd [-] | φ [h] | Ms [kg/m2] | U [W/m2K] |
|---|---|---|---|
| 0.014 | 16.94 | 312.60 | 0.1207 |

TABLE 1.8

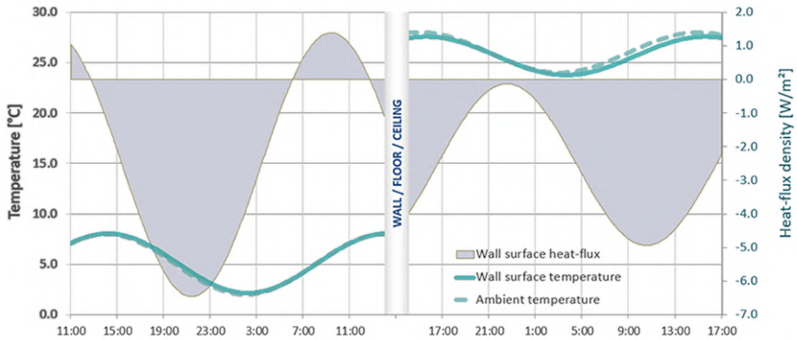



FIGURE 1.22

### Roof

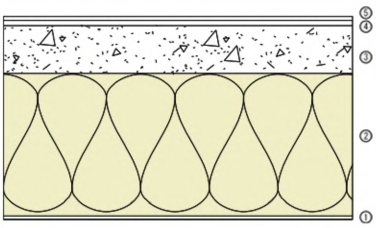



FIGURE 1.23

| N | Layers | Thickness [m] | λ [W/mK] | C [J/kgK] | ρ [kg/m3] |
|---|---|---|---|---|---|
| 1 | Plasterboard | 0.0125 | 0.21 | 840 | 900 |
| 2 | Mineral wool | 0.54 | 0.045 | 1000 | 115 |
| 3 | load bearing concrete slab | 0.18 | 0.39 | 1060 | 1200 |
| 4 | OSB (oriented strand board) | 0.02 | 0.15 | 1600 | 1000 |
| 5 | Slate Tiles (finishing) | 0.011 | 2.0 | 753 | 2700 |

*RESULTS*

| fd [-] | φ [h] | Ms [kg/m2] | U [W/m2K] |
|---|---|---|---|
| 0.010 | 3.45 | 336.35 | 0.0779 |

TABLE 1.9

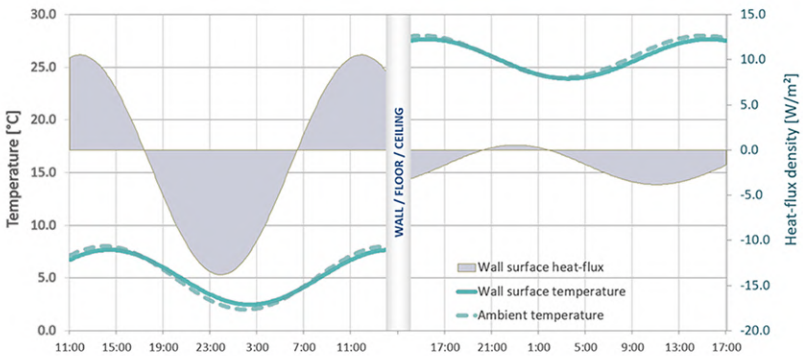



FIGURE 1.24


FIGURE 1.25

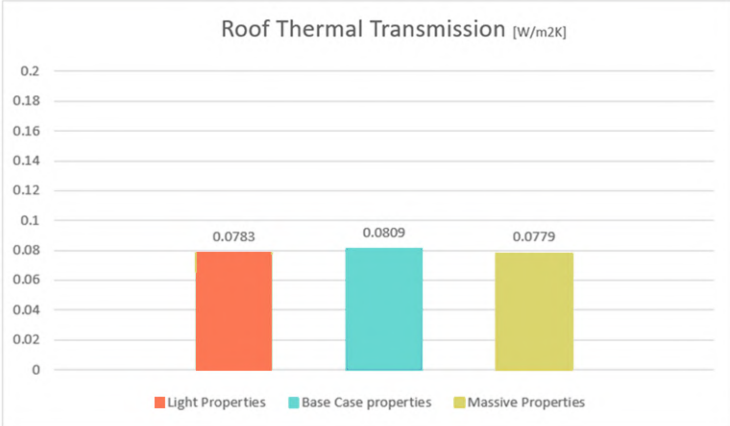



FIGURE 1.26

In this comparison chart it is visible that the thermal transmission value for all of the proposed technologies, as intended, are pretty much fixed

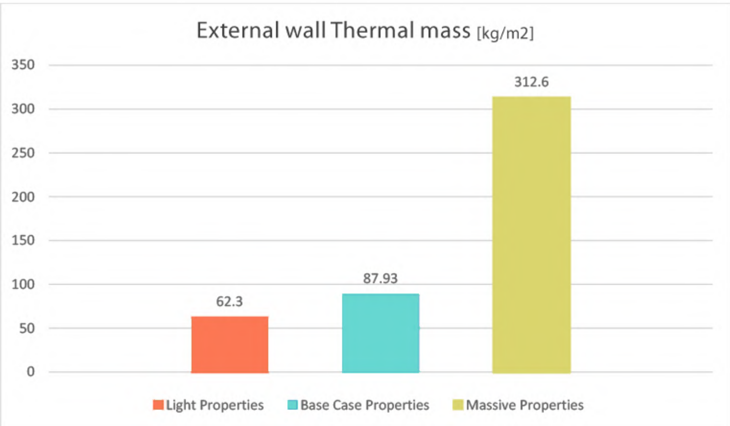



FIGURE 1.27

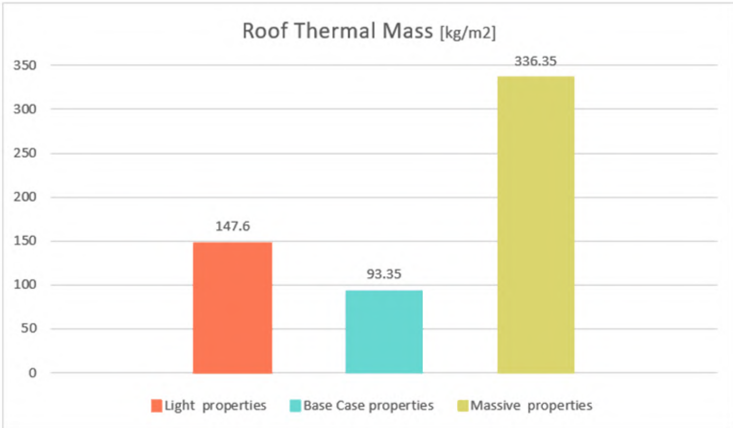



FIGURE 1.28

In the following charts we compare parts of the envelope technology that has the most effect on the house's thermal behavior. In this comparison chart it is visible that, as intended, the Massive Properties Technology as higher thermal mass characteristics in regard to the other two cases and it has the possibility to sink in more heat that the other two technologies.

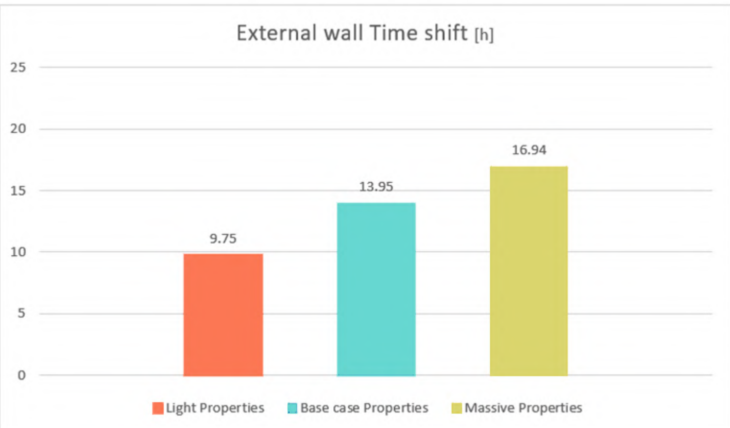



FIGURE 1.29

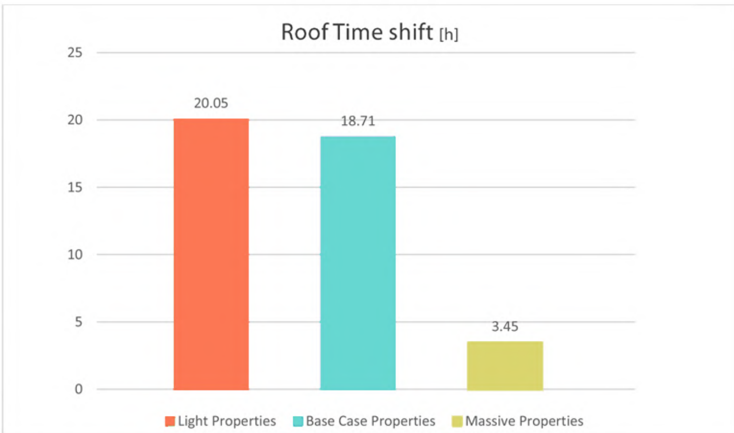
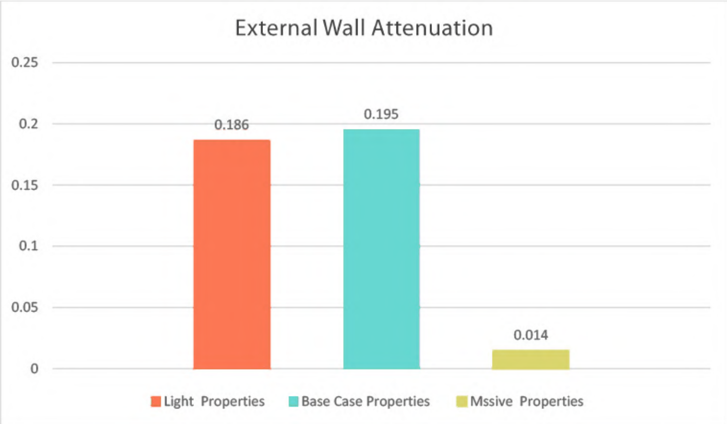
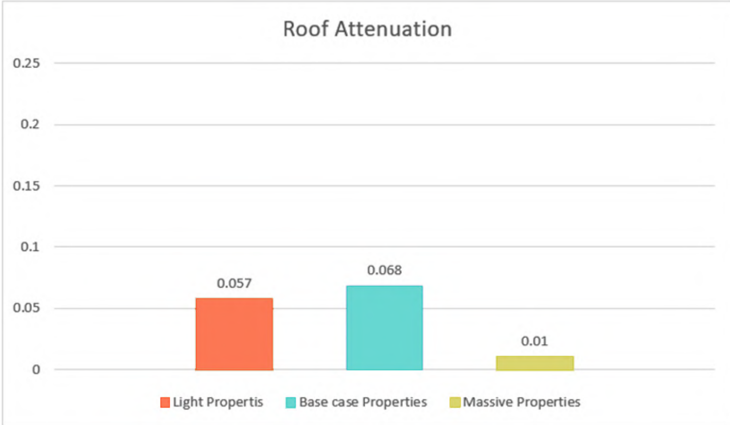


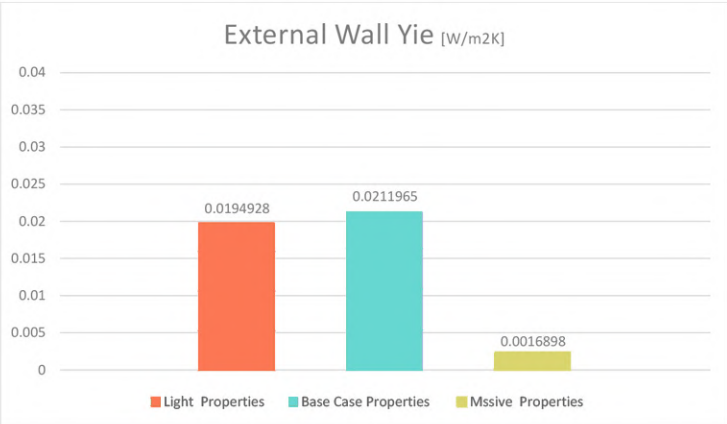

FIGURE 1.30

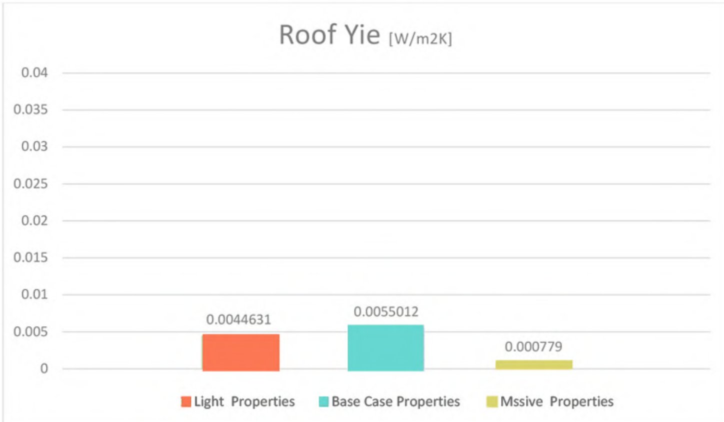
It is visible in the following charts that the Time shift behavior of the Massive technology is much higher when implemented in the External wall position, but the behavior changes when it comes to the roof technologies and the lighter technology shows a higher Time Shift characteristic.




As it can be seen in these charts, although the massive technology has higher thermal mass but it has lower attenuation a characteristic both in roof part of the envelope and external wall.




And finally we can compare all three cases in terms of Yie in the above charts.

## Summary

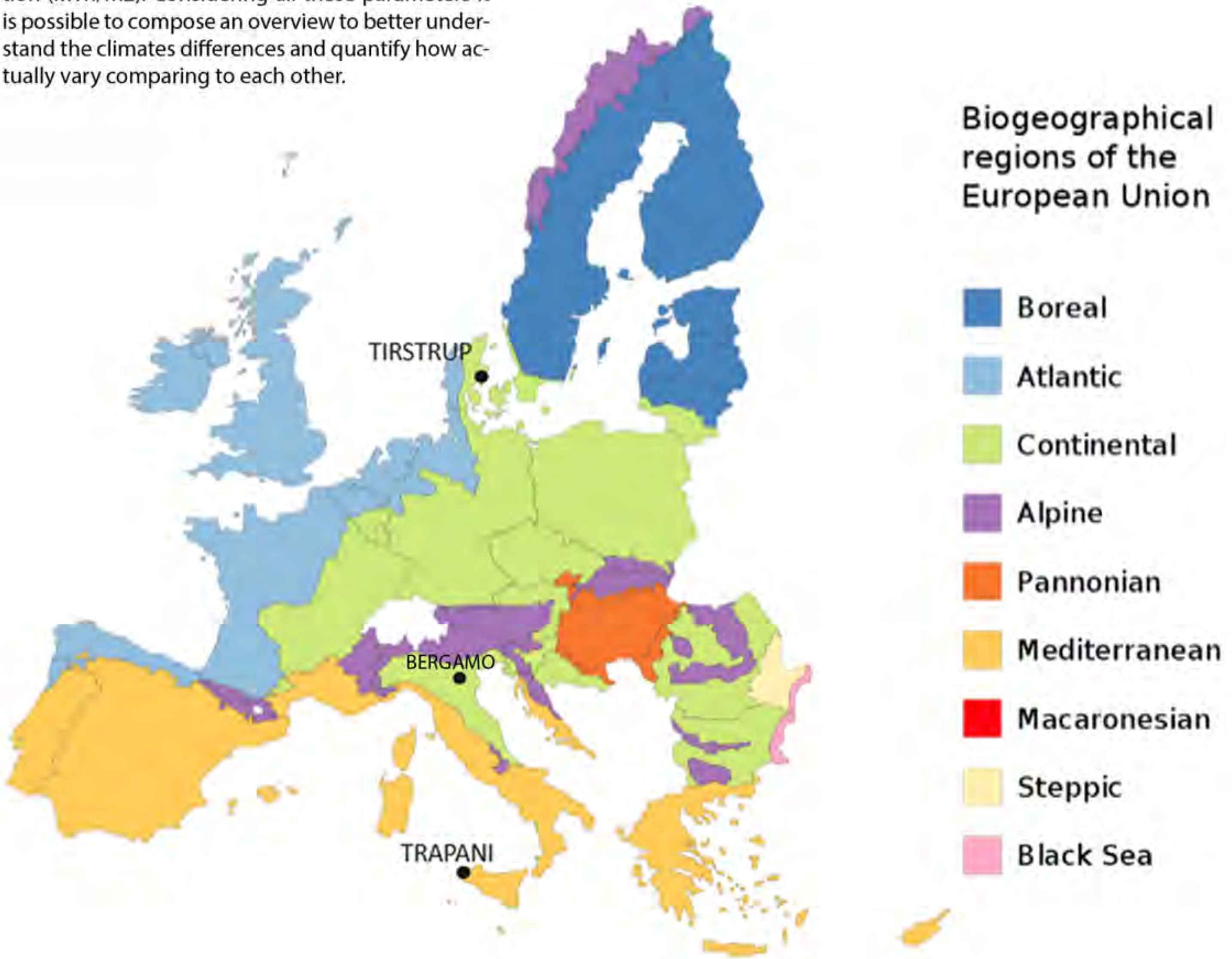
Keeping the U-Value as the constant base of comparison, three different strategies have been proposed for the most influential elements inside the envelope system. baseline strategies same as proposed by original documents, light properties (case 1) and massive properties (case 2) strategies. with a proper comparison between the final characteristics of the proposed stratigraphy, it can be identified that the proposed layering for the case 2 (massive) exhibit lower periodic thermal transmittance values which eventually means a slower rate of thermal transmittance and possibly a less scattered temperature distribution inside the building during a day. but to confirm this hypothesis further investigation has been done under the name of "free run simulations" in chapter three. (see page**29** )

# CHAPTER 2

## CLIMATE INFORMATION

This chapter is focused on the climate conditions. The climate results to be really important in order to take conscious decisions during the design process. The designer must be aware of the climate features. In the following pages it is shown an analysis and comparison between three different locations climates in order to illustrate the way the climate can affect a building conception. Since the Home for Life is located in Lystrup, we decided to consider as first location the climate data of Tirstrup, the closest location with available datas next to Lystrup. In order to understand the differences between biogeographical regions we decided to analyze other two locations Bergamo(northern Italy)and Trapani (Southern Italy) for the Mediterranean climate
By using a simplified TRNSYS model, the different climatic files were inserted as input, obtaining as output the different parameters chosen for developing climate comparison analysis. The parameters took into consideration for these kinds of analysis are: Air Temperature (°C), Relative Humidity (%), Total Horizontal solar radiation (kWh/m2), Direct solar radiation (kWh/m2), and Diffuse solar radiation (kWh/m2). Considering all these parameters it is possible to compose an overview to better understand the climates differences and quantify how actually vary comparing to each other.

| City | Country | Coordinate |
|---|---|---|
| TIRSTRUP | Denmark | 56°18'N 10°41'E |
| BERGAMO | Italy | 45°41'42''N 9°40'12''E |
| TRAPANI | Italy | 38°01' N 12°31' E |



## TOTAL SOLAR RADIATION

The first main focus on the climate is the solar radiation. This parameter is important to understand properly the distribution of the sun effects, depending on the city. The main difference, in terms of passive behaviour of the building,could be seen by focusing on the transparent elements of the building, inter alia the glass properties and how to handle solar shading systems.

While for active strategies the following results should be combined with geometry datas of the building and external shading elements for figure out how to best shape eventual solar systems, i.e. PV panels.

In the first 3 graphs it is shown how the different global solar radiation is spreaded among the year, standing on an hourly basis, and calculated on an horizontal surface. All the datas are referring to [kWh/m2] values.

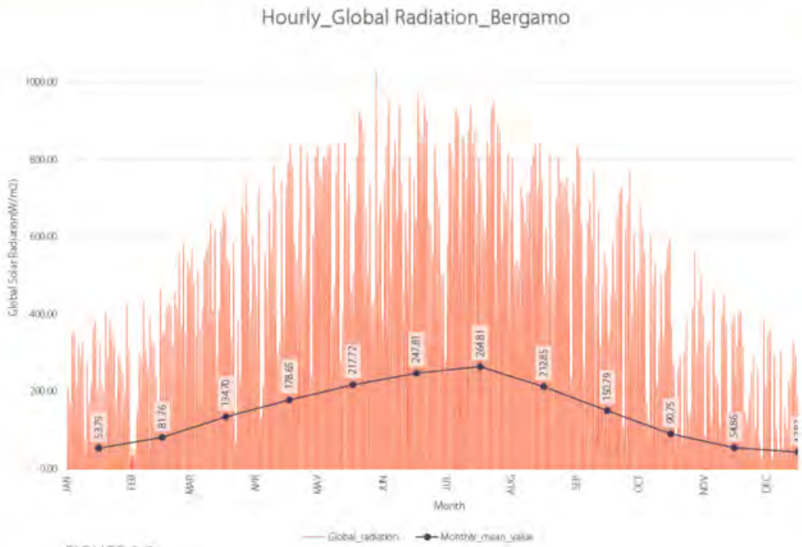



FIGURE 2.2

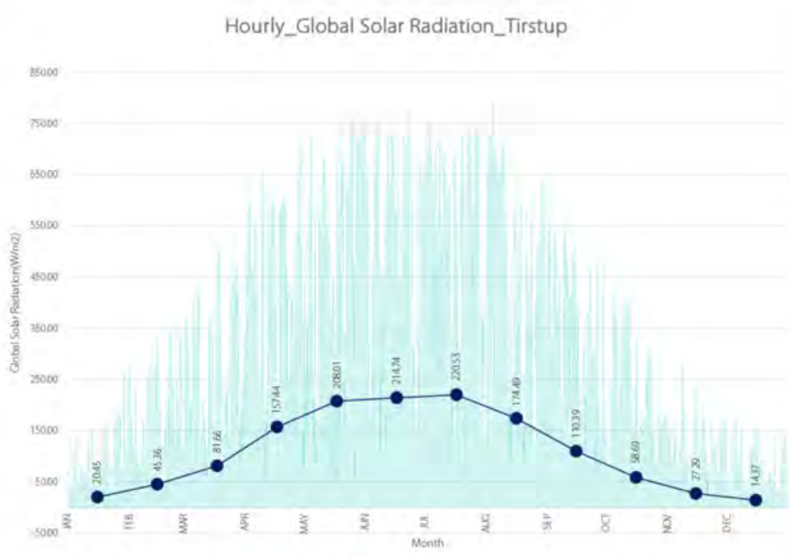



FIGURE 2.3

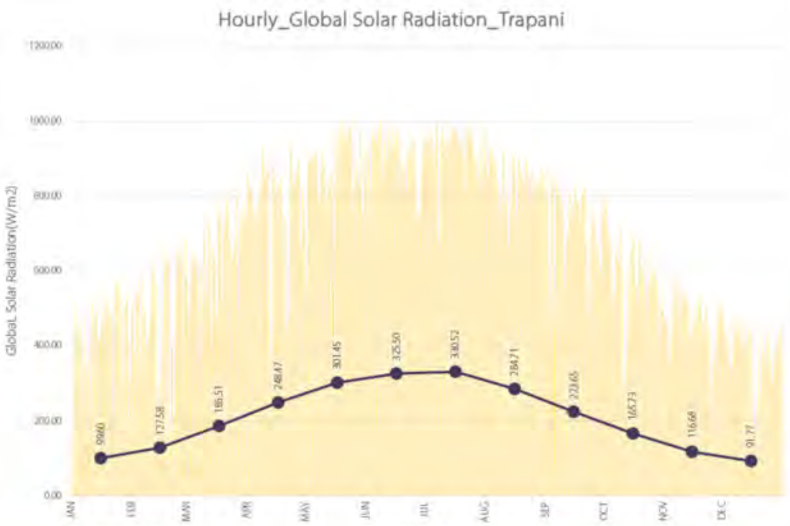



FIGURE 2.4

By comparing the graphs is possible to notice how, both among the year and among the day, there is a distribution similar to a Gaussian distribution of the radiation. In all the four different locations is possible to notice the increasing values from winter months to summer months, and vice-versa after the summer months there is an evident decrease.There are some gaps between the various expositions, caused by the latitude of the locations (Tirstrup at 56,30 °N, Bergamo at 45.6983° N and Trapani at 38,02 °N).

The following 3 graphs are showing how the hourly values are spreaded, depending on the month. Basically for every month the different values are comparable, since along the chart there are 24 different values of the hourly average value for the 24 hours of the 28, 30 and 31 days.
The same conclusion could be noticed by looking at the monthly daily values, but instead of a transition between summer and winter there is the day-night transition.

If we take a look at the mothly hourly values, where it is evident how the highest radiation, reached during summer (in Jun for Tirstrup, 657.77 kWh/m2 at 13 PM, and in July for Bergamo, 687.26 kWh/m2 at 13 PM and in 13 pM of July for Trapani, 927.55 kWh/m2).

If we take a look to the higher values of the December, which is the month with the lower values of solar exposure.among the year for all the 3 locations, it is possible to notice that on higher latitude the radiation comes lower.

Mounthly Hourly Radiation_Bergamo

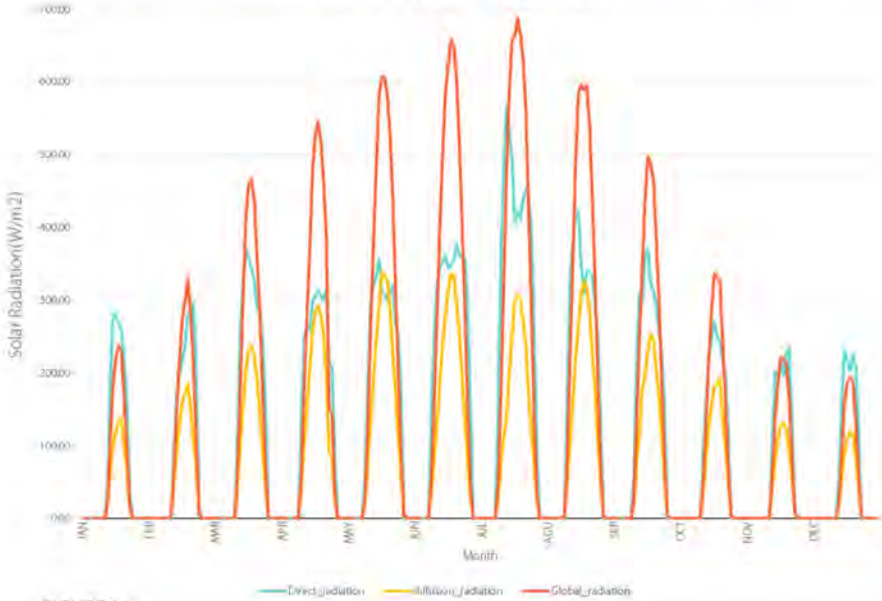



FIGURE 2.5

Mounthly Hourly Radiation_Tirstrup

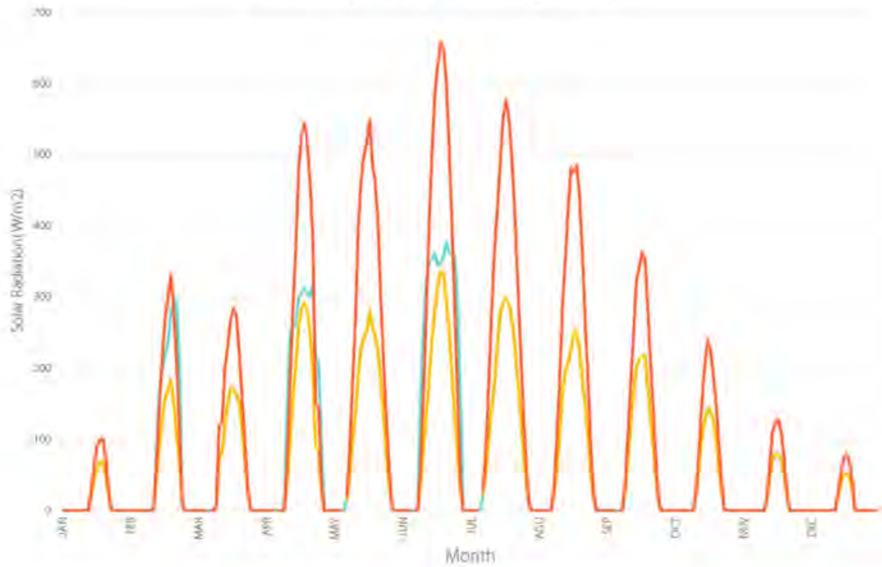



FIGURE 2.6

Mounthly Hourly Radiation_Trapani

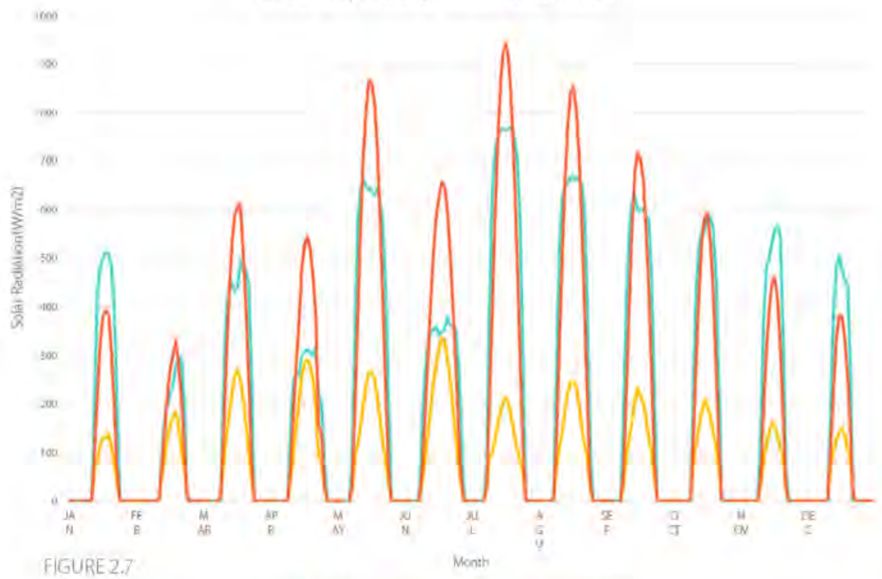



FIGURE 2.7

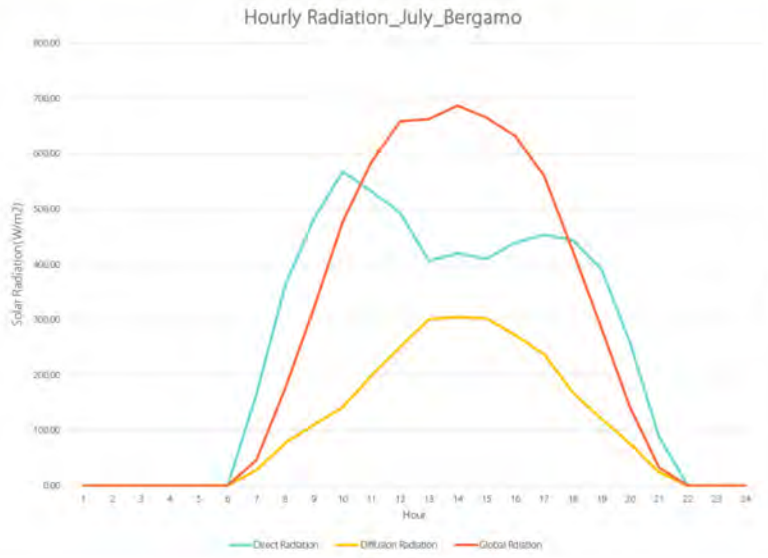



FIGURE 2.8

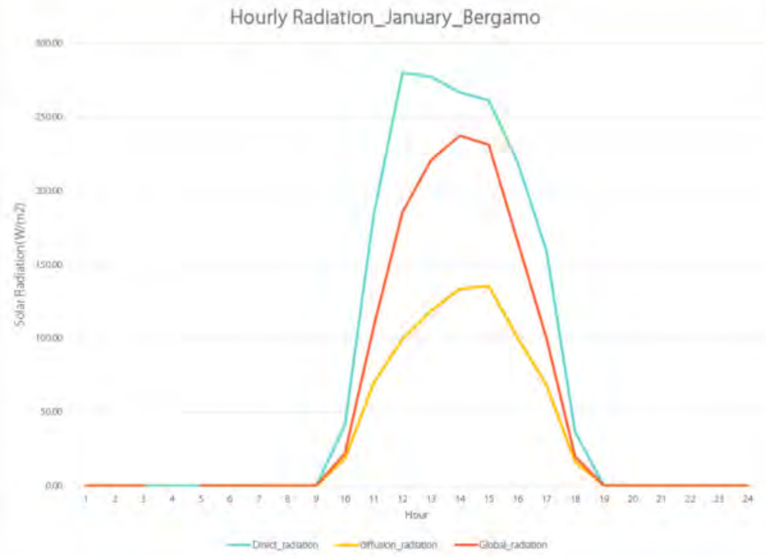



FIGURE 2.9


FIGURE 2.10

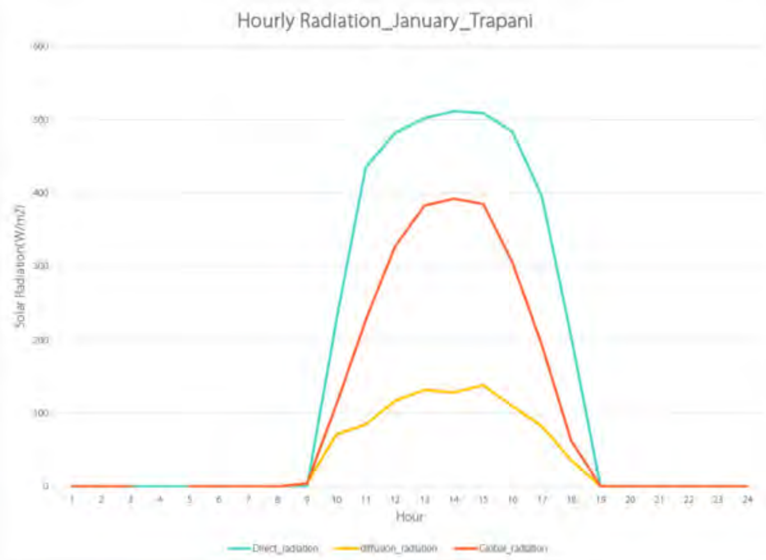



FIGURE 2.11


FIGURE 2.12

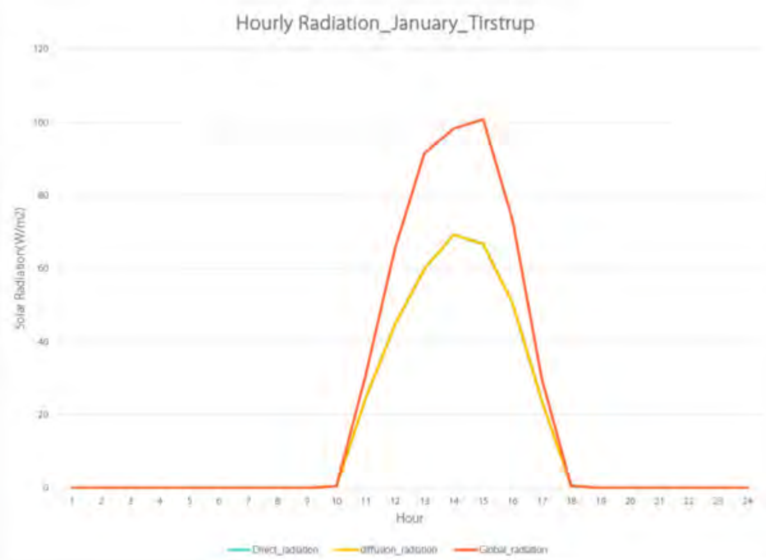



FIGURE 2.13

## AMBIENT TEMPERATURE

By looking at the distribution of temperatures is important to see how the four different climates behave among the year. All the datas are referring to [°C] values.

In Bergamo, there is a shorter winter, with few off-peaks, but instead there is a long summer. The daily temperature range shift among the winter months is comparable to the summer situation. The minimum temperature registered is -4.65°C at 8 AM, 13th of January, while the maximum is 35.50°C at 17 PM, 21th of July. The thermal excursion between winter and summer is 21,11 °C (specifically between January, the coldest month, which has an average T of 3.21°C, and July, the hottest one with an average T of 24.32°C).

In Tirstrup, there is a long cold winter and short warm summer, typical of a continental climate. The daily temperature range shift among the winter months is lower than in summer situation. The minimum temperature registered is -15,10 °C at 5 AM, 25th of February, while the maximum is 29,25 °C at 15 PM, 13th of July. The thermal excursion between winter and summer is 15,99 °C (specifically between February, the coldest month, which has an average T of -0,19°C, and July, the hottest one with an average T of 15,80 °C). May is the month with highest average thermal excursion daily, since there is an average 12,56° C (the lower range is in December, 1,50°C). Also, in May we can find the day with highest temperature range, 24.35°C on the 19th.

In Trapani, there is a short warm winter, with the temperatures that never are under 0° C, and a long hot summer. Also, here the daily temperature range shift among the winter months is comparable to the summer situation and due to sea effects, it is really limited. This is an example of a Mediterranean climate. The minimum temperature registered is 3,30 °C at 7 AM, 13th of January, while the maximum is 36,10 °C at 13 PM, 29th of July. The thermal excursion between winter and summer is 15,18 °C (specifically between February, the coldest month, which has an average T of 10.93 °C, and August, the hottest one with an average T of 26,11 °C). June is the month with highest average thermal excursion daily, since there is an average of 8,81 °C (the lower range is in December, 5,86°C). Also, in June we can find the day with highest temperature range, 10,55 °C on the 19th.

By comparing the average temperatures lines is visible how the continental climates (Tirstrup) are following the trend. The difference stands in the peaks, in fact in Tirstrup the declining peak is accentuated, because of the colder winter, while in Trapani the summer peak is accentuated.

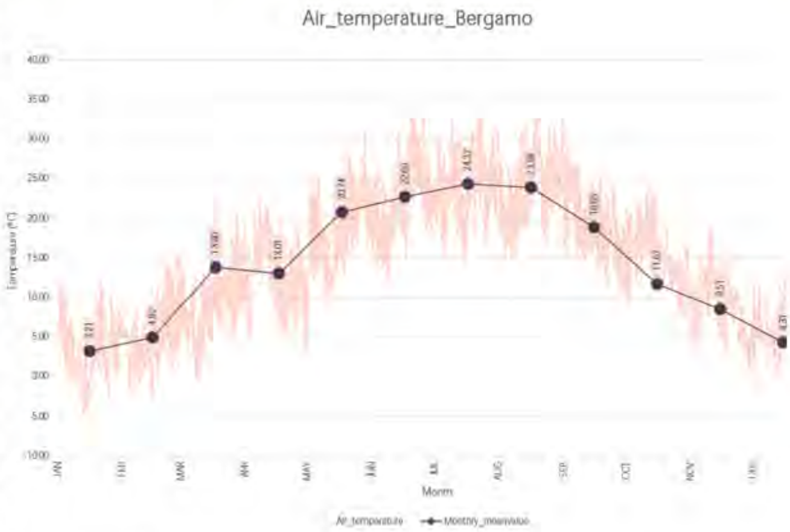



FIGURE 2.14

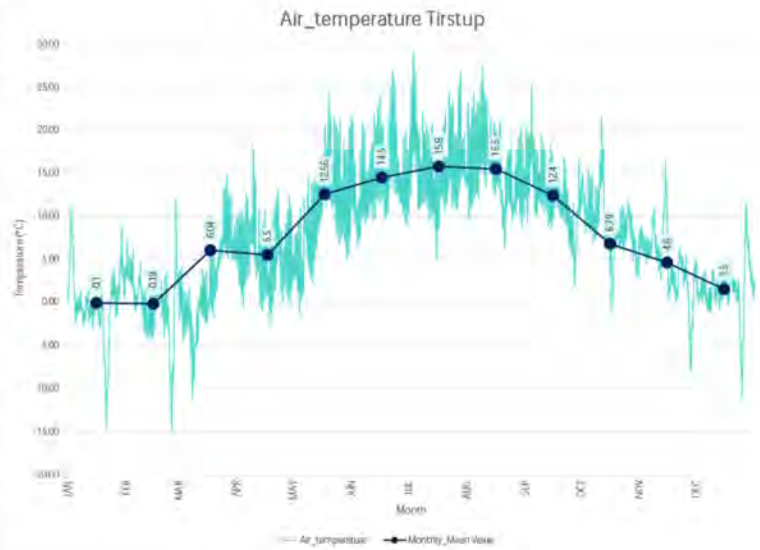



FIGURE 2.15

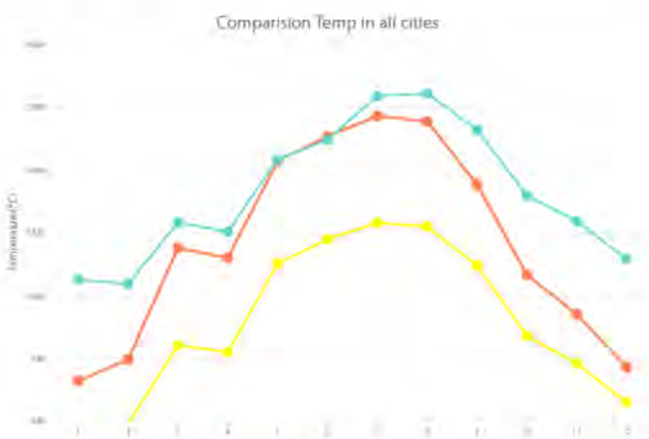



FIGURE 2.16

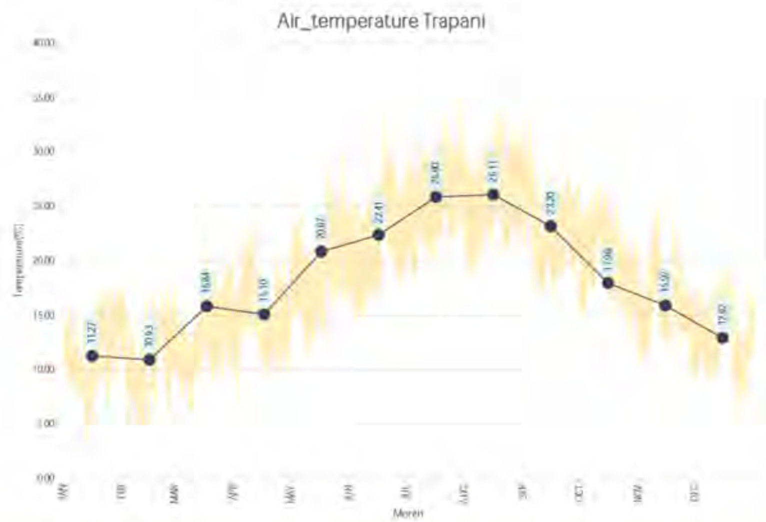


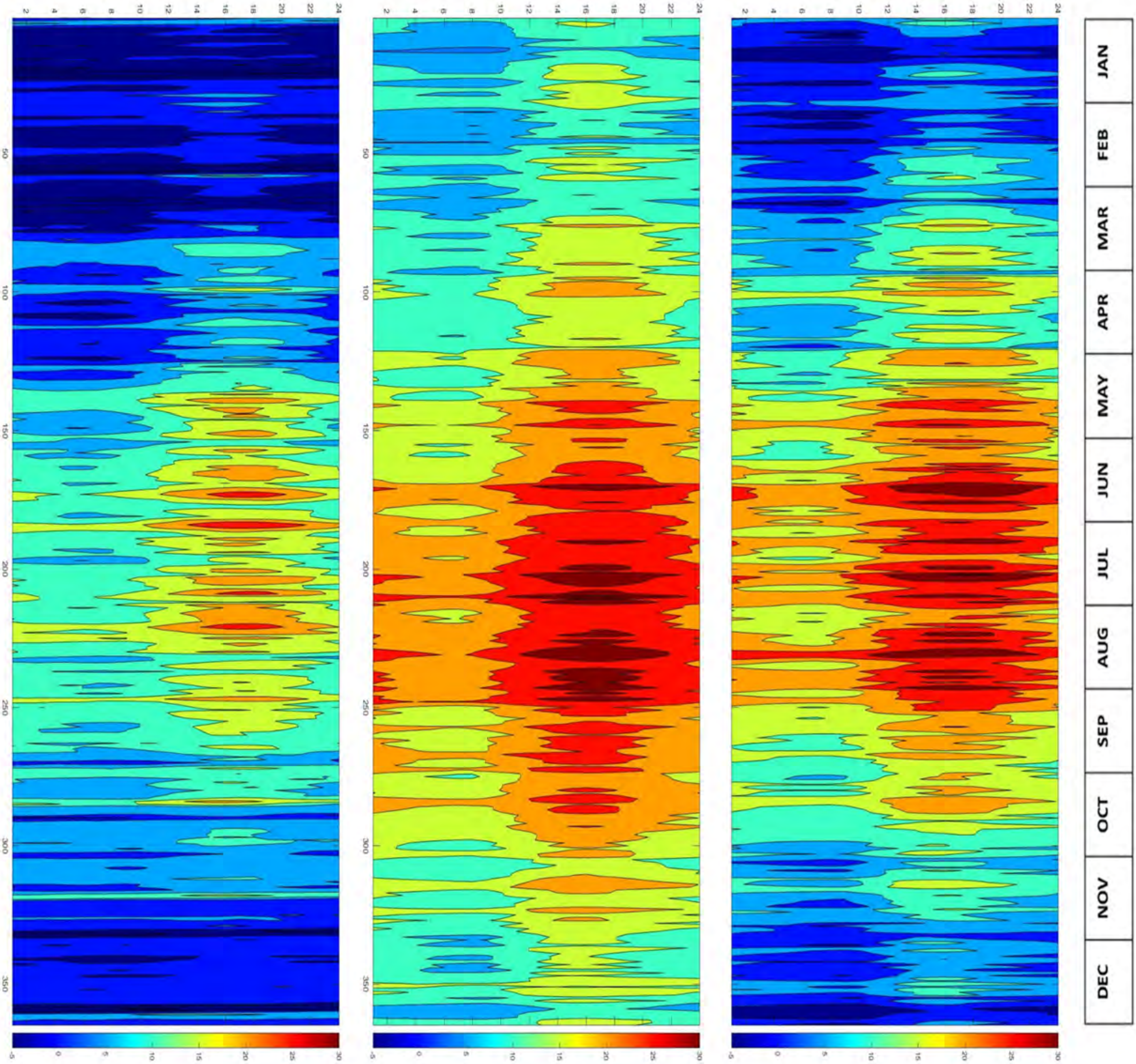

FIGURE 2.17

## Distribution of temperaturein in carpet chart

The carpet charts are showing the distribution of temperature as well, they are the results of analysing in MATLAB. with this graphical representation is easier to notice the thermal inertia effects on the locations. In order to understand the phase displacement between the different locations it is needed to figure out which elements of the environments help to mitigate the climate. For example, both in Trapani and Tirstrup, the effects of the seas are visible in the autumn months

| CITY | ANNUAL MEAN TEMPERTURE |
|---|---|
| BERGAMO | 13.94 |
| TRISTRUP | 7.63 |
| TRAPANI | 18.05 |

**TRISTRUP** **TRAPANI** **BERGAMO**



## RELATIVE HUMIDITY

Another data analysis relevant to design the best, both passive and active, strategies for the building is the relative humidity. We analysed the annual hourly trend of relative humidity, standing on the location. In the first 3 graphs it is shown how the RH [%] is spreaded among the year, standing on an hourly basis.

By comparing the first 3 charts it can be understood the general trend of the cities, so it is visible mainly which city is more humid and we can get a rough understanding about how the daily humidity range evolves troughout the year.

Bergamo is the less humid city. The most humid month is November, with an average value of 74.62 % . The minimum value reached is 25,00 %, at 17 PM, on the 27th of March. The month with the smaller average value is May, with 60,54 %.

Tirstrup is the most humid city, mainly because throughout the whole year the average maximum RH is always above 95,00 %. The maximum value of 100,00 % is reached regularly in every month, and while in summer is reached only during the night hours, in winter it can be found basically during the whole day. The most humid month is January, with an average value of 92,78 % . The minimum value reached is 40,00 %, at 13 PM, on the 25th of May. The month with the smaller average value is June, with 76,92 %.

In Trapani, the maximum value of 100,00 % is reached multiple times among the year, normally during night hours or early mornings. The average maximum is always above 89,00 % and the most humid month is January, with an average value of 82,88 %. The minimum value reached is 42,00 %, at 16 PM, on the 6th of August; while May is the less humid month, with an average value of 70,72 %.

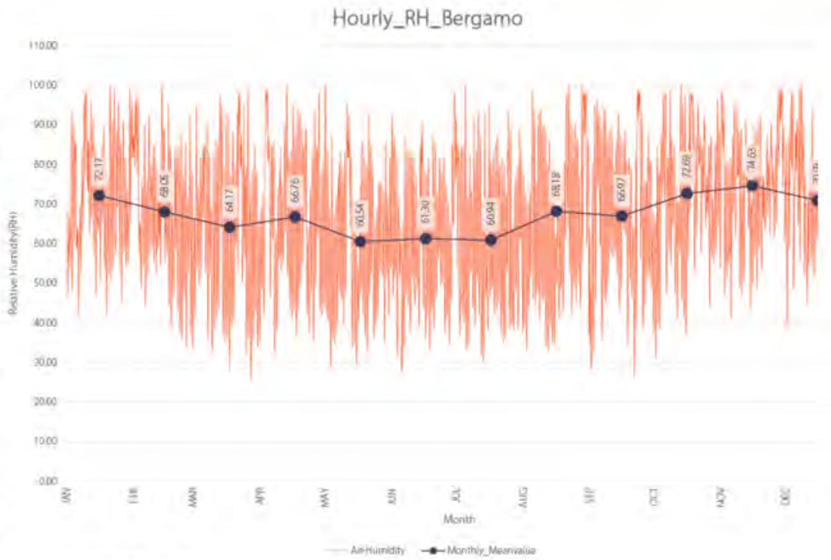



FIGURE 2.19

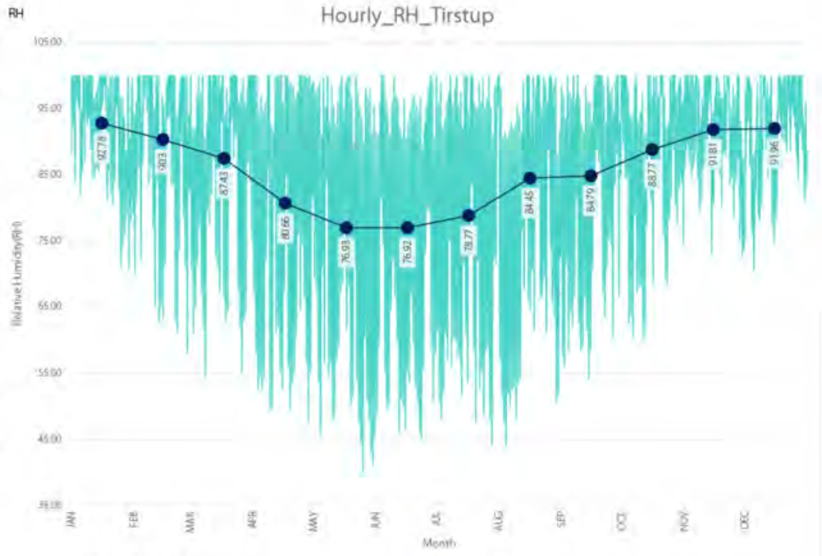
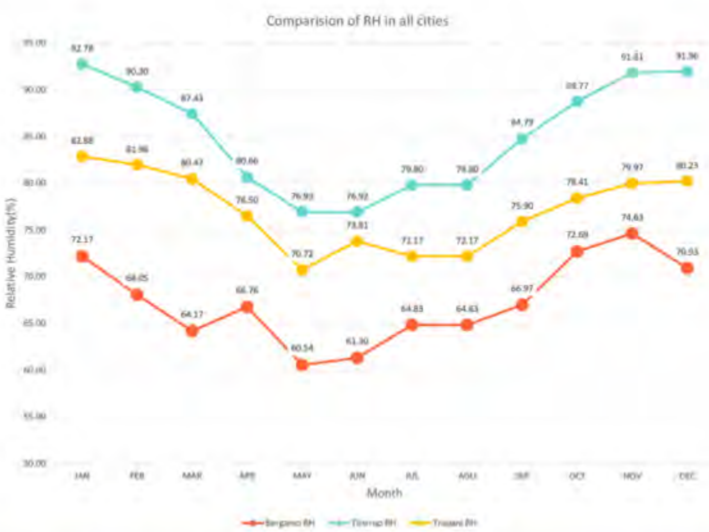



FIGURE 2.20



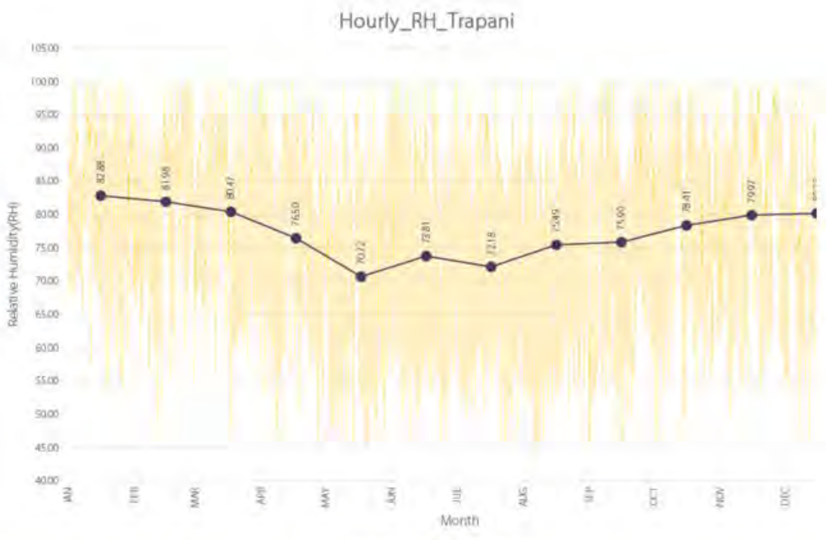




FIGURE 2.21

**RELATION BETWEEN T & RH**

In the following charts it will be shown how the temperatures and RHs are distributed, standing on an average hourly value, and so gathering an average daily behaviour depending on the month.

With this kind of analysis the two main interesting values are the daily range T [ΔT in °C] and daily range RH [ΔRH %]. The trend of these two values are similar, by changing city to city.
It is important to correlate these two parameters, because they are the main two indicators for the comfort that we want to achieve inside the building.

As it is visible from the chart, in Tirstrup, among the year there is a sensible increasement of the two parameters, with winter months with smaller thermal and hygrometric excursions, if compared to summer months. Spring and autumn months could be considered as a buffer according to this term.
Trapani's trend is more comparable to Bergamo, than Tirstrup. There are although smaller ranges than in the other Italian city.

FIGURE 2.22

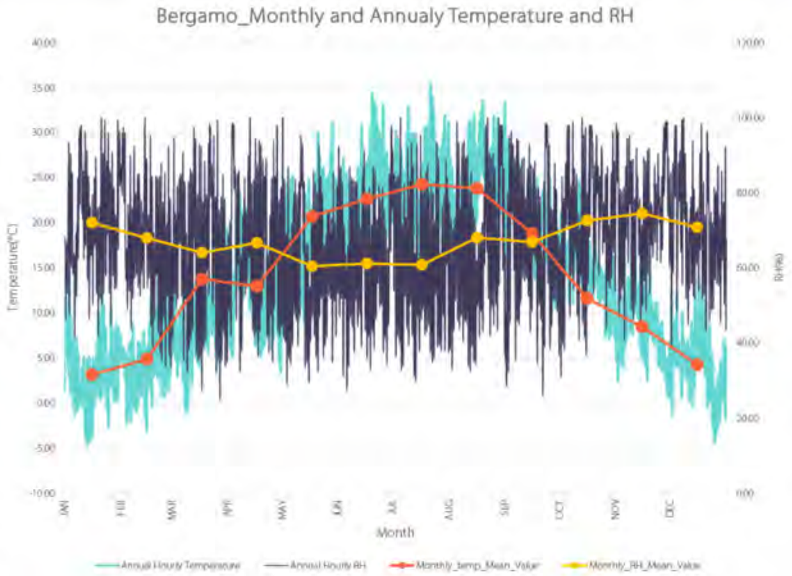



FIGURE 2.23

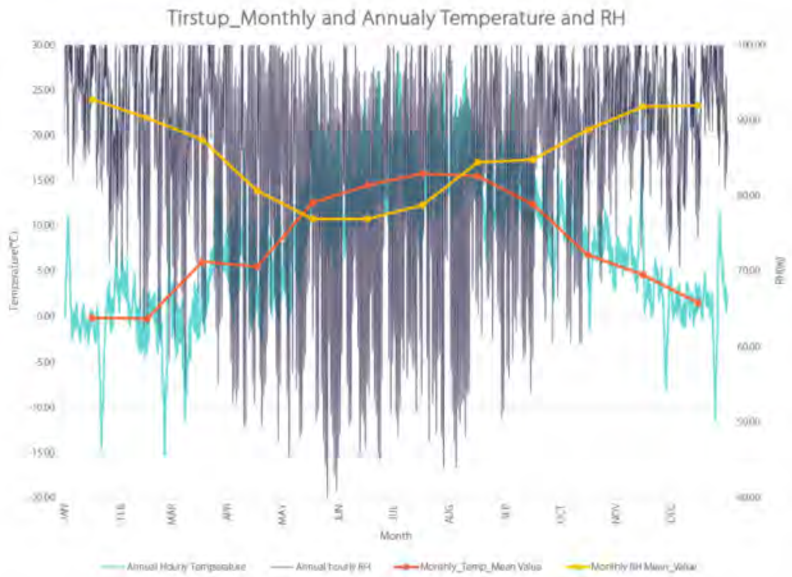
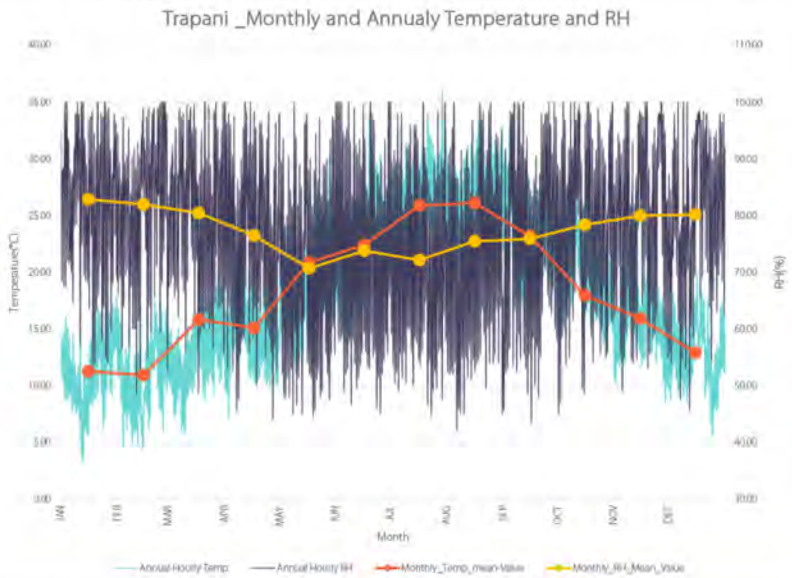


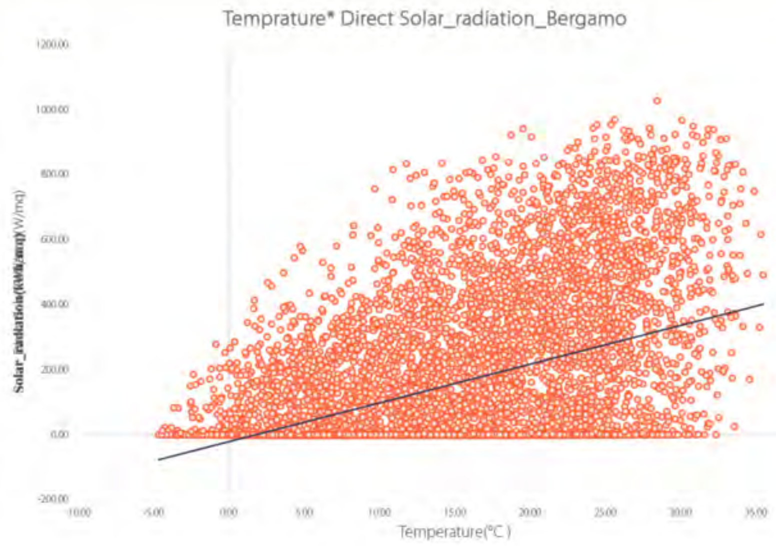

FIGURE 2.24

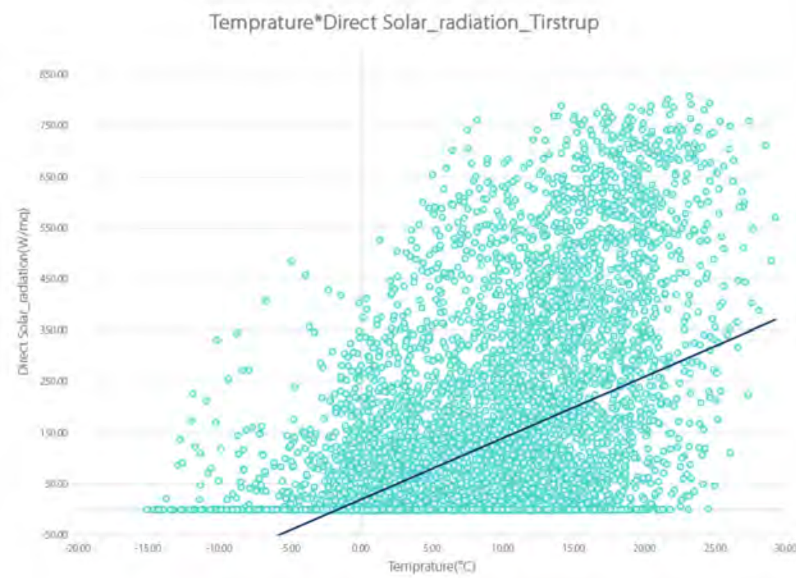


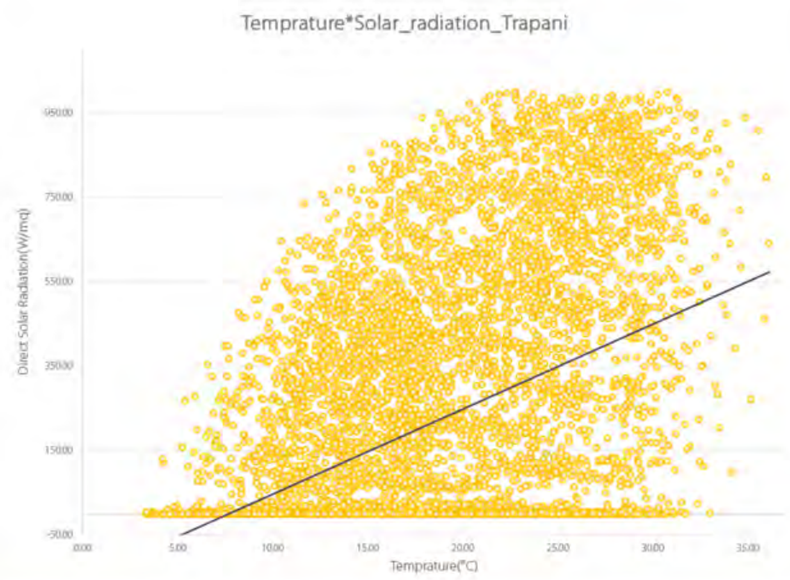
## RELATION BETWEEN T & SOLAR RADIATION

Another cross-parameters chart interesting to be seen is the correlation between the temperatures [°C] and the global horizontal solar radiation [kWh/m2]. By looking at the dispersion chart it is possible to understand how cold or warm the external environment is, related to the presence (or not) of the solar radiation and its intensity.

There is a clear observation that comes out of the comparation between the cities in this term, that is the differential of the position of density of the scattered points. Starting from the further north city (Tirstrup) and going to the more southern one (Trapani) the charts' points are translated slowly from cold temperatures and low solar radiations to warm and hot temperatures and high solar radiations



### IMAX & MIN STANDARD DEVIATION OF T

n these graphs the max and min Temperature and temperature standard deviation of each month compared for 3 cities. Bergamo and Tirstrup have same tendency, for both cities, min mean value temperature is near of standard deviation.

In Bergamo, the min mean value temperature is coincident on standard deviation graph in March, for Tirstrup this happens in July and September.

In Trapani both, mean value of max and min temperature is over the standard deviation with high distance. For Trapani both min and max mean value of temperature is over the standard deviation

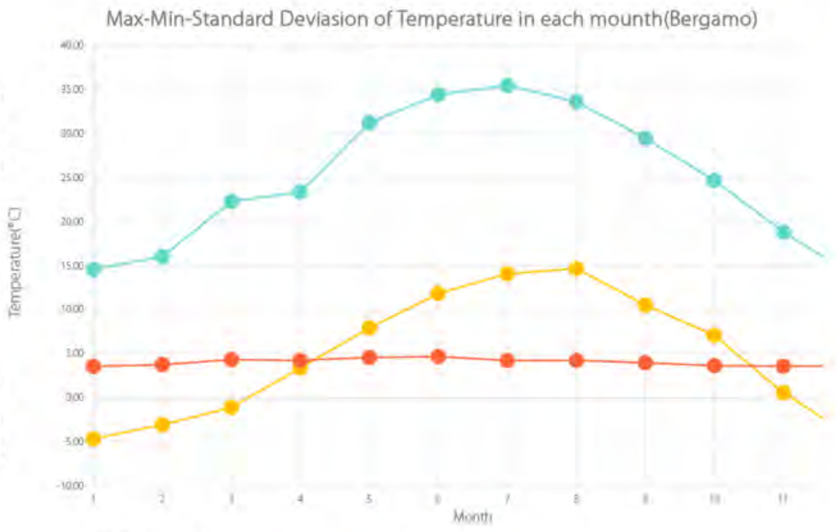



FIGURE 2.28

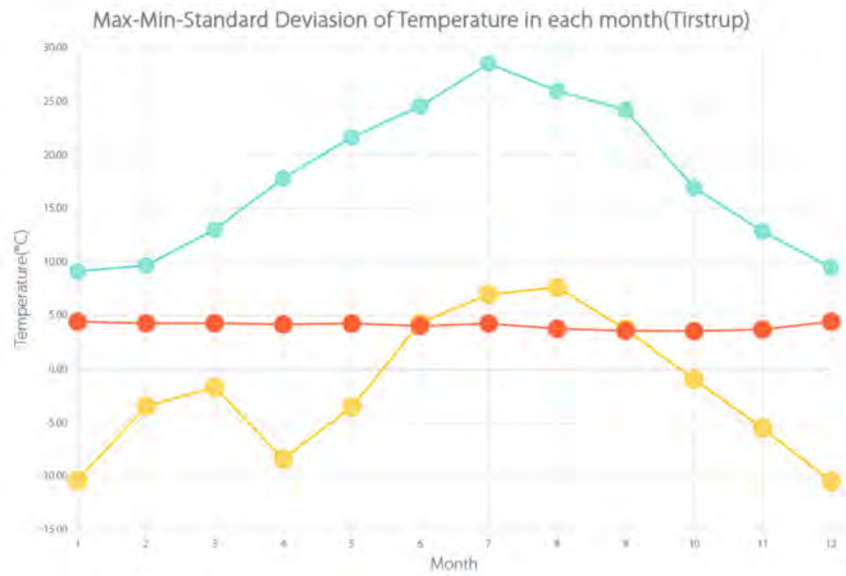



FIGURE 2.29

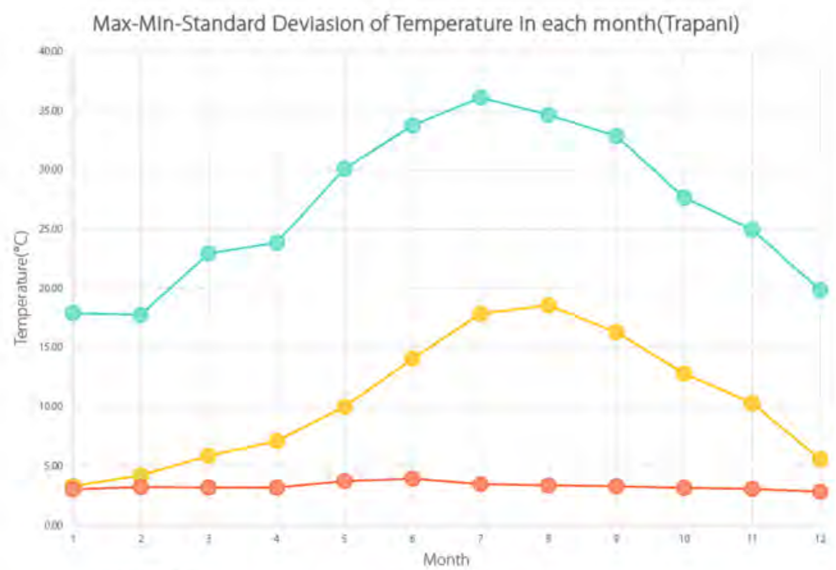



FIGURE 2.30

# CHAPTER 3

## PASSIVE STRATEGIES

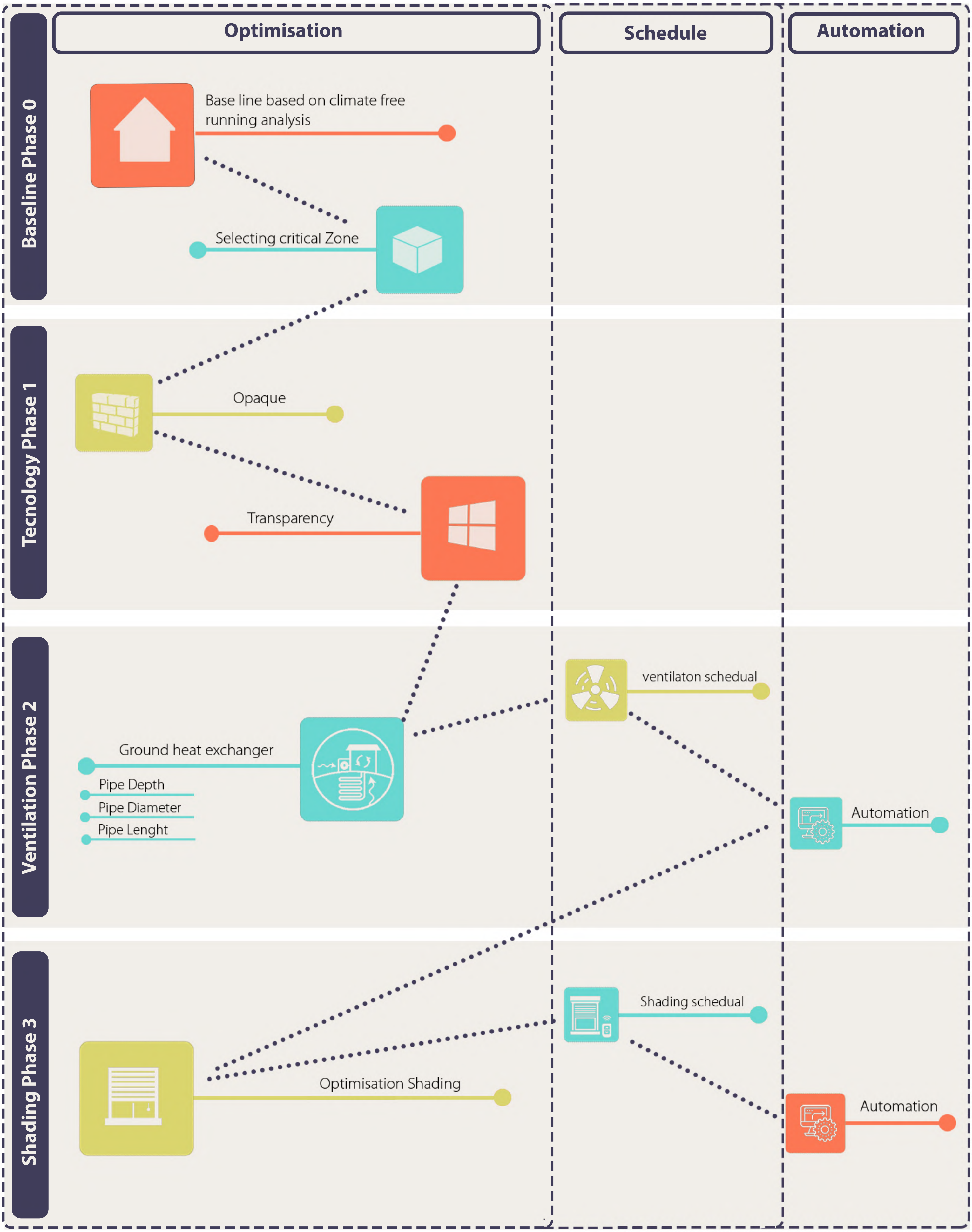

Optimisation
Schedule
Automation
Baseline Phase 0
Base line based on climate free running analysis
Selecting critical Zone
Tecnology Phase 1
Opaque
Transparency
Ventilation Phase 2
Ground heat exchanger
Pipe Depth
Pipe Diameter
Pipe Lenght
ventilaton schedual
Automation
Shading Phase 3
Shading schedual
Optimisation Shading
Automation

FIGURE 3.1

## Standard Values

To enter the passive comfort simulations, the initial requirement is a baseline as a comparison base for the optimization and optioneering steps from here onward. to reach such baseline, firstly, it is considered all the standard values that could be decided as a fixed value or a value for each of the constant conditions such as climate data.

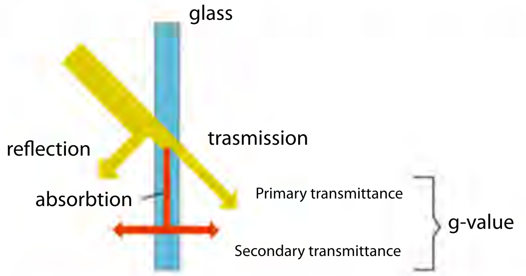
In this part, it is explained each value in the baseline and how it is reached.

Infiltration Rate has been reached for each hour of the year by using Type 932: Sherman Grimsrud Infiltration Model.

Passive heating and cooling setpoint temperatures have been reached by automation toward reaching the class B comfort limits defined by standard EN15251.

Internal heat gains are defined by given standard values divided by People, Lighting fixture, and Equipments.

Values for baseline shading, ventilation, and envelope technologies, other than windows properties which the given values are used, are reached by free run simulations.




## Baseline

| | Zone1 | Zone2 | Zone3 |
|---|---|---|---|
| Lighting Heat Gain | 1.5 W/m² | 1.5 W/m² | 0.5 W/m² |
| Equipment Heat Gain | 2.5 W/m² | 2.5 W/m² | 1 W/m² |
| People Heat Gain | 1 W/m² | 1 W/m² | 2 W/m² |
| Infiltration: | Annual Hourly | | |
| **Heating,** Cooling Set Point T | °20C°16-C °26C | | |
| Passive H/C Set Point T | Automated To EN15251 | | |
| Relative Humidity Limits | 50%-70% | | |
| Envelope Values: | TBD | | |
| Shading Percentage | TBD | | |
| Ventilation Rate | TBD | | |

### TYPE 932: SHERMAN GRIMSRUD INFILTRATION MODEL

This component contains the Sherman-Grimsrud infiltration model as described in the ASHRAE Handbook of Fundamentals, 2005. The model bases infiltration effects on an effective leakage area, indoor/outdoor temperature difference, and wind speed. The model is semi empirical, requiring that the user enter a stack coefficient (Cs) and a wind coefficient (Cw). While the ASHRAE Handbook gives these values as functions of a factor that it calls shelter class and the height of the building (in stories), this model takes the factors directly so that the user may, if desired, interpolate and extrapolate the ASHRAE tables.

| Name | Value | Unit |
|---|---|---|
| Ambient temperature | 20 | C |
| Ambient humidity ratio | 0.001 | _ |
| Ambient relative humidity ratio | 50 | % (base 100) |
| Ambient pressure | 1 | atm |
| Wind speed | 2 | m/s |
| Zone temperature | 20 | C |
| Zone humidity ratio | 0.001 | _ |
| Zone % relative humidity | 50 | % (base 100) |
| Zone pressure | 1 | atm |

| Windows properties | |
|---|---|
| Vertical Windows | U (Window): 1 W/ m² K<br>G value: 0.45 |
| Roof Facing South Windows | U (Window): 1 W/ m² K<br>G value: 0.3 |
| Roof Facing North Windows | U (Window): 1 W/ m² K<br>G value: 0.45 |

FIGURE 3.2

Variables deciding the infiltration rate are based on building geometry and components and climate, since the building is the same for the each climate, the hourly rate is extrapolated regarding each climate. the following chart (figure 3.3) shows the hourly infiltration rates for the case of the building being located in

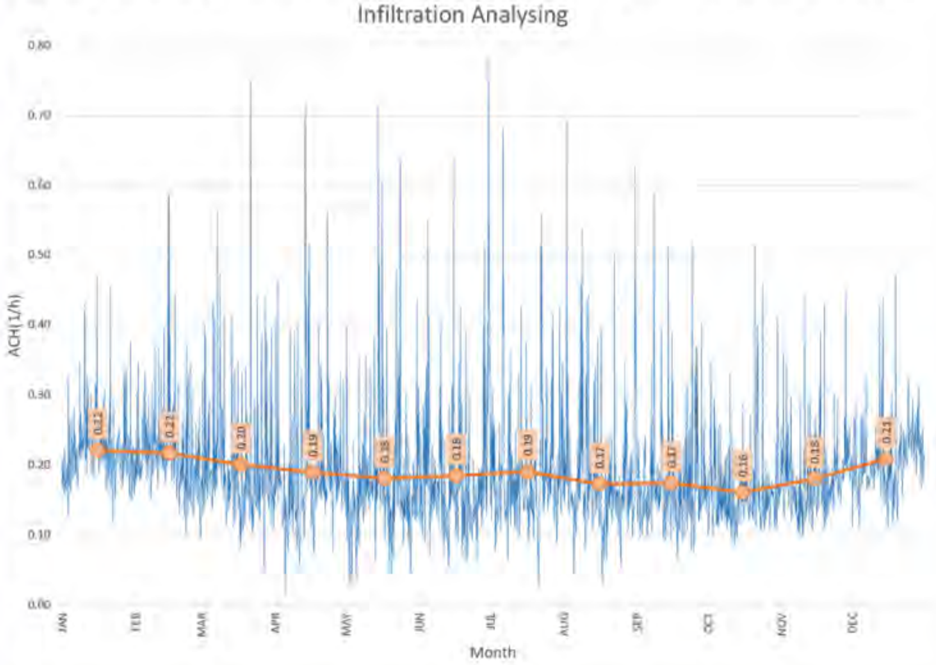



FIGURE 3.3

## Free Run Simulations

To reach the optimal baseline values for shading, ventilation rate, and envelope technologies, 27 different free run simulations have been done for each climate considering logical threshold values for each case.

In the case of the Ventilation the chosen threshold values are 0.6 part of the volume of the zone to be replaced with the new supply air for each hour as the bottom threshold and for the upper threshold 3.0 times of the volume and a middle point of 1.5 times the volume.

In the case of the Shading the upper threshold is chosen as 80% or 0.8 portion of the windows are shaded, the bottom threshold as 20% or 0.2 and the middle point of 50% or 0.5 portion of the windows.

In the case of envelope technologies, as already extrapolated in the first chapter of this report three main strategies has been acquired to decide what should be implemented as layers of opaque parts of the envelope. the same layering strategies has been used as Baseline technology, Case 1 (light) technology and Case 2 (massive) technology in the following free run simulations.

In the end, for the case of Bergamo, Case 2 technology with 0.6 Ventilation Rate and 80% Shading has been chosen as it provides the most comfort percentage among all 27 cases.

To step further into optimisation of these values, Zone 2 of the building has been chosen since it is the common space in the building and has the most importance for us in terms of comfort.

It is exhibited how to passive comfort of the Zone 2 in the chosen case is performing until this step.

### Baseline

| | Zone1 | Zone2 | Zone3 |
|---|---|---|---|
| Lighting Heat Gain | 1.5 W/m² | 1.5 W/m² | 0.5 W/m² |
| Equipment Heat Gain | 2.5 W/m² | 2.5 W/m² | 1 W/m² |
| People Heat Gain | 1 W/m² | 1 W/m² | 2 W/m² |

| | |
|---|---|
| Infiltration: | Annual Hourly |
| **Heating,** Cooling Set Point T | °**20C**°**16-C** °26C |
| Passive H/C Set Point T | Automated To EN15251 |
| Relative Humidity Limits | 50%-70% |
| Envelope Values: | Case2 |
| Shading Percentage | 0.8 |
| Ventilation Rate | 0.6 |

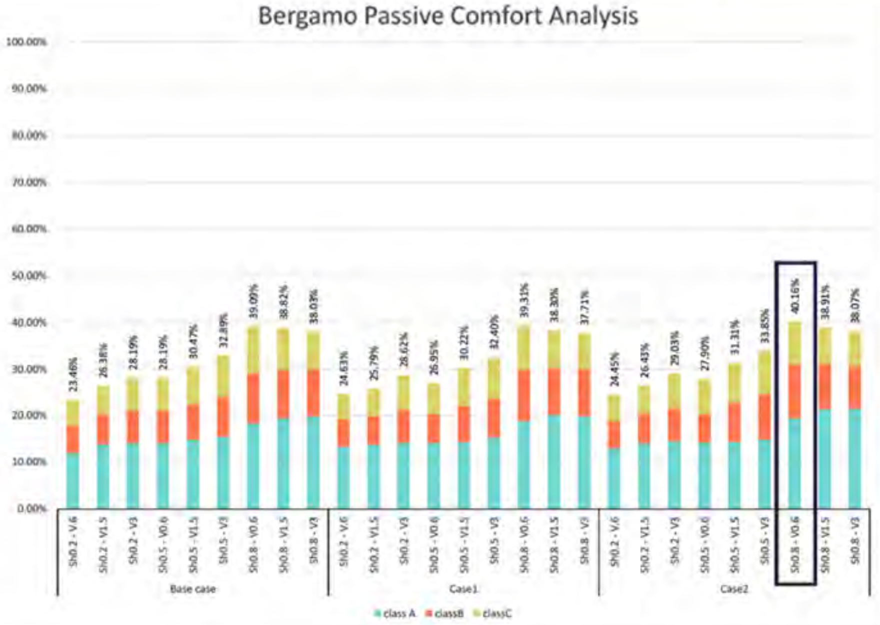
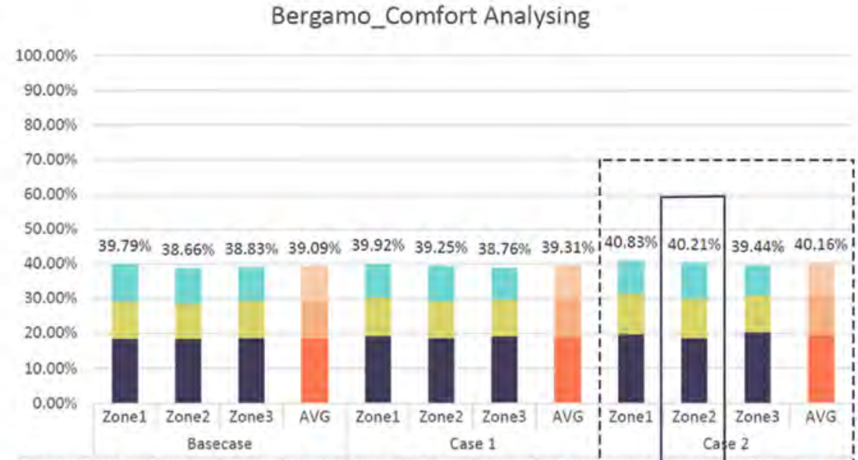



FIGURE 3.4




| | Basecase | | | | Case 1 | | | | Case 2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Zone1 | Zone2 | Zone3 | AVG | Zone1 | Zone2 | Zone3 | AVG | Zone1 | Zone2 | Zone3 | AVG |
| Totals | 39.79% | 38.66% | 38.83% | 39.09% | 39.92% | 39.25% | 38.76% | 39.31% | 40.83% | 40.21% | 39.44% | 40.16% |
| classC | 10.63% | 10.03% | 9.33% | 10.00% | 9.52% | 9.95% | 9.00% | 9.49% | 9.34% | 10.13% | 8.40% | 9.29% |
| classB | 10.83% | 10.43% | 10.98% | 10.75% | 11.30% | 10.80% | 10.75% | 10.95% | 11.80% | 11.55% | 10.91% | 11.42% |
| class A | 18.33% | 18.20% | 18.52% | 18.35% | 19.10% | 18.50% | 19.01% | 18.87% | 19.69% | 18.53% | 20.13% | 19.45% |

class A classB classC Totals

FIGURE 3.5

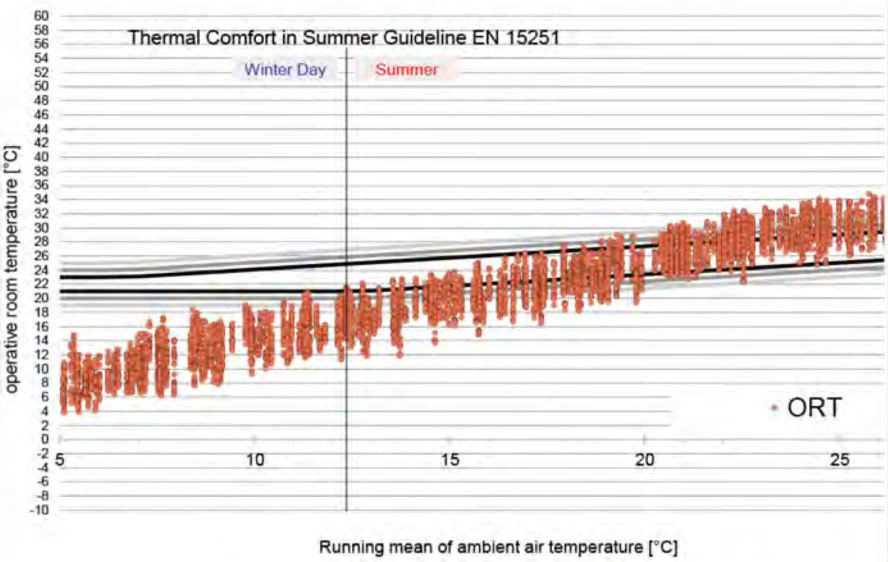



FIGURE 3.6

**Class C:** 10.13% **Class B:** 11.55% **Class A:** 18.53% **Total:** 40.21%

In the case of Tirstrup, Basecase technology with 0.6 Ventilation Rate and 50% Shading has been chosen as it provides the most comfort percentage among all 27 cases.
To step further into optimisation of these values, Zone 2 of the building has been chosen since it is the common space in the building and has the most importance for us in terms of comfort.
It is exhibited how to passive comfort of the Zone 2 in the chosen case is performing until this step.

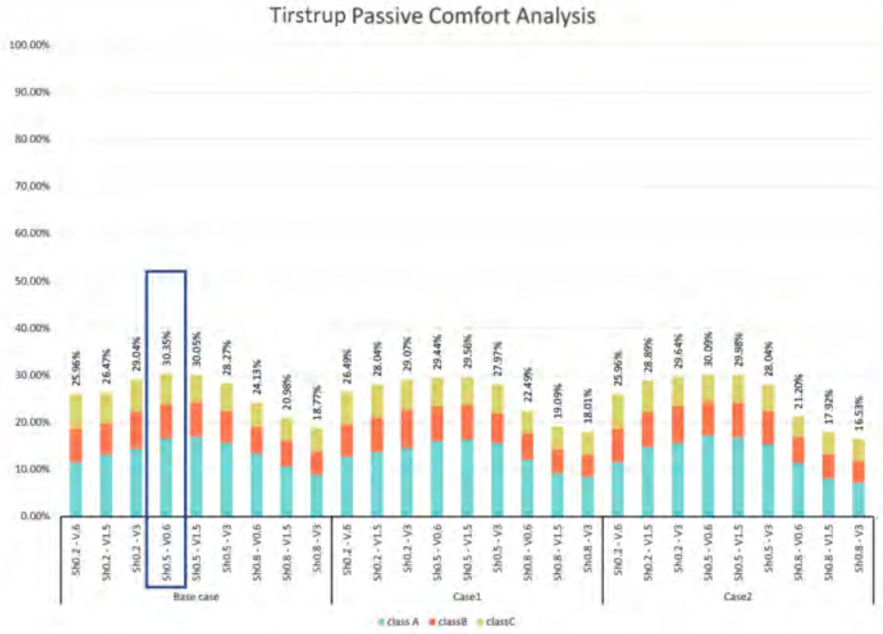
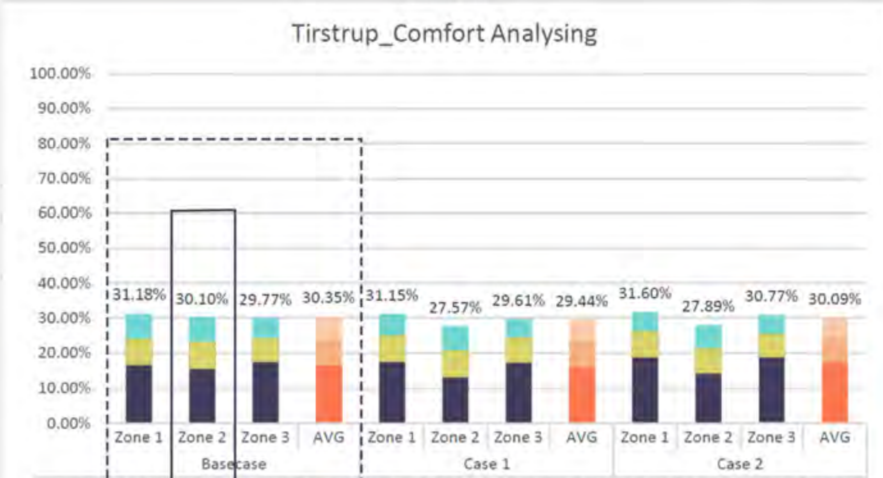


FIGURE 3.7




| | Basecase | | | | Case 1 | | | | Case 2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Zone 1 | Zone 2 | Zone 3 | AVG | Zone 1 | Zone 2 | Zone 3 | AVG | Zone 1 | Zone 2 | Zone 3 | AVG |
| Totals | 31.18% | 30.10% | 29.77% | 30.35% | 31.15% | 27.57% | 29.61% | 29.44% | 31.60% | 27.89% | 30.77% | 30.09% |
| classC | 7.05% | 6.89% | 5.47% | 6.47% | 6.10% | 6.82% | 5.17% | 6.03% | 5.41% | 6.56% | 5.27% | 5.75% |
| classB | 7.42% | 7.66% | 6.75% | 7.28% | 7.53% | 7.50% | 7.11% | 7.38% | 7.43% | 7.11% | 6.72% | 7.09% |
| class A | 16.71% | 15.55% | 17.55% | 16.60% | 17.52% | 13.25% | 17.33% | 16.03% | 18.76% | 14.22% | 18.78% | 17.25% |

FIGURE 3.8

## Baseline

| | Zone1 | Zone2 | Zone3 |
|---|---|---|---|
| Lighting Heat Gain | 1.5 W/m² | 1.5 W/m² | 0.5 W/m² |
| Equipment Heat Gain | 2.5 W/m² | 2.5 W/m² | 1 W/m² |
| People Heat Gain | 1 W/m² | 1 W/m² | 2 W/m² |

| | |
|---|---|
| Infiltration: | Annual Hourly |
| **Heating,** Cooling Set Point T | °20C°16-C °26C |
| Passive H/C Set Point T | Automated To EN15251 |
| Relative Humidity Limits | 50%-70% |
| Envelope Values: | Bacecase |
| Shading Percentage | 0.5 |
| Ventilation Rate | 0.6 |

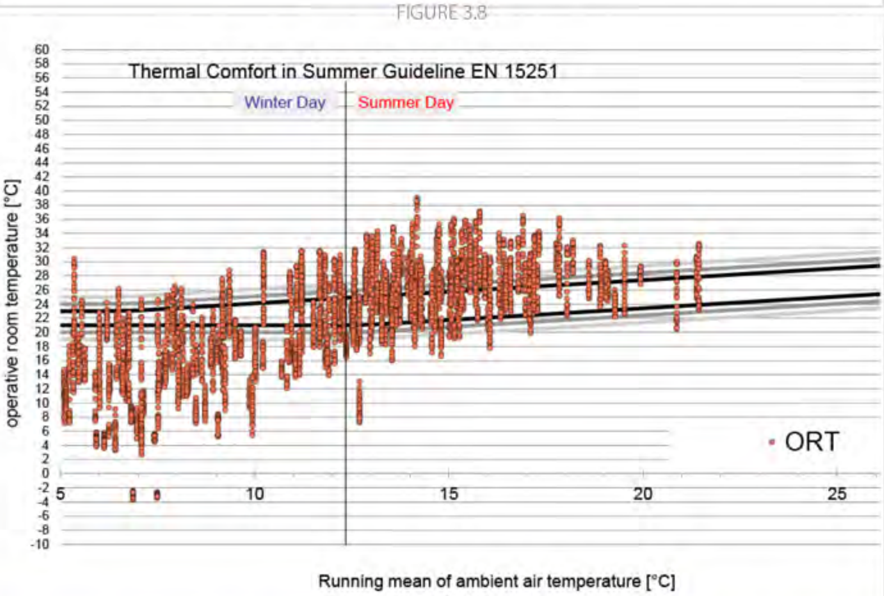


FIGURE 3.9

**Class C:** 6.89% **Class B:** 7.66% **Class A:** 15.55% **Total:** 30.10%

In the case of Trapani, case 2 technology with 1.5 Ventilation Rate and 80% Shading has been chosen as it provides the most comfort percentage among all 27 cases.
To step further into optimisation of these values, Zone 2 of the building has been chosen since it is the common space in the building and has the most importance for us in terms of comfort.
It is exhibited how to passive comfort of the Zone 2 in the chosen case is performing until this step.

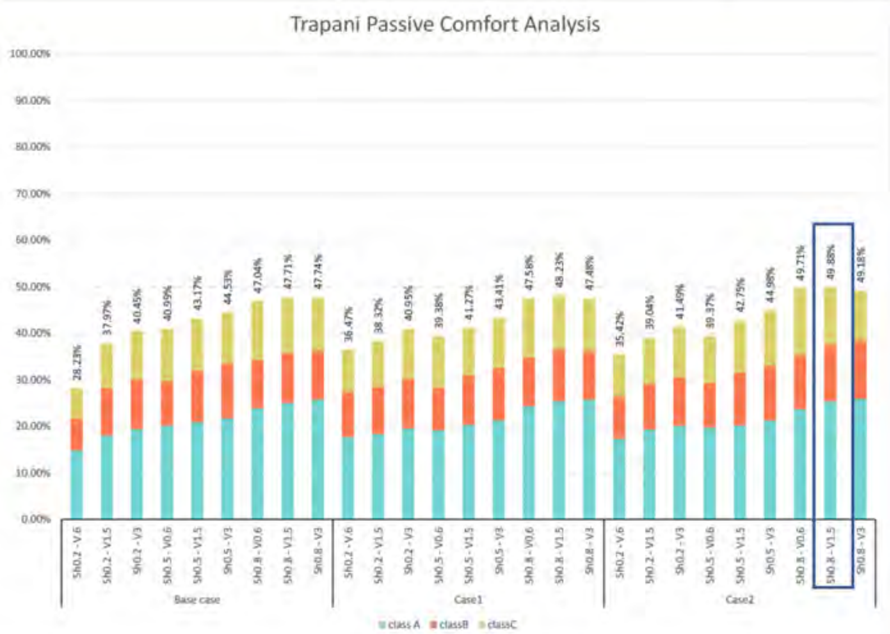
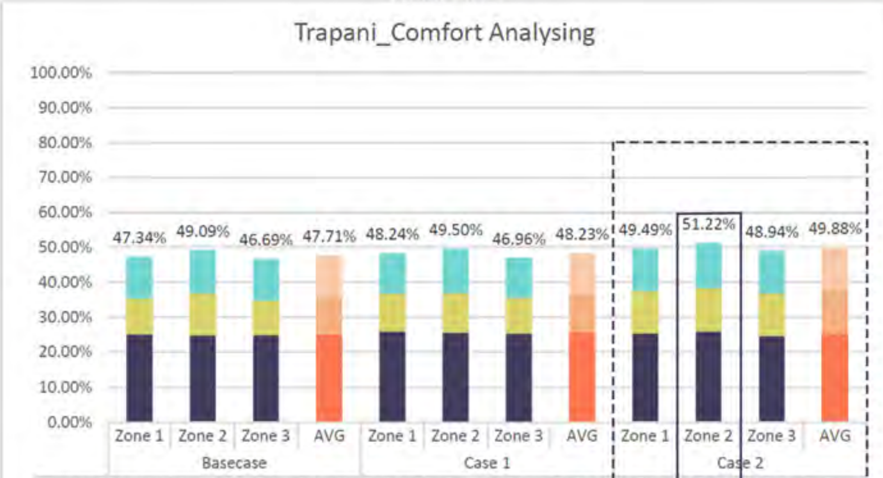


FIGURE 3.10




| | Basecase | | | | Case 1 | | | | Case 2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Zone 1 | Zone 2 | Zone 3 | AVG | Zone 1 | Zone 2 | Zone 3 | AVG | Zone 1 | Zone 2 | Zone 3 | AVG |
| Totals | 47.34% | 49.09% | 46.69% | 47.71% | 48.24% | 49.50% | 46.96% | 48.23% | 49.49% | 51.22% | 48.94% | 49.88% |
| classC | 11.89% | 12.19% | 11.97% | 12.02% | 11.36% | 12.50% | 11.30% | 11.72% | 12.13% | 12.91% | 12.08% | 12.37% |
| classB | 10.32% | 11.95% | 9.78% | 10.68% | 11.07% | 11.62% | 10.47% | 11.05% | 11.95% | 12.40% | 12.16% | 12.17% |
| class A | 25.13% | 24.95% | 24.94% | 25.01% | 25.81% | 25.38% | 25.19% | 25.46% | 25.41% | 25.91% | 24.70% | 25.34% |

class A classB classC Totals
FIGURE 3.11

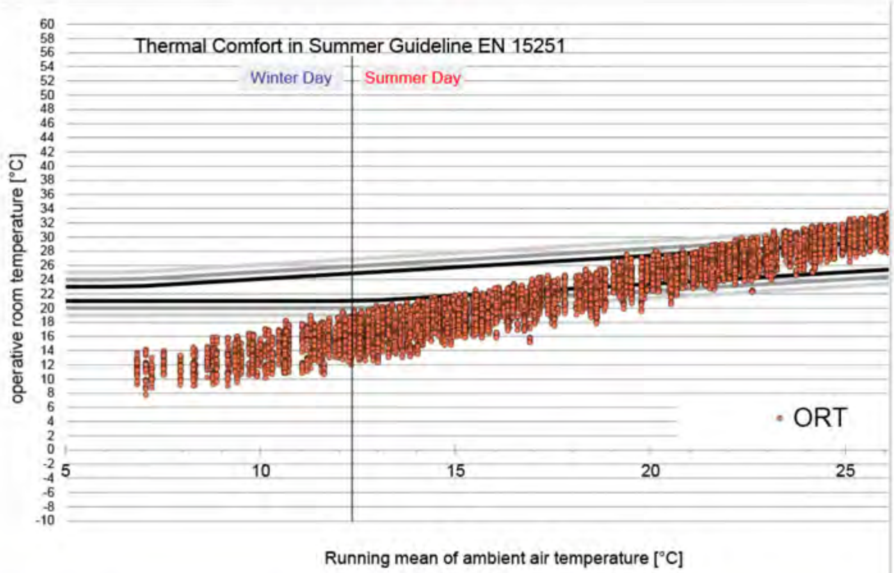


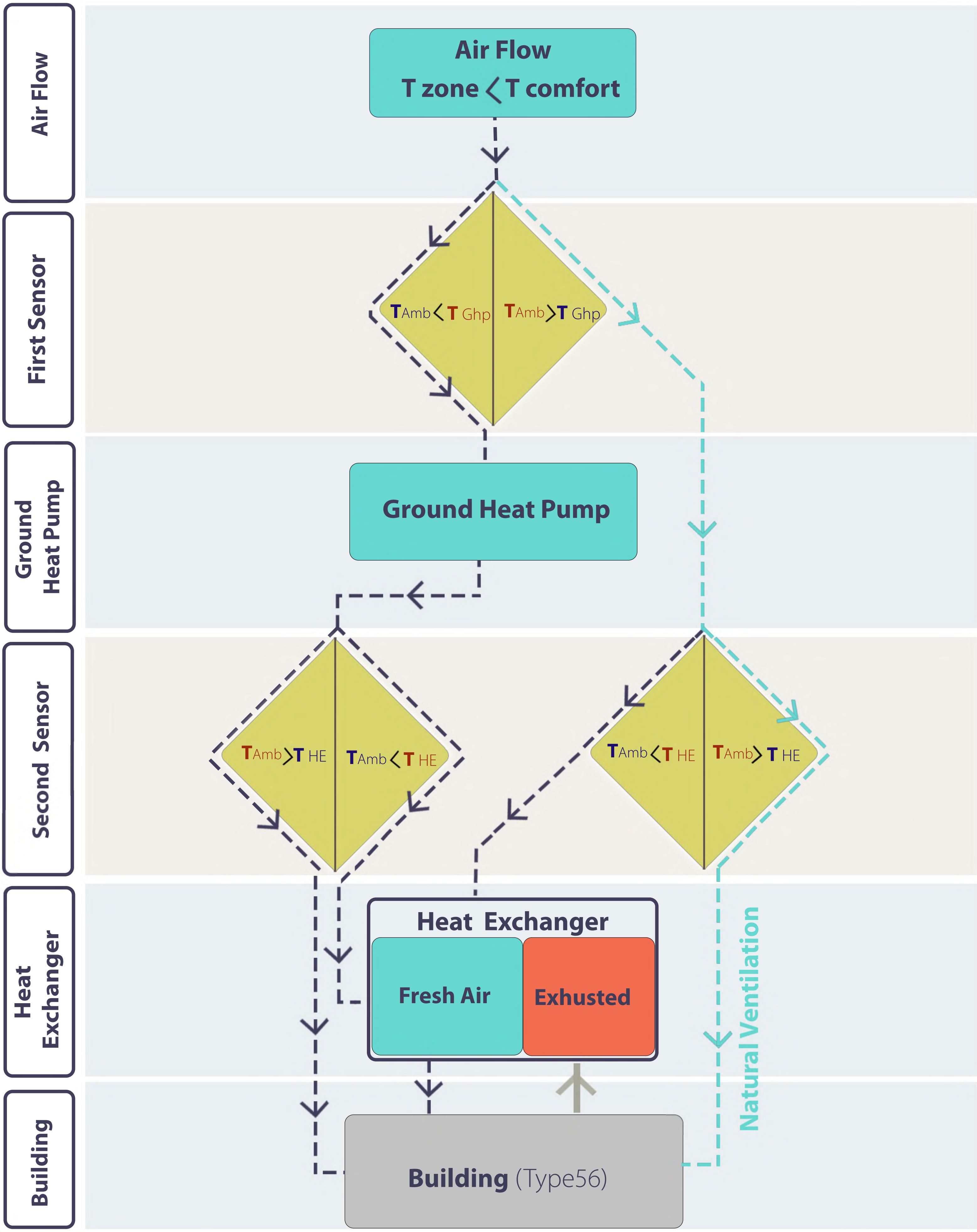
FIGURE 3.12

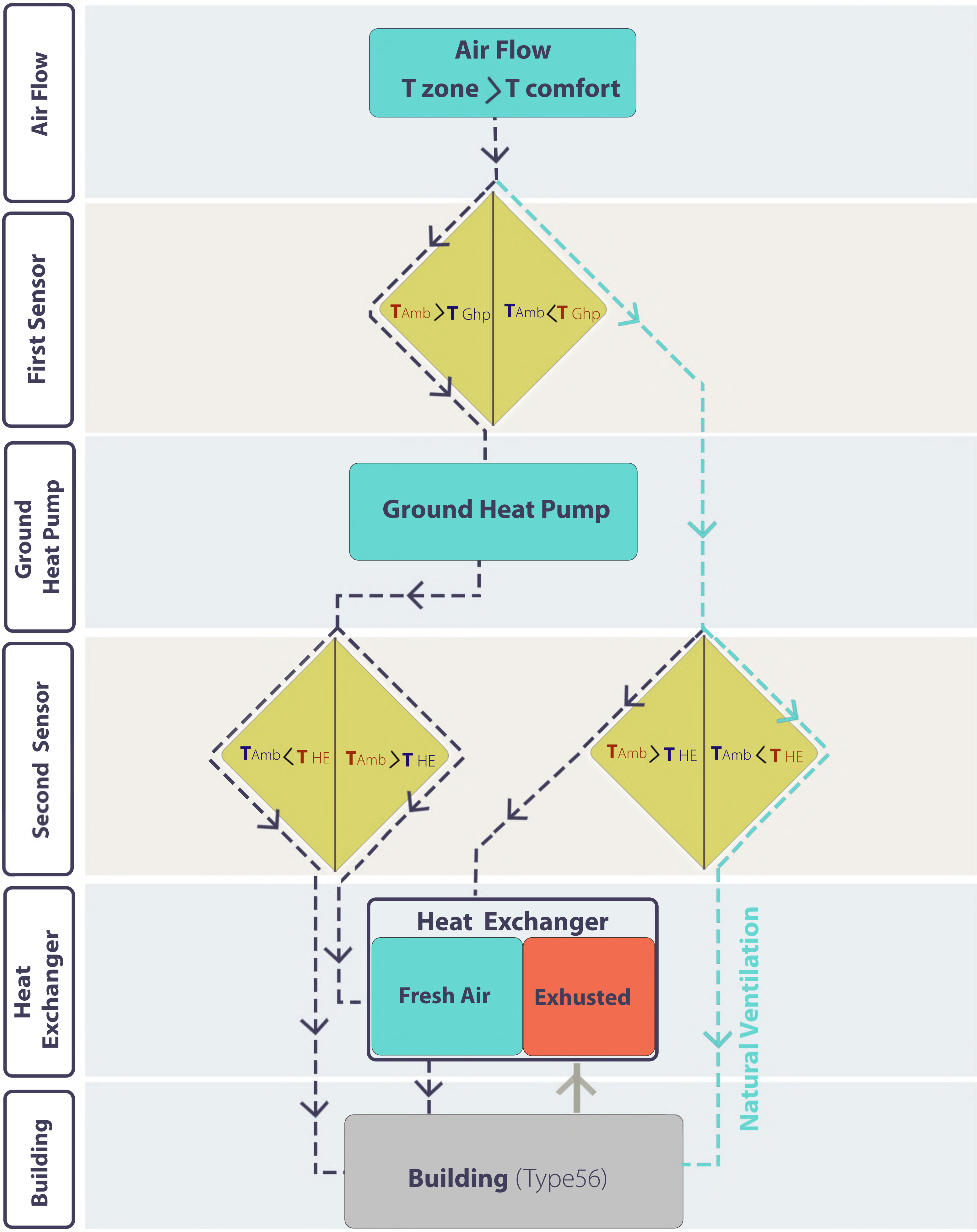
**Class C:** 12.91% **Class B:** 12.40% **Class A:** 25.91% **Total:** 51.22%

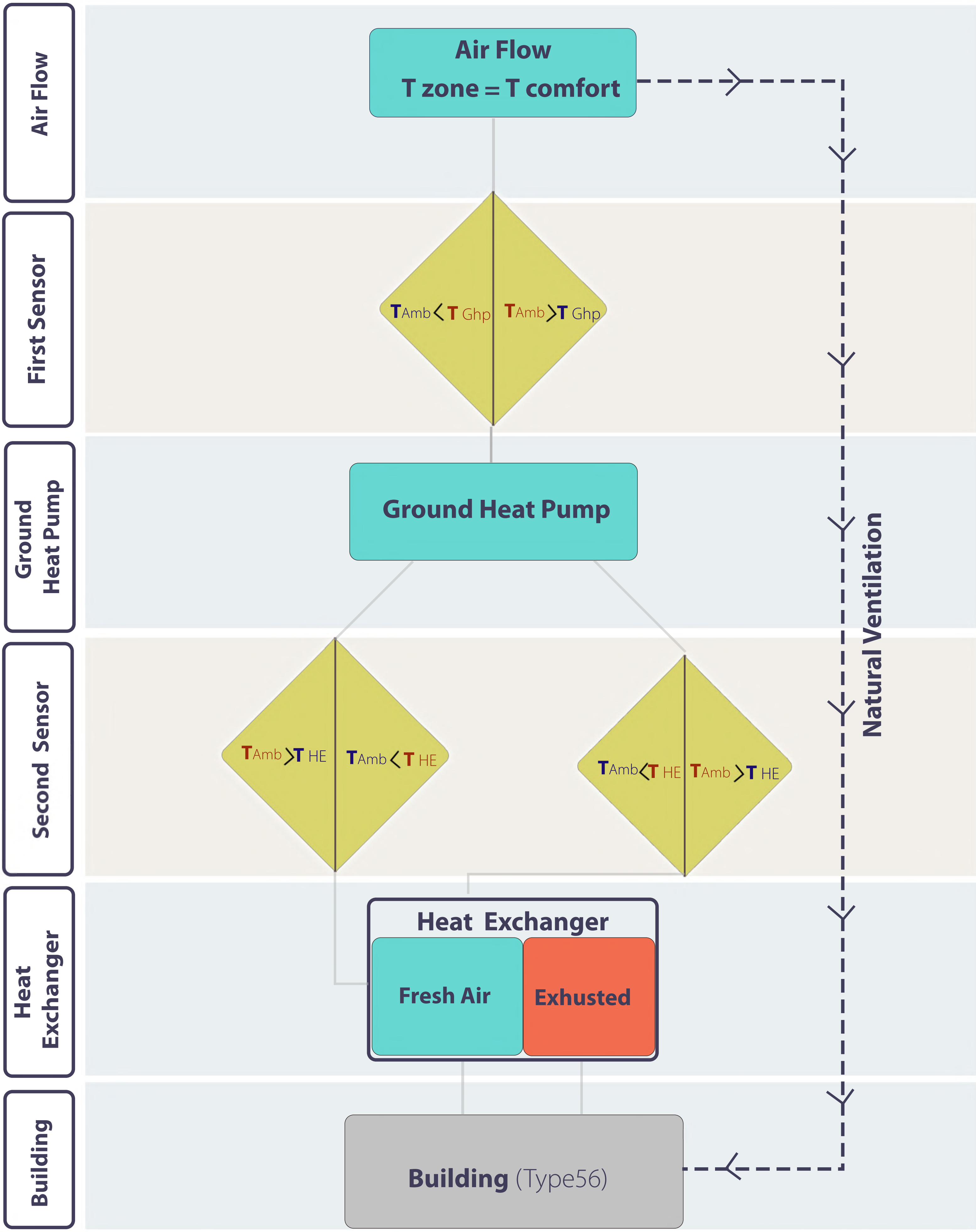
## Baseline

| | Zone1 | Zone2 | Zone3 |
|---|---|---|---|
| Lighting Heat Gain | 1.5W/m² | 1.5 W/m² | 0.5 W/m² |
| Equipment Heat Gain | 2.5 W/m² | 2.5 W/m² | 1 W/m² |
| People Heat Gain | 1 W/m² | 1 W/m² | 2 W/m² |

| | |
|---|---|
| Infiltration: | Annual Hourly |
| **Heating,** Cooling Set Point T | °20C°16-C °26C |
| Passive H/C Set Point T | Automated To EN15251 |
| Relative Humidity Limits | 50%-70% |
| Envelope Values: | Case2 |
| Shading Percentage | 0.8 |
| Ventilation Rate | 1.5 |


Air Flow
First Sensor
Ground Heat Pump
Second Sensor
Heat Exchanger
Building
Air Flow
T zone < T comfort
TAmb < T Ghp
TAmb > T Ghp
Ground Heat Pump
TAmb > T HE
TAmb < T HE
TAmb < T HE
TAmb > T HE
Heat Exchanger
Fresh Air
Exhusted
Natural Ventilation
Building (Type56)


Air Flow
First Sensor
Ground Heat Pump
Second Sensor
Heat Exchanger
Building
Air Flow
T zone > T comfort
TAmb > T Ghp
TAmb < T Ghp
Ground Heat Pump
TAmb < T HE
TAmb > T HE
TAmb > T HE
TAmb < T HE
Heat Exchanger
Fresh Air
Exhusted
Natural Ventilation
Building (Type56)


Air Flow
First Sensor
Ground Heat Pump
Second Sensor
Heat Exchanger
Building
Air Flow
T zone = T comfort
TAmb < T Ghp
TAmb > T Ghp
Ground Heat Pump
TAmb > T HE
TAmb < T HE
TAmb < T HE
TAmb > T HE
Heat Exchanger
Fresh Air
Exhusted
Building (Type56)
Natural Ventilation

## TRNSYS Model: Type 168

Natural airflows through openings are dependent on the effective opening area and the difference in air pressure inside and outside a building. The Type 168 models natural ventilation through openings like operable windows. It considers infiltration, controlled ventilation and flushing events, and provides two models to determine the maximum volumetric flow rate through an opening. Note that both models do not account for the effect of wind pressure on natural ventilation.

## TRNSYS Model: Type150-3

This component models a "sticky" controller where the outputs are set to the input values from a user-defined previous timestep. For example, the user could decide to have the outputs to another component be based on the zone temperatures from the previous hour or even from the previous day.The stickiness is set by the number of timesteps and not based on the number of hours.

## TRNSYS Model: Type 515-2

The Heating and Cooling Season Scheduler utility programs (Type515.exe and SeasonsScheduler.exe) and their companion component Type515 are used in conjunction with one another to input a heating/cooling season schedule. A heating/cooling schedule denotes which portions of the year when heating or cooling (or both) equipment may be utilized.

## TRNSYS Model: Type 1669

This component returns a control signal between 0 and 1 that is related to the current value of an input as compared to a user defined minimum and maximum value.

## TRNSYS Model: Type 31-2

This component models the thermal behavior of fluid flow in a pipe or using variable size segments of fluid. Entering fluid shifts the position of existing segments. The mass of the new segment is equal to the flow rate times the simulation timestep. The new segment's temperature is that of the incoming fluid. The outlet of this pipe is a collection of the elements that are pushed out by the inlet flow. Thisplug-flow model does not consider mixing or conduction between adjacent elements. A maximum of 25 segments is allowed in the pipe.

## TRNSYS Model: Type 760

Type760 uses an effectiveness – minimum capacitance approach to model an air to air heat exchanger that transfers only sensible energy. If moisture transfer as well as sensible energy transfer between the exhaust and fresh air streams is important.Type760 includes five different control modes. In the first of these control modes, the outlet temperatures of the two air streams are completely uncontrolled. In the other four operation modes, the temperature of either the fresh or exhaust air streams is maintained either above or below a user defined set point.

## TRNSYS Model: Type 646

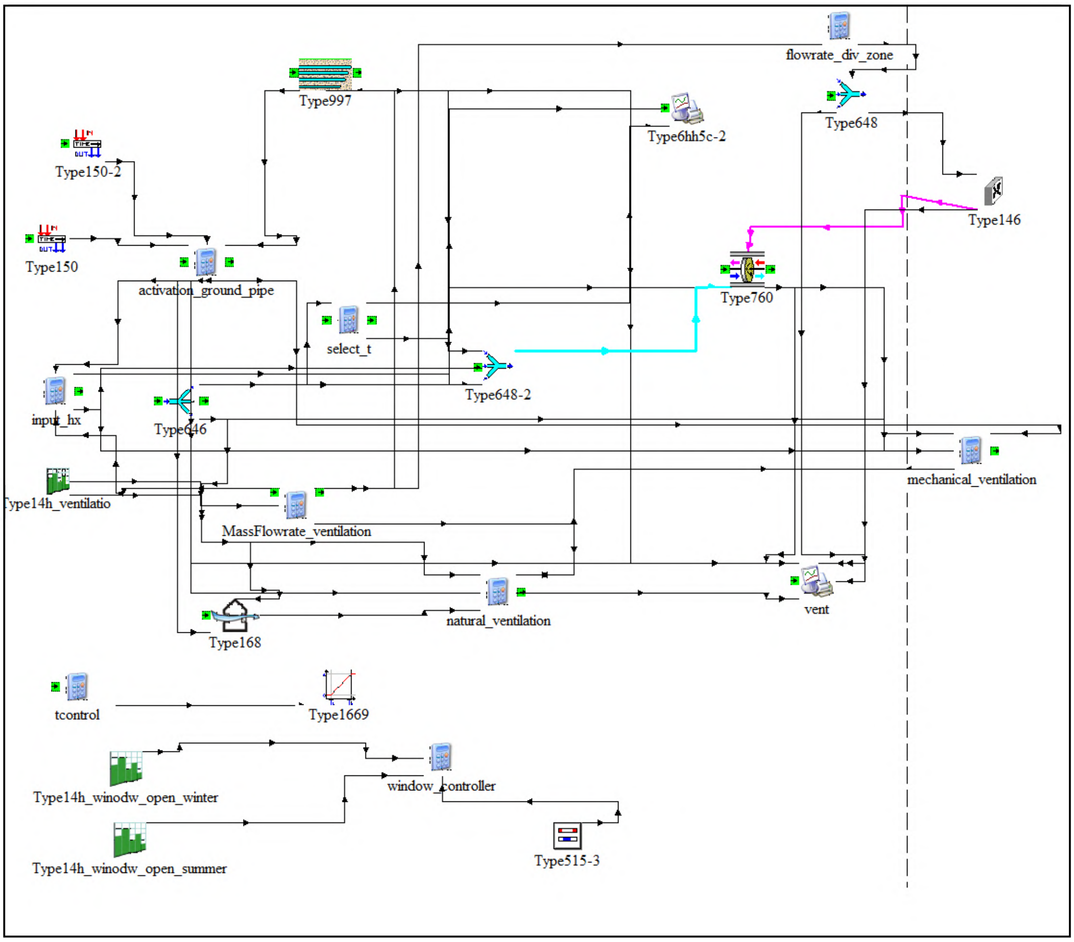
Type646 models a supply air plenum. One inlet flow of air is split up into as many as 100 individual streams whose mass flowrates are user specified fractions of the inlet air flowrate. The limit of 100 inlet flows can be modified in the Fortran source code.

## TRNSYS Model: Type 648

Type648 models a return air plenum. Up to 100 individual flows of air are mixed together to determine the properties of the air exiting the plenum. The limit of 100 inlet flows can be modified in the Fortran source code.

## TRNSYS Model: Type 997

This component models a series of fluid-filled, parallel, horizontal pipes buried in the earth. The user may also specify a flow pattern from one pipe to another. This model allows the user to specify groundwater flows through a horizontal layer of soil (user specified thickness) and multiple soil layers.




SC.2. TRNSYS simulation model for ventilation

## Ground Pipes Heat Exchange

To exploit the most out of the possible options helping to decrease heating and cooling loads on the building, It is decided to implement ground heating and cooling pipes to provide more suitable air to the mechanical ventilation system.

To find the best settings for the system in terms of depth of the pipes, length of the pipes, number of the pipes, and the diameter of each pipe the design is divided into steps of optioneering with the criterion of Outlet Temperature Optimization and Least Annual Fluctuation in temperature.

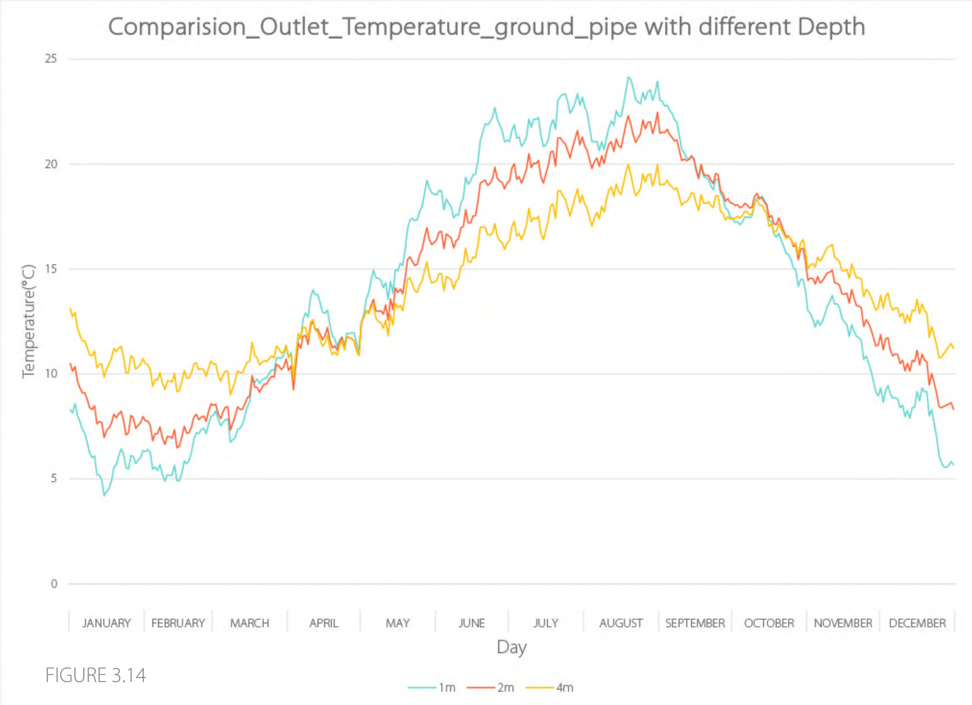



FIGURE 3.14

## Step 1 - Depth

To reach the optimal depth for the heat exchange pipes under the ground, it is proposed three different depths, 1m, 2m, and 4m.

It is visible in the following chart (figure 3.15) that the installing the pipes in the depth of 4m under ground level not only changes drastically in terms of Temperature_ Cooler in summer and warmer in winter_ but also it exhibits the least fluctuation helping the building to maintain a more linear Temperature close to the comfort requirements.

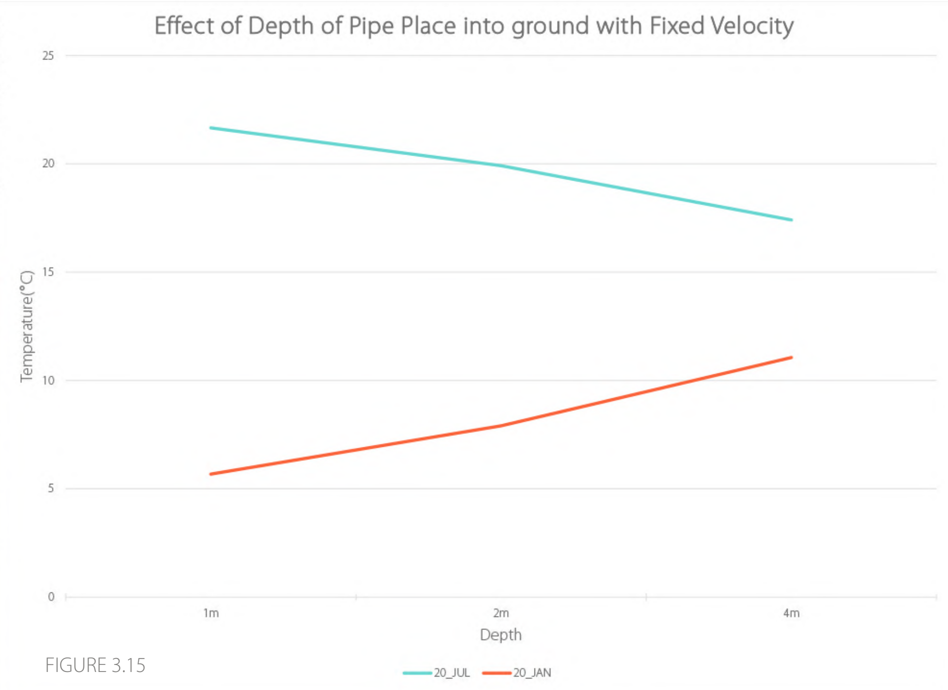
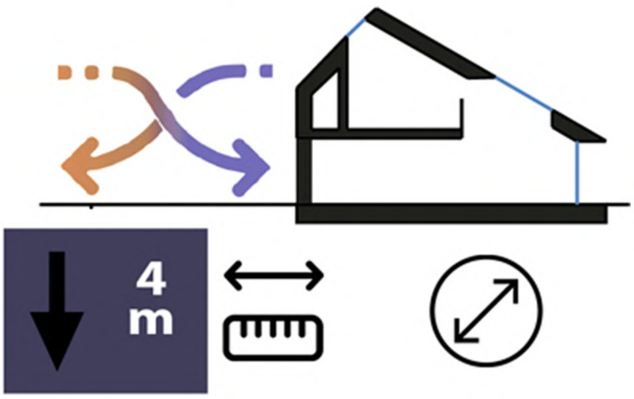



FIGURE 3.15

| Baseline | | | |
|---|---|---|---|
| | Zone1 | Zone2 | Zone3 |
| Lighting Heat Gain | 1.5 W/m² | 1.5 W/m² | 0.5 W/m² |
| Equipment Heat Gain | 2.5 W/m² | 2.5 W/m² | 1 W/m² |
| People Heat Gain | 1 W/m² | 1 W/m² | 2 W/m² |
| Infiltration: | | | Annual Hourly |
| Heating, Cooling Set Point T | | | °20C°16-C °26C |
| Passive H/C Set Point T | | | Automated To EN15251 |
| Relative Humidity Limits | | | 50%-70% |
| Envelope Values: | | | case 2 |
| Shading Percentage | | | 0.8 |
| Ventilation Rate | | | 0.6 |



## Step 2- Length

To reach the optimal Length for the heat exchange pipes under the ground, it is proposed three different Lengths, 10m, 20m, and 30m.

It is visible in the following chart (figure 3.17) that the installing the pipes with the length of 30m under ground level, not only changes drastically in terms of Temperature_ Cooler in summer and warmer in winter_ but also it exhibits the least fluctuation helping the building to maintain a more linear Temperature close to the comfort requirements.

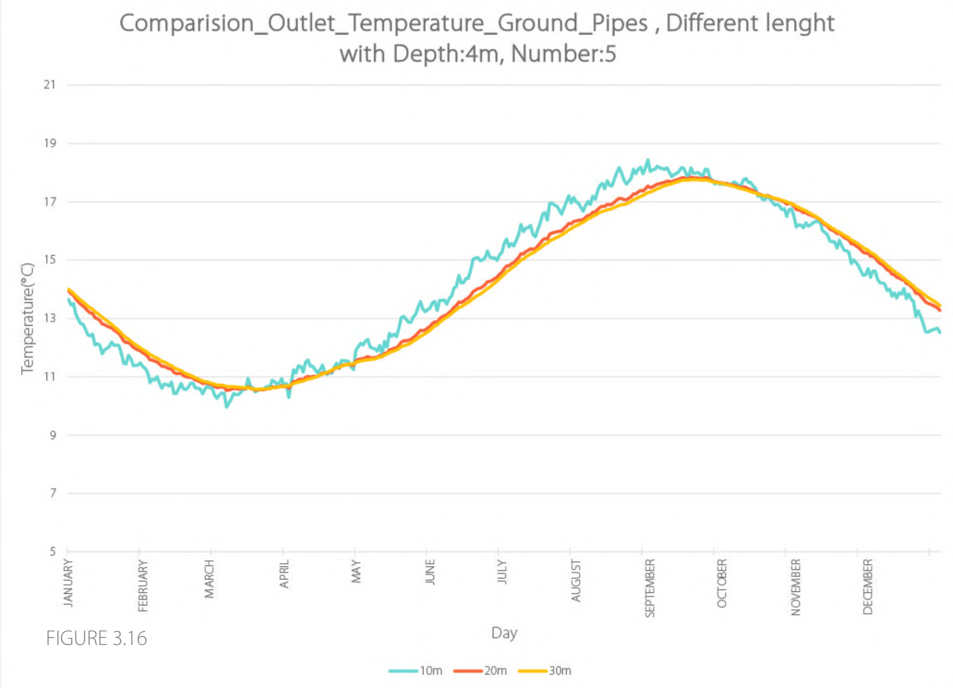



FIGURE 3.16

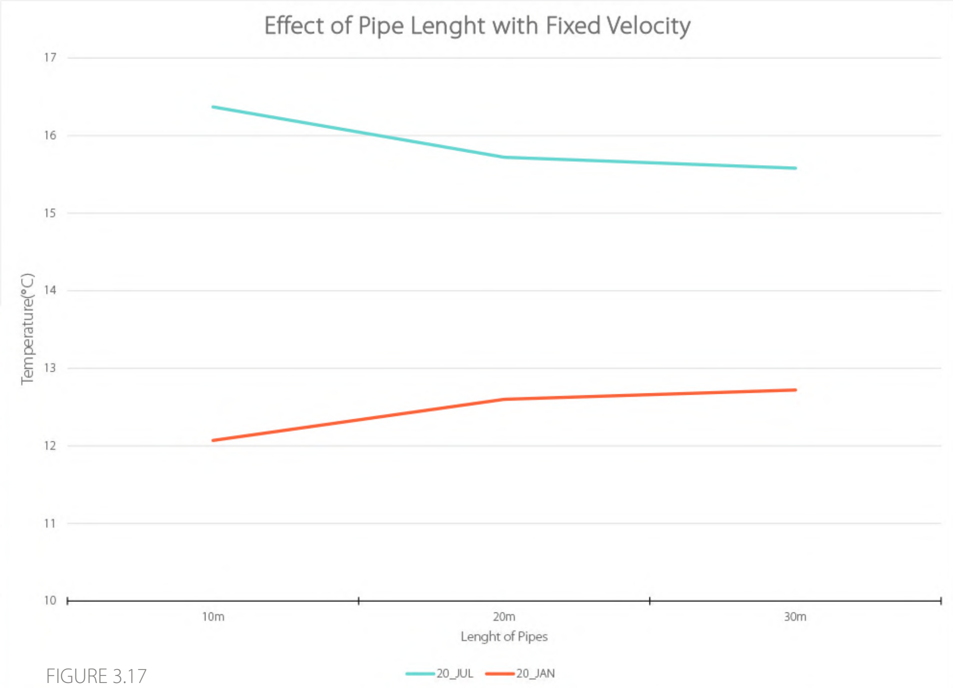
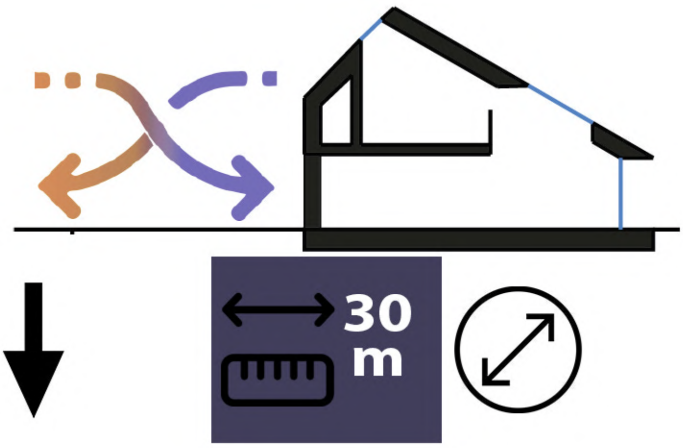



FIGURE 3.17

## Baseline

| | Zone1 | Zone2 | Zone3 |
|---|---|---|---|
| Lighting Heat Gain | 1.5 W/m² | 1.5 W/m² | 0.5 W/m² |
| Equipment Heat Gain | 2.5 W/m² | 2.5 W/m² | 1 W/m² |
| People Heat Gain | 1 W/m² | 1 W/m² | 2 W/m² |
| Infiltration: | | | Annual Hourly |
| **Heating,** Cooling Set Point T | | | °20C°16-C °26C |
| Passive H/C Set Point T | | | Automated To EN15251 |
| Relative Humidity Limits | | | 50%-70% |
| Envelope Values: | | | Case2 |
| Shading Percentage | | | 0.8 |
| Ventilation Rate | | | 0.6 |



## Step 3 - Number & Diameter

Since the standard requires the mechanical ventilation to maintain a 2m/s velocity for the airflow to keep the velocity constant the number and diameter of the pipe are proportional to each other, so to divide them into different settings for optioneering it is chosen 1 pipe, 3 pipes, and finally 5 pipes to reach the optimal number of pipes for the heat exchange pipes under the ground.

It is visible in the following chart (figure 3.19) that the installing the setting with 5 pipes under ground level not only changes drastically in terms of Temperature_ Cooler in summer and warmer in winter_ but also it exhibits the least fluctuation helping the building to maintain a more linear Temperature close to the comfort requirements.

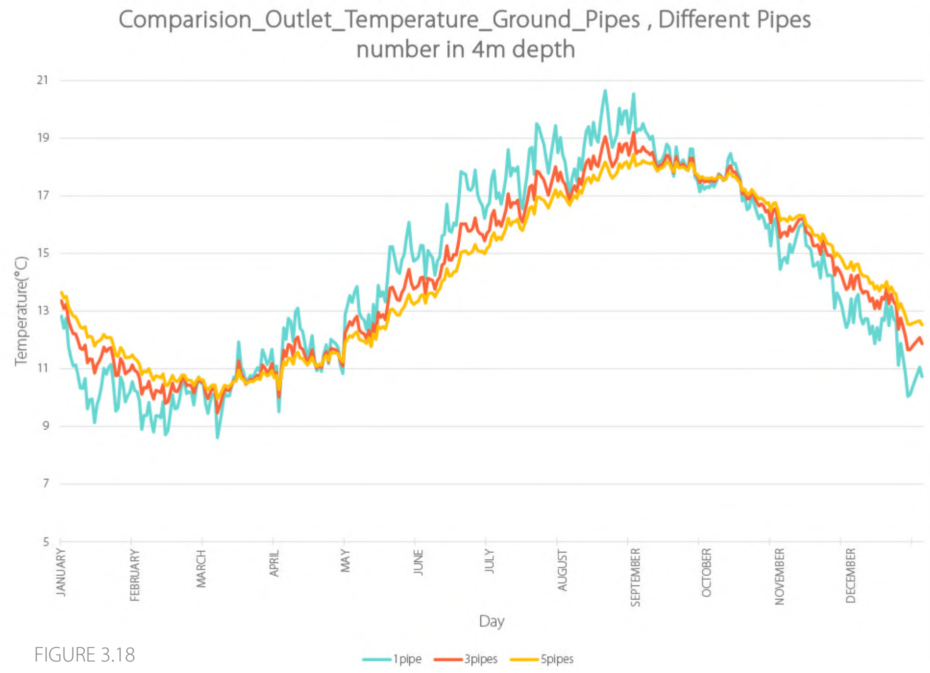



FIGURE 3.18

Flowrate = density of air * volume * Air changes per hour

1.2 * 517.7 * 0.6 = 372.744 Kg/h   372.744/3600 = 0.103 kg/s

0.103/1.2 = 0.086 $m^3/s$

0.086/2 = 0.045 $m^2$

TABLE 3.1

| | pipe | inside diameter |
|---|---|---|
| case 1 | 1 | 0.25 |
| case 2 | 3 | 0.15 |
| case 3 | 5 | 0.1 |

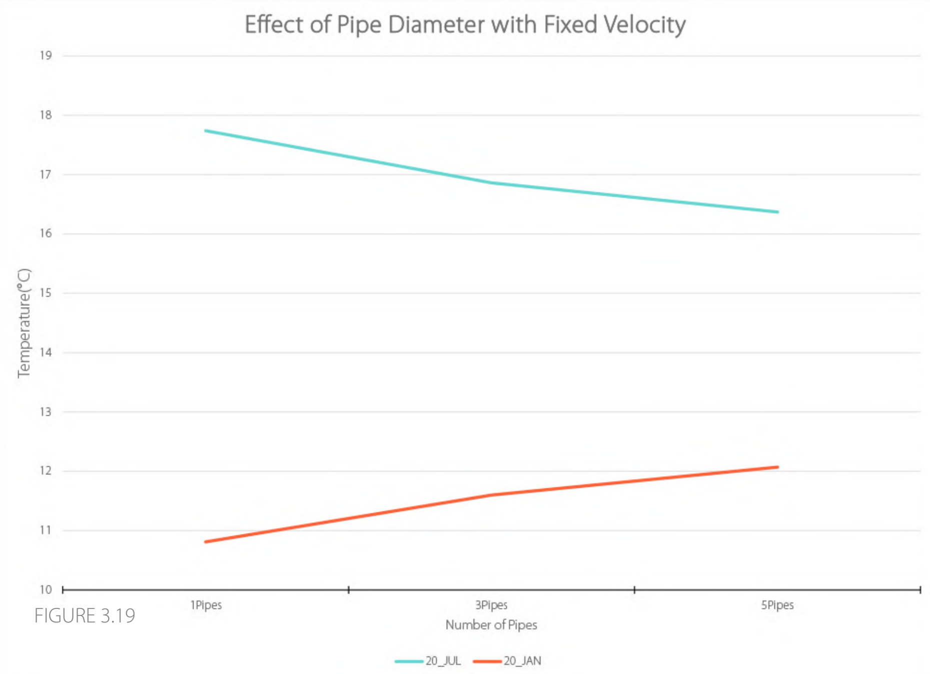
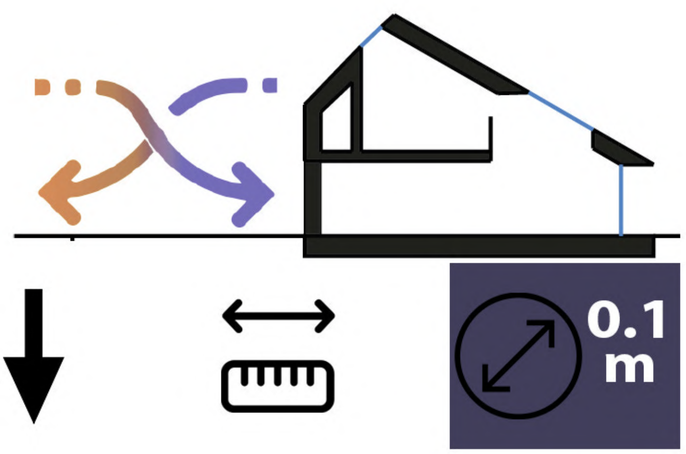



FIGURE 3.19

## Baseline

| | Zone1 | Zone2 | Zone3 |
|---|---|---|---|
| Lighting Heat Gain | 1.5 W/m² | 1.5 W/m² | 0.5 W/m² |
| Equipment Heat Gain | 2.5 W/m² | 2.5 W/m² | 1 W/m² |
| People Heat Gain | 1 W/m² | 1 W/m² | 2 W/m² |
| Infiltration: | | | Annual Hourly |
| **Heating,** Cooling Set Point T | | | °20C°16-C °26C |
| Passive H/C Set Point T | | | Automated To EN15251 |
| Relative Humidity Limits | | | 50%-70% |
| Envelope Values: | | | Case2 |
| Shading Percentage | | | 0.8 |
| Ventilation Rate | | | 0.6 |



## Ventilation Automation

To optimize the use of three different means of providing airrow to the building, it is required an automation system that decides when and how each system should work. The three systems are Natural Ventilation, Ground Pipes alone, and Heat exchange system following Ground pipe system.

The automation system takes into account the outlet Temperature of ambient air, GHPs, Exhaust air, and Operative Temperature of the zones and, by considering the Class B EN15251 comfort criteria, monitors the performance of the building hour by hour and chooses the best performing system.

as you can see the automation alone causes the system to choose not the optimal option during the summer since it does not save the cooling energy from the morning hours which the building is performing in comfort conditions for the evening hours. it is visible in the chart of hourly temperature comparison of June 13th (figure 3.23) and hourly ventilation flowrate (figure 3.22) you can see that the use of natural ventilation causes the building to go very near the ambient T in the evening.

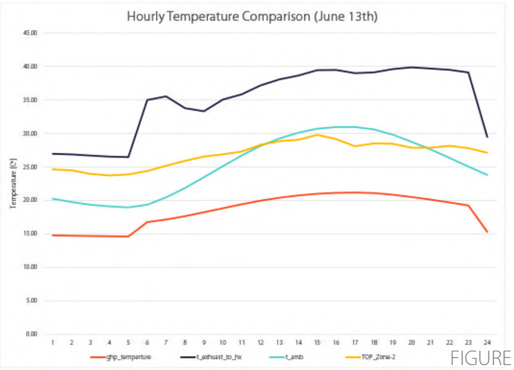



FIGURE 3.23

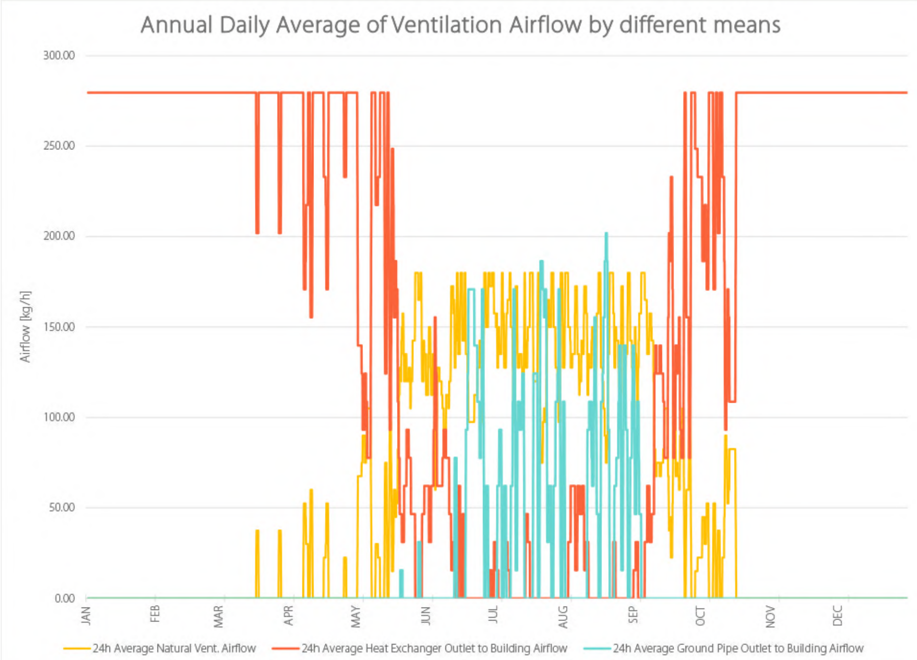



FIGURE 3.20

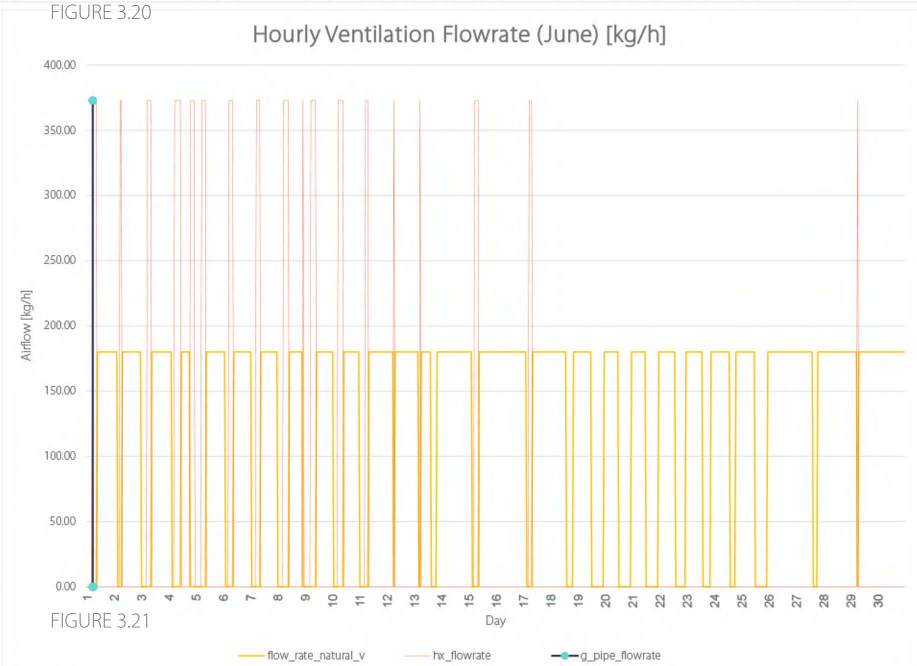



FIGURE 3.21

## Baseline

| | Zone1 | Zone2 | Zone3 |
|---|---|---|---|
| Lighting Heat Gain | 1.5 W/m² | 1.5 W/m² | 0.5 W/m² |
| Equipment Heat Gain | 2.5 W/m² | 2.5 W/m² | 1 W/m² |
| People Heat Gain | 1 W/m² | 1 W/m² | 2 W/m² |
| Infiltration: | Annual Hourly | | |
| **Heating,** Cooling Set Point T | **°20C**°16-C °26C | | |
| Passive H/C Set Point T | Automated To EN15251 | | |
| Relative Humidity Limits | 50%-70% | | |
| Envelope Values: | TBD | | |
| Shading Percentage | TBD | | |
| Ventilation Rate | TBD | | |

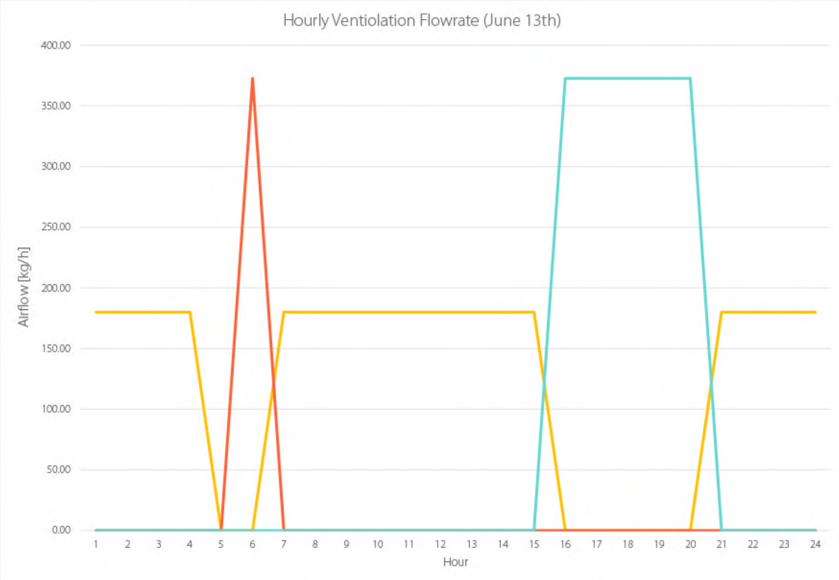



FIGURE 3.22

By using a simple schedule during the summer which limits the use of natural ventilation during the peak hours of Ambient Air Temperature which in this climate is 10am to 4pm, it is possible to increase the performance of the system.

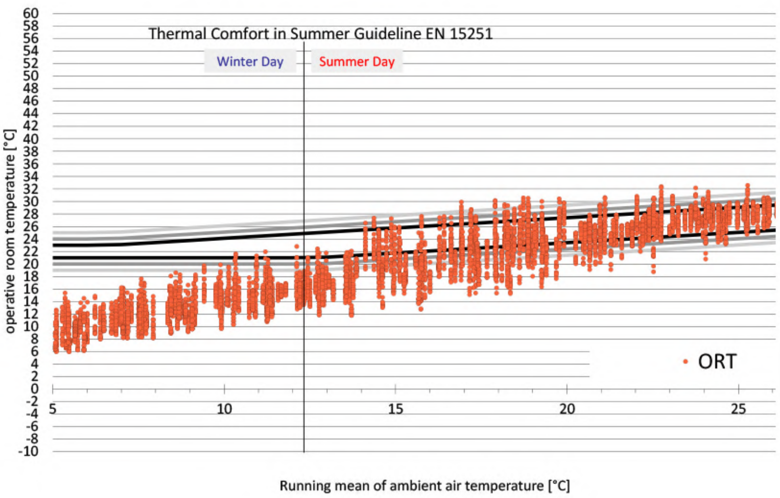



FIGURE 3.24

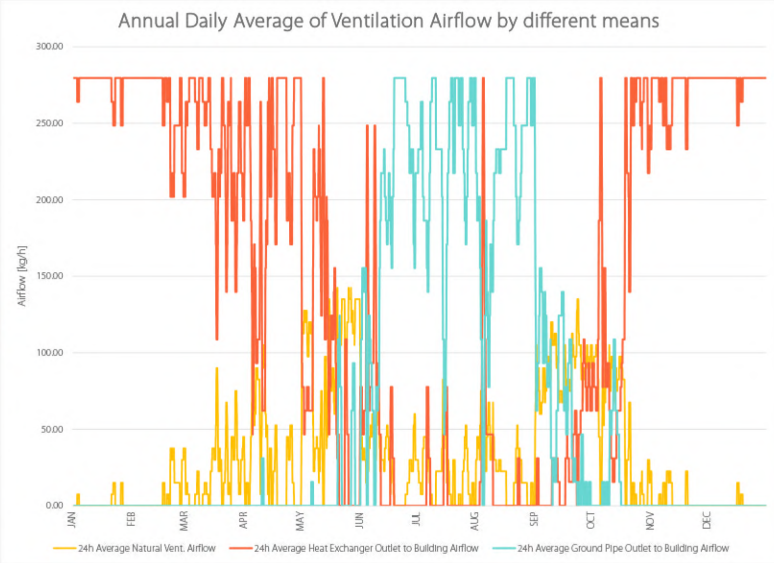



FIGURE 3.25

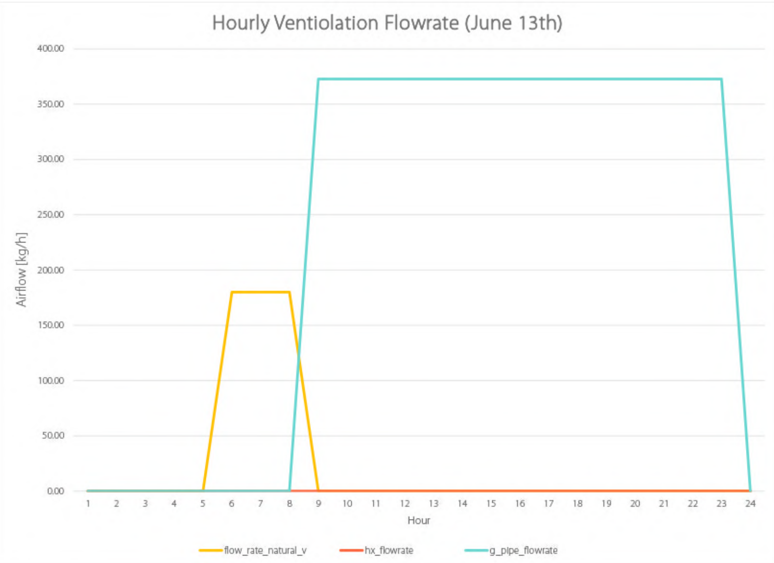



FIGURE 3.26

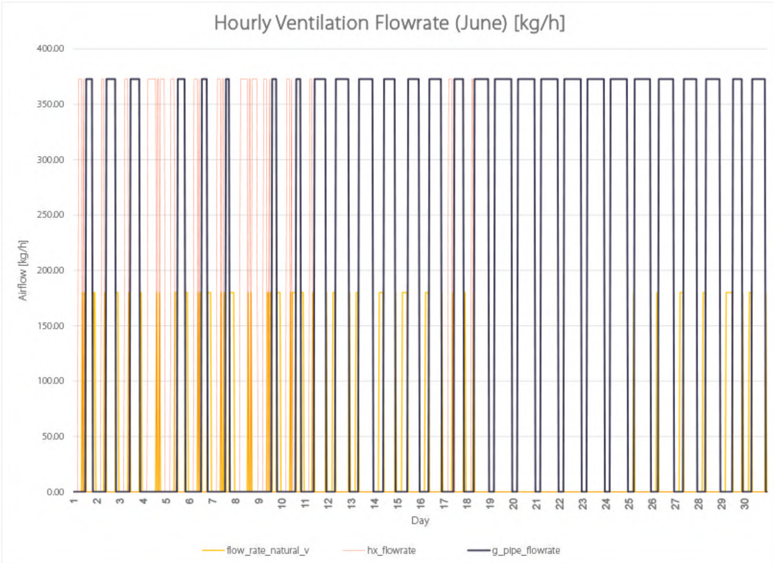



FIGURE 3.27

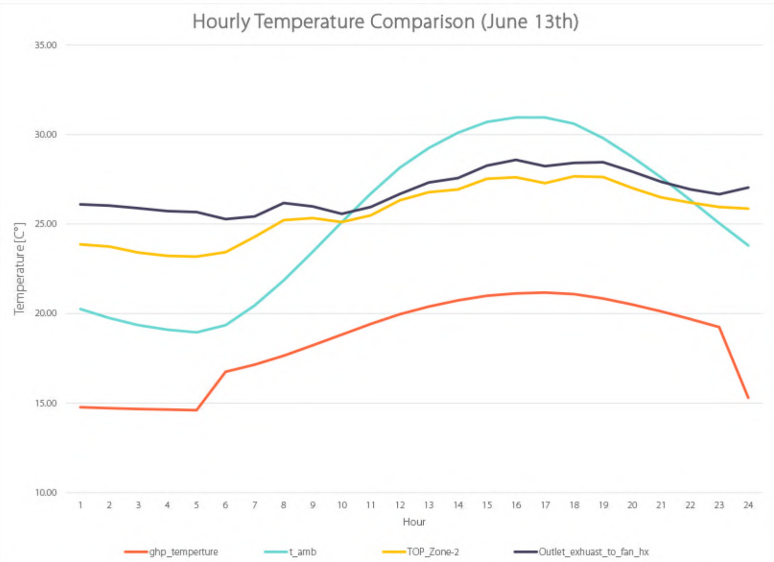



FIGURE 3.28

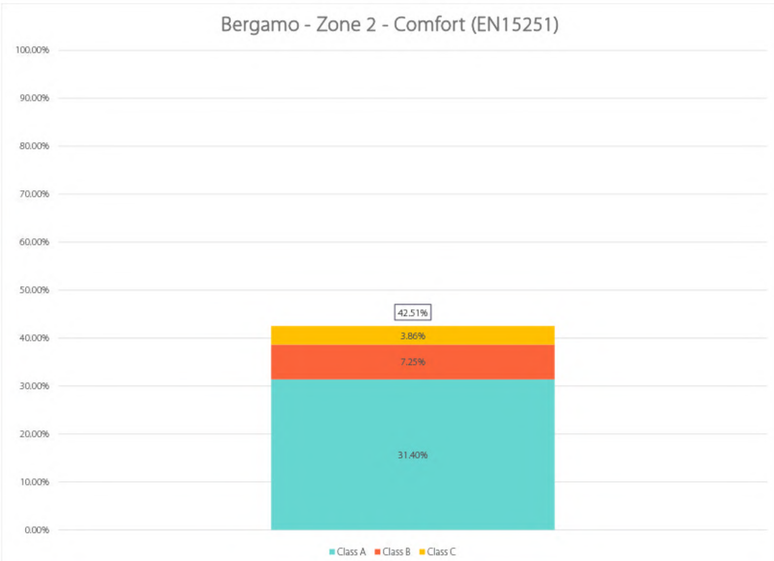



FIGURE 3.29

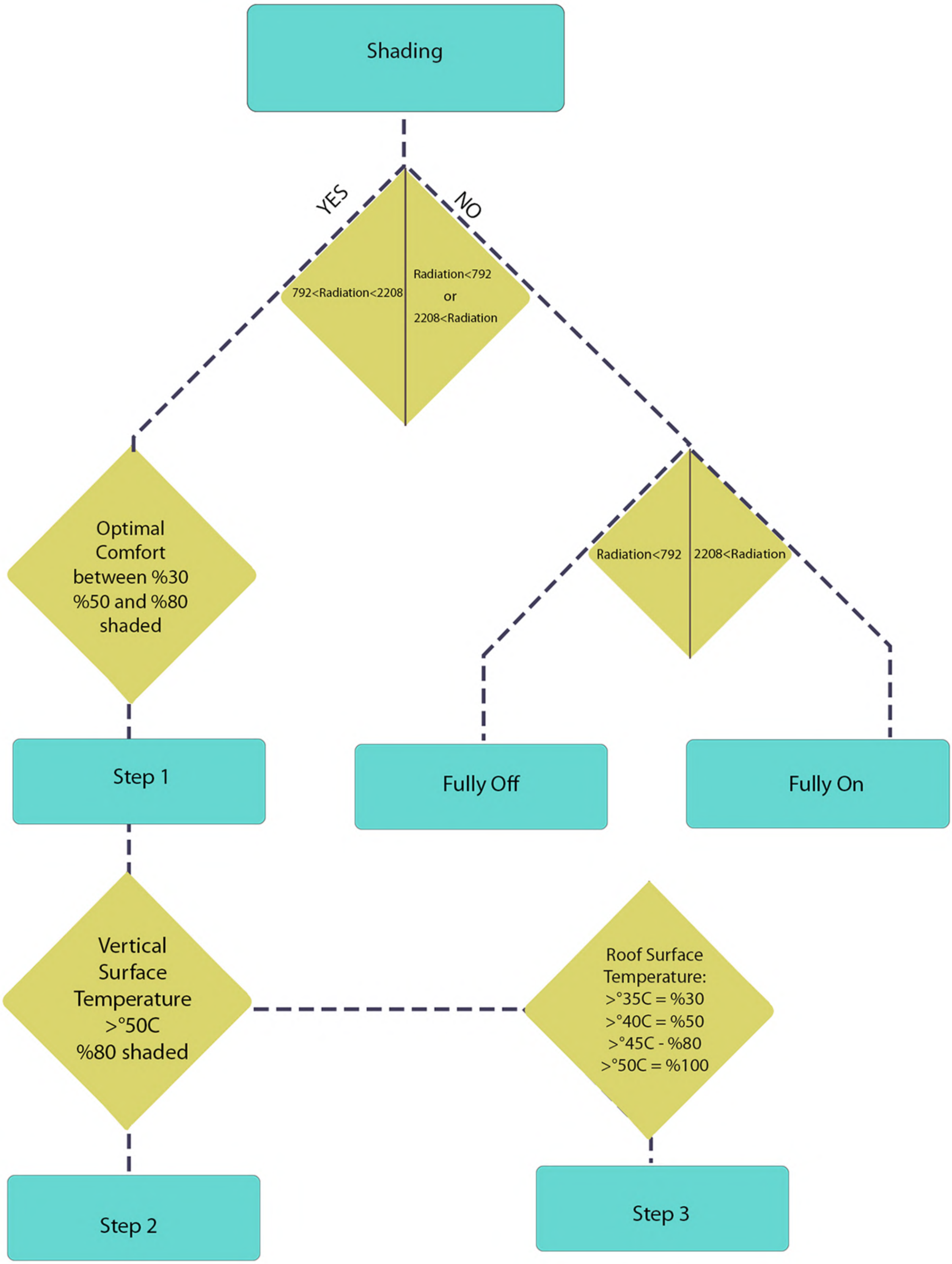

Shading
YES
NO
792<Radiation<2208
Radiation<792
or
2208<Radiation
Optimal Comfort between %30 %50 and %80 shaded
Radiation<792
2208<Radiation
Step 1
Fully Off
Fully On
Vertical Surface Temperature >°50C %80 shaded
Roof Surface Temperature:
>°35C = %30
>°40C = %50
>°45C - %80
>°50C = %100
Step 2
Step 3

FIGURE 3.30

## TRNSYS Model: Type 9c

This component serves the purpose of reading data at regular time intervals from a data file, converting it to a desired system of units, and making it available to other TRNSYS components as time-varying forcing functions. This component is very general in nature and can read many different types of files. The data from line to line must be at constant time intervals.

## TRNSYS Model: Type150-3

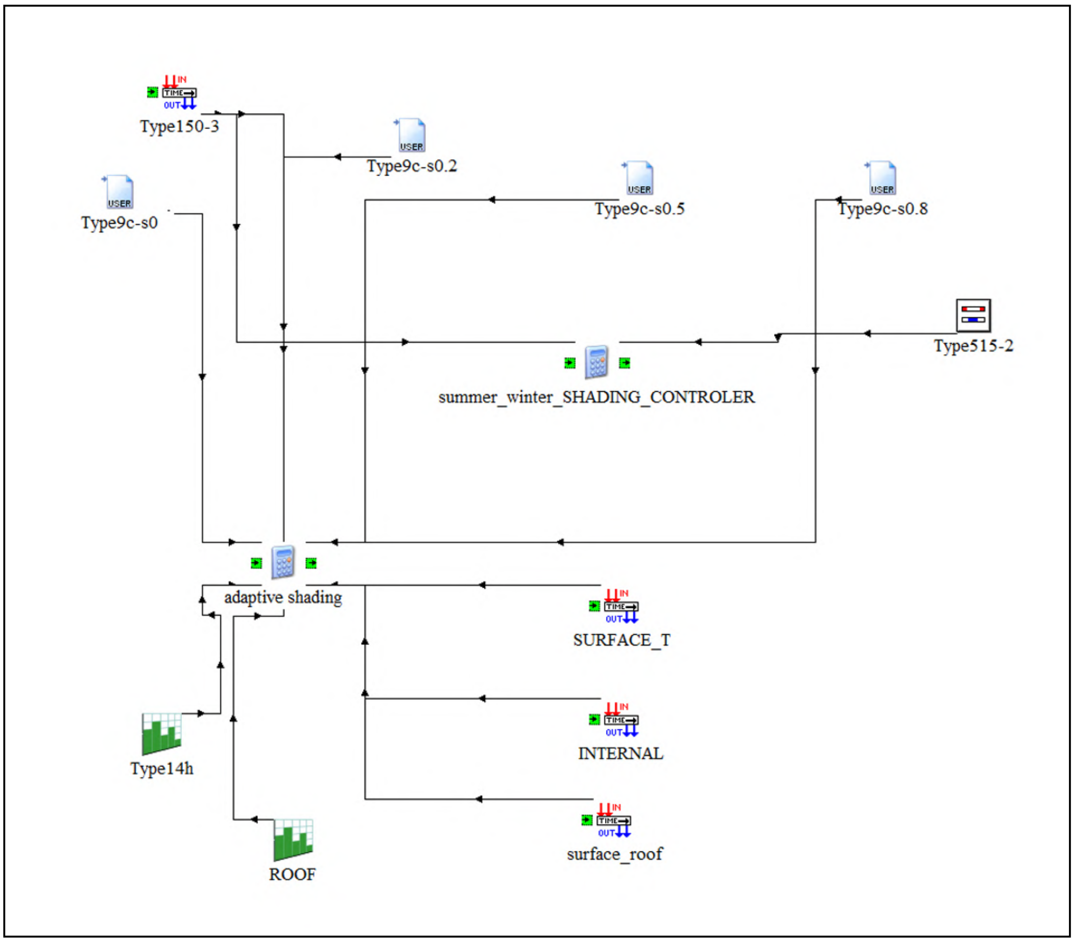
This component models a "sticky" controller where the outputs are set to the input values from a user-defined previous timestep. For example, the user could decide to have the outputs to another component be based on the zone temperatures from the previous hour or even from the previous day.The stickiness is set by the number of timesteps and not based on the number of hours.

## TRNSYS Model: Type 515-2

The Heating and Cooling Season Scheduler utility programs (Type515.exe and SeasonsScheduler.exe) and their companion component Type515 are used in conjunction with one another to input a heating/cooling season schedule. A heating/cooling schedule denotes which portions of the year when heating or cooling (or both) equipment may be utilized.

## TRNSYS Model: Type 14h

The pattern of the forcing function is established by a set of discrete data points indicating the value of the function at various times throughout one cycle. Linear interpolation is provided in order to generate a continuous forcing function from the discrete data. The cycle will repeat every N hours where N is the last value of time specified. While the code of Type14 is entirely general, this version of the component uses dimensionless units so that it too can be used in a very generic manner.




SC.1. TRNSYS simulation model for shading

# SHADING AUTOMATION

The shadings over the transparent parts of the buildings play an important role. They are directly affective on both visual comfort of the residence and the amount of solar gain inside the thermal zone. To enhance the performance of the building toward optimal exploitation of the both visual comfort and solar gain, an automation technology has been reached.
The automation as you saw on the schematic chart (figure 3.30) starts with a radiation control if the total radiation over the surface of the windows in the scheduled hours (6am to 12pm) is less than 800 the Automation turns the shadings fully off (0%) on the other hand if the total radiation surpass 2200 the system would totally shut down the shadings (100%).
After that preliminary control the shading automation system is controlled hourly to reach the optimum comfort in three main steps.
First chart of the page (figure 3.31) shows the annual hourly radiation values with indication of the upper and lower boundaries.

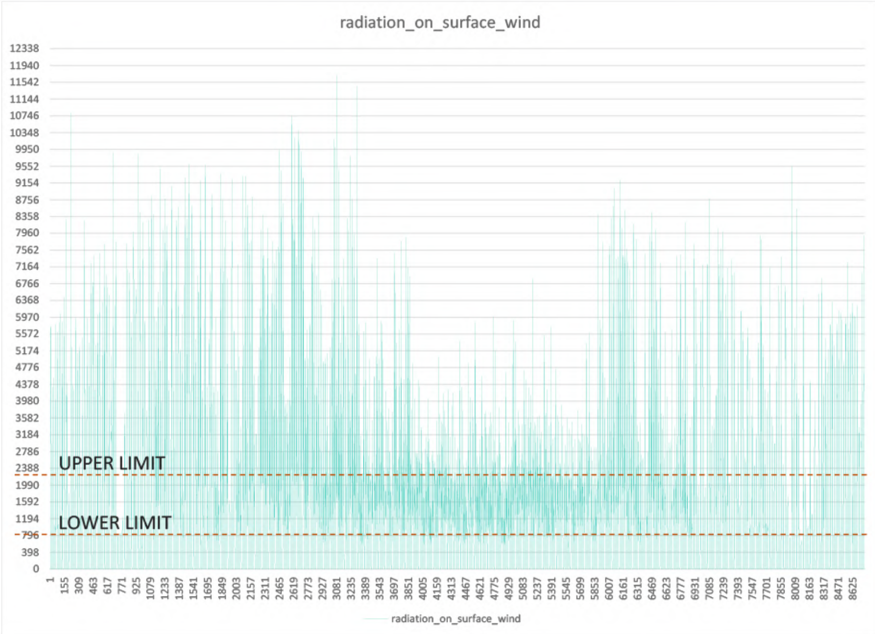
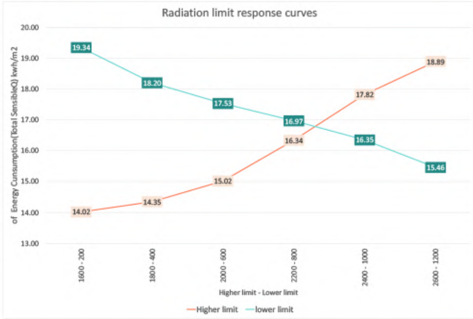



FIGURE 3.31




## Radiation limit optioneering

Overlaping the response curve for the higher and lower limit of the radiation control in terms of total loads imposed inside the building, it has been obtained the optimum values.

# COMFORT EVALUATION

To evaluate the comfort for each hour of the analysis an equation has be imposed that as an outcome it will plot if the room is in comfort conditons, or colder than comfort range, or warmer than so. all comfort temperatures are taken with regards to ashrae 15251 standards and considering the ambient temperature. As of here on, all positive or negative outcome in terms of comfort is considered the outcome of the mentioned equation for the last hour as decision base for the upcoming hour.

It is visible in this chart the number of hours during the year that the radiation is in and out of the boundary of the shading control condition, thus how many hours in a year the system is operating.

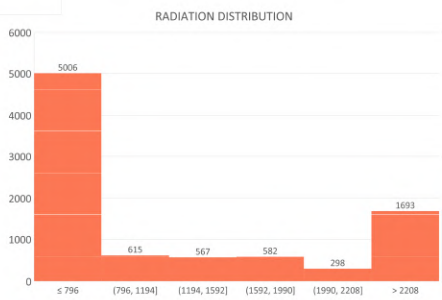



FIGURE 3.32

# STEP ONE

To begin with, there has been done a total control of the comfort with 0%, 30%, 50%, and 80% shaded ratio and the optimal performance of the building in terms of comfort has been chosen for that operative hour inside the working schedule. In case of equal performance in terms of comfort the lower value of shading ratio has been chosen to provide **better visual comfort.**
In this page you can see how the shading control is operating in January (figure 3.33).

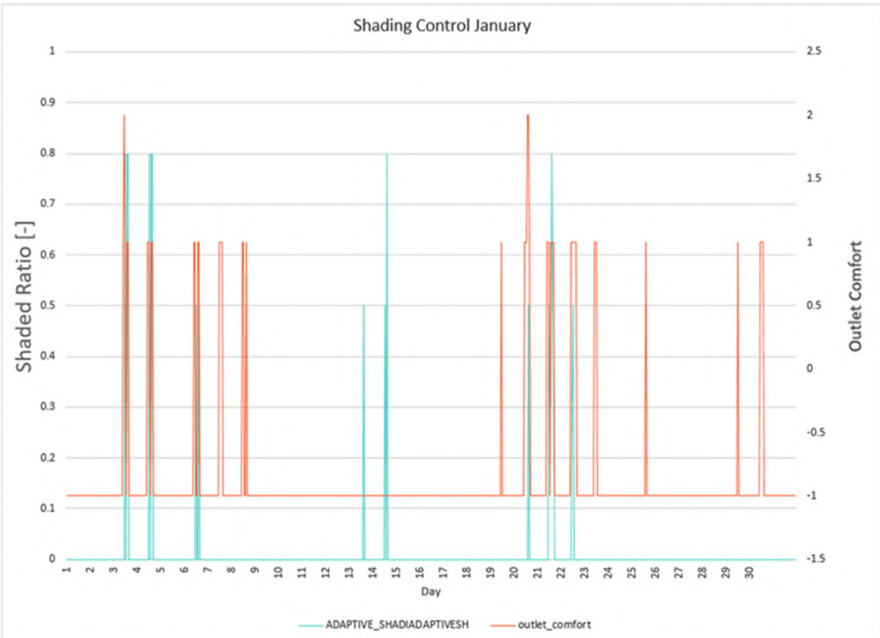



FIGURE 3.33

In the following chart (figure 3.34) the outlet of comfort is rendered with the values -1, 1, and 2 with -1 meaning the room being out of comfort for the last hour and temperature being lower than the comfort range adapted by EN15251 standards. similarly 2 means out of comfort but temperature being higher than comfort temperature range. and finally outlet comfort equal to 1 exhibits the room being inside comfort temperature range for the past hour. It is visible in the first chart that the adaptive shading control is responding to the comfort outlet. for instance, it is visible that two times during the sixteenth of February the operative temperature inside the room has exceeded the comfort quality, hence a proper shading ratio has been imposed by the control system consluding in regaining the comfort condition for the next hours.

The next two charts compare the adaptive shading operation for one week in the low solar radiation months of the year, in this case first week of the February, and one week in the high solar irradiation time of the year, in this case first week of May.

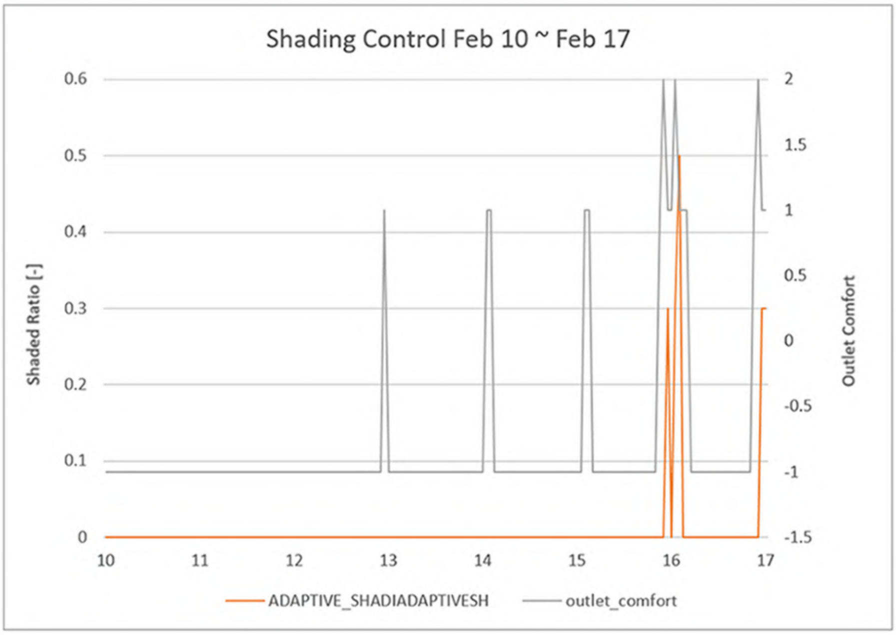



FIGURE 3.34

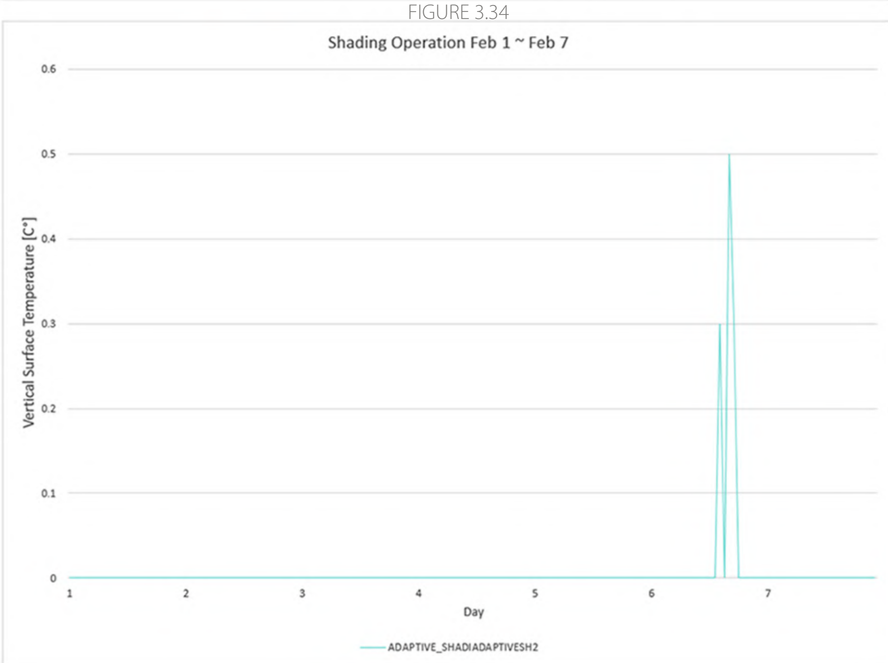



FIGURE 3.35

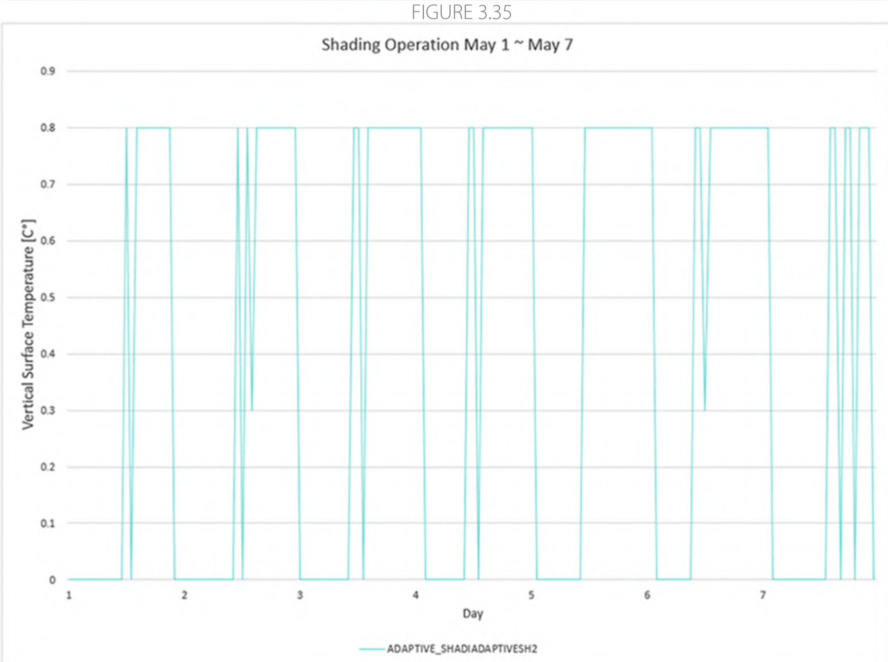
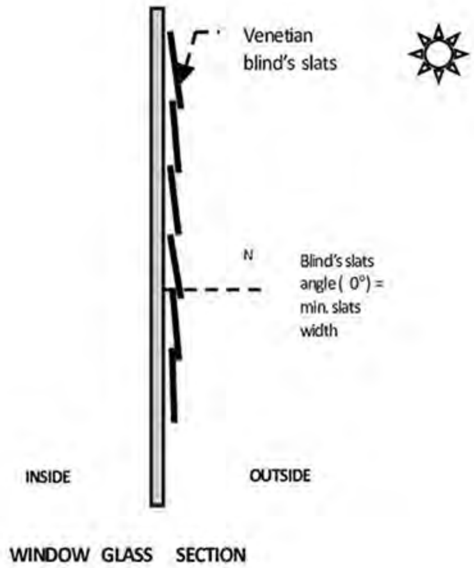



FIGURE 3.36

Zooming further in, it has been exhibited by the means of following charts the hourly operation of the adaptive shading control for specific days during the year, in this case January 21, June 15, and May 24 has been chosen. It is clearly visible that the adaptive shading is responsive to hourly change.

To keep the automation in moderation in comparison to the expenses and also limiting the possible complications and errors that the system can cause by working too much or being too senstive, further control of the shading is given to the users by internal semi-transparent shadings, hence the adaptive shading operation would not change as result of comfort outcome for a time unit lower than hour.



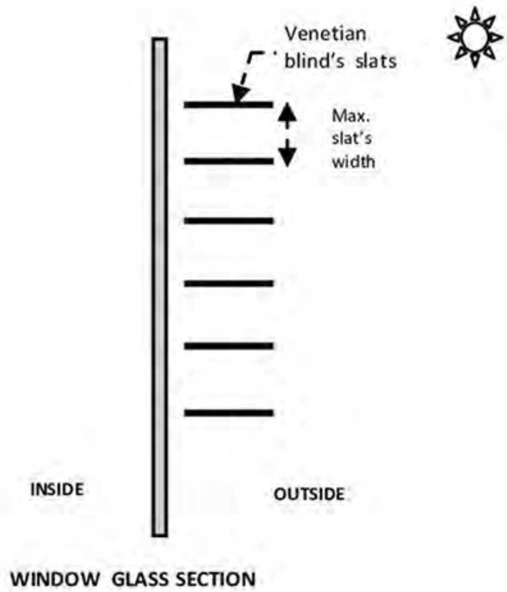





FIGURE 3.37


FIGURE 3.39


FIGURE 3.40

## ANNUAL OPERATION OUTCOME

It is visible on the "shading control annual" (figure 3.41) the annual hourly operation of the adaptive shading in respect to the comfort outlet aforementioned.
Furthermore, on the "Annual ADAPTIVE _SHADIADAPTIVESH Changing" it is visible the number of hours that shading is working with configuration equal to respectively, 30%, 50%, and 80% shading ratio to the glazing.

## EFFECT ON COMFORT

It has been exhibited the effect of the first step of the shading automation on the comfort situation inside the chosen thermal zone. An obvious improvement in the total comfort percentage can be perceived, especially the improvement consists the summer days since the shading works mostly to control the solar heat gain, this improvement is exactly what was intended by this part of the study.

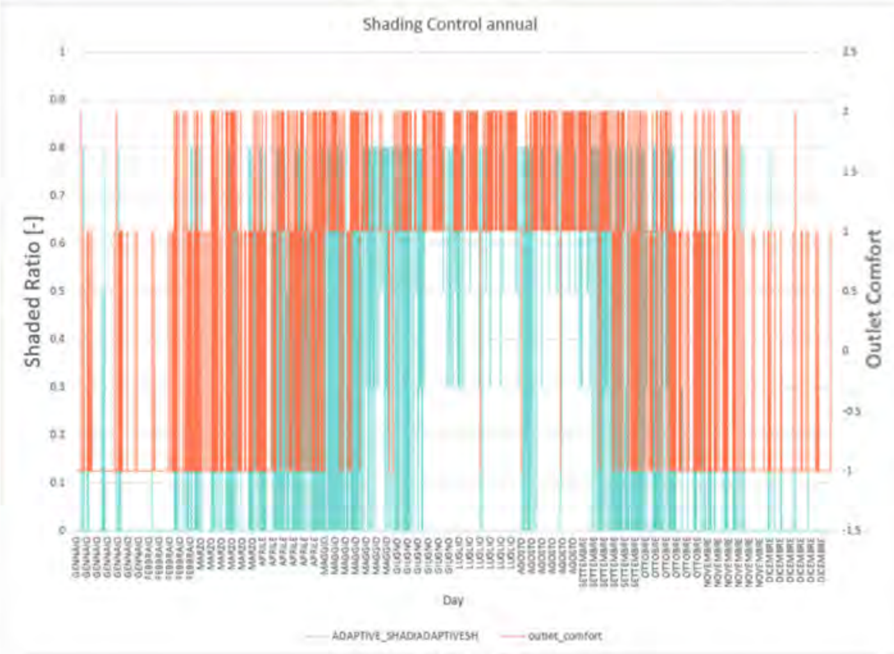



FIGURE 3.41


FIGURE 3.42

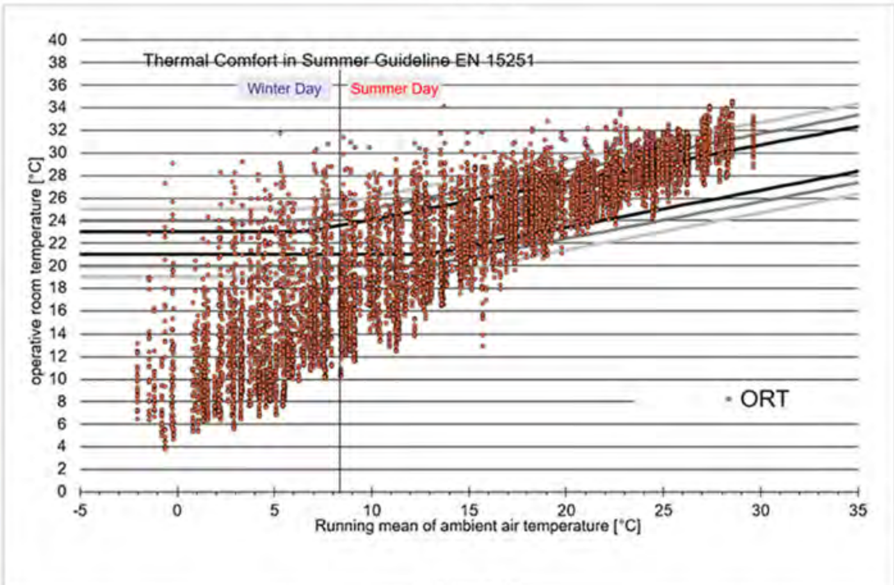



FIGURE 3.43

## Baseline

| | Zone1 | Zone2 | Zone3 |
|---|---|---|---|
| Lighting Heat Gain | 1.5 W/m² | 1.5 W/m² | 0.5 W/m² |
| Equipment Heat Gain | 2.5 W/m² | 2.5 W/m² | 1 W/m² |
| People Heat Gain | 1 W/m² | 1 W/m² | 2 W/m² |
| Infiltration: | | | Annual Hourly |
| **Heating,** Cooling Set Point T | | | °20C°16-C °26C |
| Passive H/C Set Point T | | | Automated To EN15251 |
| Relative Humidity Limits | | | 50%-70% |
| Envelope Values: | | | Case 2 |
| Shading Percentage | | | Automated |
| Ventilation Rate | | | Automated |

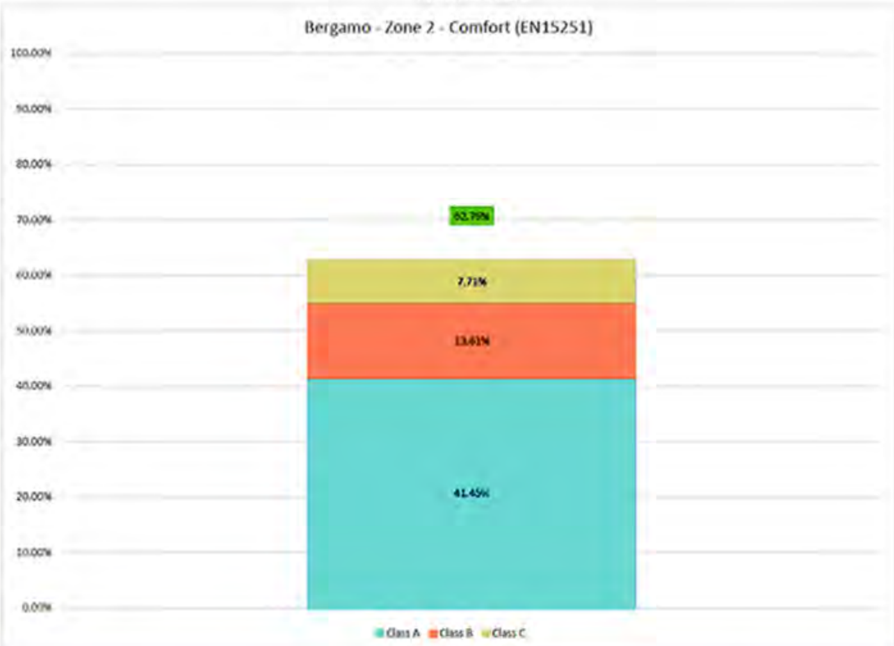



FIGURE 3.44

## STEP TWO

It has been demonstrated in the first step of the automation that the shading works mainly based on the comfort outcome of the last hour controlled by the aforementioned equation. But this approach causes a problem that must be forseen.
The risen issue relates to the hours of the day that while using the maximum shading imposed by the system reaches the required comfort conditions, but this alerts system for false comfort allowing the automation to reduce shading for the next hour, which was originally a command to reach maximum visual comfort. But this reduction causes the room to again exceed the comfort temperature range.
To prevent such occasion, it has been imposed inside the equation another control by the means of surface temperatures on the outer layer of the Envelope, indicated as "Solar_Imdie" in the following charts.
By a number of simulations it has been demonstrated that there exists a proportional relationship between the surface temperature of the outer layer and the average comfort operative temperature of the next hour inside the building, thus this value is chosen as the base for prediction of discomfort due to operative temperature higher than comfort range for the next hour inside the thermal zone.
Such control is imposed by chosing average surface temperature more than 50°C as the top threshold above which the shading will only operate on maximum ratio even if the comfort outlet is plotting a wholesome result.
Similar to the explanatory charts in the first step, the following three charts exhibits the operation of the adaptive shading in relation to the comfort outcome for the second week of February, Last week of June and First week of May.

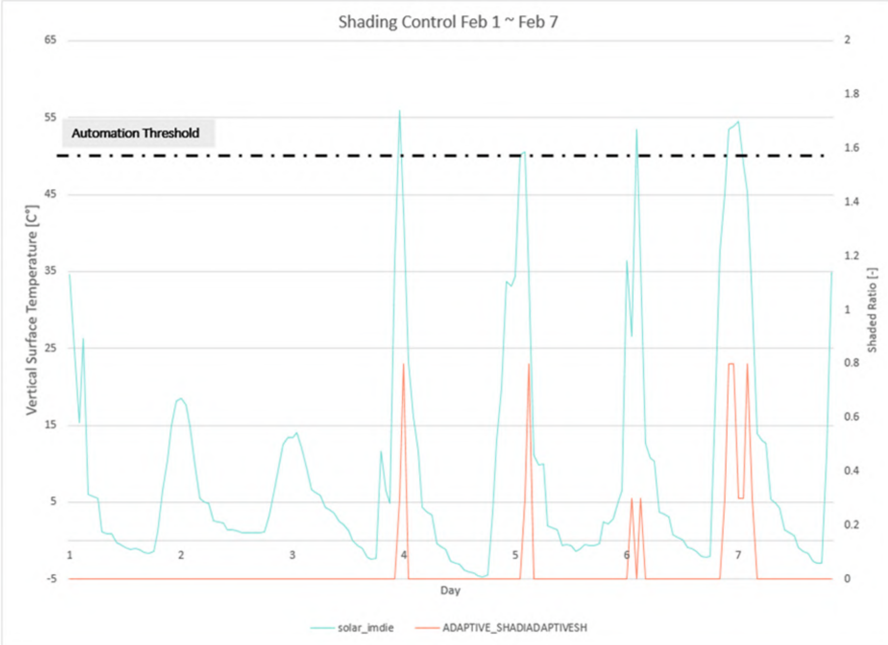



FIGURE 3.45

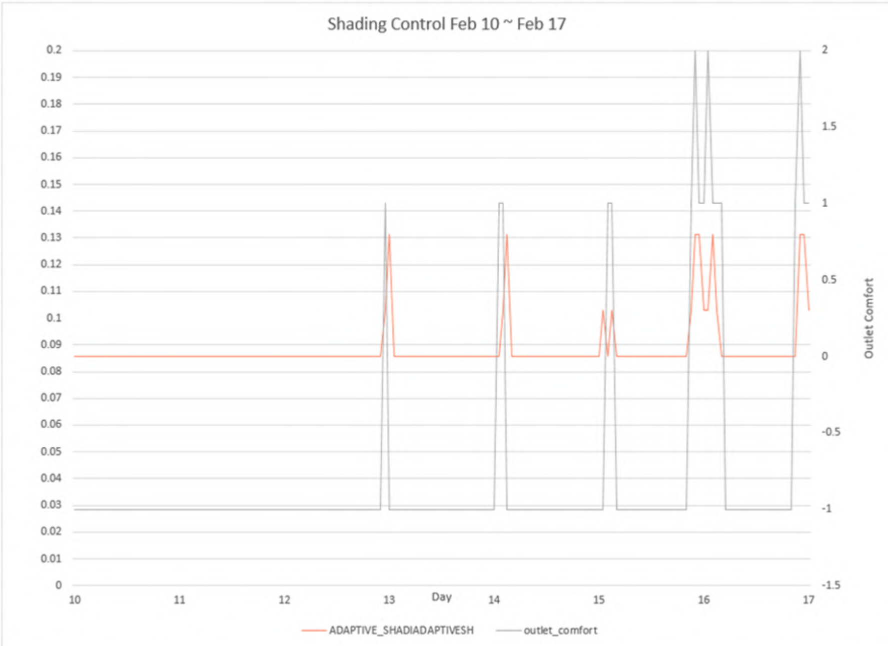



FIGURE 3.46

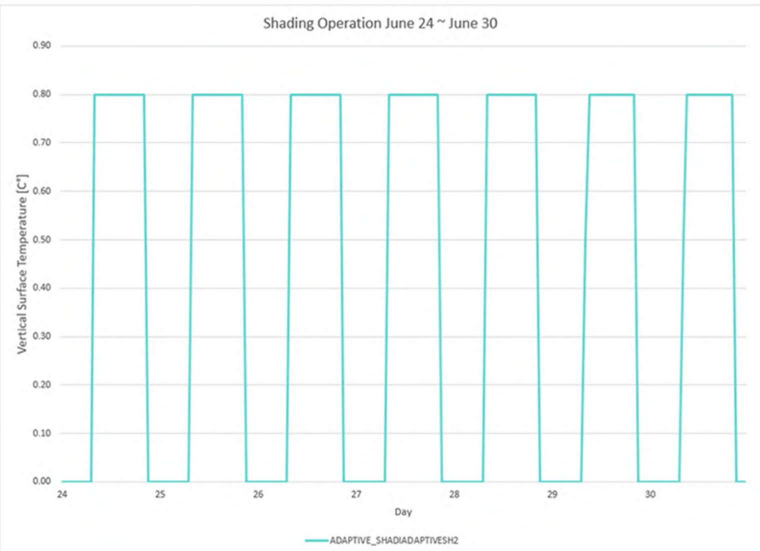



FIGURE 3.47

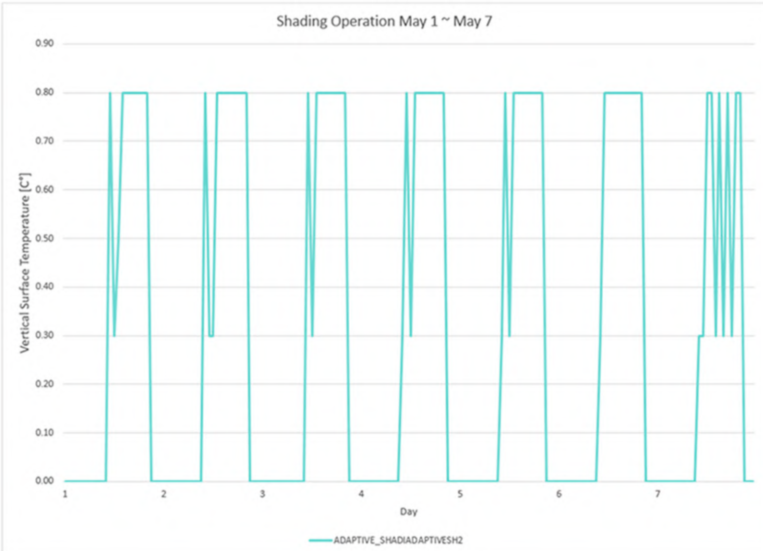



FIGURE 3.48

Similar to the first step, charts in this page exhibit, zooming on more precise hours during the year, the hourly operation of the adaptive shading system for two days in the year, specifically July 8th and May 9th.

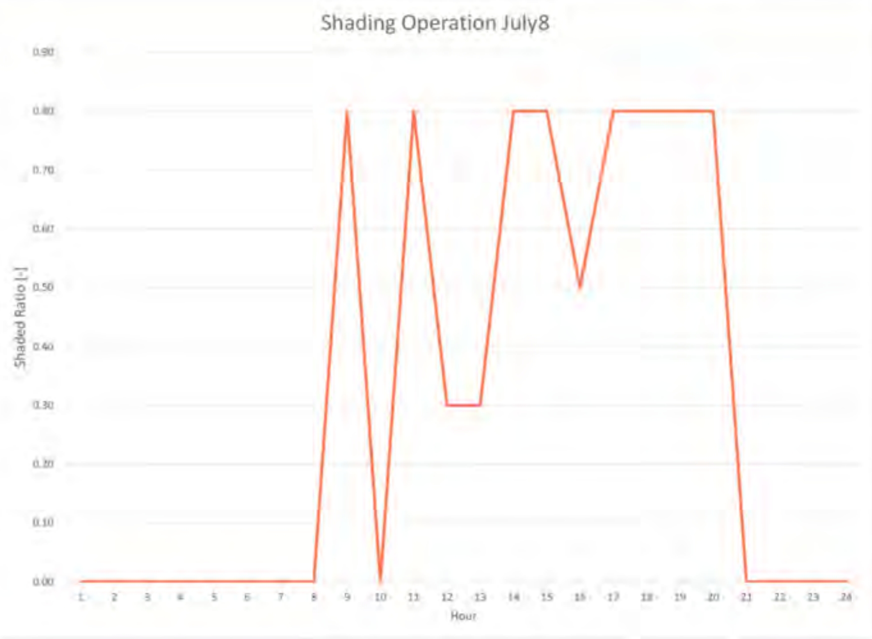



FIGURE 3.49

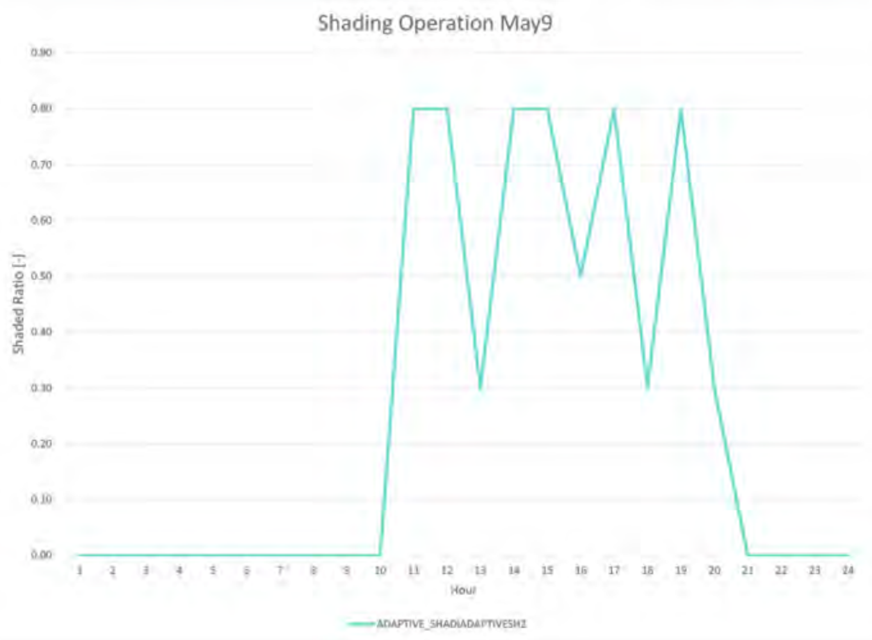



FIGURE 3.50

## ANNUAL OPERATION OUTCOME

It is visible on the "shading control annual" (figure 3.51) the annual hourly operation of the adaptive shading in respect to the comfort outlet aforementioned.

Furthermore, on the "Annual ADAPTIVE _SHADIADAPTIVESH Changing" (figure 3.52) it is visible the number of hours that shading is working with configuration equal to respectively, 30%, 50%, and 80% shading ratio to the glazing.

it is visible the change in the count of different shading ratio values due to the newly imposed controlling operation.

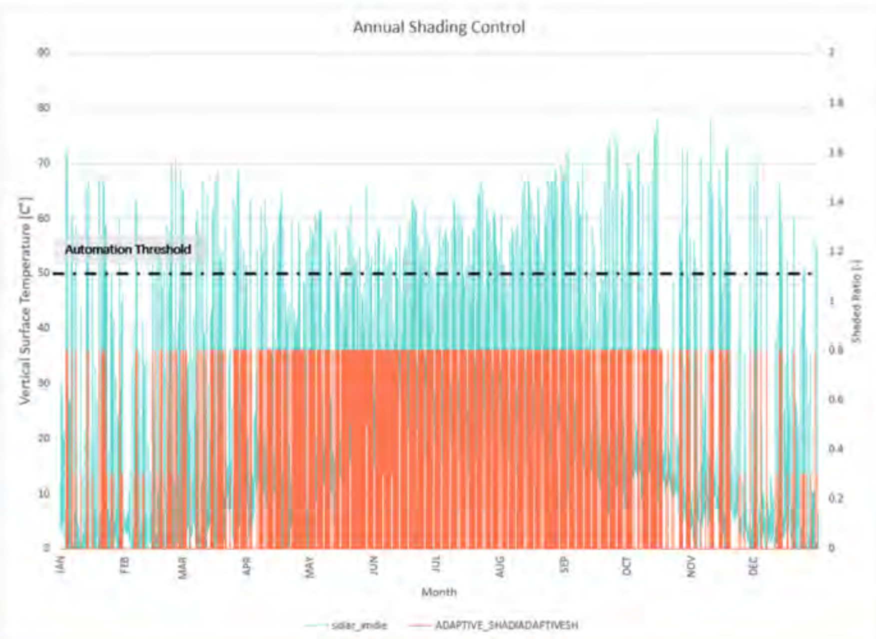
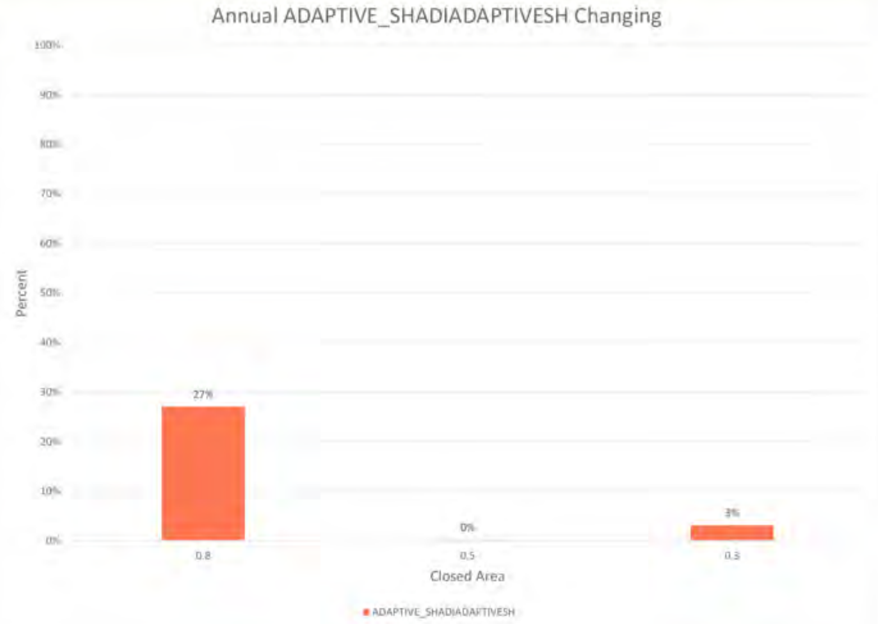



FIGURE 3.51

# EFFECT ON COMFORT

It has been exhibited the effect of the second step of the shading automation on the comfort situation inside the chosen thermal zone.



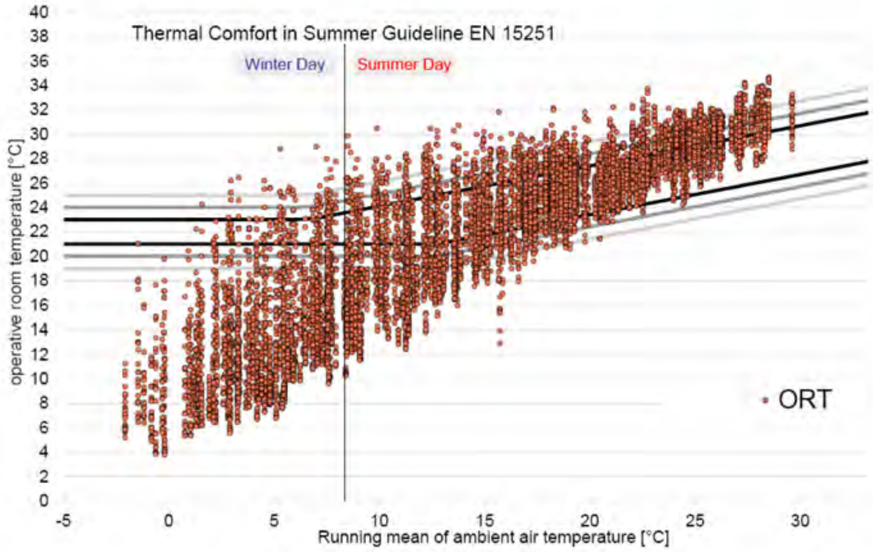




FIGURE 3.53

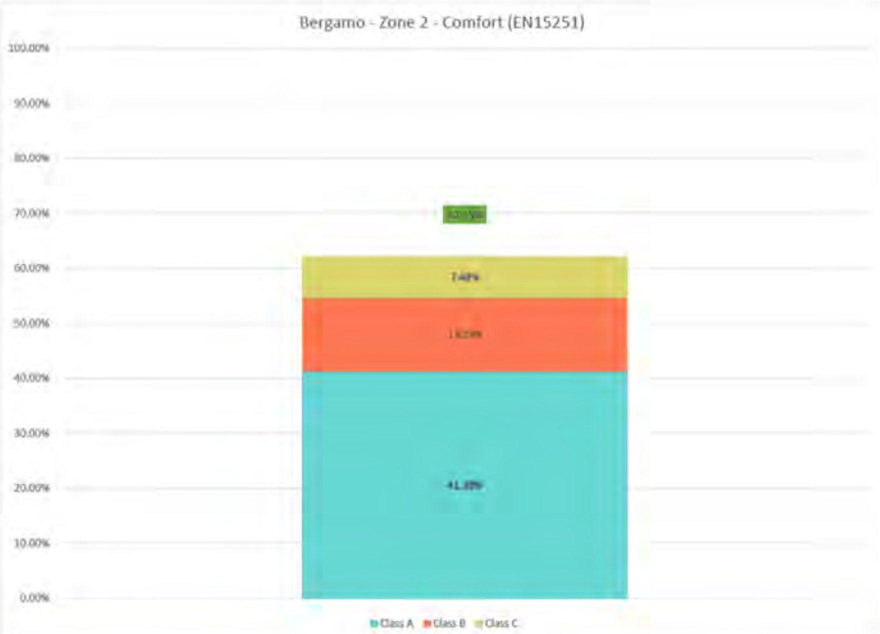



FIGURE 3.54

## Baseline

| | Zone1 | Zone2 | Zone3 |
|---|---|---|---|
| Lighting Heat Gain | 1.5 W/m² | 1.5 W/m² | 0.5 W/m² |
| Equipment Heat Gain | 2.5 W/m² | 2.5 W/m² | 1 W/m² |
| People Heat Gain | 1 W/m² | 1 W/m² | 2 W/m² |
| Infiltration: | Annual Hourly | | |
| **Heating,** Cooling Set Point T | °20C°16-C °26C | | |
| Passive H/C Set Point T | Automated To EN15251 | | |
| Relative Humidity Limits | 50%-70% | | |
| Envelope Values: | Case 2 | | |
| Shading Percentage | Automated | | |
| Ventilation Rate | Automated | | |

# STEP THREE

In this step, it has been tried to further optimize the performance by separating the operational controls of the vertical windows in from the Roof windows.

For the case of the vertical windows the adaptive control system is the same as demonstrated in the second step of the study.

You can see the annual (figure 3.55) and second week of February performance of the Vertical Windows (figure 3.56) in comparison to the comfort outlet (first controlling operation) and top vertical surface temperature threshold (second controlling operation) in the following charts.

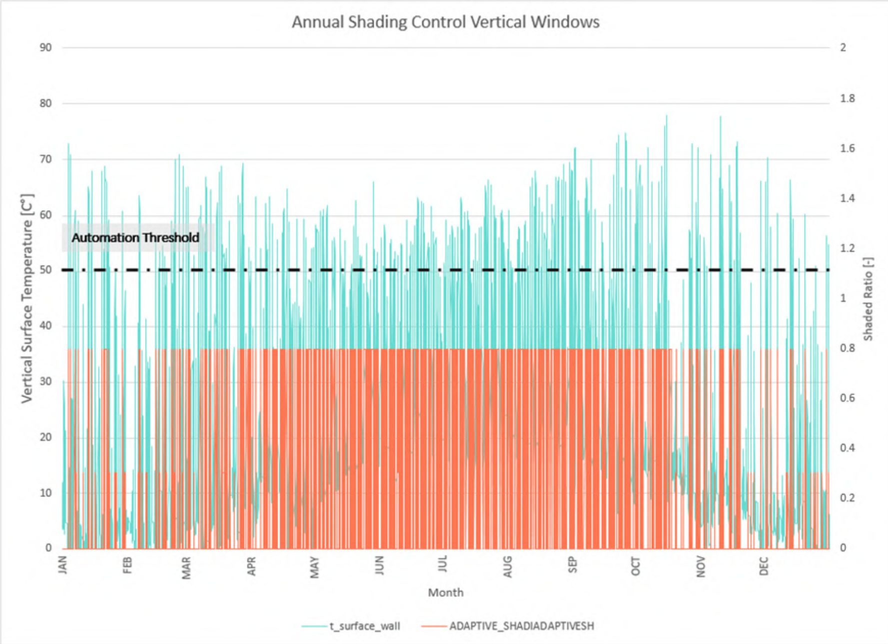



FIGURE 3.55

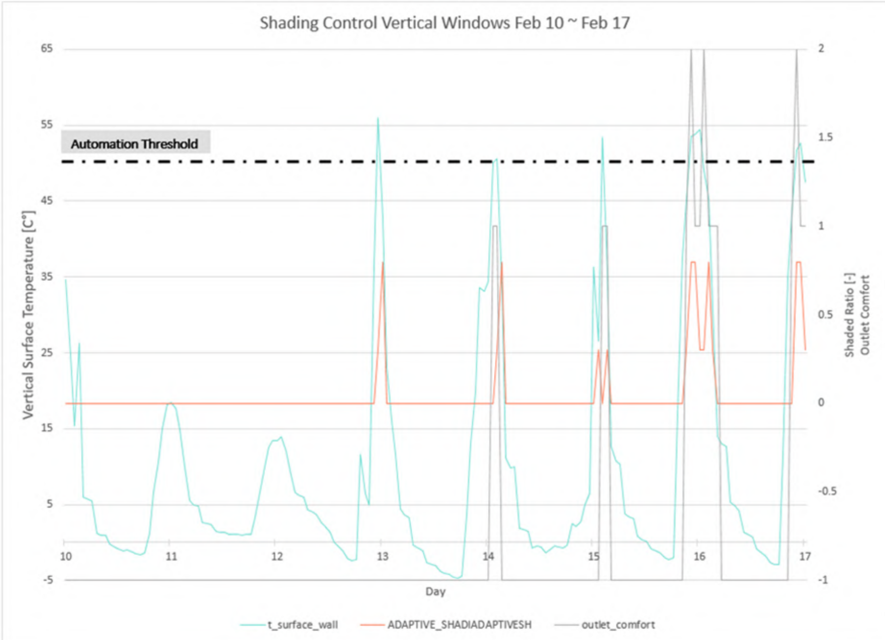



FIGURE 3.56

Although, In the case of the vertical windows, the same criteria of the last step is functioning, but for the roof windows the criteria has been further developed for higher efficiency and is as follows.

Again the comfort is the base of the criteria but coupled with the surface temperature of the roof, indicated with t_surface_roof in the following charts. In the cases of the temperature rising over 35°C the roof windows would be 30% shaded or more. In case of temperature rising over 40°C the roof shadings would be 50% or more. In case of **Roof Surface temperature rising over** 45°C or more the shaded ratio would be 80% or more. And finally if the Surface Temperature of the roof rises over 50°C or more the shading would compelety shut down and the roof windows will be fully covered.

It is exhibited in the following charts the hourly operation of the adaptive shading system together with the comfort outlet (first controlling operation) and top temperature threshold in regard to each shading ratio imposed for the whole year and also the cases of second week of February and second week of May.

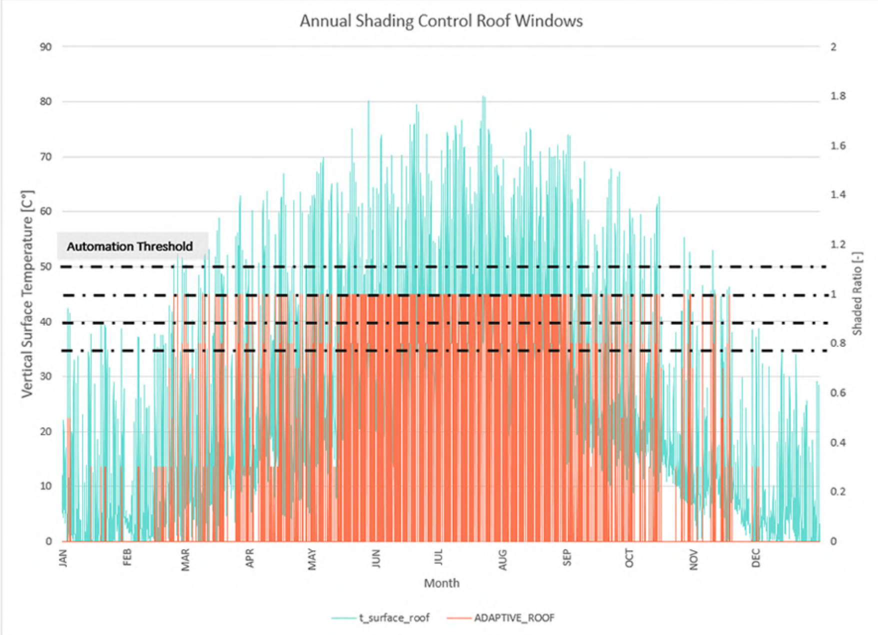



FIGURE 3.57

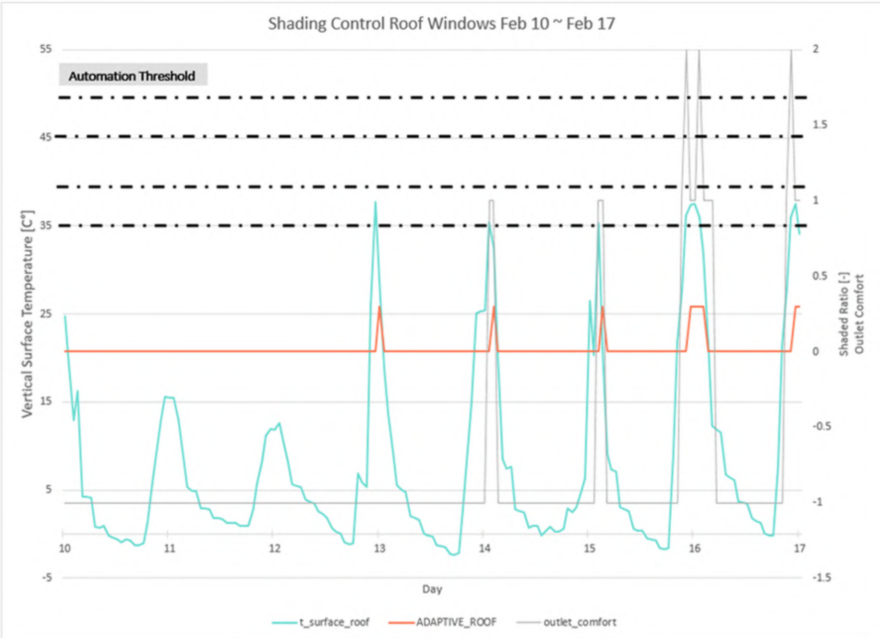



FIGURE 3.58

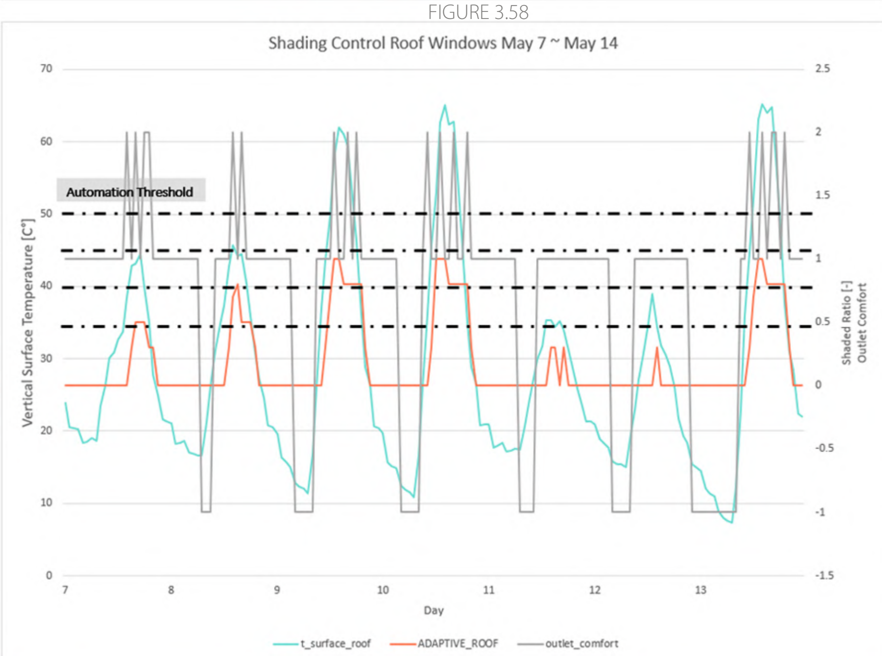



FIGURE 3.59

It is exhibited in the following charts how the shading control of the roof is operating independently from the vertical windows' shadings.

Specifically, the operation during first week of Feb (figure 3.60), as presentative of low radiation period of the year, first week of May (figure 3.61), as presentative of moderate radiation period of the year, and last week of June, as presentative of high radiation period of the year, are presented.

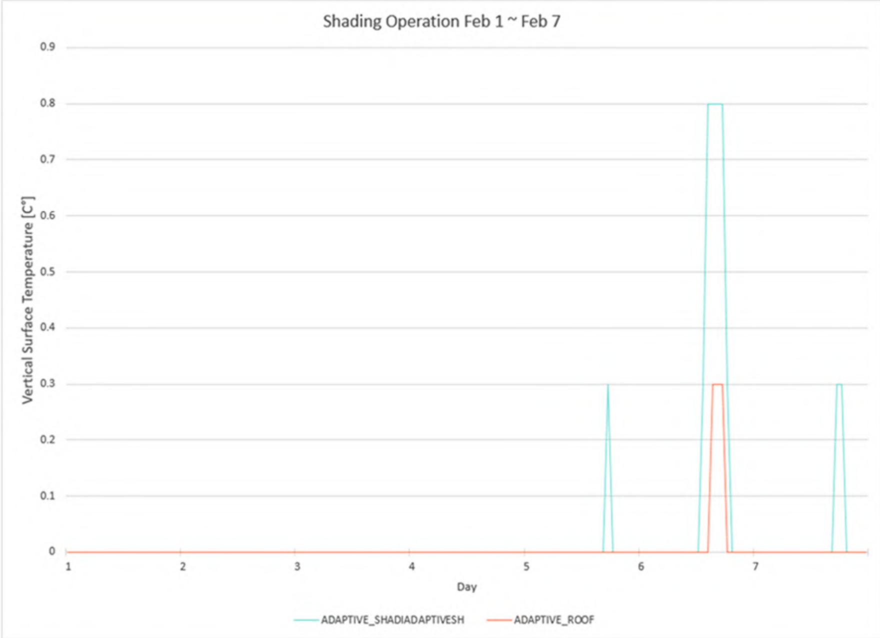



FIGURE 3.60

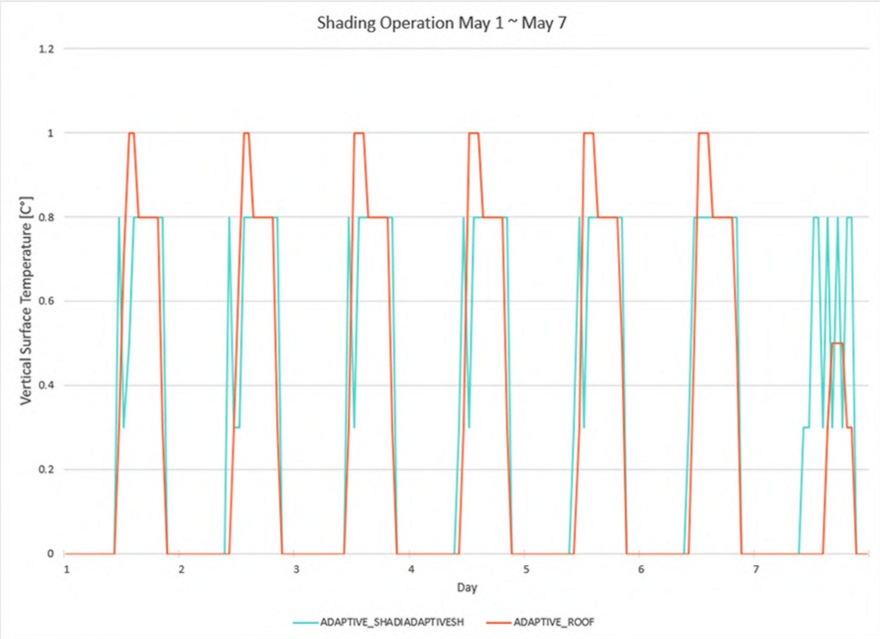



FIGURE 3.61

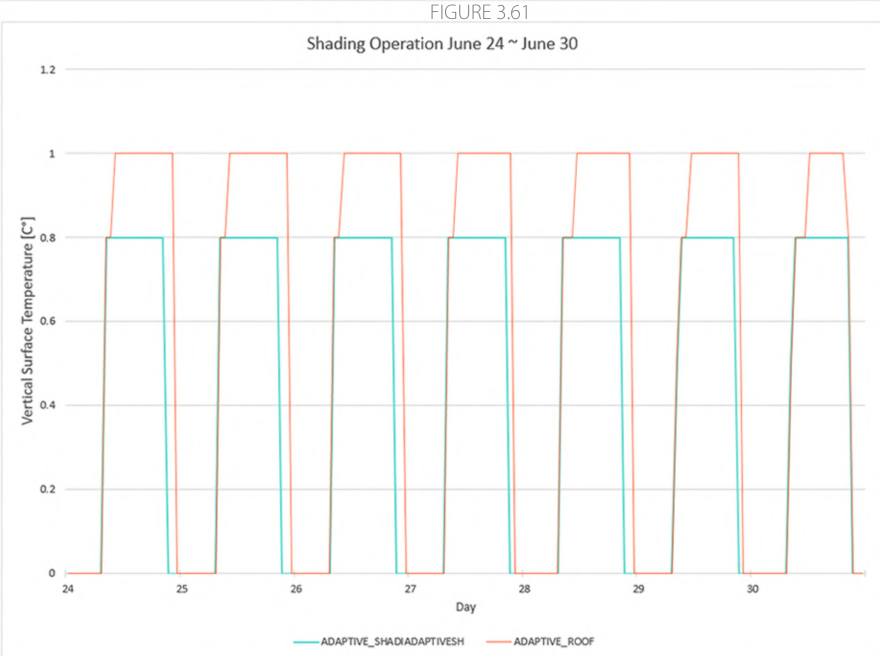



FIGURE 3.62

## ANNUAL OPERATION OUTCOME

It is visible on the “shading control annual” (figure 3.63) the annual hourly operation of the adaptive shading both for vetical window’s shadings and roof windows’s shadings.
Furthermore, on the “Annual ADAPTIVE _SHADIADAPTIVESH Changing” (figure 3.64) it is visible the number of hours that shading is working with configuration equal to respectively, 30%, 50%, and 80% shading ratio to the glazing.

## EFFECT ON COMFORT

It has been exhibited the effect of the third step of the shading automation on the comfort situation inside the chosen thermal zone.

FIGURE 3.63

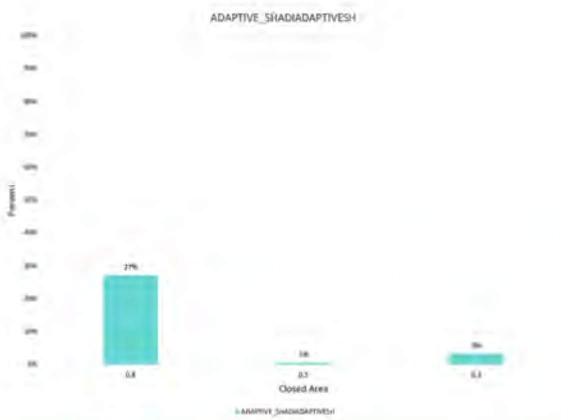


FIGURE 3.64

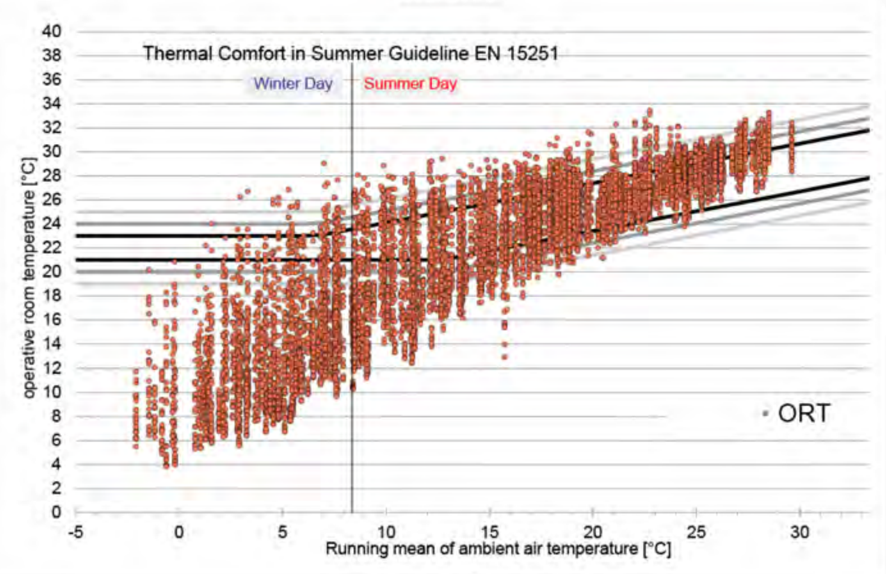


FIGURE 3.65

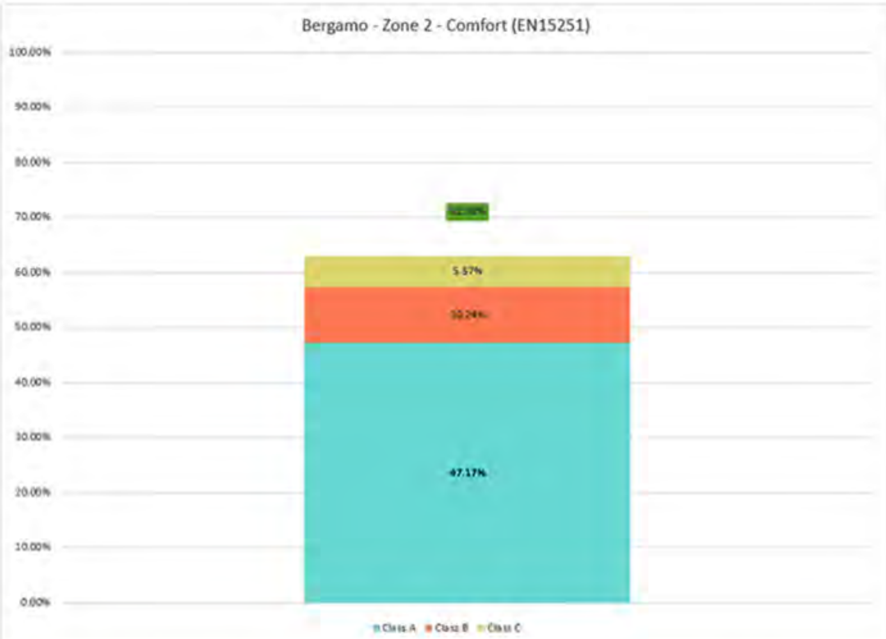


FIGURE 3.66

## Baseline

| | Zone1 | Zone2 | Zone3 |
|---|---|---|---|
| Lighting Heat Gain | 1.5 W/m² | 1.5 W/m² | 0.5 W/m² |
| Equipment Heat Gain | 2.5 W/m² | 2.5 W/m² | 1 W/m² |
| People Heat Gain | 1 W/m² | 1 W/m² | 2 W/m² |
| Infiltration: | | | Annual Hourly |
| **Heating,** Cooling Set Point T | | | °20C°16-C °26C |
| Passive H/C Set Point T | | | Automated To EN15251 |
| Relative Humidity Limits | | | 50%-70% |
| Envelope Values: | | | Case 2 |
| Shading Percentage | | | Automated |
| Ventilation Rate | | | Automated |

## TRNSYS Model: Type1b

This component models the thermal performance of a flat-plate solar collector. The solar collector array may consist of collectors connected in series and in parallel. The thermal performance of the collector array is determined by the number of modules in series and the characteristics of each module. The user must provide results from standard tests of collector efficiency versus a ratio of fluid temperature minus ambient temperature to solar radiation.

## TRNSYS Model: Type31

This component models the thermal behavior of fluid flow in a pipe or using variable size segments of fluid. Entering fluid shifts the position of existing segments. The mass of the new segment is equal to the flow rate times the simulation timestep. The new segment's temperature is that of the incoming fluid. The outlet of this pipe is a collection of the elements that are pushed out by the inlet flow.

## TRNSYS Model: Type 110

Type110 models a variable speed pump that is able to maintain any outlet mass flow rate between zero and a rated value. The mass flow rate of the pump varies linearly with control signal setting. Pump power draw, however, is modeled using a polynomial. Pump starting and stopping characteristics are not modeled, nor are pressure drop effects.

## TRNSYS Model: Type 534

All of the TESS tank components, Type531, 532, 533, and 544 have different physical geometry, yet the subroutines have very similar physics. These subroutines model a fluid-filled, constant volume storage tanks with immersed heat exchangers. The fluid in the storage tank interacts with the fluid in the heat exchangers (through heat transfer with the immersed heat exchangers), with the environment (through thermal losses from the top, bottom and edges) and with up to two flow streams that pass into and out of the storage tank.

## TRNSYS Model: Type 661

This component models a "sticky" controller where the outputs are set to the input values from a user-defined previous time step the environment (through thermal losses from the top, bottom and edges) and with up to two flow streams that pass into and out of the storage

## TRNSYS Model: Type 11b

This instance of the Type11 model uses mode 4 or mode 5 to model a temperature controlled liquid flow diverter. In mode 4 the entire flow stream is sent through outlet 1 when Th < Ti. In mode 5, the entire flow stream is sent through outlet 2 under these circumstances

## TRNSYS Model: Type 11h

This instance of the Type11 model uses mode 1 to model a tee piece in which two inlet liquid streams are mixed together into a single liquid outlet stream.

## TRNSYS Model: Type 14b

in a transient simulation, it is sometimes convenient to employ a time dependent forcing function which has a behavior characterized by a repeated pattern. The pattern of the forcing function is established by a set of discrete data points indicating the value of the function at various times throughout one cycle. Linear interpolation is provided to generate a continuous forcing function from the discrete data.

## TRNSYS Model: Type 652

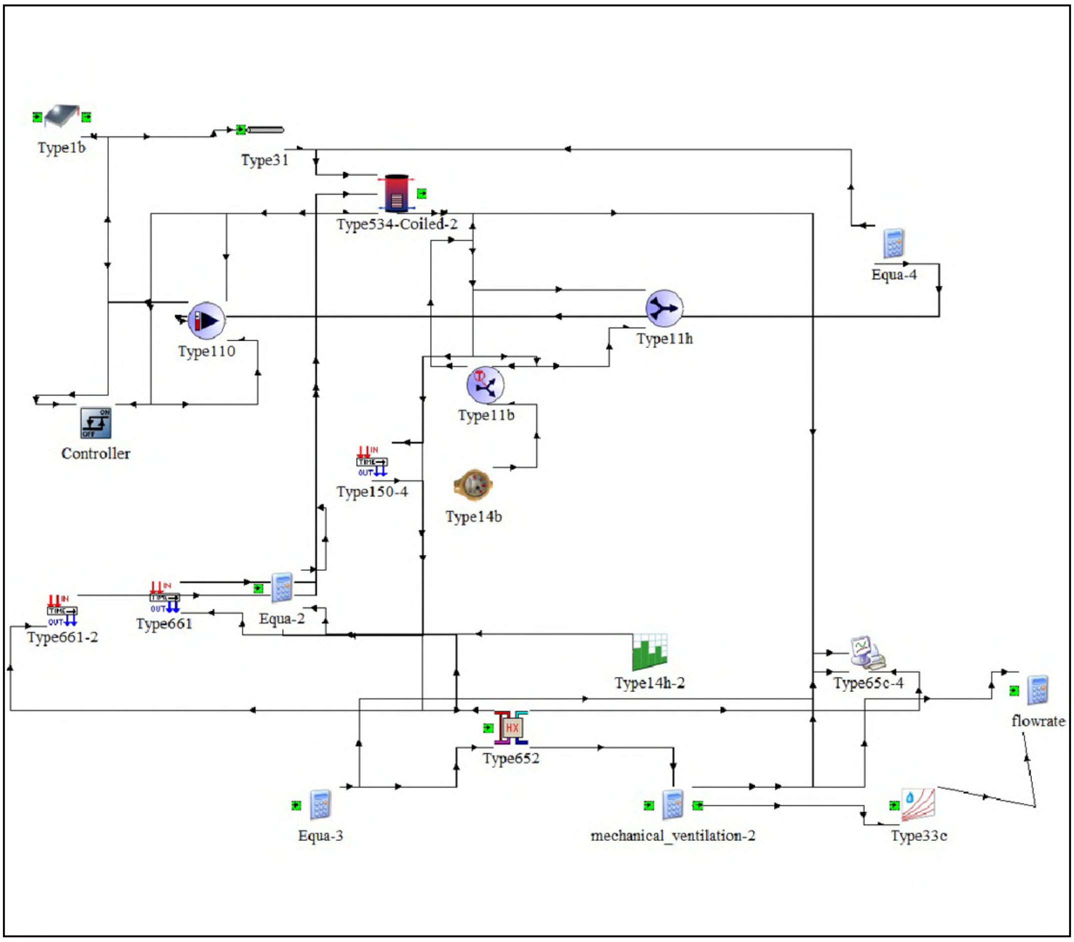
Type652 models a constant effectiveness / Cmin heat exchanger that is able to automatically bypass hot-side fluid around heat exchanger in order to maintain the cold-side outlet temperature above a user specified, time dependent set point.

## TRNSYS Model: Type14h

1In a transient simulation, it is sometimes convenient to employ a time dependent forcing function which has a behavior characterized by a repeated pattern. The pattern of the forcing function is established by a set of discrete data points indicating the value of the function at various times throughout one cycle. Linear interpolation is provided in order to generate a continuous forcing function from the discrete data

## TRNSYS Model: Type33c

This component takes as input the dry bulb temperature and humidity ratio of moist air and calls the TRNSYS Psychrometrics routine, returning the following corresponding moist air properties: dry bulb temperature, dew point temperature, wet bulb temperature, relative humidity, absolute humidity ratio, and enthalpy.




SC.3. TRNSYS simulation model for solar collector

## SOLAR THERMAL COLLECTOR

A solar thermal collector is a device designed specifically to collect heat by absorbing sunlight and may be used to heat air or water for building heating. A solar collector operates on a very simple basis. The radiation from the sun heats a liquid that goes to a hot-water tank.
Implementing such technology immensely reduces the heating loads required by not only providing hot domestic water but also a secondary usage of the heating energy in the mechanical ventilation system as passive heating.

## AREA (PARAMETRIC ANALYSIS)

In this part simulations were done by Using **TRN**Edit
To evaluate the impact of different roof area covered by the solar collector, the solar fraction has been chosen as the basis for comparison. through such methodology it can be chosen the optimal area of 10 m² for the solar collector which not only provides enough energy to compensate the building heating load but also it enables the building to use the rest of roof area for the usage of PhotoVoltaic panels as producer of electricity especially for auxilary heating during the nights.

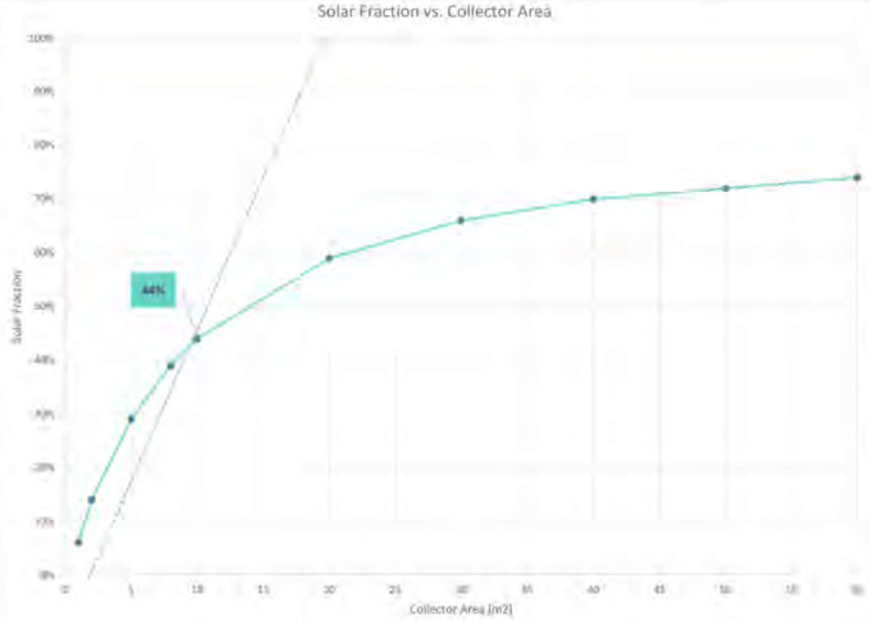



FIGURE 3.67

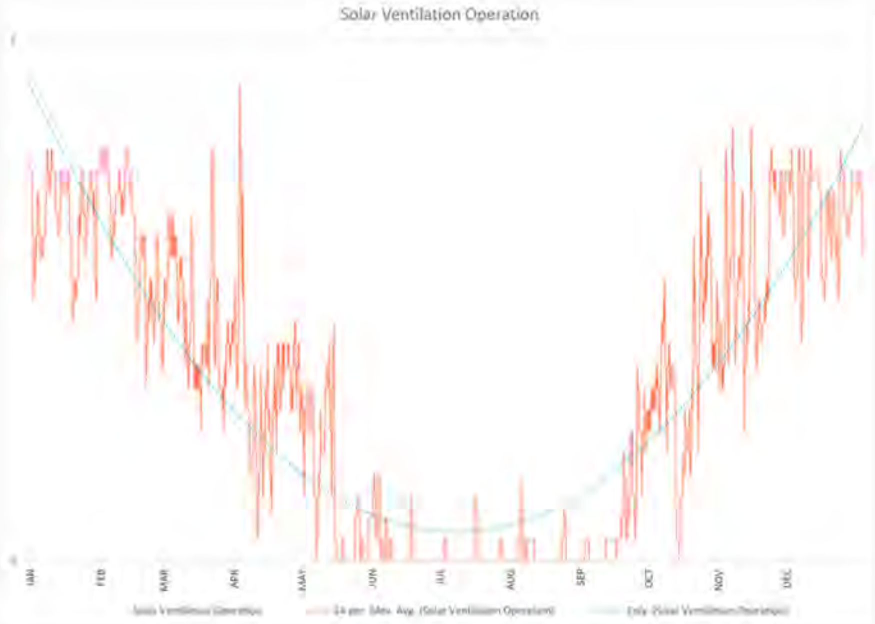



FIGURE 3.68

## USAGE IN VENTILATION

As mentioned before, one of the implementations of the exploited solar energy is to heat up the supply temperature of the air mechanically ventilated into the building. But, doing so requires adequate integration with the automation system imposed before. Thus, another step of automation has been added to the equation of the ventilation automation considering the possible supply temperature using solar energy ventilation and supply temperature without this technology and also the operative temperature inside the room and the comfort conditions. Other than cases of causing over heating (mainly during summer as can be seen in the mid-hours of second chart) this technology provides most of the required energy to offset the heating loads of the building.

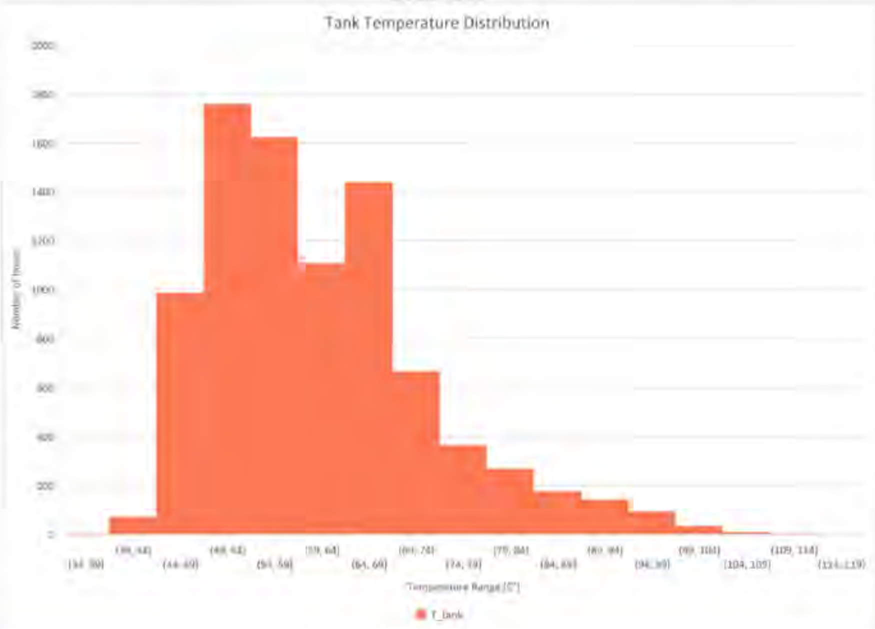



FIGURE 3.69

## WATER TANK

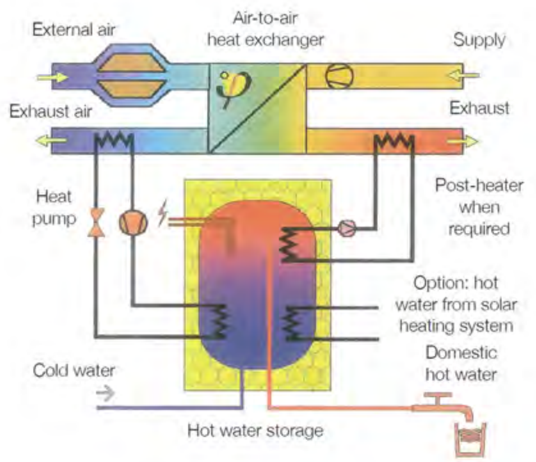
As you can see in the third chart (figure 3.69) the temperature of the water tank cannot be kept constant with sole usage of solar thermal collector technology and an auxilary heating and control system is required to keep the temperature of the water tank constant to an acceptable temperature.

# EFFECT ON VENTILATION

It has been exhibited on the first chart (figure 3.70) the annual distribution of supply temperature of the ventilation duct after the implementation of solar thermal collector, and it is visible the effect on pushing the temperature distribution curve toward a narrower range which is ideally the goal of this practice.

In the second chart (figure 3.71) and the third chart (figure 3.72) it is visible a zoom toward the first month of the year and January first to exhibit the effect during one month and during one day for a clearer exhibition.

**Typical scheme of the building ventilation system and solar collector**



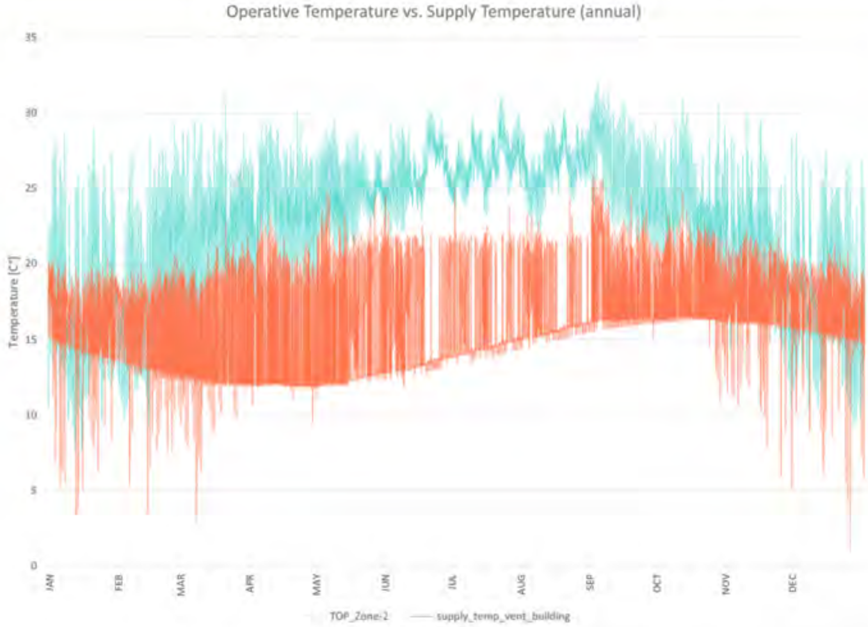




FIGURE 3.70

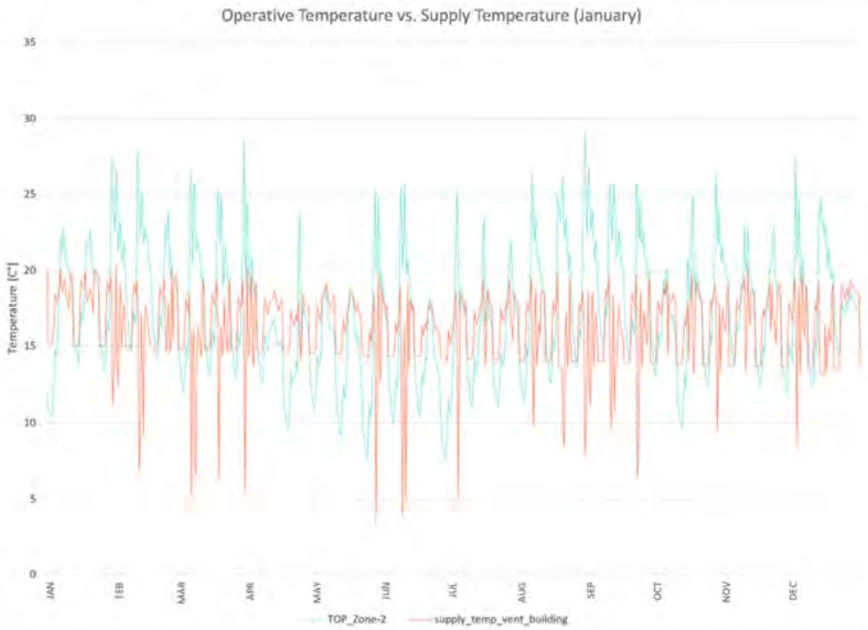



FIGURE 3.71

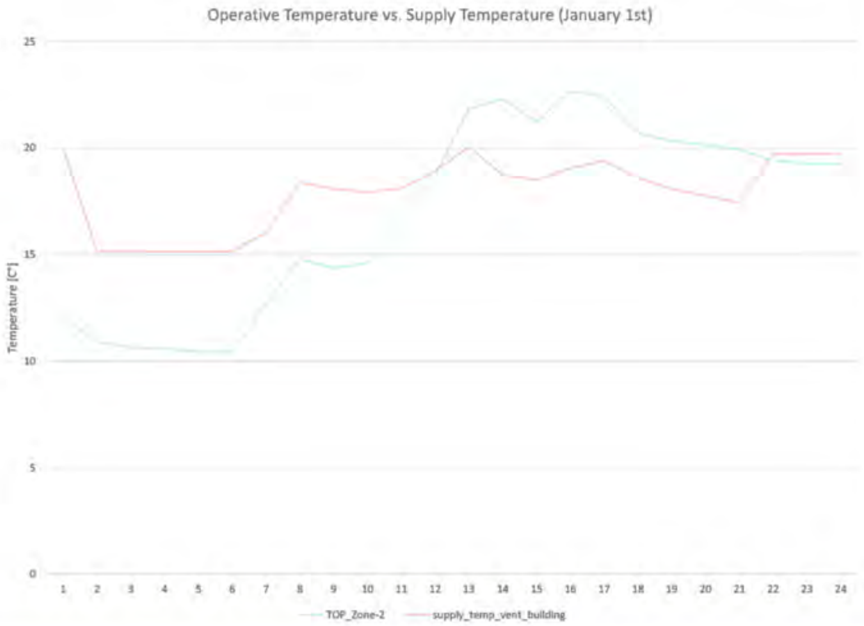



FIGURE 3.72

## EFFECT ON DOMESTIC HOT WATER

As it is shown on the first chart (figure 3.73) the solar thermal collector enables the building to offset most of its required domestic hot water load by direct solar energy. The rest of the load can be produced by an auxilary heating device, which will be covered in the fourth chapter.

## EFFECT ON COMFORT

It is visible the clear improvement in the total comfort percentage of the thermal zone, especially towards a class A comfort range. It can be seen on the second chart (figure 3.74) a clear improvement in the winter out of comfort hours which could not have had much change during the last two steps of the optimization process.

## Baseline

| | Zone1 | Zone2 | Zone3 |
|---|---|---|---|
| Lighting Heat Gain | 1.5 W/m² | 1.5 W/m² | 0.5 W/m² |
| Equipment Heat Gain | 2.5 W/m² | 2.5 W/m² | 1 W/m² |
| People Heat Gain | 1 W/m² | 1 W/m² | 2 W/m² |
| Infiltration: | Annual Hourly | | |
| **Heating,** Cooling Set Point T | °20C°16-C °26C | | |
| Passive H/C Set Point T | Automated To EN15251 | | |
| Relative Humidity Limits | 50%-70% | | |
| Envelope Values: | Case 2 | | |
| Shading Percentage | Automated | | |
| Ventilation Rate | Automated | | |

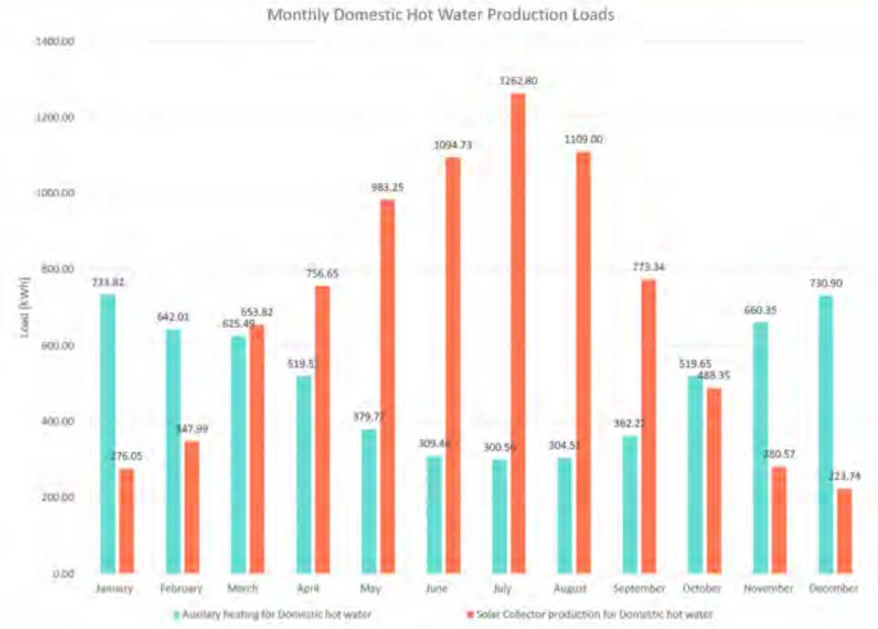


FIGURE 3.73

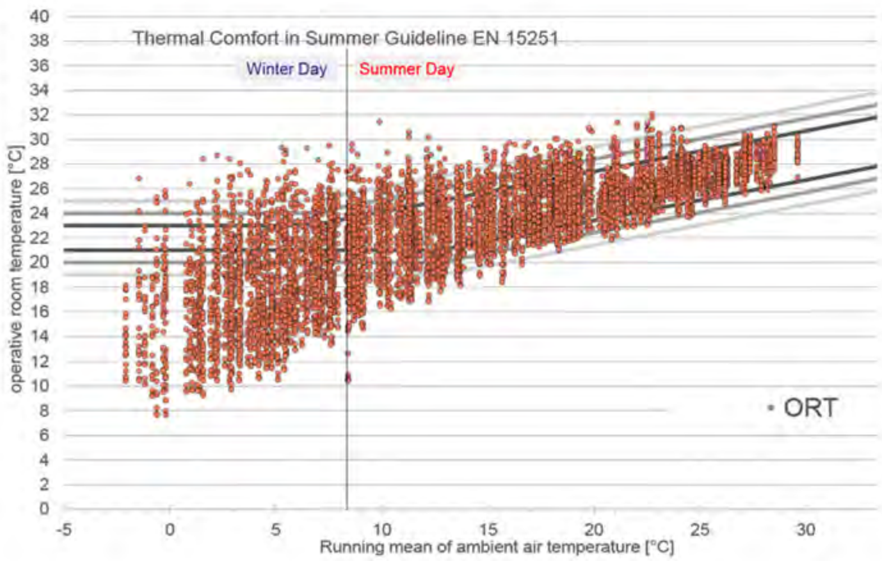


FIGURE 3.74

FIGURE 3.75

# Un-Glazed Building-Integrated PV System

This component is intended as an un-glazed solar collector which has the dual purpose of creating power from embedded photovoltaic (PV) cells and providing heat to an air stream passing beneath the absorbing PV surface. The waste heat rejected to the air stream is useful for three reasons; 1) it cools the PV cells allowing higher power conversion efficiencies and 2) it provides a source of heat for many possible low-grade temperature applications including heating of room air and 3) lowering the heat loss through the roof.
In this chapter, it has only been explained the effects of this component on the ventilation system and passive comfort. The consequent active electrical power production will be further explained the chapter four of the report.

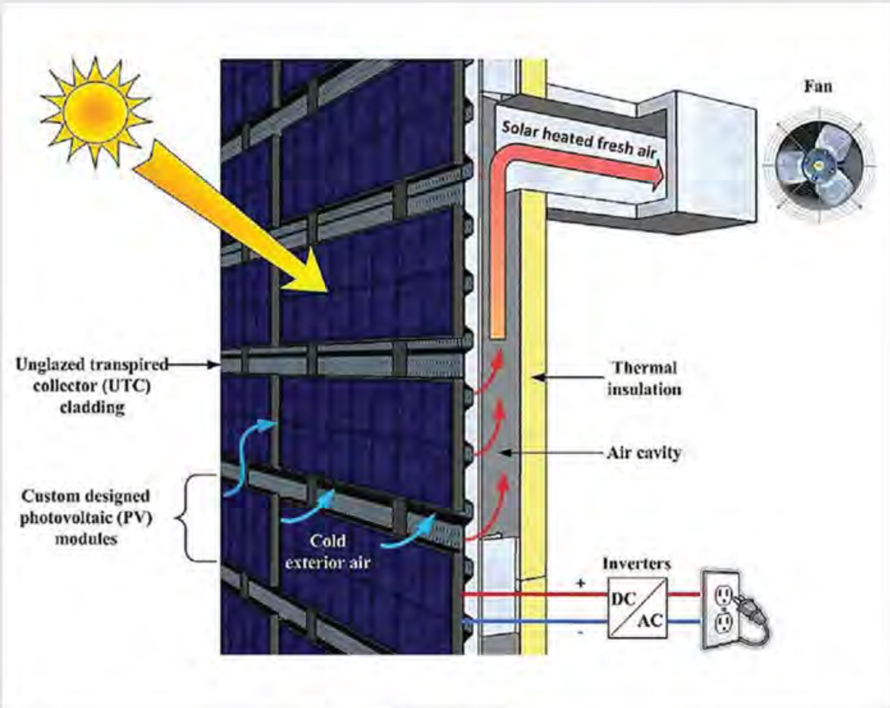



FIGURE 3.76

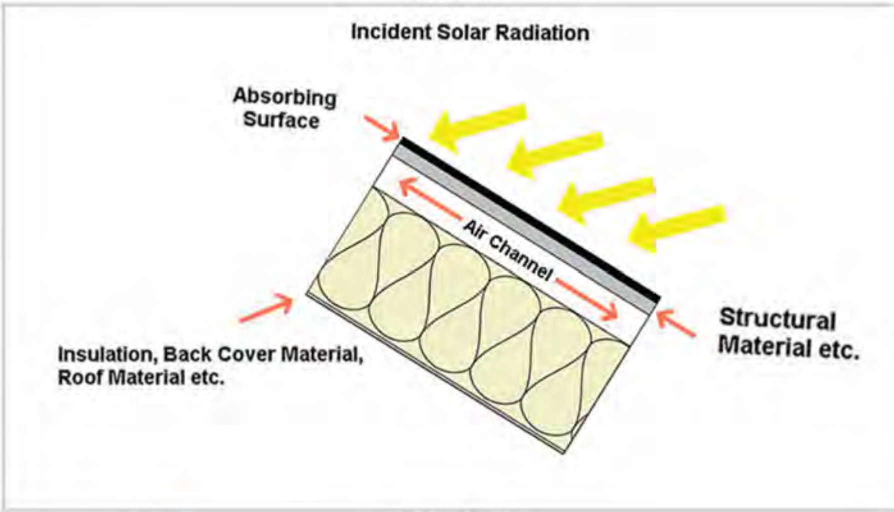



FIGURE 3.77


FIGURE 3.78

## EFFECT ON VENTILATION

It has been exhibited on the first chart (figure 3.79) the annual distribution of supply temperature of the ventilation duct after the implementation of BIPV, and it is visible the effect on pushing the temperature distribution curve toward a narrower range which is ideally the goal of this practice.

## EFFECT ON COMFORT

It is visible an improvement in the total comfort percentage of the thermal zone, especially towards a class A comfort range. It can be seen on the second chart (figure 3.80) a clear improvement in the winter out of comfort hours.

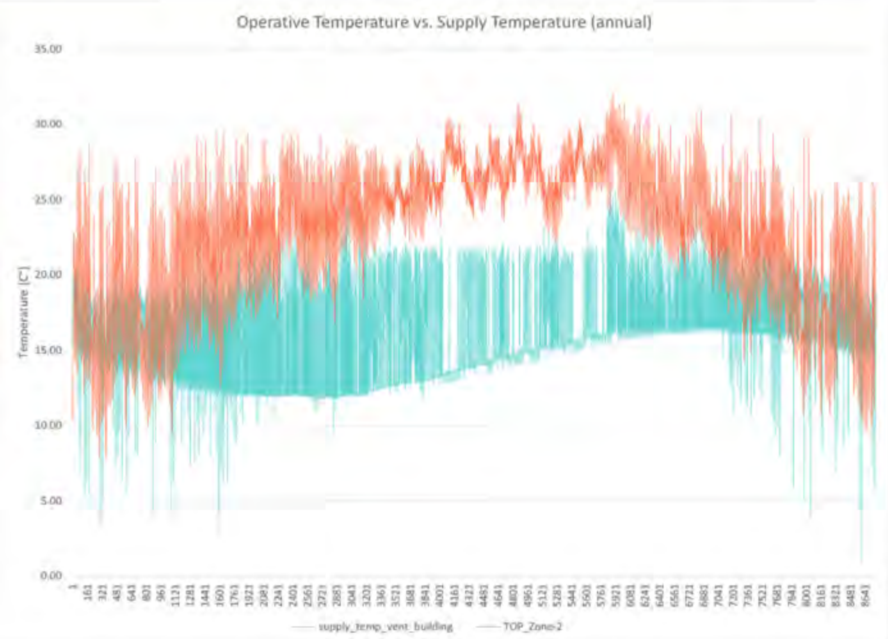



FIGURE 3.79

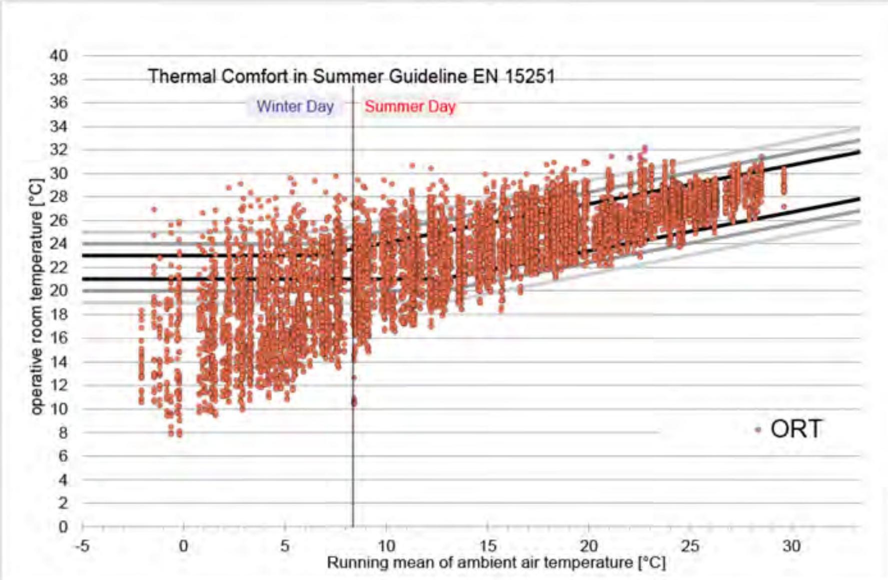



FIGURE 3.80

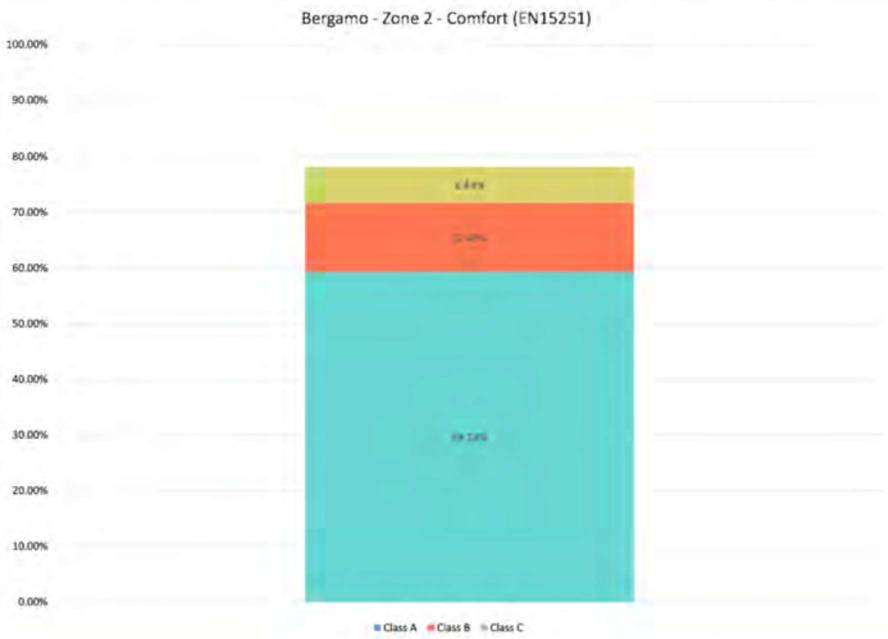



FIGURE 3.81

## Baseline

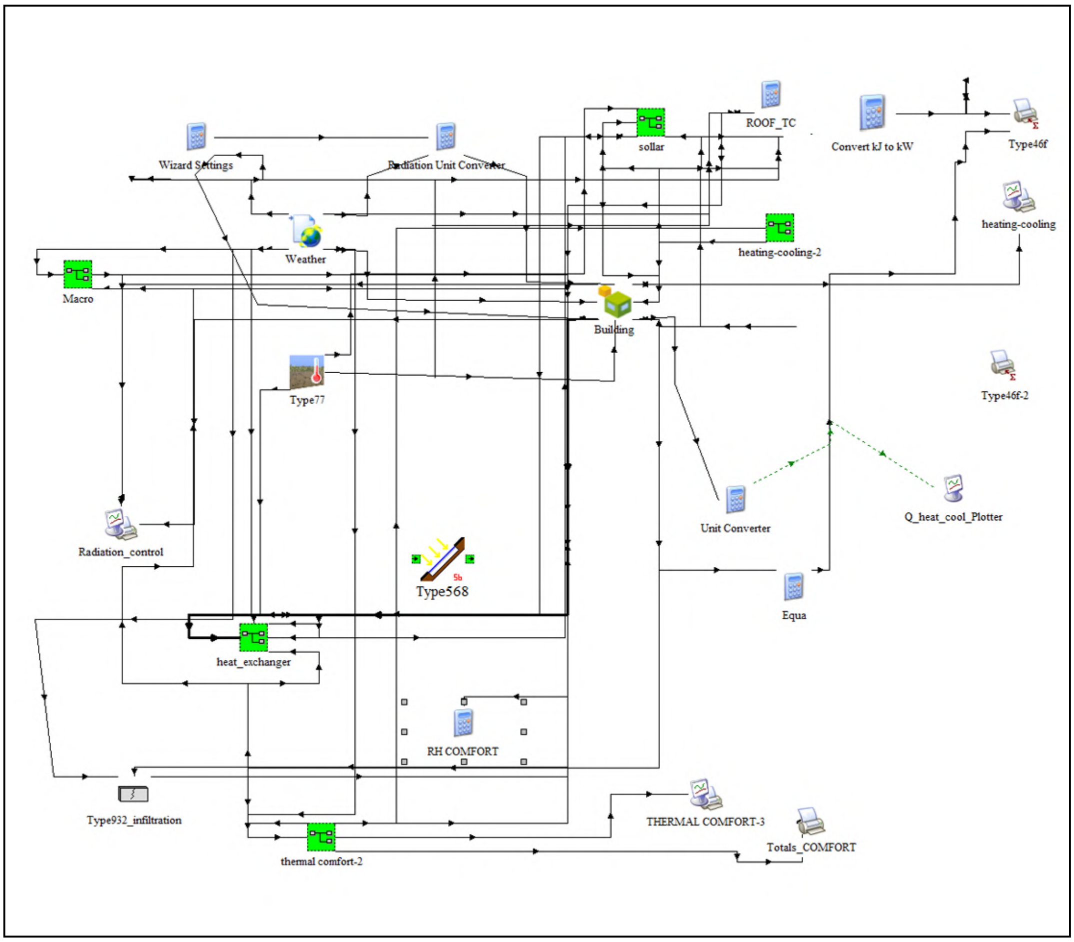
| | Zone1 | Zone2 | Zone3 |
|---|---|---|---|
| Lighting Heat Gain | 1.5 W/m² | 1.5 W/m² | 0.5 W/m² |
| Equipment Heat Gain | 2.5 W/m² | 2.5 W/m² | 1 W/m² |
| People Heat Gain | 1 W/m² | 1 W/m² | 2 W/m² |
| Infiltration | | | Annual Hourly |
| **Heating,** Cooling Set Point T | | | **°20C°16-C** °26C |
| Passive H/C Set Point T | | | Automated To EN15251 |
| Relative Humidity Limits | | | 50%-70% |
| Envelope Values | | | Case 2 |
| Shading Percentage | | | Automated |
| Ventilation Rate | | | Automated |

# CHAPTER 4

## ACTIVE STRATEGIES

## TRNSYS Model: Type568- BUILDING-INTEGRATED PHOTOVOLTAIC SYSTEM

This component is intended to model an un-glazed solar collector that has the dual purpose of creating power from embedded photovoltaic (PV) cells and providing heat to an air stream passing beneath the absorbing PV surface. The waste heat rejected to the air stream is useful for two reasons; 1) it cools the PV cells allowing higher power conversion efficiencies and 2) it provides a source of heat for many possible low-grade temperature applications including heating of room air. This model is intended to operate with detailed building models that can provide the temperature of the back surface of the collector (zone air/collector back interface) given the mean surface temperature of the lower flow channel. The Type 56 multi-zone building model in TRNSYS in one of these detailed zone models




SC.4. TRNSYS simulation model for general overview

## PhotoVoltaic Panels

To offset the additional loads of the building which was not possible to be reduced or optimized by passive strategies, it has been introduced a PV panel system on the roof.
The area occupied for such reason has been reached by usage of most possible area on the south-facing slope of the roof, subtracting the area occupied by the solar thermal collector system and 30% free area for the maintenance, piping, and other needs.
In the second chart (figure 4.3) it has been exhibited the amount of power production by the PV panels system in comparison to the pure energy demand of the building, although it needs to be pointed out the electrical power produced would be used less than the visible amount considering the different coefficient of performance related to the HVAC system proposed which has not been developed during this investigation.

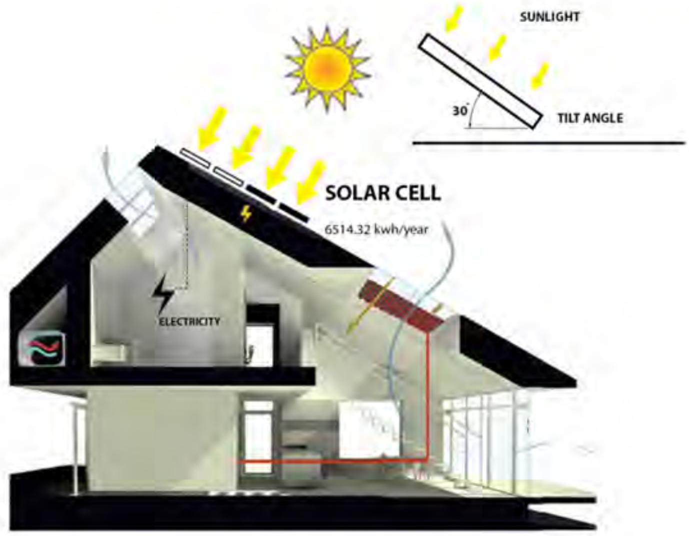



FIGURE 4.1


FIGURE 4.2

| Name | Value | Unit |
|---|---|---|
| Collector Length | 18 | m |
| Collector Width | 3 | m |
| Absorptance of PV surface | 0.8 | Fraction |
| Substrate resistance | 0.01 | h.m2.k/kJ |
| Emissivity of PV surface | 0.9 | Fraction |
| Channel Emissivity - Top | 0.9 | Fraction |
| Channel Emissivity – Bottom | 0.9 | Fraction |
| Back Resistance | 12 | h.m2.k/kJ |

TABLE 4.1

| Name | Value | Unit |
|---|---|---|
| Back Resistance | 12 | h.m2.k/kJ |
| Channel height | 0.0208 | m |
| PV efficiency mode | 1 | - |
| Reference PV efficiency | 0.12 | Fraction |
| Reference temperature | 25 | C |
| Reference radiation | 3600 | KJ/hr.m2 |
| Efficiency modifier - temperature | -0.005 | 1/C |
| Efficiency modifier - radiation | 0.000025 | h.m2/kJ |

TABLE 4.2

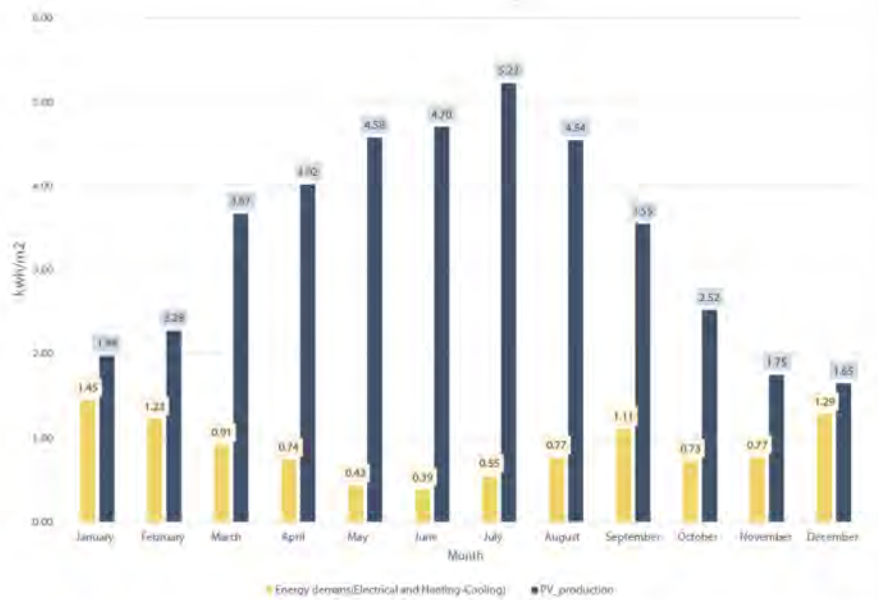



FIGURE 4.3

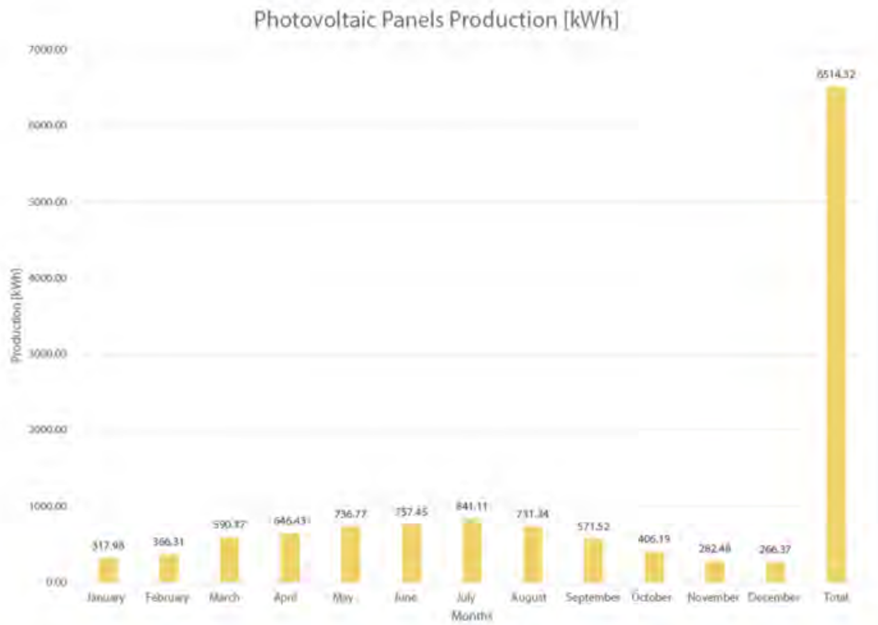



FIGURE 4.4

# CHAPTER 5

## OUTCOMES ANALYSIS

In this chapter there has been exhibited all the final outcomes reached with a step by step comparison indicating the main improvements of each important quantity in this project.

## Cooling and Heating Loads

First and one of the most important quantities related to the final outcome of this energy optimization project are the heating and cooling loads. In the following charts it has been shown the monthly distribution of the said loads considering each of the six main steps toward the optimization of the building energy consumption. the steps being 1) after free run simulation which means the baseline project definition 2) after ventilation optimization using ground heat exchanger and automation 3) after ventilation optimization using exhaust heat exchanger and automation 4) after shading optimization and automation 5) after BIPV installation without considering the active production 6) final configuration of the whole building considering also the active production.

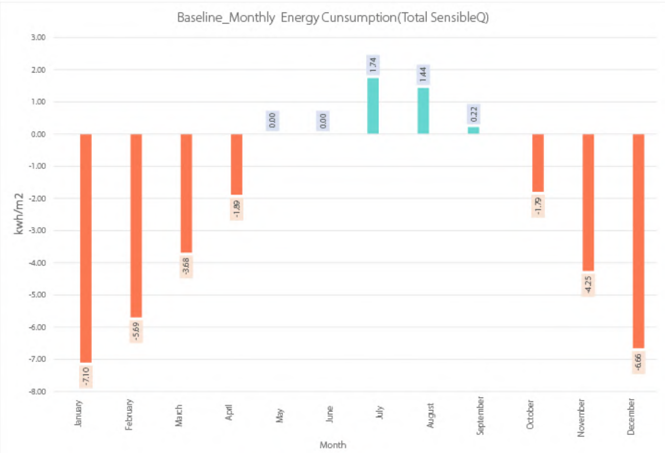


FIGURE 5.3

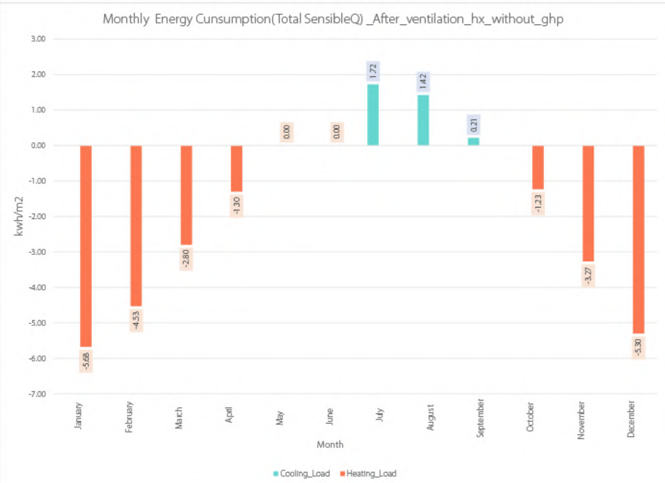


FIGURE 5.5

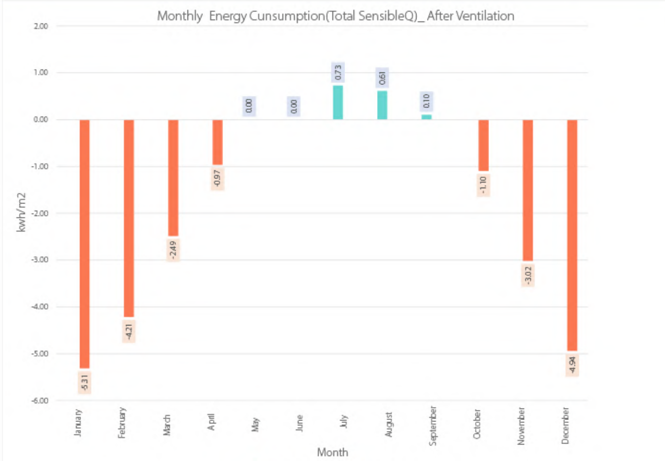


FIGURE 5.1

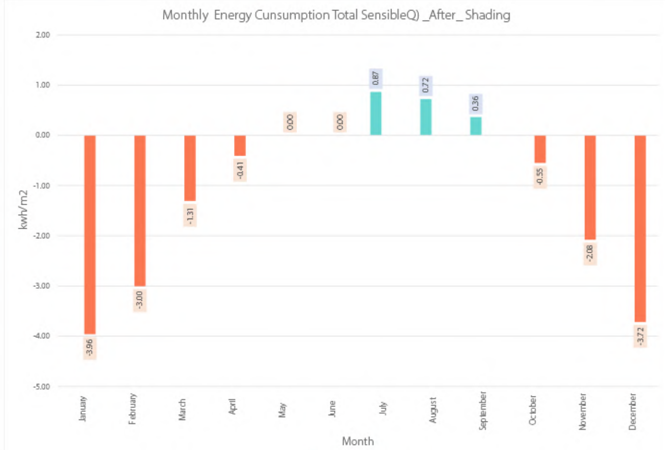


FIGURE 5.2

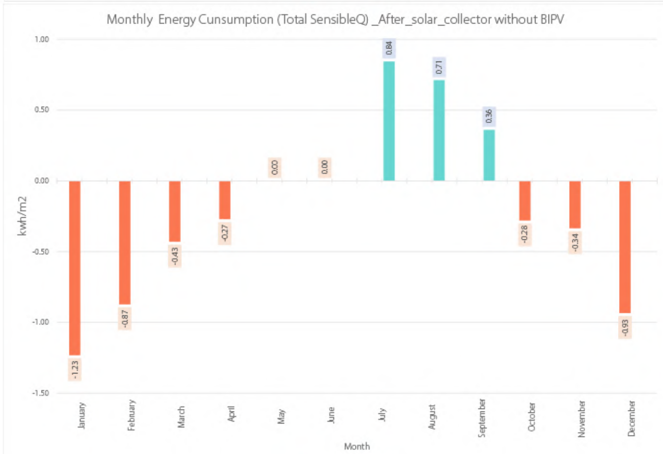


FIGURE 5.4

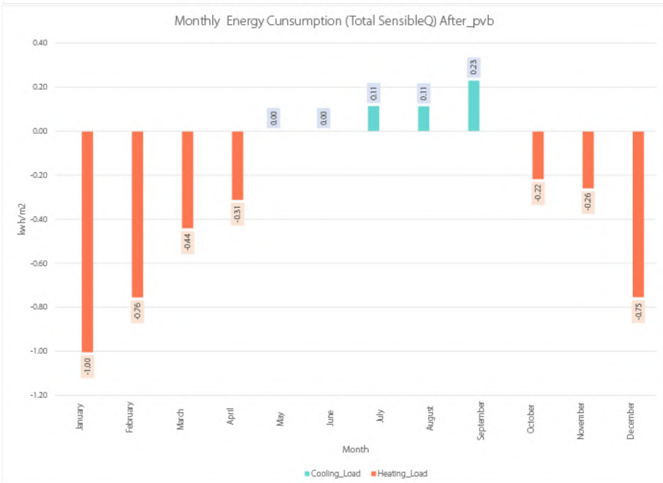


FIGURE 5.6

In the first chart (figure 5.7) it has been exhibited the the final annual loads of cooling and heating for each of the steps aforementioned in comparison. The total effect of the optimization is quite clearly visible.

In the second chart (figure 5.8) the same comparison has been done in consideration of the total sensible and latent heat in relation to each of the steps.

And in the third chart (figure 5.9) the optimization steps comparison has been broke down into months of the year.

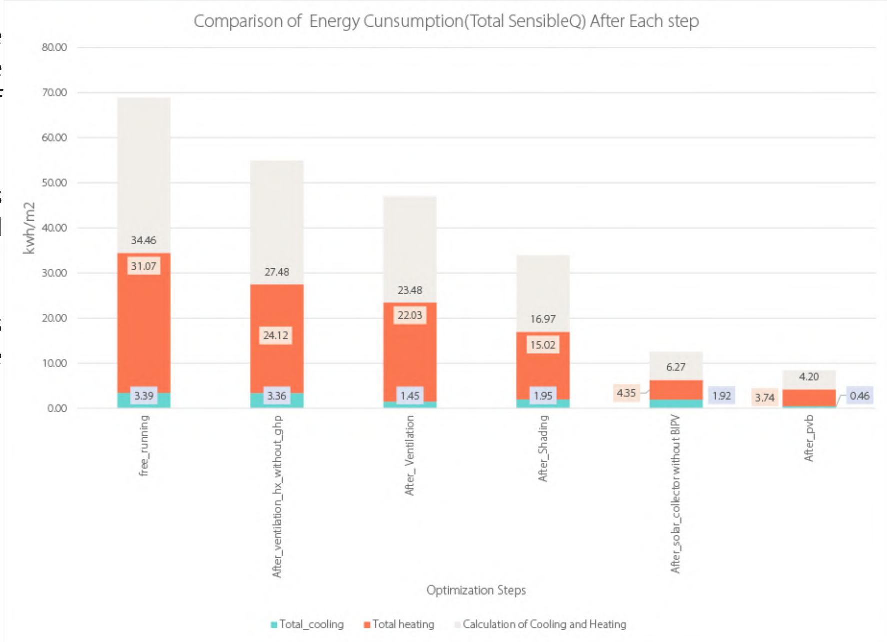
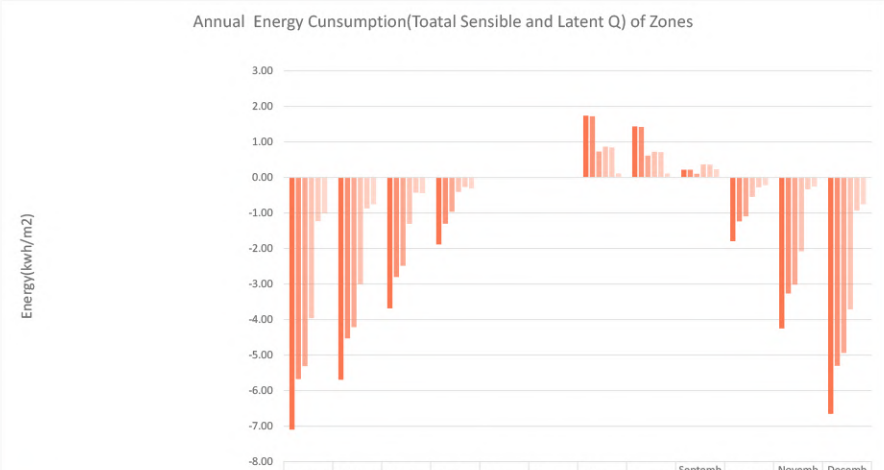



FIGURE 5.7


FIGURE 5.8




| | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| QSensible_Total free_running | -7.10 | -5.69 | -3.68 | -1.89 | 0.00 | 0.00 | 1.74 | 1.44 | 0.22 | -1.79 | -4.25 | -6.66 |
| QSensible_Total After_ventilation_hx_without_ghp | -5.68 | -4.53 | -2.80 | -1.30 | 0.00 | 0.00 | 1.72 | 1.42 | 0.21 | -1.23 | -3.27 | -5.30 |
| QSensible_Total After_ Ventilation | -5.31 | -4.21 | -2.49 | -0.97 | 0.00 | 0.00 | 0.73 | 0.61 | 0.10 | -1.10 | -3.02 | -4.94 |
| QSensible_Total After_Shading | -3.96 | -3.00 | -1.31 | -0.41 | 0.00 | 0.00 | 0.87 | 0.72 | 0.36 | -0.55 | -2.08 | -3.72 |
| QSensible_Total After_solar_collector without BIPV | -1.23 | -0.87 | -0.43 | -0.27 | 0.00 | 0.00 | 0.84 | 0.71 | 0.36 | -0.28 | -0.34 | -0.93 |
| QSensible_Total After_pvb | -1.00 | -0.76 | -0.44 | -0.31 | 0.00 | 0.00 | 0.11 | 0.11 | 0.23 | -0.22 | -0.26 | -0.75 |

Month

FIGURE 5.9

# Total Loads Distribution

The following charts indicate a break down comparison of the total energy consumption in the building by different means, considering Cooling, Heating, Dehumidication, Equipments, Lighting fixtures, and domestic hot water. Although at first glance it might seem that the domestic hot water is consuming more energy than traditionally required but it worths mentioning that the energy consumed in this section is mostly used not by the domestic hot water itself but the usage of hot water in the tank to provide heating in the building, which since it is mostly done by solar thermal collector is a much better choice than usage of active and auxiliary heating fixtures.

The six main steps toward the optimization of the building energy consumption. the steps being 1) after free run simulation which means the baseline project definition 2) after ventilation optimization using ground heat exchanger and automation 3) after ventilation optimization using exhaust heat exchanger and automation 4) after shading optimization and automation 5) after BIPV installation without considering the active production 6) final configuration of the whole building considering also the active production.

ENERGY CONSUMPTION_AFTER_SHADING

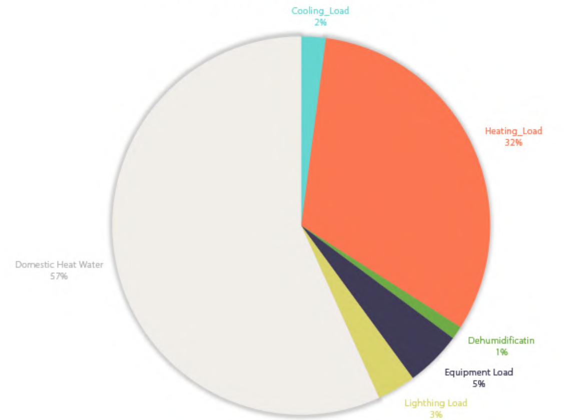



FIGURE 5.10

ENERGY_CONSUMPTION_AFTER_VENTILATION

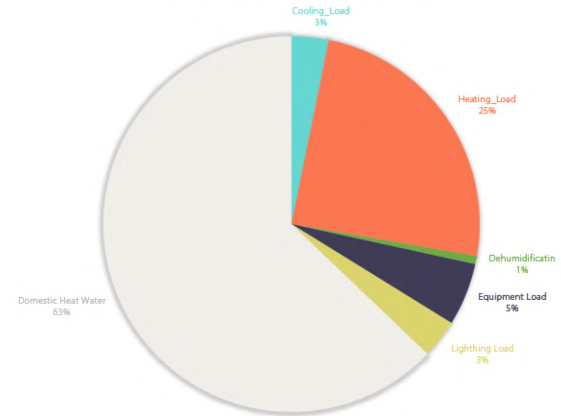



FIGURE 5.11

BASELINE ENERGY CONSUMPTION

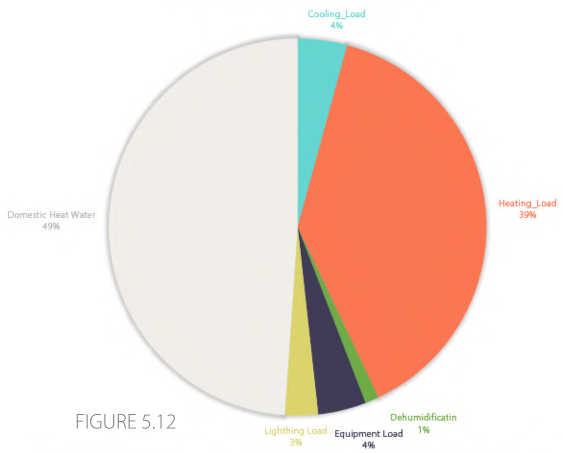



FIGURE 5.12

ENERGY CONSUMPTION AFTER_SOLAR_COLLECTOR_WITHOUT BIPV

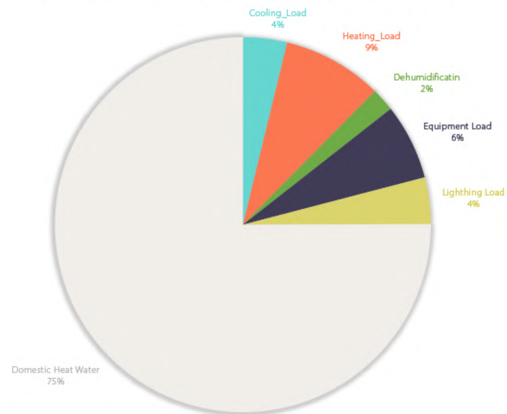



FIGURE 5.13

ENERGY CONSUMPTION_AFTER_VENTILATION_HX_WITHOUT_GHP

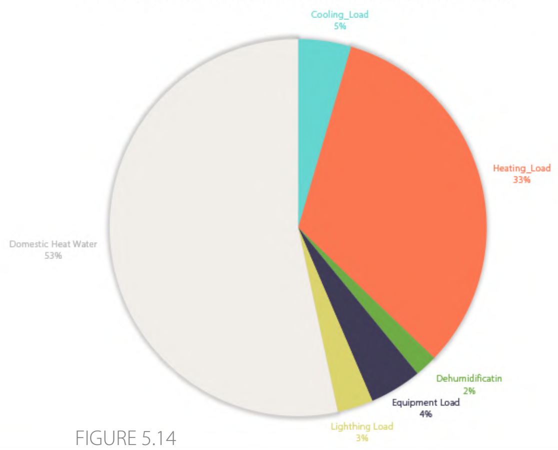



FIGURE 5.14

ENERGY CONSUMPTION AFTER BIPV

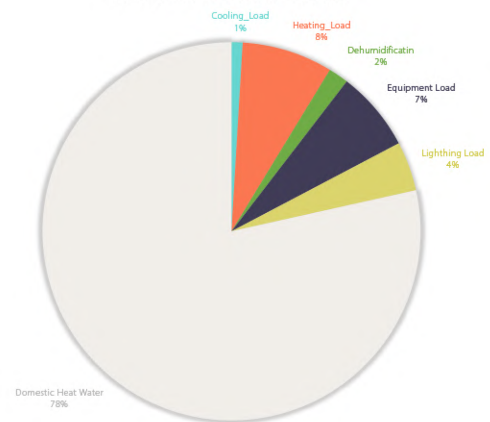



FIGURE 5.15

The first chart (figure 5.16) indicates the amount of energy demand in the building in comparison to the active production. Eventhough, to some percentage, the produced energy will be reduced whilst being used by different systems due to the different coefficient of performance but still the amount of over production by the active system is considerable. Clearly, some of the produced energy by the active system is going to be released back to the grid but the overal sum of the energy usage of the building would be negative which means it will release more energy to the grid than will receive.

The second (figure 5.17) and the third (figure 5.18) charts indicate the final outcome of the building in terms of sensible and latent heat and heating and cooling loads.

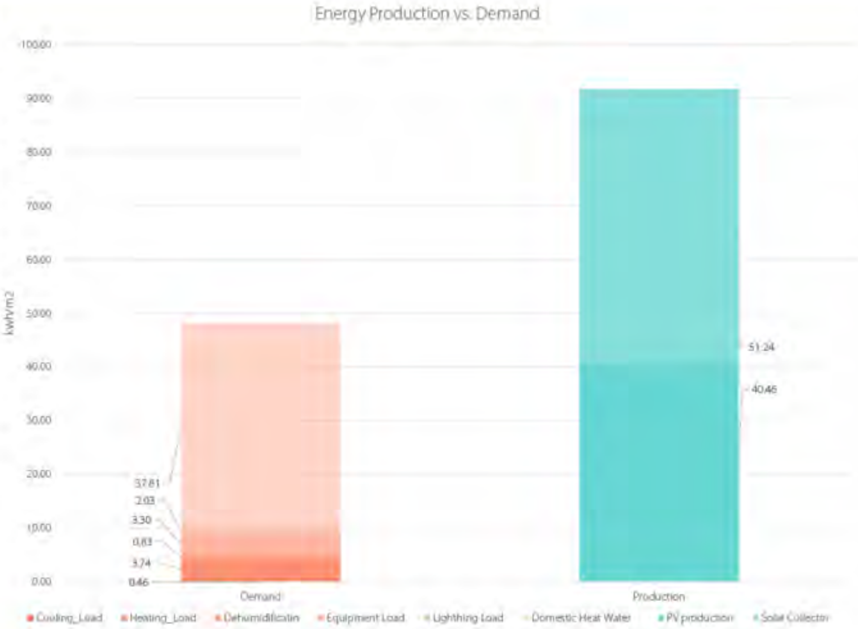


FIGURE 5.16

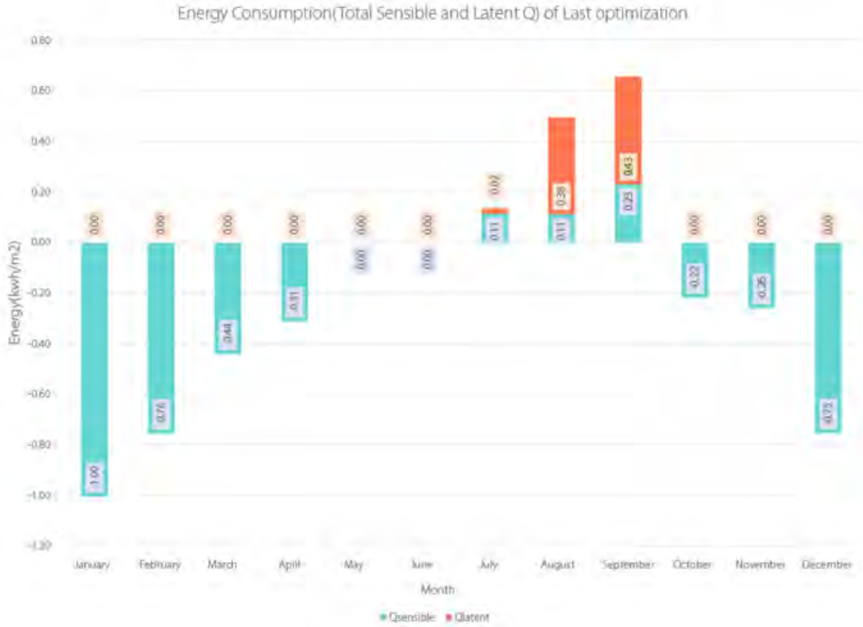


FIGURE 5.17

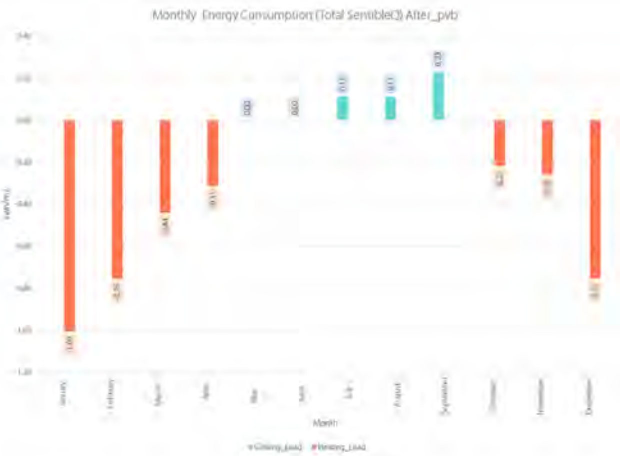
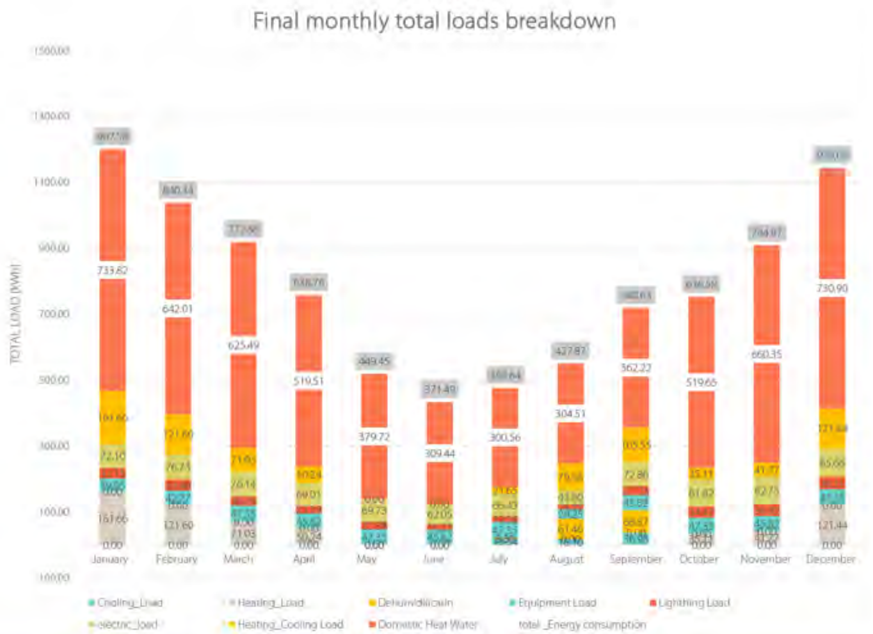


FIGURE 5.18



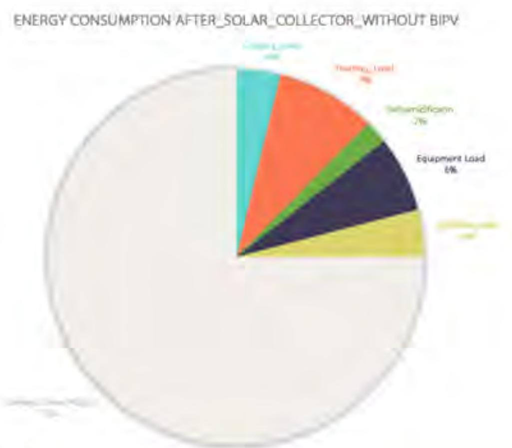



FIGURE 5.13

## BaseLine/After Ventilation and Shading Comfort Analysis

Following the optimization process the main criteria was to reach the atmost comfort percentage possible through passive strategies. Such comfort has been evaluated by the guideline and equation provided by EN15251 standard.

In the following part it has been exhibited the overall passive comfort reached after each of the main steps in a detailet hourly scattered operative temperatures inside the thermal zones and also a chart indicating the percentage of the sum of the hours inside each classes of A, B, and C defined by the EN15251 standard.

In the end, there has been put in one chart the step by step optimization in comparison together.

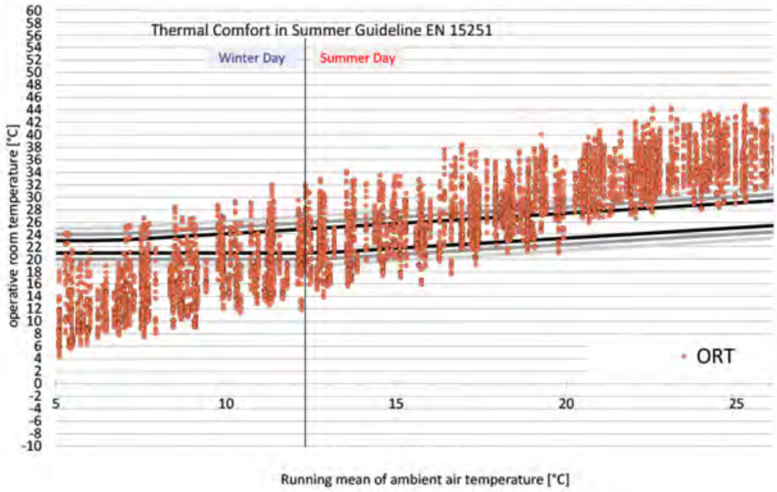



FIGURE 5.19


FIGURE 5.22

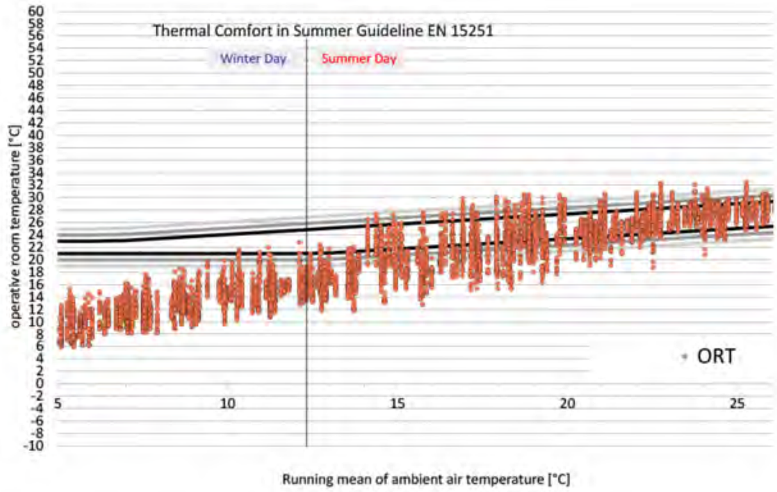



FIGURE 5.20


FIGURE 5.23

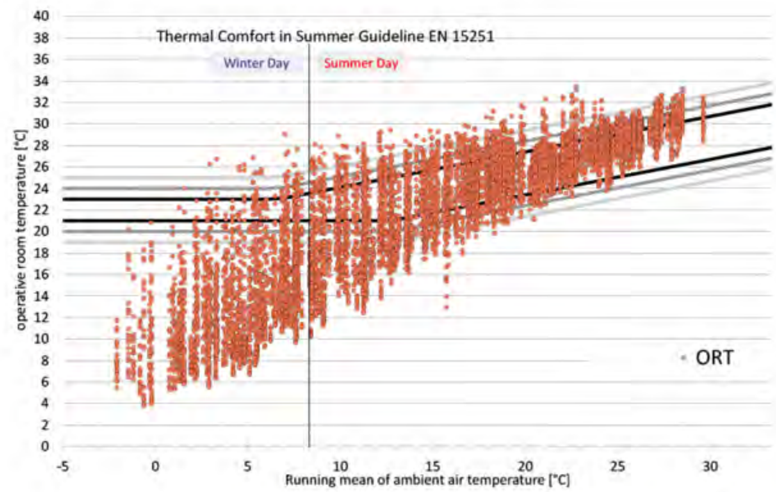



FIGURE 5.21

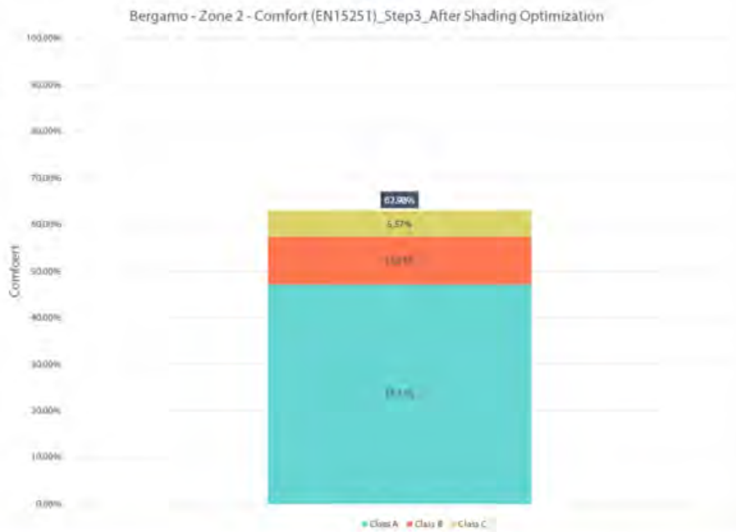



FIGURE 5.24

## After Solar Collector and BIPV / Final Comfort Analysis

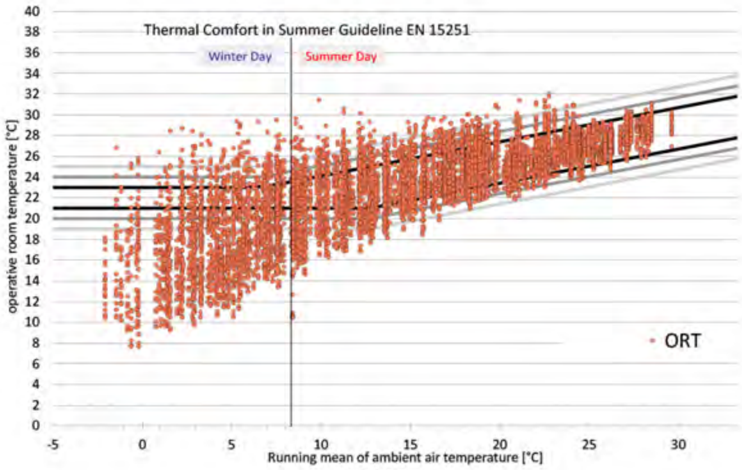



FIGURE 5.25

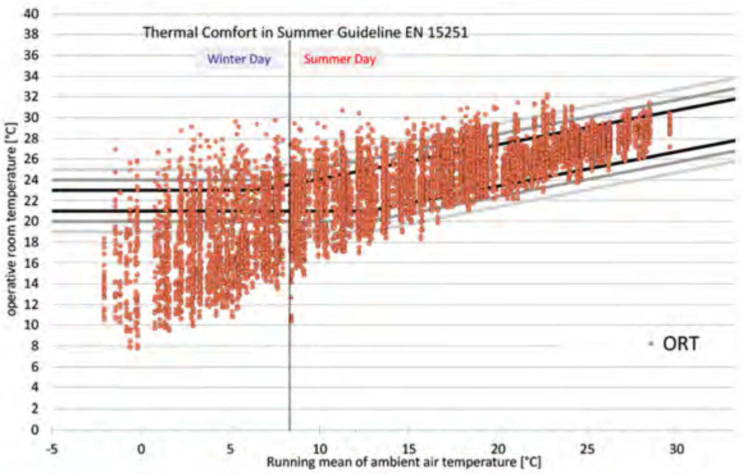



FIGURE 5.26


FIGURE 5.27

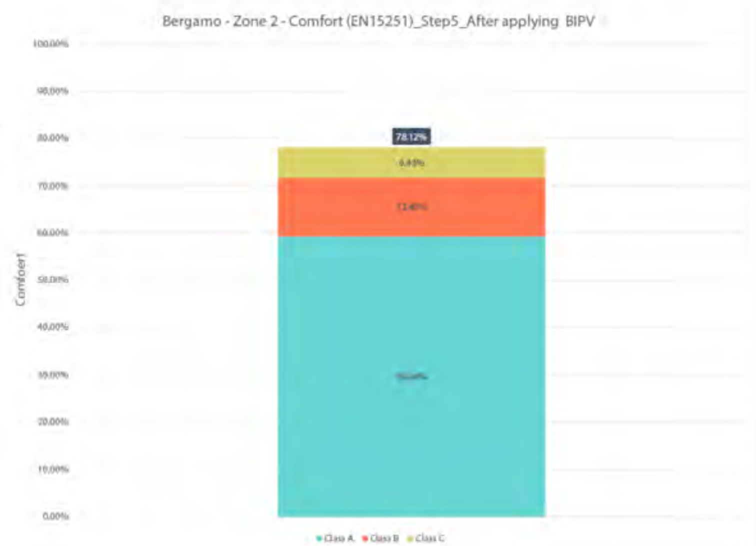



FIGURE 5.28

## Baseline

| | Zone1 | Zone2 | Zone3 |
|---|---|---|---|
| Lighting Heat Gain | 1.5 W/m² | 1.5 W/m² | 0.5 W/m² |
| Equipment Heat Gain | 2.5 W/m² | 2.5 W/m² | 1 W/m² |
| People Heat Gain | 1 W/m² | 1 W/m² | 2 W/m² |
| Infiltration | | | Annual Hourly |
| **Heating,** Cooling Set Point T | | | °20C°16-C °26C |
| Passive H/C Set Point T | | | Automated To EN15251 |
| Relative Humidity Limits | | | 50%-70% |
| Envelope Values | | | Case 2 |
| Shading Percentage | | | Automated |
| Ventilation Rate | | | Automated |

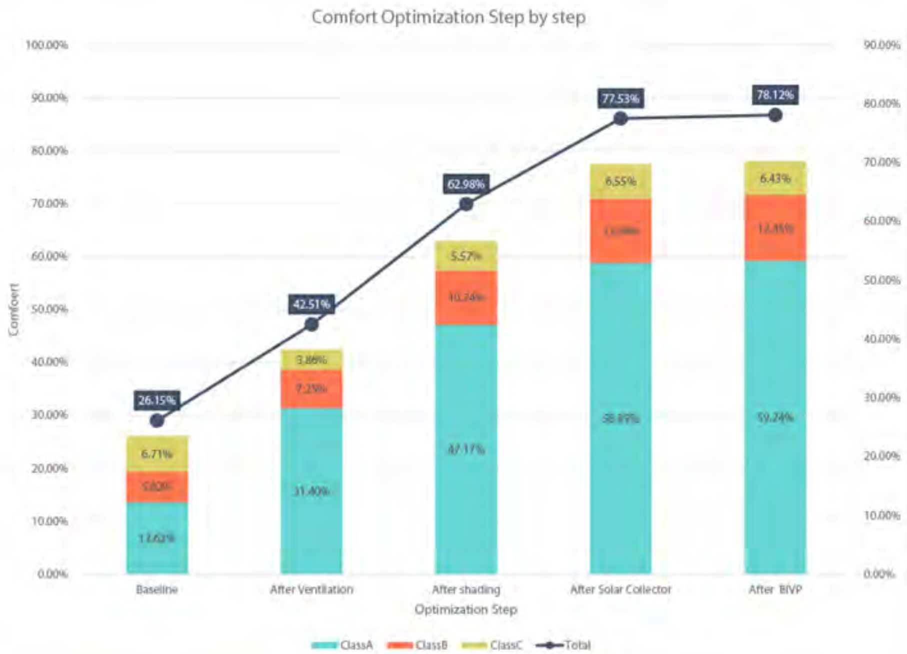
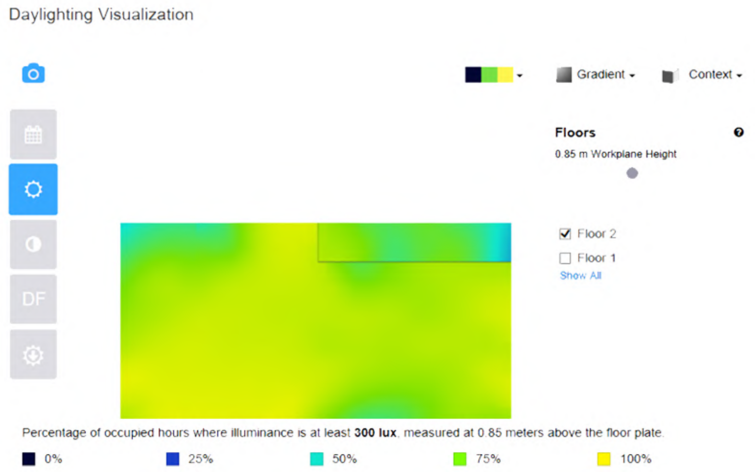



FIGURE 5.24

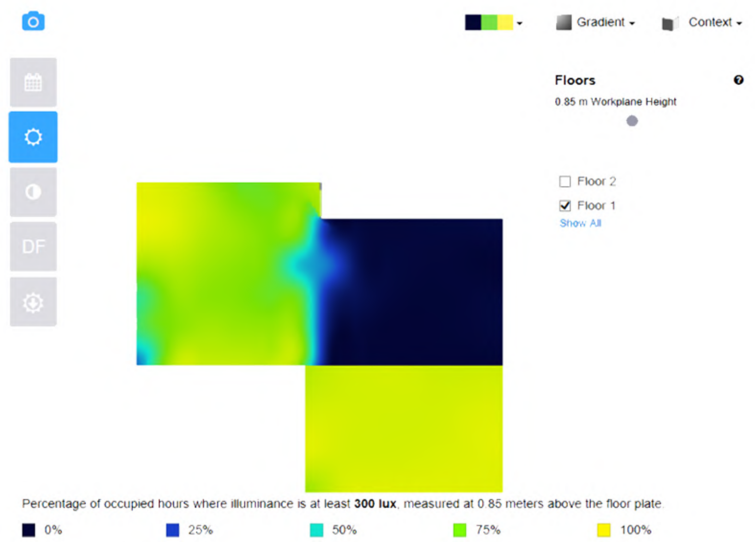
# ANNUAL DAYLIGHT

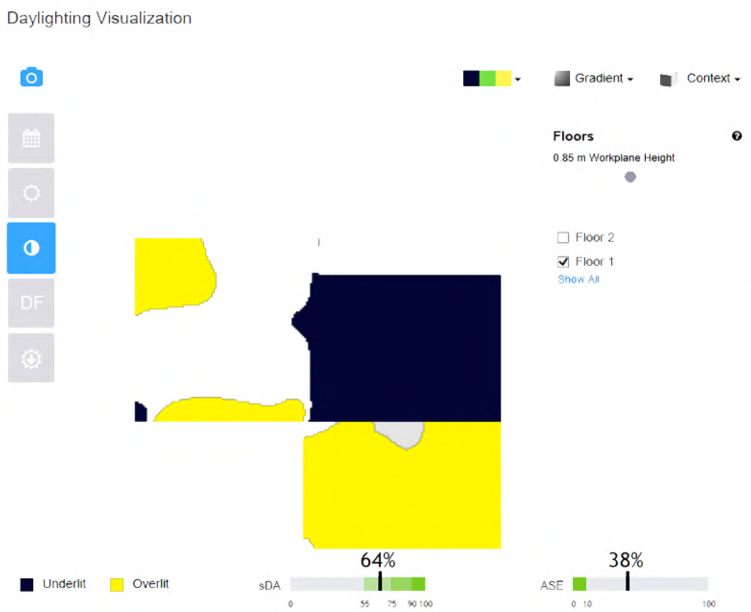
It has been exhibited in the first two charts the percentage of illuminance equal to at least 300% lux (optimum standard for residential buildings) during the operating hours on each point of the building considering solely the stationary shadings original exisiting on the building architectural design.
From this analysis it can be seen that enough daylight is reaching the required zones such as bedrooms and living room.

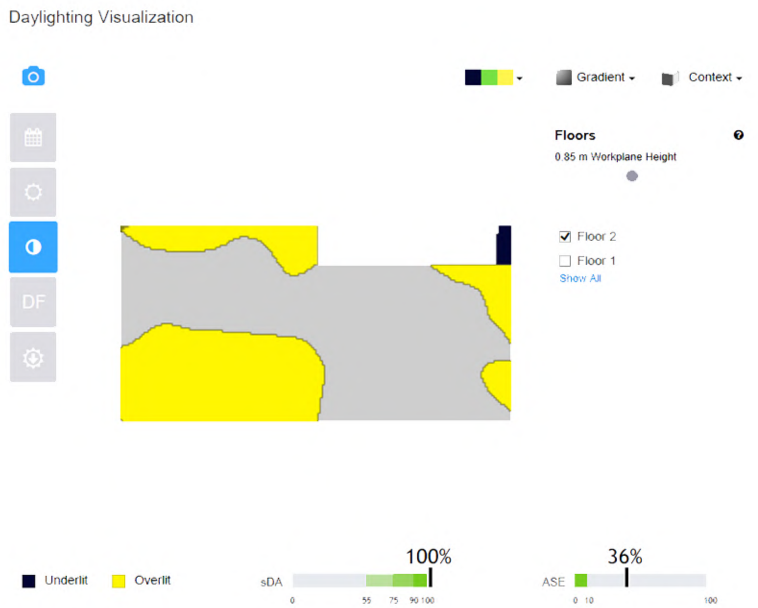



# ASE & sDA ANALYSIS

The last two charts are indicating the percentage of underlit using the definition of spatial Daylight Autonomy (sDA) which is the percentage of the points on the working plane (85cm height) that are receiving less than 300 lux illuminance for the half of the simulation duration (annually) and the definition of Annual Sunlight Exposure (ASE) which is the percentage of the points on the working plane (85cm height) that are receiving more than 1000 lux illuminance for at least 250 hours a year.
This analysis indicates that although there is enough daylight received in the rooms but there is a high possibility of overlitting the building during the year in case of usage of default stationary shadings. such problem could be addressed partly by the introduction of the automated shadings. The outcome of the automated shading can be done by areal node analysis in TRNSYS.

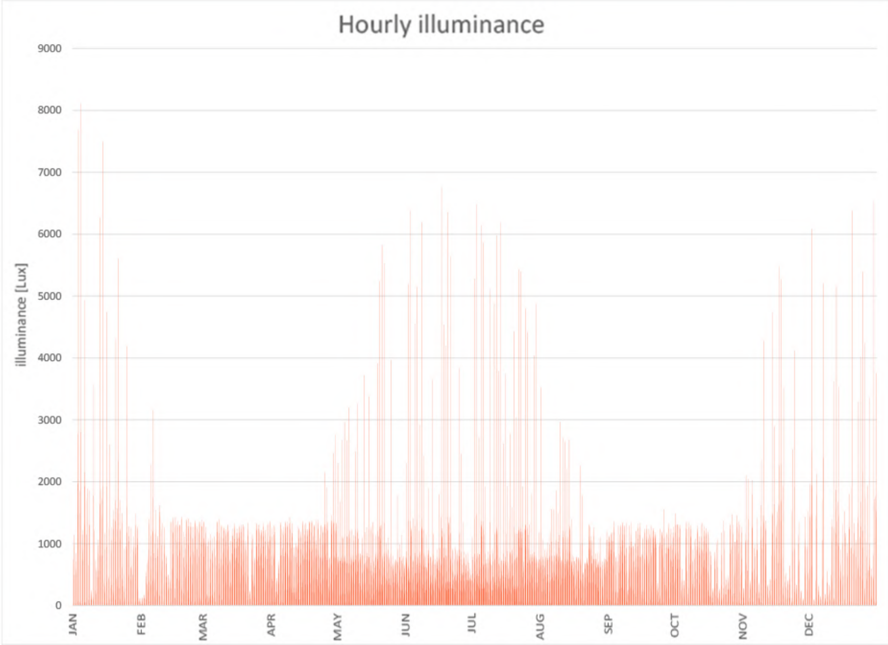


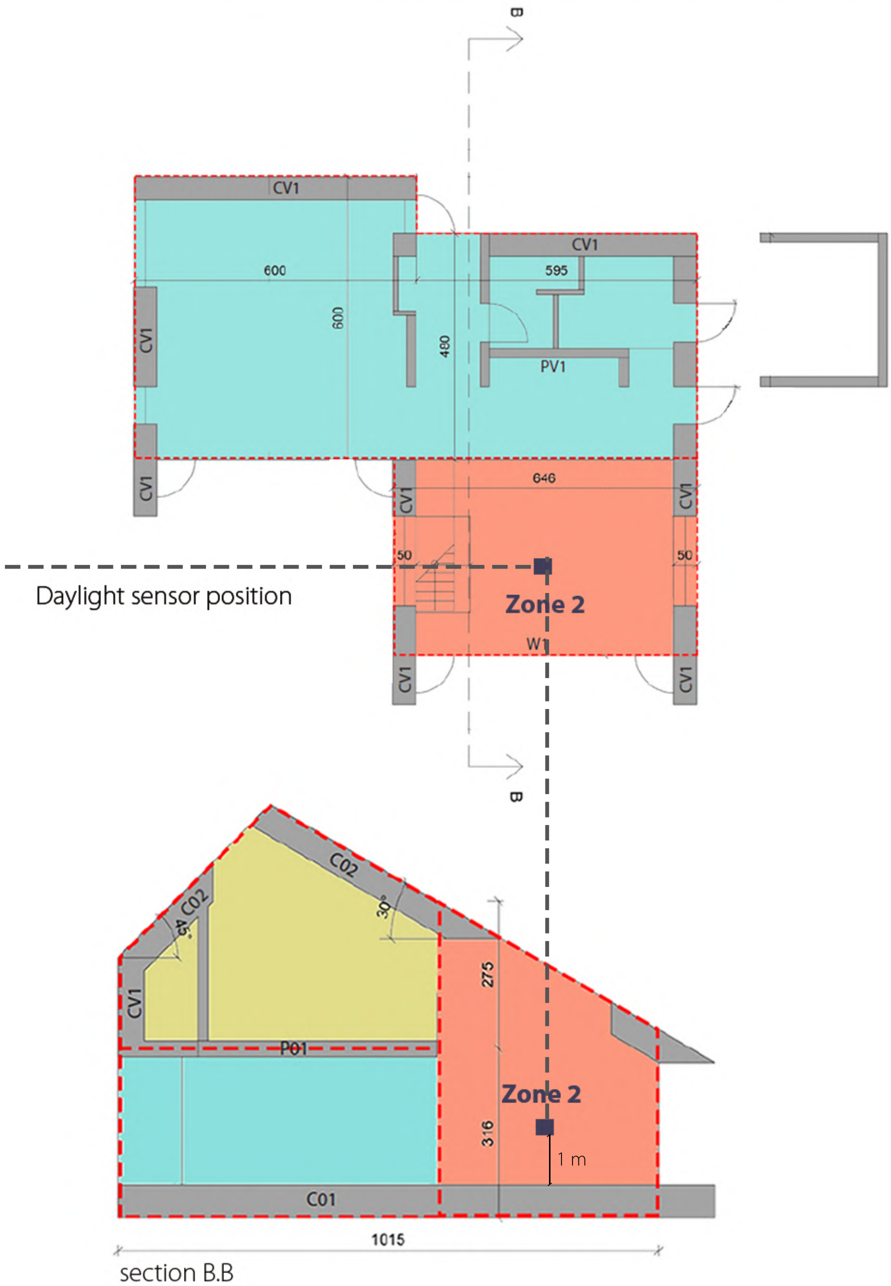



## AREAL NODE ANALYSIS

To investigate the effect of the automated shading proposed to reach the optimum thermal comfort on the visual comfort the following analysis has been done.
The middle point of the thermal zone 2 that is the living room of the building and the most important space to reach optimum comfort both thermally and visually has been chosen to put the daylight sensor and be investigated.
The first chart shows the annual hourly illuminance of the aforementioned node. although most of the hours reach the minimum of 300 lux and in terms of sDA being rated as well lit node, but the number of the hours reaching more than 1000 lux are more than 250 hours which indicates the node being rated as overlit.
This investigation points out that although the automated shading helps the room to reach a proper thermal comfort but in terms of visual comfort it is not of much use, but as mentioned in the last chapters, the user controlled curtain system can be of immense help here because its effect on the thermal discomfort is negligible in terms of blocking the solar gain but in terms of visual comfort it can be a proper tool to hinder the overlitting effect for the hours that the illuminance jumps above 1000 lux.



section B.B

| | |
|---|---|
| >300 lux | 3327 |
| >1000 lux | 1153 |
| Total | 4745 |

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