Table of Contents

01.Abstract

Building is the main contributor in the energy and environmental areas of the country. The building sector in European Union is trying to improve its sustainability and to meet its target for reduction in amount of carbon emissions by 2050 which will be more than that set out in Kyoto agreement. This work aims to design a community of 8 low energy office building in Rome, Italy. Various factors such as building fabric, form and passive ventilation strategies were analyzed using the IES virtual environment software. The base case of the building was modelled with less insulation and normal building U-values for the floor, the roof, the walls and windows. The total primary energy demand, demand for space heating and cooling and the amount of carbon emissions were calculated for the base case. To improve the energy efficiency of the building standards such as Passivhaus, ASHRAE and CIBSE were analyzed and considering the local climatic conditions, the U-values were changed as per the Passivhaus and there was 31% reduction in the energy demand for space heating and cooling and 18% reduction in the primary energy demand of the building. The impact of window to wall ratio, overhang and building orientation has been examined on the energy demand of the building. The energy demand is further reduced by 38.8% compared to the base case by using night ventilation strategy. The change in set point temperature reduced the energy by 61% compared to the base case. The carbon emission was reduced by 34.4% compared to the base case. A solar analysis is done, and the on-site energy production is calculated which reduced the net energy demand of the building by 93% compared to the base case.

02.Introduction

In the twenty first century global warming is one of the biggest challenges for the mankind and the increase in emission of greenhouse gases is its main cause (Asif, 2008). Over one third of the greenhouse gas emissions in the world is due to the building and construction sector (Asif, Muneer and Kubie, 2005). In the European Union, buildings account for 40% of total energy consumption (Bosseboeuf, 2015). Statistics shows that in the European Union, non-residential buildings have an annual primary energy consumption of 286kWh/m^2 which is 55% more than residential buildings which account for 185 kWh/m^2 (Bosseboeuf, 2015). Due to the increased amount of energy consumption the building sector started using renewables as the major source of energy generation in which Italy contributes 68.4% of the total indigenous supply mix (International Energy Agency IEA, 2016). Therefore, the European Union member states have set a target of reducing the CO_2 by 20% and energy consumption in the building by 2020 (Kurnitski *et al.*, 2011) as per the European Union's Energy Efficiency Directives (EED) which suggested to submit National Energy Efficiency Action plans (NEEAP) (D'Agostino, Zangheri and Castellazzi, 2017). As per the Energy Performance of Building Directive (EPBD) all the buildings in European Union countries need to be zero-energy buildings by the end of 2020 (Li, Yang and Lam, 2013). Wang suggested a three-step design process which is the climatic data analysis, passive design to reduce energy demand and renewable energy technology to meet the remaining energy needs (Wang, Gwilliam and Jones, 2009). Further study suggested that after the application of three simple steps to design zero energy building, which are passive design strategies and energy efficiency measures, proper combination of strategies and pairing up of energy demand with onsite energy production in six different climates, the annual energy demand was reduced by 19-30% when compared to the baseline (Stephens, 2011). In this report, the design goals were set for reducing the energy demand in building and is achieved through passive strategies.

03.Design Criteria

The report aimed to design a low energy building in Rome, Italy with the key objectives being to

- minimize the use of mechanical services and to increase the use of natural ventilation.
- choose suitable U-values and materials for building fabric
- To provide overhangs, change form of the buildings and the orientation of the building and observe their effect on building energy demand.
- Minimize the energy consumption with specific heating and cooling demand less than 30 kWh/m^2.year and the primary energy demand less than 135 kWh/m^2.year.
- To reduce 20% of the carbon emissions from the baseline design (16).
- To maximize the thermal comfort and indoor air quality.

The proposed design of the buildings aimed to comply with the local building regulations such as the Energy Performance in Building Directive (EPBD) and the European Union's Energy Efficiency Directives (EED).

In order to achieve the design goals, a better understanding of the climatic conditions of Rome, Italy is required and appropriate construction materials for the building fabric should be selected considering climatic conditions.

The Rome Metropolitan city is situated in the western side closer to the coastal region near the Tyrrhenian sea. Project site is shown in Fig.1, where the 8 office buildings had to be designed. The floor area of one office unit is 80 m^2. The site is surrounded by tall buildings on all the sides. On the south west side, the building height is 7m which is of less height than others.

Figure 1 Site location

The indoor environmental criteria are taken from CIBSE and ASHRAE and is compared in Appendix A Table 7. The internal heat gain is taken from CIBSE Guide A and shown in Appendix Table 8. From Table 7 the final indoor environmental criteria are selected from the ASHRAE for the office building since the air change rate is lesser which will reduce the energy demand for the building. The internal heat is taken as per the CIBSE suggestion. Thus, the indoor environmental criteria set for office building is shown in Table.1.

Table 1 Indoor Environmental Criteria for Office building

Description	Indoor criteria
Summer Air Temperature	23^{o}C
Winter Air Temperature	20^{o}C

Relative Humidity	50%
Air change rate	8.5 L/s/per person
Air speed	0.15 m/s

CIBSE suggests for an office building the occupancy density as 12 m^2 per person which is considered in this analysis. A statistical analysis for the occupancy pattern was done by Wen-kuei Chang (Wen-Kuei and Tianzhen, 2013) in which the typical office building occupancy time in the weekdays is from 09.00 – 17.00 hrs. Further study by Simona also suggests the above schedule (D'Oca and Hong, 2015). Therefore, the occupancy schedule was created for the office as shown in Table.2.

Table 2 Occupancy Schedule

Time	00.00 – 09.00	09.00 – 17.00	17.00 – 24.00
Occupancy density	0	1	0

04.Climate Analysis

Rome is located at 21m of altitude with the coordinates 41°54' North, 12°30' East. The weather in Rome is considered a Hot-Summer Mediterranean climate zone. From Fig.2 the maximum temperature is about 30.6 °C in the July and the minimum temperature is about 3.8 °C in the month of January. The rainfall in the region is mostly throughout the year and the precipitation is more. From Fig.3 it is noted that the least rainfall is in the month of July and the most rain falls in the month of November.

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature (°C)	7.7	8.9	10.8	13.7	17.7	21.7	24.4	24.3	21.3	16.8	12.3	8.9
Min. Temperature (°C)	3.8	4.5	6.1	8.5	12.2	15.9	18.3	18.4	15.9	11.7	8	5
Max. Temperature (°C)	11.7	13.3	15.5	18.9	23.3	27.5	30.6	30.2	26.7	21.9	16.7	12.9
Avg. Temperature (°F)	45.9	48.0	51.4	56.7	63.9	71.1	75.9	75.7	70.3	62.2	54.1	48.0
Min. Temperature (°F)	38.8	40.1	43.0	47.3	54.0	60.6	64.9	65.1	60.6	53.1	46.4	41.0
Max. Temperature (°F)	53.1	55.9	59.9	66.0	73.9	81.5	87.1	86.4	80.1	71.4	62.1	55.2
Precipitation / Rainfall (mm)	79	70	70	62	46	35	17	33	73	103	114	96

*Figure 2 Maximum and Minimum Temperature (*Climate-Data.org*, 2017)*

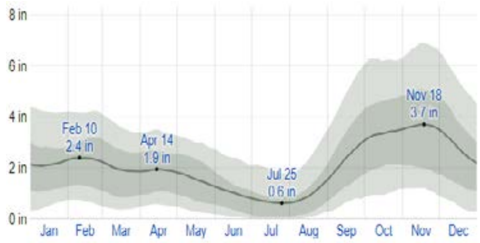

*Figure 3 Maximum and Minimum Rainfall(*Weather Spark*, 2016)*

The incident solar radiation in the region shows that there is a lot of opportunity to use renewable energy system. The daylight in the region is shown in Fig.4 and it varies between 9 hours to 15 hours throughout the summer and winter. Due to length of day there is a potential of overheating is possible. Therefore, care should be taken while using daylighting so that it should not overheat the building and increase the cooling loads.

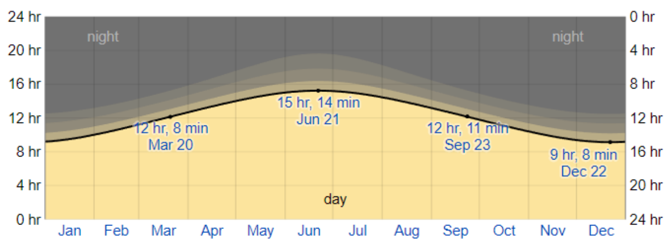

*Figure 4 Daylight hours in Rome (*Weather Spark*, 2016)*

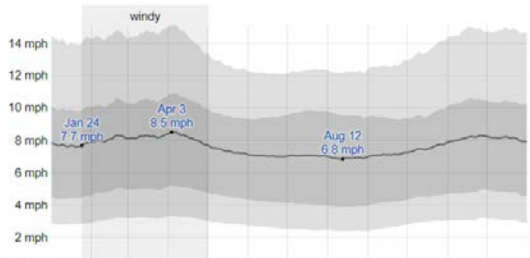

*Figure 5 Wind speed in Rome (*Weather Spark*, 2016)*

The winter period has a temperature between 8°C and 3.8°C but the summer has peak temperatures of 27°C to 30°C, therefore care should be taken while designing for the summer case. From Fig.5, the average wind speed in this region shows mild seasonal variation throughout the year with the highest wind speed during the month of April. Therefore, the building should be airtight in order to prevent infiltration.

05.Initial Design proposal

The initial model or the base case model of the building was considered with the conventional building materials and the U-values were taken from CIBSE Guide A. This model helps us in giving the baseline building energy demand for our project. The materials and the U-values of the building fabric are shown in Appendix A Table.9. The initial formation and orientation of the buildings as shown in the Fig.6. The 8-office building were positioned in such a way that it forms the U shape and the opening of the U shape facing the North direction.

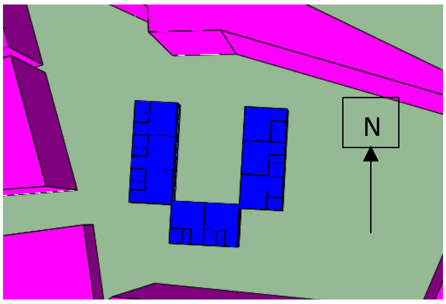

Figure 6 Initial Design Proposal (Base case)

06.Results and Analysis

6.1. Base Model Simulation Results

The initial model was designed and analyzed using the IES software. The results were shown in Table.3.

Table 3 Base case Simulation Results

Content	**Energy demand (kwh/m^2.year)**
Primary Energy Demand	125.12
Space heating demand	19.28
Space Cooling demand	49.8

The values are higher than the design targets that we have set for the project in section 03. The space heating demand and cooling demand is greater than 30 kWh/m^2/yr. Therefore, the following design changes has been made in section 6.2 to achieve the energy targets.

6.2. Alternate Design changes

The main objective of this project is to achieve the design energy targets using the passive strategy. The challenge in the building sector is to maximize the functionality of the building with focus on increasing the thermal comfort of the occupants and reducing the operating cost (Khan, Asif and Mohammed, 2017). The strategy as suggested by the hierarchy in Brent Stephens (Stephens, 2011) is followed and the different cases were employed in this project which are shown in Table.4.

Table 4 Proposed Design changes

Case	Strategies
Case 1	Change in building formation shape, Highly insulated windows, roofs, floor and walls (Passivhaus U-values) and infiltration rate from 0.5 ach to 0.25 ach
Case 2	Same as in case 1 in addition to increase in window to wall ratio and change in orientation
Case 3	Same as in case1 and 2 in addition to overhangs, night ventilation and change in building formation shape
Case 4	Change in set point temperature (thermal comfort)
Case 5	PV technology application (net zero energy approach)

6.2.1. Case-1

In case-1, all materials proposed for walls, windows, roofs, floor are light weight construction materials (Pokorny, Zelger and Torghele, 2009) as shown in Appendix A Table.10 and are highly insulated. Moreover, the air infiltration is considered from 0.5 ach to 0.25 ach due to highly insulated material application. The building formation shape is changed as shown in Fig.7 in order to create an enclosed environment. The simulation is carried out and the results were shown in Fig.8.

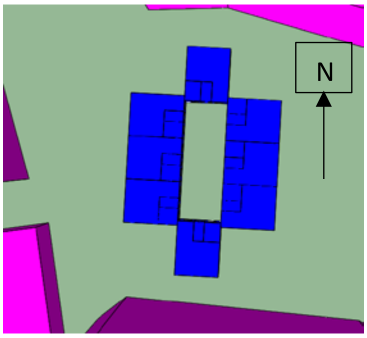

Figure 7 Building Formation Case 01

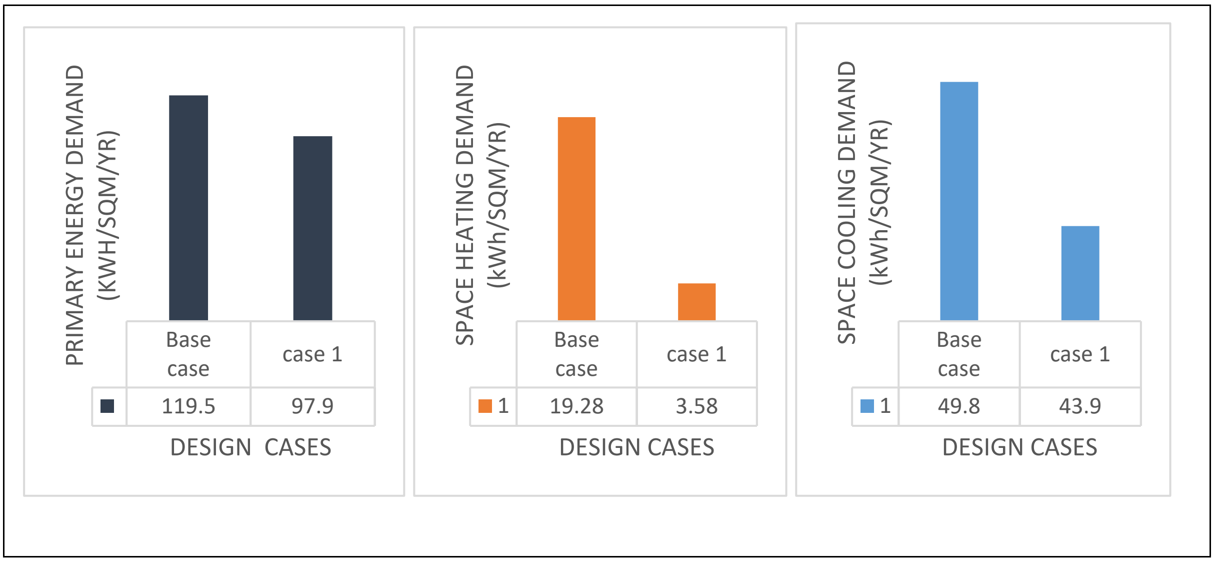

Figure 8 Energy output comparison for base case and case 01

From Fig.8 it is noted that the primary energy demand is reduced by 18%. This is because due to high insulation there is 81% reduction in the space heating demand. Even though there is not much difference in space cooling demand it has a reduction of 11.8%. But still the space heating and cooling demand is above the design targets. The high insulation has significantly reduced the heating demand, but the cooling demand is reduction is very less.

6.2.2 Case 2

In order to reduce the cooling load the orientation of the building was set to NE and SW as shown in Fig.10. So that only few windows facing the SW direction because during summer the sun is at the SW during the mid-day as seen in Fig.9. The window to wall ratio of the building is changed in order to increase the daylight as shown in Appendix A Table.11.

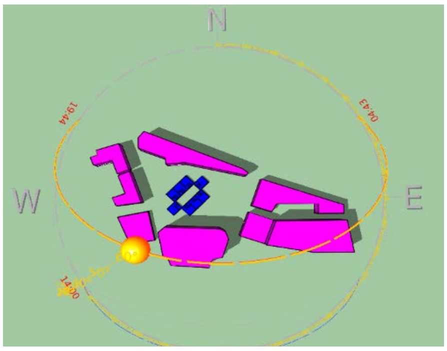

Figure 9 Sun Position in mid-day during July

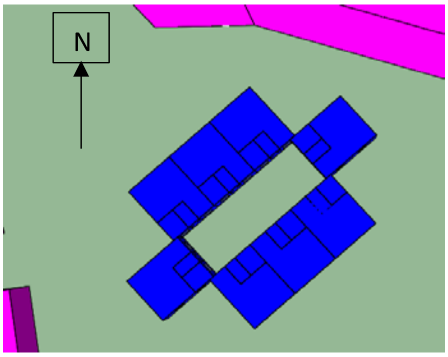

Figure 10 Orientation of building in case 2

The South facing windows are kept the same in order to reduce the solar gain.

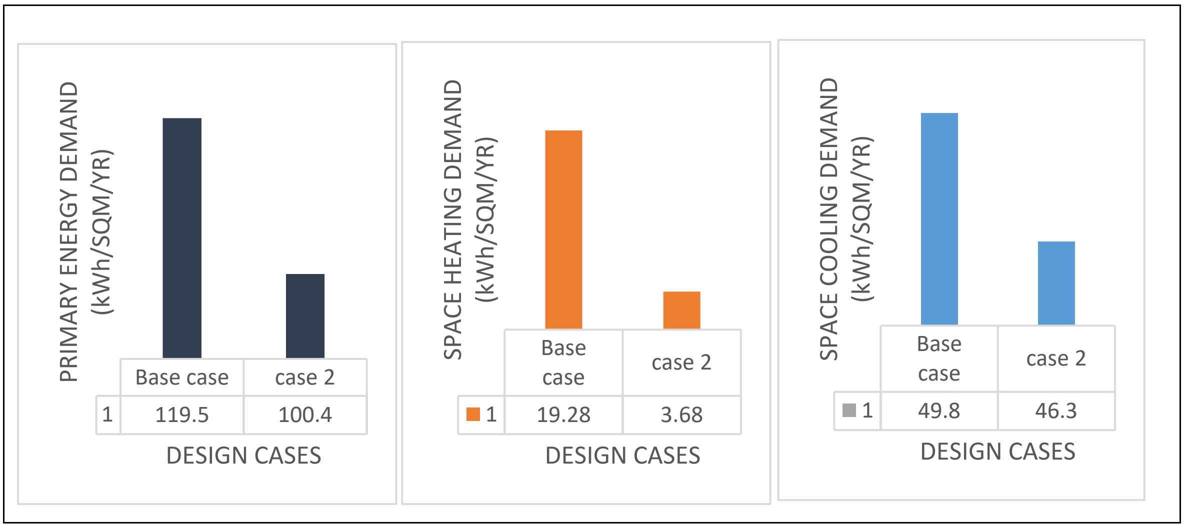

Figure 11 Energy output comparison for base case and case 02

As per the case 2, the simulation output is shown in Fig.11, the primary energy demand is reduced by 16%. Also, the cooling demand is reduced by 7%. Thus, the increase in window to wall ratio has increased the heat inside the space during summer and therefore the cooling load has increased from case 1.

6.2.3 Case 3

In the case 3 the formation of the building shape is changed as shown in Fig.12 so that the building is compact. Due the increase in cooling load in the previous case, overhangs are provided in all the external windows to provide solar shading as shown in Fig.12 in order to reduce the solar impact of the sun and increasing the temperature inside the space. In addition to that night ventilation strategy is applied to reduce the cooling loads in summer. The night ventilation is applied as shown in Table.5.

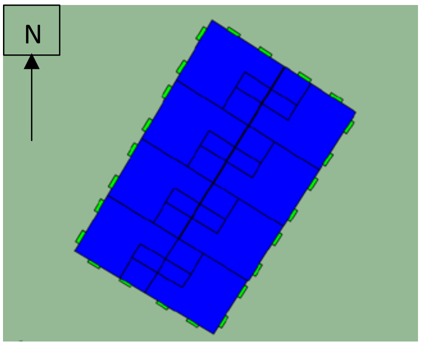

Figure 12 Building formation and overhangs

Table 5 Night ventilation strategy

Time	00.00 – 05.00	05.00 – 21.00	21.00 – 00.00
Night ventilation	gt(ta,23,4) & (ta>to)	0	gt(ta,23,4) & (ta>to)

Therefore, the night ventilation is activated when if 21ºC ≤ T_{inside} ≤ 25ºC and T_{inside} > $T_{outside}$. Thus, the simulation is carried out and the results are shown in Fig.13.

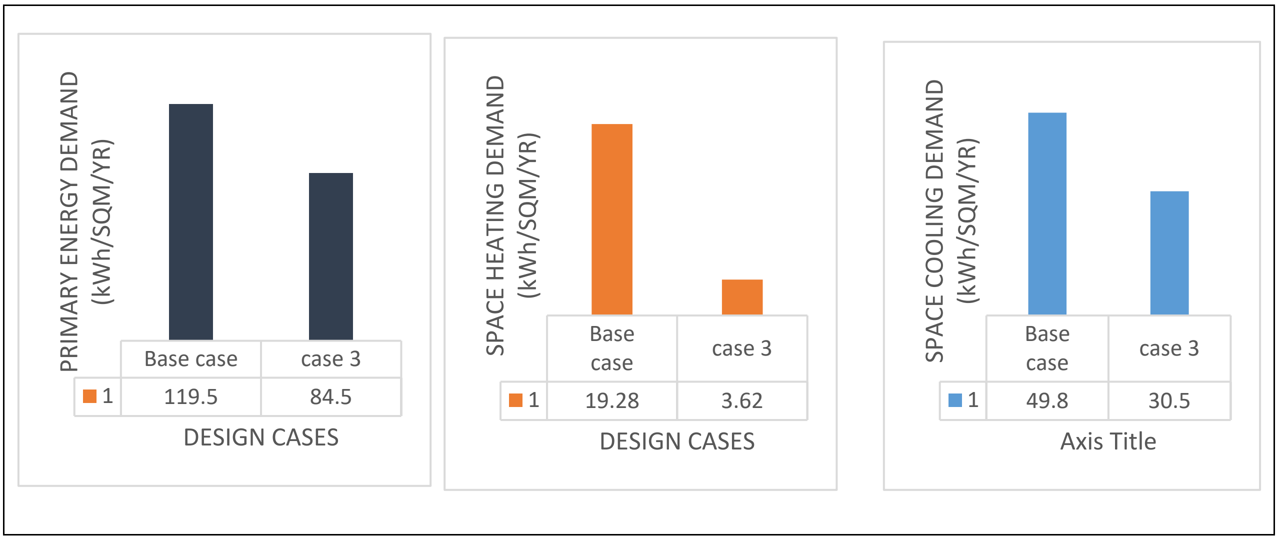

Figure 13 Energy output comparison between base case and case 03

From the above results it is noted that the cooling demand has been reduced by 38.8% but still the space heating and cooling demand is 4.12 kWh/m^2/yr more than our design targets. The primary energy demand has reduced by 29.3% from the base case.

6.2.4 Case 4

In order to reduce the cooling demand further the strategy of increasing the set point temperature for the cooling period but it is important to keep the thermal comfort conditions in mind and the inside temperature should not result in overheating. Therefore, as per ASHRAE 55 the CBE comfort tool (Tyler *et al.*, 2013) is used to check the thermal comfort condition for increasing the set point to 25ºC and it complies with ASHRAE 55 as shown in Fig.14.

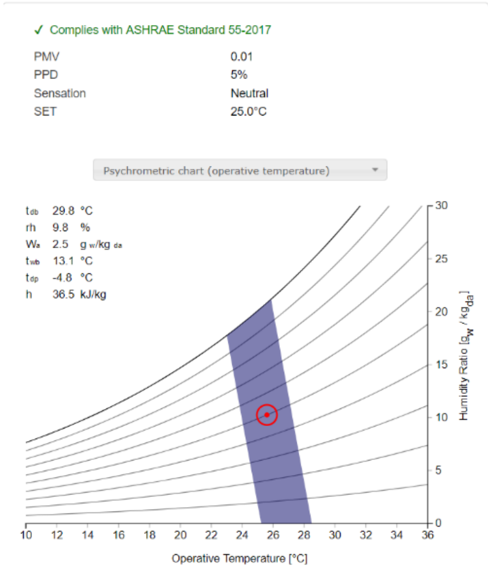

Figure 14 Thermal comfort evaluation

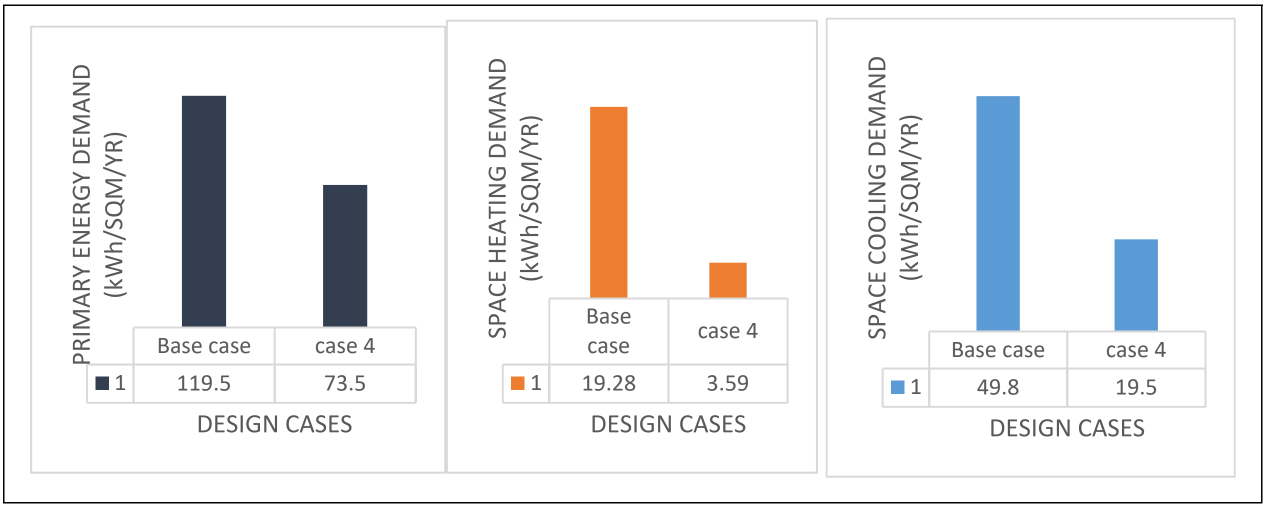

Figure 15 Energy output comparison between base case and case 04

From the results shown in Fig.15, the cooling load is 61% and the total space heating and cooling demand is 23.09 kWh/m²/yr which is less than the design targets set in section 3. The primary energy demand is 38.5% less than the base case. The carbon emission is reduced by 34.4% from the base case as shown in Fig.16. Thus, the carbon emission reduction of 20% set in section 3 is achieved.

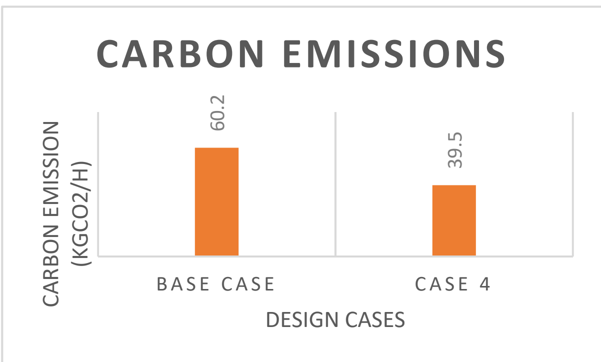

Figure 16 Carbon Emission comparison between base case and case 04

6.2.5 Case 5

Thus, in case 4 the design targets have been achieved but in order to reduce the primary energy demand of the building and to achieve a near net zero energy the onsite energy generation is needed (Khan, Asif and Mohammed, 2017). Thus, the Photovoltaic panels are used to generate electricity from the solar energy. The in plane solar irradiation for 35º angle and 0º South is shown in Fig.17. (*Photovoltaic Geographical Information System*, 2017).

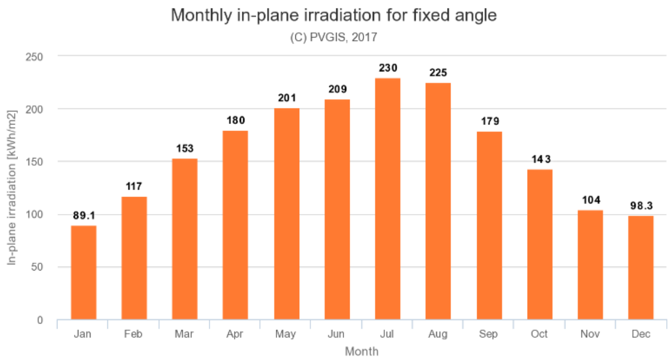

Figure 17 Monthly in plane solar irradiation

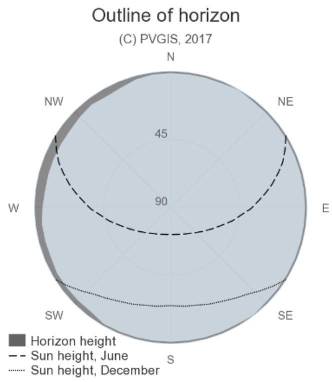

Figure 18 Solar Horizon

Therefore, the photovoltaic calculation is carried out (*Photovoltaic Geographical Information System*, 2017) and the inputs values and the simulation outputs are shown in Fig.20

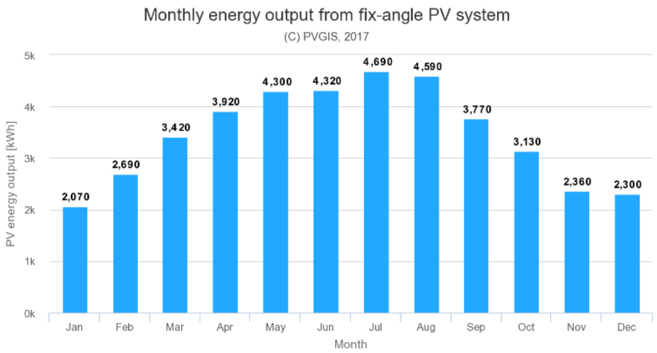

Figure 19 Monthly Energy output from PV system

Provided inputs:	
Location [Lat/Lon]:	41.878, 12.469
Horizon:	Calculated
Database used:	PVGIS-CMSAF
PV technology:	Crystalline silicon
PV installed [kWp]:	28.8
System loss [%]:	14
Simulation outputs:	
Slope angle [°]:	35
Azimuth angle [°]:	0
Yearly PV energy production [kWh]:	41600
Yearly in-plane irradiation [kWh/m²]:	1930
Year to year variability [kWh]:	1550.00
Changes in output due to:	
Angle of incidence [%]:	-2.7
Spectral effects [%]:	0.9
Temperature and low irradiance [%]:	-11.3
Total loss [%]:	-25.1

Figure 20 PV Simulation inputs and outputs

The total output for 192 m² of PV panel is 41600 kWh/yr. The remaining area is used for maintenance purpose. Therefore, this value is converted in terms of the total building floor area to meet the energy demand. Thus, the PV produces 65 kWh/m²/yr of energy. This is just electricity produced by the PV. But since an onsite energy is generated, this can be reduced from the total energy demand of the building. Thus, the energy demand of the building is reduced to 8.5 kWh/m²/yr. Finally, the energy is reduced by 93% from the base case with the use of PV panels. Thus, it equals a near net zero energy building.

07.Final Discussion

Low Energy building concepts incorporates need for minimizing heating and cooling loads, using better building envelope and the onsite generation of energy through renewable resources. The final comparison between the energy demand between the base case and all the design cases is shown in Fig.21.

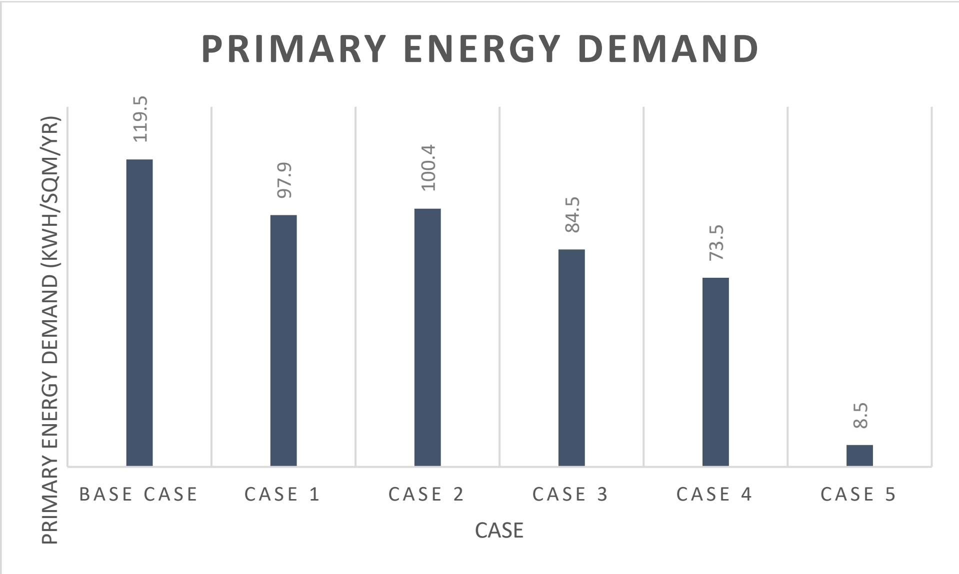

Figure 21 Energy demand for all design cases

The building envelope change was applied in case 01 as shown in Appendix A Table.10 which significantly reduced the energy demand for the building. Optimal insulation thickness is the best solution in terms of energy and cost savings (Khan, Asif and Mohammed, 2017). A study conducted by Pikas involved various insulation thickness in a concrete sandwich wall and six types of glazing systems were also analyzed but there was no change involved in the HVAC system and the PV system was an active technique used in it Results showed that triple glazing with argon filling and 200 mm insulation thickness in the walls were cost optimal solution (Pikas, Thalfeldt and Kurnitski, 2014). Therefore, triple glazed windows and the insulation thickness of nearly 200mm is used in the proposed building envelope. One of most important part of building envelope is the roof as it is exposed most of the time during the day to solar radiation. In order to reduce thermal gain 150mm thick polystyrene was used as per Asif (Khan, Asif and Mohammed, 2017). According to a study conducted in Italy polystyrene is chosen because it is widely available (Zehnder, 2014). The orientation of the building was set to SW and NE since the solar gain was more in the South West direction as shown in Fig.9 so the glazing facing the area was reduced and the window to wall ratio was increased in order gain more daylight but due to no shading the cooling loads were increased in case 2. As per Artmann, whenever the outdoor air temperature is low enough during the night time, natural ventilation can be used to cool the building thermal mass so that it provides a heat sink during the next day (Artmann, 2009). Therefore, night ventilation strategy was applied in case 3 to reduce the cooling loads in the daytime. Overhangs were provided in order to give solar shading. As per ASHRAE standard the comfortable temperature band is 18^{o}C and 26^{o}C. Therefore using the comfort tool developed by Hoyt (Tyler *et al.*, 2013) the PMV and PPD was carried out and the optimum temperature was selected as 25^{o}C in case 4 for summer which reduced the cooling load significantly. Onsite energy generation is an important approach in low energy building; thus, the PV panels were used in the case 5.

The Final design proposal referencing back to the result and analysis is shown in Table 6.

Table 6 Final Design Proposal

Design Proposal	Reference
Building Formation	Case 3 – Figure 12
Building Envelope	Case 1 – Table 8
Building Orientation	Case 2 – Figure 9 & 10
Window to wall ratio	Case 2 – Table 9
Night ventilation	Case 3 – Table 10
Thermal comfort set point	Case 4
PV technology	Case 5 – Figure 19 & 20

Finally, with PV application the net energy demand for building is reduced to 8.5 kWh/m^2/yr. Therefore, the low energy building can be attained using appropriate passive techniques.

08.Conclusion

In Europe the primary energy demand for non-residential building is 286 kWh/m^2/yr which is 55% more than the residential building energy demand. This project was a design challenge to design a low energy building in Rome, Italy. Rome has hot summers with moderate cold winters and a high level of precipitation. In this project we considered five different strategies to reduce the energy demand of the building. In base case the base building envelope and standard inputs were used. Then the case 1 has the building envelope change according to the climatic condition of the region which showed 18% reduction in energy compared to the base case energy demand. In case 2 the building orientation and the window to wall ratio was changed as per the position of the sun and the solar gain. In order to reduce the cooling loads further, the night ventilation strategy and overhangs were introduced in the case 3 and the energy demand was reduced by 38.8% compared to the base case energy demand. In case 4 in order to maintain the thermal comfort and to reduce energy the set point temperature was changed to 25^{0}C and it is noted that the energy is reduced by 61% compared to the base case energy demand. The carbon emissions are reduced by 34.4% compared to the base case. Thus, all the energy targets and the carbon emission targets were met as set in section 3 in creating a low energy office building design.

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Appendix A

Table 7 Indoor Environmental Criteria (ASHRAE, 2013)(*CIBSE Guide A*, 2016)

Description	CIBSE	ASHRAE
Summer Air Temperature	23	23
Winter Air Temperature	21	20
Relative Humidity	50%	50%
Air change rate	10 L/s/per person	8.5 L/s/per person
Air speed	0.15 m/s	0.15 m/s

Table 8 Internal heat gain

Description	Sensible heat gain (W/m^2)	Latent heat gain (W/m^2)
People	6.7	5
Lighting	12	-
Equipment	15	-

Table 9 Building Envelope for Base case

Component	Construction	U-Value (W/m^2K)
External wall	Block wall (inner leaf) + insulated cavity (30mm)+ brick (outer leaf)	0.56
Roof	Cast concrete ceiling	0.51
Floor	Cast concrete + insulation (50mm) + screed + vinyl floor covering	0.3
Internal wall	Lightweight plaster + Insulation +lightweight plaster	1.11
Windows	Double glazed window with aluminum frame	2.86
Doors	Wooden doors (44 mm)	3

Table 10 Proposed Building Envelope

Component	Construction	Thickness (mm)	Conductivity (W/mK)	Total Thickness (mm)	U-value (W/m^2K)
Flooring	Chipboard Flooring	50	0.13	497	0.151
	Dense EPS Insulation	25	0.025		
	Glass Fibre slab	172	0.035		
	Reinforced concrete	250	2.3		
Roof	Ceiling tiles	50	0.056	462.5	0.13
	Gravel	50	0.36		

	Cement bonded particle board	100	0.23		
	Polyurethane board	150	0.025		
	Reinforced concrete	100	2.3		
	Plasterboard	12.5	0.21		
External Wall	Weatherboard	25	0.14	234.5	0.15
	Wood Blocks	50	0.14		
	Polyurethane board	147	0.025		
	Plasterboard	12.5	0.21		
Window	Outer pane	6	1.06		0.96
	Cavity (Argon gas)	25			
	Inner Pane	6	1.06		
	Cavity (Argon gas)	25			
	Outer pane	6	1.03		
Door	Hardwood (Medium)	80	0.08	80	0.85

Table 11 Window to Wall ratio

Direction	Window to Wall ratio (Base)	Window to Wall ratio (Case 2)
SW	10%	10%
NW	12.5%	25%
NE	10%	25%
SE	12.5%	12.5%