# RETROFITTING AN OFFICE BUILDING TOWARDS A NET ZERO ENERGY BUILDING (NZEB)

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## ABSTRACT

Energy consumption in buildings for heating, cooling and lighting needs to be reduced in all European countries in order to achieve the goals set by the latest European Directives for reducing energy consumption by 20% and increase the introduction of Renewable energy sources by 20%. The present paper focuses initially on the reduction of energy consumption for a university building in Crete and then covering the minimized energy demands with renewable energy sources. The approach is simulation based. At first, current heating and cooling demands of the building are estimated. Subsequently, through the application of basic energy conservation techniques, such as applying cool materials in the façade of the building, a detailed analysis is performed for the energy requirements to cover new demands. Finally, Renewable Energy Sources are implemented in order to provide energy to the building or directly into the grid, thus having a zero energy building.

## KEYWORDS

Zero Energy Building (ZEB); Net Zero Energy Building; Office building; Simulation-based approach; Renewable Energy Sources

## 1 INTRODUCTION

One of the most controversial issues nowadays is Global Warming which concerns not only the scientific realm, but it also has obvious impacts on various sciences such as economics and sociology. Both the impact of global warming and the increase of primary energy demand and electrical energy, is forcing international communities to propose future targets in order to deal with this threat, mainly through public awareness, new standards/regulations and other measures (Silva et al. 2013).

Buildings today account for 40% of the world's primary energy use and 24% of the greenhouse gas emissions (IEA 2011). It is estimated that 26% of the total final energy consumption of Europe was consumed in residential buildings and 13% in non-residential buildings (Berggren et al. 2013). The tertiary sector (non-residential building and agriculture) is one of the fastest growing energy demand sectors and it is expected to be 26% higher in 2030 than it was in 2005, compared to only 12% higher for residential buildings (Boyano et al. 2013). This estimation makes it necessary to investigate the use of energy in the non-residential buildings sector, but the difficulty is to find the way to achieve smart consumption strategies without causing negative consequences to people's standard of living and productivity.

The ZEBs have great potential in helping to alleviate the problems related to the deterioration of the environment and the depletion of energy sources. In the building sector, net energy is considered as the balance between the energy consumption in a building and the energy produced by its renewable energy systems. To this respect, the Net ZEB refers to buildings which are connected to the energy grids and the ZEB is more general and may include autonomous buildings (Li et al. 2013). Several countries have proposed future building energy targets to establish ZEBs such as the Building Technology Program of the US Department of Energy and the EU Directive on Energy Performance of Buildings (Sartori et al. 2012). Achieving a Net ZEB includes two main strategies; firstly by minimizing the required energy through energy efficient measures and then by meeting the minimal energy needs by adopting renewable energy.

Energy-efficient measures, applied to existing buildings during minor/major retrofits, which can reduce the energy consumption in buildings, can be grouped into three categories (Li et al. 2013):

- Building envelopes - thermal insulation, thermal mass, windows/ glazing (including daylighting) and reflective/green roofs.
- Internal conditions - indoor design conditions and internal heat loads (due to electric lighting and equipment/appliances).
- Building services systems - HVAC (heating, ventilation and air conditioning), electrical services (including lighting) and vertical transportation (lifts and escalators).

Even if the most effective energy-efficient measures are applied, energy will still be required in order to power the daily running of a building. The main difference between energy efficient buildings and ZEBs is that in ZEBs the minimized energy is covered by the use of renewable energy. The most common technologies which are adopted for onsite applications are the following (Li et al. 2013):

- PV (Photovoltaic) and BIPV (building-integrated photovoltaic)
- Wind turbines
- Solar thermal (solar water heaters)
- Heat pumps

This paper will examine the potential of retrofitting an office building in order to become Net Zero Energy Building using TRNSYS and HOMER software. Thus, this paper has two objectives; applying energy efficient measures divided in the basic three categories listed above and the adoption of renewable energy technologies which includes the combination of Photovoltaic panels and Wind turbines. Especially, the methodology will be presented in chapter 2, the simulation details, in which all scenarios will be explained, are presented in chapter 3 and finally, the results and the conclusions are in chapter 4 and 5 respectively.

## 2 METHODOLOGY

Firstly, the present building was modeled on TRNSYS software and its energy behavior was examined. The second step was the minimization of energy consumption applying energy-efficient measures. Finally, the minimized energy was covered applying Renewable Energy Sources on building in order to try to achieve the conversion of the present building into Net Zero Energy Building. The steps are presented in the Figure 1.

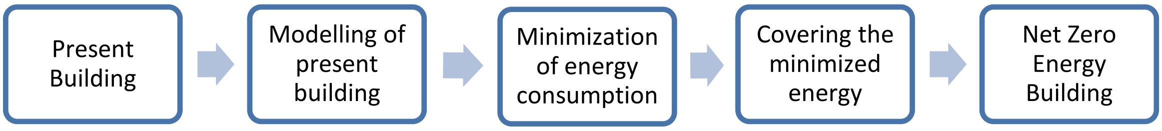



Figure 1: The steps of the project

The minimization of energy consumption requires energy-efficient measures to be applied. Energy efficient measures can be classified into three categories; Measures which could be applied in Building Envelopes, in Internal Conditions and in Building Services Systems (Li et al. 2013).

Four different scenarios were examined in order to minimize the consumption of the building and three more scenarios in order to cover this minimized energy with renewable energy sources. Thus, the following scenarios are going to be presented in Table 1.

Table 1: Description of scenarios

| Description of Scenarios | | | | | |
|---|---|---|---|---|---|
| **Initial condition** | Present condition of the building | | | | |
| **Scenario 1** | Combination of the following improvements on **building envelopes** | Insulation on walls | Replacement of windows | Cool coating on external walls | Insulation of ceiling |
| **Scenario 2** | Combination of the following improvements on **internal conditions** | Replacement of the present lights | | Reduction of consumption of computers | |
| **Scenario 3** | Combination of the following improvements on **building services systems** | Changes on heating and cooling settings | | Changes on ventilation settings | |
| **Scenario 4** | Combination of Scenarios 1,2 and 3 | | | | |
| **Scenario 5** | Installation of photovoltaic panels | | | | |
| **Scenario 6** | Installation of wind turbines | | | | |
| **Scenario 7** | Combination of Scenarios 5 and 6 | | | | |
| **Best case scenario** | Combination of scenarios 4 and 7 | | | | |

## 3 SIMULATION DETAILS

The TRNSYS software (Klein S.A. et al 2012) was used in order to simulate the building and find its yearly consumption. The central part of the simulation was the Type-56 (multi-zone building) which gives the opportunity to divide the office building into 31 thermal zones (Provata 2012). After minimizing the consuming energy, HOMER software ((Kassam & Implementation n.d.), (Giatrakos et al. 2009)) was used in order to combine two Renewable Energy Sources - PVs and Wind turbines - in the most appropriate way, aiming at covering the remaining energy.

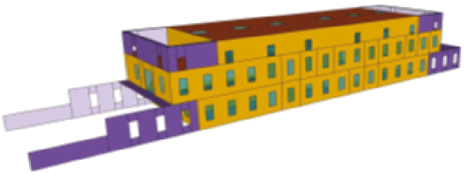
### 3.1 Initial condition of the building

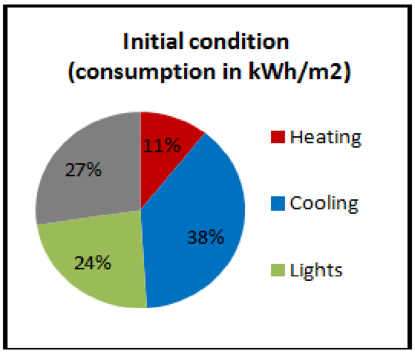
General building description

The office building of Environmental Engineers at Technical University of Crete is situated in the campus of the Technical University of Crete in the suburbs of Chania, Greece and its coordinates are 24°A (longitude) and 35°B (latitude). The building was constructed in 1997 and it is a two-storey building with a total height of 11m and total length of 48m. The ground floor (605 $m^2$) and the first floor (610 $m^2$) consist of office rooms, laboratories, stairways, elevators, toilets, hallways and PC labs and concerning the second floor (421 $m^2$), it

accommodates the mechanical equipment as no employees work there. The electricity demands of the building are covered by the grid.
It is considered that the building is occupied by 56 persons performing seated, light work such as typing. Its operating schedule is from 8:00 am until 6:00 pm every weekday.
The ventilation rate depends on the size of each zone, the number of persons and the use of each zone. The infiltration rate is considered constant value of 0.5 ach.

The characteristics of the building (Katerina Paulidou 2008) are presented in Figure 2.






| Characteristics of the building | |
|---|---|
| General information | |
| Location | Chania, Crete, Greece |
| Building type | Office building |
| Floors | 3 (The ground and the first floor are in operation and the second floor is used for the installation of HVAC systems |
| Surface area | 1296 m2 (including the surface area of ground and first floor) |
| Operation hours | 08:00 - 18:00 Monday - Friday |
| Orientation | SE |
| Building envelope | |
| Walls | Three-layer (plasterboard, polysterine, concreteboard) outer walls of total U-value = 0.915W/m2K |
| Roof | Two-layer (concrete iron, polysterene) ceiling of total U-value = 1.449W/m2K |
| Windows | Double glazing windows with U-value = 2,83 W/m2K) |
| Floor | Two-layer (polysterene and marble) with U-value = 0,945 W/m2K) |
| Building services | |
| Cooling system | VRV system (6.44 kW) with separate mechanical ventilation support |
| Heating system | Same with cooling system |

Figure 2: Initial Characteristics of the Building

The energy consumption is approximately 37600 kWh (29 kWh/m$^2$) for cooling and 10400 kWh (8 kWh/m$^2$) for heating. The electricity consumption for lighting and computers is 23300 kWh (18 kWh/m$^2$) and 26800 kWh (20.7 kWh/m$^2$) respectively.

Initial Building Envelopes

Thermal insulation of external walls (See

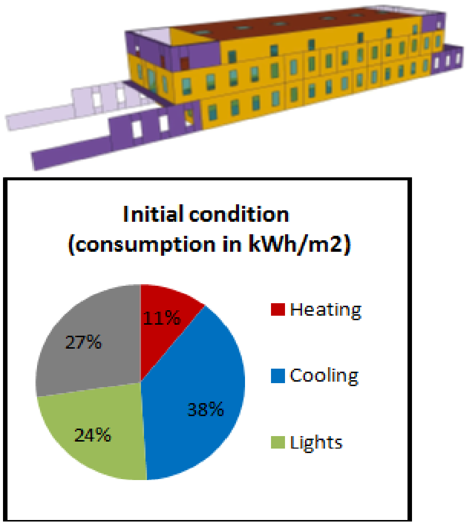



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Figure 2: Initial Characteristics of the Building

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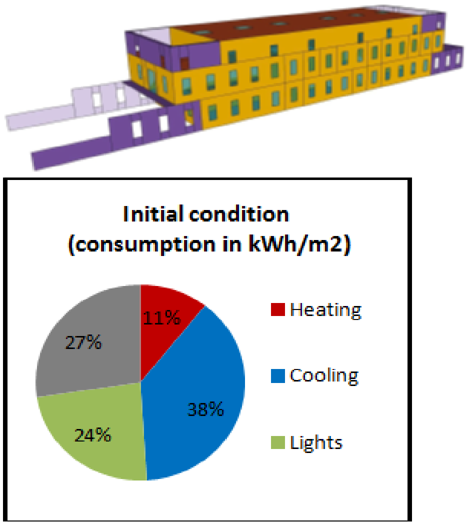
Windows (See


| Characteristics of the building | |
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| **Building services** | |
| Cooling system | VRV system (6.44 kW) with separate mechanical ventilation support |
| Heating system | Same with cooling system |

Figure 2: Initial Characteristics of the Building


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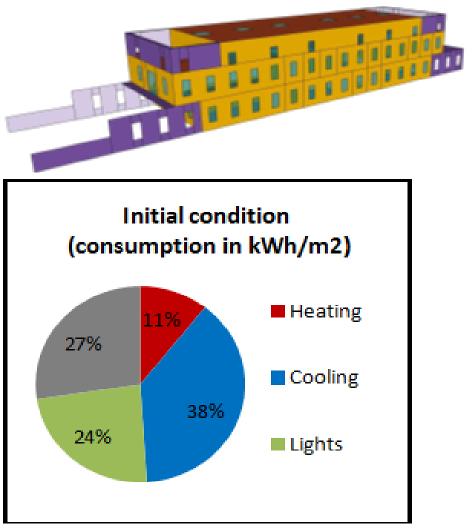
- Solar absorption of external walls; the solar absorption of the external area of the walls is equal to 90%, which means that part of the reflected radiation is only 10%.

Thermal insulation of the ceiling (See




| Characteristics of the building | |
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| Floor | Two-layer (polysterene and marble) with U-value = 0,945 W/m2K) |
| Building services | |
| Cooling system | VRV system (6.44 kW) with separate mechanical ventilation support |
| Heating system | Same with cooling system |

Figure 2: Initial Characteristics of the Building

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Initial Internal Conditions

- **Electric lighting;** It is considered that lighting is provided 8:00-10:00a.m. and 16:00-18:00a.m. every workday, while the rest of the daytime, lighting is provided mainly from the windows. The present lights consume 19 W/m$^2$.
- **Appliances;** The main appliances which are used are the computers which consume 140 W when they are in operation.

Initial Building Services Systems

- Infiltration; The infiltration of the present building is 0.5 ach
- Ventilation; According to the HVACs' characteristics, the average ventilation rate of each thermal zone of the office building is estimated at 20 L/s/person.
- Heating; Temperature set point is defined to be 20 $^o$C in winter months only when the building is operating.
- Cooling; cooling system is responsible to keep the temperature at 26 $^o$C only when the building is operating.

## 3.2 Scenarios of minimizing the consuming energy of the building

➢ **Scenario 1** - Energy-efficient measures in **Building Envelopes**

Table 2: Measures of Scenario 1 (Building Envelopes)

| | | Walls | Ceiling | Windows | | | Walls | Ceiling | Windows |
|---|---|---|---|---|---|---|---|---|---|
| **Initial condition** | Polysterene insulation (cm) | 2 | 1 | - | **Scenario 1** | Polysterene insulation (cm) | 5 | 3 | - |
| | Total U-value (W/m$^2$) | 0.915 | 1.449 | 2,83 | | Total U-value (W/m$^2$) | 0.436 | 0.671 | 1,04 |
| | g-value | - | - | 0,755 | | g-value | - | - | 0,227 |
| | Solar reflectance (%) | 10 | - | - | | Solar reflectance with **cool paint** | 89 | - | - |

(%)

In this scenario changes in the building envelope are examined. These changes include firstly the increase of wall insulation which achieves the reduction of the U-value. The next measure is to replace the present windows with windows with lower U-value and g-value. One more change in the building envelope which can be applied is to paint the external walls with cool paint in order to increase the reflective radiance from 10 % to 89 % (Kolokotsa et al. 2012). The last measure to be applied is the increase of the ceiling insulation. Those measures are presented in the Table 2.

- **Scenario 2 -** Energy-efficient measures in **Internal Conditions**

Table 3: Measures of Scenario 2 (Internal Conditions)

| | **Lights (W/m$^2$)** | **Computers (W)** |
|---|---|---|
| **Initial condition** | 19 | 140 |
| **Scenario 2** | 10 | 98 |

In this study the internal conditions include the lights and the computer (Table 3). The present lights consume 19W/m$^2$ and the total consumption of lights is 23300 kWh. In terms of the computers, taking under consideration that each computer consumes 140 W and that there are 92 computers which operate when the offices are open, the total consuming energy of computers is 26800 kWh.

The change which is examined in this scenario is to reduce the consuming energy of lights and computers. In terms of lights, the scenario studies the case of the replacement of the present lights with others which consume 10W/m$^2$ instead of 19 W/m$^2$. Regarding the computers, one possible scenario is to replace the power supply of personal computers with new ones which consume 30 % less energy.

- **Scenario 3 -** Energy-efficient measures in **Building Services System**

Table 4: Measures of Scenario 3 (Building Services System)

| | **Heating in common areas ($^O$C)** | **Cooling in common areas ($^O$C)** | **Ventilation (L/s/person)** |
|---|---|---|---|
| **Initial condition** | 20 | 26 | 20 |
| **Scenario 3** | 17 | 28 | 8.3 |

Heating, cooling and ventilation conditions in one office are very important factors in order to make people feel comfortable and productive. For this reason it was impossible to increase the temperature in winter and to reduce the temperature in summer time in offices for energy saving reasons. But, one scenario which can be examined is to apply this energy saving in common areas such as corridors, stairways and toilets. So, one part of scenario 3 is to reduce the heating set point in common areas from 20 $^O$C to 17 $^O$C and to increase the cooling set point in those areas from 26 $^O$C to 28 $^O$C. This change will prove effective because the comfort conditions of workers will not be degraded as they stay in these locations for only a limited time.

The second part of scenario 3 is to change the ventilation settings. According to the constructor, the air which is delivered for each person is approximately 20 L/s, but regarding to (Greece 2010), 8.3 L/s/person are satisfactory for offices. The changes made in Scenario 3 are shown in Table 4.

- **Scenario 4** – **Combination** of Scenarios **1,2 and 3**

In this scenario it is examined how energy consumption can be achieved applying measures on building envelopes, internal conditions and building services system. Table 5 describes the combination of measures taken in each scenario.

Table 5: Measures of Scenario 4 (Combination of scenarios 1, 2 and 3)

| | | **Walls** | **Ceiling** | **Windows** | **Lights ($W/m^2$)** | **Computers (W)** | **Heating (common areas) ($^{O}C$)** | **Cooling (common areas) ($^{O}C$)** | **Ventilation (L/s/person)** |
|---|---|---|---|---|---|---|---|---|---|
| **Initial** | insulation (cm) | 3 | 2 | - | 19 | 140 | 20 | 26 | 20 |
| | Total U-value ($W/m^2$) | 0.915 | 1.449 | 2,83 | | | | | |
| | g-value (0 - 1) | - | - | 0,755 | | | | | |
| | Solar reflectance (%) | 10 | - | - | | | | | |
| **Scenario 4** | insulation (cm) | 5 | 3 | - | 10 | 98 | 17 | 28 | 8.3 |
| | Total U-value ($W/m^2$) | 0.436 | 0.671 | 1,04 | | | | | |
| | g-value (0 - 1) | - | - | 0,227 | | | | | |
| | Solar reflectance with **cool paint** (%) | 89 | - | - | | | | | |

## 3.3 Measures for covering the minimized energy

HOMER software was used for finding the best combination of photovoltaic panels and wind turbines, aiming at producing the same quantity of energy which is consumed.

- **Scenario 5** – Installation of **photovoltaic panels** on the roof

Table 6: Characteristics of photovoltaic panels

| Electrical dara (STC) | |
|---|---|
| Rated power (W) | 265 |
| Rated voltage (V) | 31.4 |
| Rated current (A) | 8.44 |
| Open-circuit voltage (V) | 38.3 |
| Short-circuit current (A) | 8.91 |
| Efficiency (%) | 16.1 |
| Length x width x height ($mm^3$) | 1660*990*50 |
| Weight (kg) | 20 |

The case of installing 76 photovoltaic panels on the roof of the building with south direction was examined in order to produce energy and give this to the building or directive into the grid. Each photovoltaic panel has the characteristics which are presented in Table 6.

- **Scenario 6** – Installation of **wind turbines**

Four Wind Turbines Roof Mount Towers are selected to be installed in order to cover a significant part of the remaining energy. The main characteristics of these turbines are presented in the Figure 3.

and the power curve is presented in Figure 3.

| Wind Turbin characteristics | |
|---|---|
| Rated power (kW) | 3 |
| Output Voltage (V) | 120/220 |
| Rotor Blade Diameter (m) | 4.8 |
| Start-up Wind Speed (m/s) | 2.5 |
| Generator Efficiency | >0.96 |
| Turbine Weight (kg) | 138 |
| Noise (db(A)) | 40@5m/s |
| Temperature Range (Oc) | -20 to +50 |

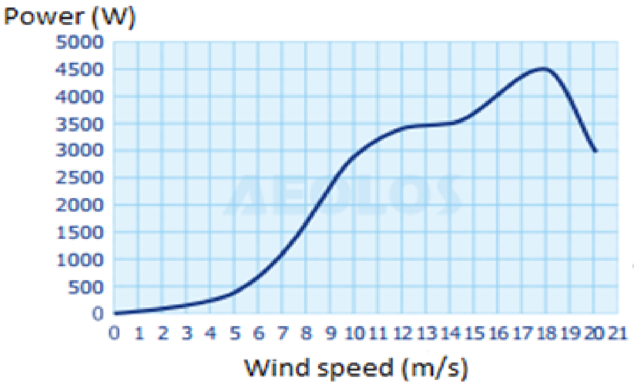


Figure 3: Characteristics of wind turbines

- **Scenario 7 – Combination** of scenarios **5 and 6**

It is obvious that in this scenario the case of having photovoltaic panels and wind turbines to function at the same time will be examined. The target of this scenario is to produce as much energy as possible.

# 4 RESULTS

- Concerning the measures for minimizing the consuming energy

In the initial condition, the higher proportion (38 %) of the energy is consumed for cooling needs and it is logical taking into consideration that the building is situated at Chania, Greece, which is categorized in A category (Greece 2010). The lower proportion (11 %) is consumed for the heating needs and approximately the same proportion of the energy used for lighting and computers (24 % and 27 % respectively).

It can be inferred from Figure 4 that the changes in the building envelope (Scenario 1) cause on important reduction on the consumption for cooling that reaches 69%. In this Scenario, the energy which is consumed is reduced from 76 kWh/m$^2$ (initial condition) to 56 kWh/m$^2$. So, by applying measures on building envelopes a 26% reduction on the total consuming energy is achieved.

Applying Scenario 2, the total energy consumed by lights will be reduced from 76 kWh/m$^2$ kWh to 66 kWh/m$^2$, achieving 13% energy saving and the total energy consumed by computers will be reduced from 76 kWh/m$^2$ kWh to 68.5 kWh/m$^2$, achieving 9 % energy saving. It can be inferred that these measures cause a slight decrease in consumed energy for cooling and a slight increase in energy for heating.

Examining the case of applying measures on Building Services System (Scenario 3), it can be inferred that both heating and cooling requirements are reduced approximately 3 kWh/m$^2$. The energy saving application of this scenario reaches the rate of 9 % having reduced the energy requirement from 76 kWh/m$^2$ to 69 kWh/m$^2$.

The combination of all previous scenarios which is presented from Scenario 4 shows that all consuming energy sources reduce their needs. The major reduction can be detected in cooling needs in which a reduction of 83 % occurs. The reduction of lighting, heating and computer needs follow with the rates of 47 %, 38 % and 30 % respectively. In general, the total consuming energy is reduced from 76 kWh/m$^2$ to 34 kWh/m$^2$ and the energy saving reaches the value of 55 %.

| | Energy consumption (kWh/m²) | | | | |
|---|---|---|---|---|---|
| | Initial | Scen. 1 | Scen. 2 | Scen. 3 | Scen. 4 |
| Heating | 8.0 | 8.0 | 9.5 | 4.0 | 5.0 |
| Cooling | 29.0 | 9.0 | 26.0 | 26.0 | 5.0 |
| Lights | 17.8 | 17.8 | 9.4 | 17.8 | 9.4 |
| Computers | 20.7 | 20.7 | 14.5 | 20.7 | 14.5 |
| Total | 75.5 | 55.5 | 59.4 | 68.5 | 33.9 |
| Energy Saving | | 26% | 21% | 9% | 55% |

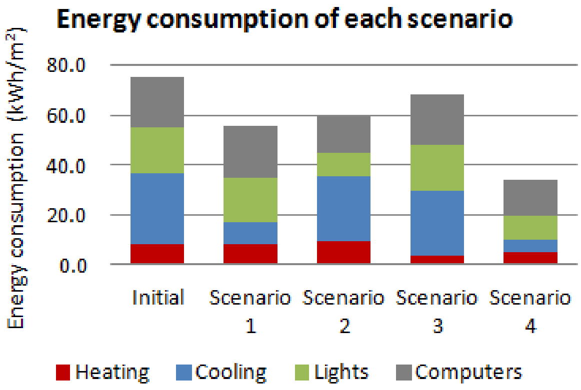


Figure 4: The reduction of energy consumption applying different scenarios

- <u>Regarding the measures for covering the minimized energy</u>

The minimized energy, which needs to be covered by renewable energy sources, is 44000 kWh/yr. The photovoltaic panels installed on the roof of the building produce approximately 24000 kWh/yr and the wind turbines Roof Mount Towers produce 20000 kWh annually. So, the renewable energy sources produce almost the same quantity of energy which is consumed. But the photovoltaic panels and wind turbines cannot function every day due to different daily weather conditions. For this reason, it is necessary to have 23000 kWh/yr grid purchases.

Figure 5 shows how much energy is covered by each source.

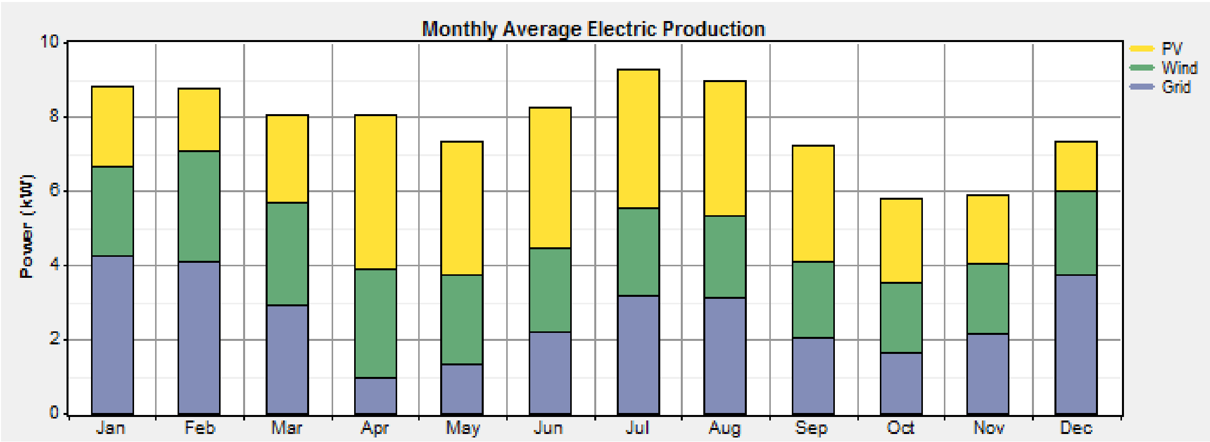


Figure 5: Monthly average electric production

## 5 CONCLUSIONS

Considering only the energy reduction by applying energy efficient measures without considering the cost required to apply the measures, it can be concluded that the most energy-efficient scenario is Scenario 4. It is expected to be the best scenario while it is the combination of three other energy-efficient scenarios each of which cause a reduction in the required energy.
Scenario 1, according to which changes on Building Envelope were applied, proved the more energy-efficient among the first three scenarios. This was caused because it managed to reduce the cooling needs, which are the main source of consuming energy in the building, by

69 %. The less effective scenario proved to be Scenario 3 while it brought about only a slight reduction in required energy.

To sum up, the energy-efficient measures with ascending order are the following;

- Increasing the insulation on the walls and ceiling, replacement of windows and applying cool paint to the external walls.
- Replacement of lights and power supply of personal computers.
- Changing the temperature setpoint in common areas and adjusting the ventilation rate in required values.

Concerning the renewable energy sources, it can be inferred that the more energy is produced by photovoltaic panels (24000 kWh/yr) in contrast to the production by the wind turbines (20000 kWh/yr). It can also be inferred from Figure 5 that the photovoltaic panels produce the most significant quantity of energy during the months of February until April while wind turbines produce an almost stable quantity of energy during all months with only a slight difference from February and April, when the quantity of energy produced is higher. In general, the building needs more energy than what is offered by renewable energy sources during the months of November until March and July and August, but the opposite is true in the other months. Thus, the energy production come from Renewable Energy Sources has the same quantity with the energy consumption of the building. Subsequently, applying the best case scenario (energy efficient measures in combination with Renewable Energy Sources) the retrofitting of the present building in order to become a Net Zero Energy building is achieved.

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