Student Modeling Competition
Design and Simulation of a Near-zero Energy Building
Building Simulation 2013

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Executive Summary

Introduction
The purpose of this report is to document an interative process of energy simulation for optimizing energy usage in a house by the use of integrated passive technologies and to present and analyze the results. As a part of a competition, a site (with weather data), a building and occupancy, light and appliance schedules were provided and the goal was to come up with a design solution with lowest energy demand.

Strategies
The process was started by analyzing the base model in its climatic context and understanding the opportunities for improvement. Since heat loss through windows in the model was huge, it was necessary to improve the glazing to begin with. Next, the study of climatic data suggested that using natural ventilation along with thermal mass would prove beneficial for cooling the house during the summer and shoulder months. This helped us reduce the cooling load and thus the electricity usage in the house. The heating requirement during the winter was significantly reduced when the balcony on the south side of the house was converted into a trombe wall, capturing the solar radiation and emitting heat inside. At this point, there was only a small amount of heating demand remaining. This was still reduced by introducing earth berming around the building to minimize the heat loss to the atmosphere.

The small amount of energy requirement remaining for the house was fulfilled by on-site generation of electricity and heat using PV panels and solar thermal collectors.

Results
The results show that the final model has an annual energy demand of 3006.04 KWh (2868 KWh of electricity and 138.04 KWh of Gas). On the other hand, more than 6.06 MWh of energy is being generated annually on site using solar panels. Thus the production is 202% of the energy demand and thus the house is an energy positive building.
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Nomenclature
A Trombe wall is a sun-facing wall separated from the outdoors by glass and an air space, which absorbs solar energy and releases it selectively towards the interior at night.

DesignBuilder: is a software tool for checking building energy, carbon, lighting and comfort performance. DesignBuilder uses the latest EnergyPlus simulation engine to calculate the energy performance of the building.

DIVA-for-Rhino: is a highly optimized daylighting and energy modeling plug-in for the Rhinoceros - NURBS modeler.

Introduction
The aim of this project is to design an energy-plus house through the “integrated design of whole building concepts”. The house is located at Chambery, France and the needed site’s weather data was provided. Also, the design, occupancy schedule and energy usage of the residence were given. The competition requires a restricted thermal comfort for the occupants. We needed to demonstrate that the operative temperature is not exceeding 27°C for not “more than 50 hours of the year and 3 consecutive hours”. Also, the operative temperature should not exceed 30°C at all times. During the colder months the operative temperature cannot be lower than 19°C while the occupants are present however the operative temperature can be reduced to 16°C when the building is not occupied.

Softwares
For our project we have used several softwares such as DesignBuilder, Diva and Therm 6.3. It is important to note that the selection of each software was a mediate process. We selected each software according to their efficiency and accuracy. Each software has been selected very carefully to simulate the specific needed information or verification of the simulated results. Within our process we were are continuously questioning the simulations’ results and the relevance of the softwares within our design process. Below is a brief description of each used software:

Weather Analysis
Chambery, France is the project’s site. The weather data was provided through a text file. The WeatherConverter program in EnergyPlus was used to convert the text file to EPW file. Since we were not provided with *.def file a customized file was used. Please see Appendix for details on *.def file. Echotect weather tool was used to create below monthly diurnal average weather chart of Chambery. Below are bullet points of our observation:

- Average temperature shows that Chambery has mild winters and summers with maximum temperature of 35°C in the month of June and minimum temperature of -10 °C in the month of December.
- The diurnal shift in sholder months and summer months make Chambery a perfect climate for use of thermal mass
- Average temperature of the summer months are mostly not exceeding the comfort range which makes use of natural ventialtion a possebility for coolling strategy.
• Also, the chart shows that Chambery receives above 0.2 KW/m² direct solar gains throughout all the months except the month of December

Base Model

Setting up the base model in Design Builder

Geometry

The base model for the Design Builder has been built according to the floor plans and the section drawings that were provided. The dimensions match the drawings as close as possible. The wall construction is an insulated concrete wall, i.e. two concrete layers with XPS insulation sandwiched in between, as suggested in the drawings. The partitions are gypsum plaster boards. The ground floor and the roofs are made of concrete with insulation whereas the internal floor does not have any insulation. (Refer to the appendix 01:A for details of materials and their dimensions).

The balcony and the extended roof for shading on the south façade have been modeled as component blocks. The void created by the staircase on the floor has been modeled as an internal hole on the first floor.
Schedule

The heat gains for occupancy and the schedules are based on the data provided, but have been modified to be fed into Design Builder. It has been assumed that a person is equivalent to 80 Watts of heat gain, and the resulting number of people has been divided by the area of the respective spaces to obtain the number of people per unit area, and this value has been used in the model.

The heat gains provided for lighting and appliances were lumped into a single number. In order to be able to account for lighting and appliances separately, a number was assumed for lighting depending on the type of space, and the rest was assigned to appliances. Then the numbers were converted per unit area to be used in the model. The schedules used are based on the data provided (Refer to appendix 01: B,C,D for details of how all the heat gains were calculated).

Results

The normalized annual fuel totals for the base model were as follows:

- Electricity: 49.45 KWh/m²
- Gas: 110.28 KWh/m²

Looking at the monthly fuel breakdown (included in the following section), it shows that most of the energy for the house is used for heating during winters. There is a relatively small amount of energy used for cooling during the summers. The energy for lighting and equipment stays relatively constant all year long.
Conclusions

Analyzing the numbers alongside the monthly weather data helped us understand the opportunities available on the site and develop a strategy involving integrated design solutions to reduce the energy consumption.

Since the average monthly temperatures during the summer do not exceed the comfort range, natural ventilation can be used to cool the house during this period. To minimize the heat loss from the window surfaces, better glazing can be used. Solar radiation can be used in the form of a Trombe wall during the colder months to provide heating for the house. Since the month of December has very less solar radiation available, the concept of earth berming can be applied to conserve heat during this period. These strategies have been summarized in the figure that follows. Comprehensive explanations are included in their respective sections later.
Overall Design Strategies

**Floor Slab Designed for Thermal Mass**
There is a potential of using external air for natural ventilation during these months. Moreover, the diurnal shift in temperatures (the difference in daytime and nighttime temperature) and availability of solar radiation during winters means that interior thermal mass will be helpful to maintain internal temperatures within a comfortable range when the external air exceeds or drops below the desirable range.

**Glazing Configuration**
The type of external windows used in the building was changed from single glazing, clear to triple glazing, clear, low-e, argon filled type. Also, the internal windows were changed from single, clear to double glazing windows (Refer to appendix 02 for details on the window types).

**Trombe Wall System**
The trombe wall was created by adding a glass façade to the edge of the balcony 0.9m apart from the south exterior wall. The south exterior wall type was change to 0.56m concrete wall.

**Photovoltaic Solar Heating Panel**
To use the solar generated energy even more efficiently and to minimize the requirement of gas for heating, we propose to split the solar usage on the roof into two parts. A larger (30m2) area will be used for the solar PV to generate electricity and a part (10m2) of the roof will be used for installing solar thermal panels that will be used for generating hot water for domestic hot water usage and also can be used in an auxiliary heater for space heating (Refer to appendix 06: C fro calculations).

**Earth Berming**
To reduce the impact of heat loss from the envelope of the building we created a 1.2m berming on the north perimeter of the building.

**Wall Configuration for Natural Ventilation**
The arrangement of partition walls were changed thus the layout of rooms on the lower floor in order to promote better air circulation inside the building and thus maximize the effect of natural ventilation. Transom windows were introduced above internal doors to promote air circulation.
Glazing Configuration

Concept

An analysis of the monthly heat balance for the base model shows that the largest heat loss in the building is through glazing, which accounts for 43% of the total heat loss. This suggests that a better glazing system with more insulative properties will clearly benefit in reduction of energy consumption for the house.

Design and Method

The type of external windows used in the building was changed from single glazing, clear to triple glazing, clear, low-e, argon filled type. Also, the internal windows were changed from single, clear to double glazing windows (Refer to appendix 02 for details on the window types).

Result

The normalized annual fuel totals after reconfiguring the windows were as follows:

- Electricity: 47.74 KWh/m²
- Gas: 66.65 KWh/m²

Compared to the previous results, the heating energy has reduced by 60%.
Natural Ventilation + Thermal Mass

Concept
The monthly diurnal average data for Chambery suggests that the external temperatures during the summer months are mostly within the comfort range. This means that there is a potential of using external air for natural ventilation during these months. Moreover, the diurnal shift in temperatures (the difference in daytime and nighttime temperature) and availability of solar radiation during winters means that interior thermal mass will be helpful to maintain internal temperatures within a comfortable range when the external air exceeds or drops below the desirable range.
Design
The major change introduced was in the arrangement of partition walls and thus the layout of rooms on the lower floor in order to promote better air circulation inside the building and thus maximize the effect of natural ventilation. Transom windows were introduced above internal doors to promote air circulation. The drawings below show the changes that were made in the wall layout. Also, the internal floor was changed to 150mm thick concrete slab and was exposed by removing the finishing layers so that it would become a thermal mass (Refer to appendix 03:C for floor details). Furthermore, doors and windows were re-assessed and changes in size and type were made as required, which has been shown in the drawings below.
Method
The Natural Ventilation was turned on in the model. However, it was kept off during the winter months. The opening schedules were set to correspond to the natural ventilation schedule as well (Refer to appendix 03:A for Natural Ventilation schedule). Since the cooling was being done by natural ventilation, the mechanical cooling and the ventilation were turned off. Initial results showed that there was significant amount of gain through the openings. Thus the openings were re-assessed. With the help of a series of tests, some glass doors were changed to wooden doors, some window area were reduced and transom windows were introduced above internal doors.

Result
The normalized annual fuel totals after introducing natural ventilation were as follows:

- Electricity: 40.78 KWh/m²
- Gas: 30.76 KWh/m²

Compared to the previous results, the electricity for cooling has been taken off from the fuel totals. But in order to confirm that the natural ventilation really worked, the indoor operative temperatures were checked per zone. Even without mechanical cooling, the operative temperatures were almost entirely within the comfortable range (Refer to appendix 03:D for operative temperatures per zone).

Trombe Wall

Concept
Through our analysis of the weather file it was clear that Chambéry receives a significant direct solar radiation throughout the year except the month of December. We used Diva to verify this observation.
The solar radiation during the months of Nov, Jan and Feb can be used to heat the building by converting the south façade to a trombe wall (refer to software section for definition). Adding the thermal mass of the trombe has the potential to significantly reduce the operative temperature during the summer months as well.

**Design**
The trombe wall was created by adding a glass façade to the edge of the balcony 0.9m apart from the south exterior wall. The south exterior wall type was change to 0.36m concrete wall. The south exterior windows and doors were not changed from the previous model. Since we wanted to maintain natural ventilation through the warmer months we schedules the trombe wall’s glazed façade to fully open from May to September. Customized exterior and interior window schedules were developed for the months of Mar, Apr, and Nov by testing different schedules and verifying the result through each zone’s hourly operative temperature (refer to Appendix for detailed final interior and exterior window schedules and operative zone temperature).
**Method**

We start the simulation by assigning the outer glazing façade to a single pain clear (sgl clr 6mm). The annual gas was 17.30 KW/m² which is almost half of the usage from the previous model (30.76 KW/m²). Looking into the monthly heat gains and losses shows that the building is losing heat mostly through inverse conduction from south concrete thermal mass and south glazed façade during the cold months. This problem becomes even more acute during December which is receiving very limited solar gains.

To respond to this result the trombe wall glazing was changed to Double glazing, clear, LoE, argon-filled (Dbl LoE(e2=2)Clr 6mm/13mm Arg) and the model was simulated again. Also, the interior transom windows on the south concrete façade was scheduled to close during the months of Nov, Dec and Jan. The result showed that the gas usage was significantly lowered to 2.88 KW/m².

We further tested the model with triple glazing, clear, LowE, argon-filled (trp LoE (e2=e5=1)Clr 3mm/13mm Arg) glass façade and the result showed further reduction of gas usage to 2.37 KW/m².

**Result**

Trombe wall proved to be a strong solution to the building’s heating demands. The normalized annual fuel totals after introducing the trombe wall were as follows:

- **Electricity:** 40.30 KW/m²
- **Gas:** 2.37 KW/m²

Operative temperature per zone has been studied and most of the zones are meeting the comfort requirements (refer to Appendix for detailed average operative temperature per zone). The detail adjustment and fine-tuning of each zone will be conducted in the next and final model.
Graph above shows that heating can be fully provided through trombe wall except in the month of December 2.15 KW/m² due to limited direct solar radiation. The total gas required for heating is 2.26KWh/m².

**Earth Berming**

**Concept**
Months of December, January and February are the coldest months of the year. According to weather data file dry bulb can drop down to below -10°C at times in December. In oppose to the months of January and February the building receives as little as 0.2 KWh/m² solar gains during the month of December. As the result during the month of December gas usage reaches up to 2.15 KWh/m², which is significantly higher in relation to the months of January 0.34 KWh/m² (refer to graph above).

**Design**
Limited direct solar gains render the trombe wall less effective during the month of December due to inverse conduction through glazing. To reduce the impact of heat loss from the envelope of the building we created a 1.2m berming on the north perimeter of the building. This strategy reduces the remaining heating loads of the building to1.95 KWh/m².

**Method**
An earth berming component with the height of 1.2m were modeled adjacent to the north façade and was simulated. Berming of the north façade reduced the annual gas usage to 1.95 KWh/m². The hourly operative temperature of each zone of the building was studied and customized window schedules for trombe wall faced were developed so that the excess heat built up in
trombe wall can leave the cavity without compromising the thermal comfort of the occupants (refer to Appendix to see detailed window schedule and per zone hourly operative temperature).

**Result**

By creating berming with the height of 1.2m around the north façade of the building we were able to reduce the gas usage of the building drastically. The normalized annual fuel totals after introducing berming were as follows:

- Electricity: 40.30 KW/m²
- Gas: 1.95 KW/m²

The hourly operative temperature per zone has been studied and a detailed report has been documented in Appendix. All hours within a year are meeting the required operative temperature.

The final model reduces December gas usage for heating from 2.15 KWh/m² to 0.80 KWh/m². However, since the trombe wall glass façade was scheduled to open at hours that the excess heat would accumulate in the cavity, small amount of gas usage for heating been calculated to accommodate the required thermal comfort in the months of Jan and Nov. It is apparent to us that this added gas can be reduced by occupants' behavior.
Site Renewable Energy

Concept
To achieve a net-positive energy design of the house, we realized the importance of harnessing the solar energy as much as possible. After minimizing the net energy consumption of the house, we calculated the amount of energy that can be generated from available solar irradiation to fully compensate the annual energy consumption. Owing to the location of the site in northern hemisphere, the solar energy can be best harnessed from the south façade of the building. Therefore we chose the south facing pitched roof as the primary location for any solar panels. Apart from the roof, additional solar panels such as BIPV (Building Integrated Photo-Voltaic) can be added on the south façade to add to the electricity generation.

Method
To calculate the possible energy generation, we used hand calculations in combination with simulation software such as DIVA for Rhino and PVsyst. First, a detailed radiation analysis was done on the base model using DIVA. The radiation analysis was done for 3 different angles (35, 40 and 45 degrees) and for winter (January to April and October to December) and summer season (May to September). The values of radiation we obtained were averaged for the two seasons. These average values were then used to calculate the possible electricity generation considering 15% efficient solar PV array.
Design
The results from radiation analysis tells us that the roof plane rotated at 35° is the most efficient to capture solar radiation in winters and in summers. The higher rotation angles receive more radiation in the winters but less in summers. To make the house net-positive, the radiation in summers is equally important, and therefore the lower angles is the apt. We then used the values obtained from DIVA to calculate the electricity generation potential.

The DIVA results predict an average Solar Irradiation of approx. 1447 kWh/m². To estimate the total electricity generation based on this irradiation value, we assume the efficiency of the solar panels to be 15% and covering the entire 50m² of the south facing roof surface. At 15% efficiency, the solar PV will generate 217.05 kWh/m² electricity. Therefore the total electricity generated from 50m² roof area is approx. 10852.5 kWh or 10.8 MWh (Refer to appendix 06:A for detail calculations). We validated this value using the solar simulation software PVSyst and get a similar electricity generation of 10.1MWh per year (Refer to appendix 06:B for calculations).

To use the solar generated energy even more efficiently and to minimize the requirement of gas for heating, we propose to split the solar usage on the roof into two parts. A larger (30m²) area will be used for the solar PV to generate electricity and a part (10m²) of the roof will be used for installing solar thermal panels that will be used for generating hot water for domestic hot water usage and also can be used in an auxiliary heater for space heating (Refer to appendix 06:C for calculations). The Solar thermal system will require a tank of approx. 600 liters and uses an open system to heat water. The remaining 10m² will be left for installation purposes.

Using PVSyst, the electricity generation from the 30m² of solar PV was estimated to be 6.06 MWh per year (Refer to appendix 06:D for calculations). This is in excess to the annual energy consumption of 3006 KWh by 202%, therefore making the house net positive.
Final Results and Conclusion

The table above summarizes our process of simulation and the savings that were made in each step.

We were able to predict that we can save 8759KWh of the annual required energy total, which is 74.4% less consumption compared to the base model. Through the iterative simulating process, we were able to design our final building system requiring 3006KWh, which consisted of 2868KWh electricity and only 138KWh of gas for heating and DHW. Besides reducing the energy we need, we were able to design the solar thermal panel system and PV panel system based on the careful balancing of the amount of the heating and DHW and electricity we need. Finally, we came to conclusion that we are able to generate 202% more energy we need which is far exceeding the expectation of the net-zero building standard.

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