Design and Simulation of Near Zero Energy Building: A Case Study of an Existing Residential Building

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Abstract:- The building energy consumption has increased over the past decade due largely to population growth, increased average temperatures and more frequent extreme weather events as a result of the influence of human activities on climate change. There is increased pressure on maintaining a comfortable environment for building occupants while minimizing building energy use. This study attempts to quantify the building energy savings potentials using the concept of near zero energy building (NZEB) protocol by validating model of building through the collection of real data for existing buildings using DESIGNBUILDER SOFTWARE version 6.1.8.021 simulation tool to evaluate energy performance of a prototype building. The Design Builder model building performance and energy consumption were validated using real data from the case study, from the results, energy consumed by the building in the dry season is 182.98 kWh/m^2. This translates to 1.52 kWh/m^2/day for this period. Similarly, the energy consumed by the building in the rainy season is equivalent to 168.10 kWh/m^2 which also translates to 1.37 kWh/m^2 /day. The average building energy consumed per day is 4,000 kWh/day. This equates to 1.99 kWh/m^2/day. This reveals that design changes can greatly affect the performance of NZEBs, with significant savings in NZEBs and conventional buildings if appropriate building energy efficient strategies are adopted. Presently case studies of near zero energy buildings are not common, especially in the context of a Nigerian climatic space. Hence this work is a veritable source of information on the benefits of NZEBs to built environment energy profile.

Keywords:- *NZEB; HVAC; Green House Gases; Energy Efficiency; Global Warming*

I. INTRODUCTION

There has been concerns over global warming which has continued to increase into the 21st century. There is, therefore, the need to device ways to minimize energy consumption and consistently improve energy efficiency. The concept of Zero Energy Building is no longer perceived as a hypothesis of a remote future, but as a realistic solution for the mitigation of carbon dioxide emissions and/or the reduction of energy use in the building sector. The Zero Energy Building (ZEB) has been receiving international attention over the years now and has become part of the energy policy schemes in several countries of the world as a result of challenges of energy supply constraints, decreasing energy resources, increasing energy costs and rising impact of greenhouse gases on world climate [1].

Large scale development of Net Zero Energy Buildings (NZEBs) is seen as a potential solution to overcome the future energy challenges in the building sector [2]. In the recast of the EU Directive on Energy Performance of Buildings (EPBD) [3], it is specified that by the end of 2020 all the new buildings shall be “nearly zero energy buildings” (NZEB). The above target is ambitious and innovative to say the least; however, such are missing in most developing countries where this type of transition is highly needed. An instance is Nigeria, where the NZEB concept is still perceived/viewed as a complex concept.

An increase in the number of ZEBs (or NZEBs) appears to be a very interesting strategy in order to reduce energy use. This is because both in construction and operation [2], buildings are responsible for the use of about 40% of the whole energy available globally. In large scale, buildings present one of the best opportunities to economically reduce energy consumption whilst it also limits greenhouse gases (GHGs) [4]. Without the various energy efficiency policies that have been implemented since 1973, worldwide energy consumption would be 56% percent higher today than it would have otherwise been [5], [6].

The increasing number of ZEB demonstration projects [1], [7], [8] and research interest in the field [9], [10] internationally highlights the growing attention that ZEBs attract. In Nigeria, the Federal Ministry of Power, Works and Housing (FMPWH) in collaboration with the Nigerian Energy Support Programme (NESP) and relevant stakeholders in the building sub-sector have collaborated to develop building energy efficiency guideline [11]. The output of this effort produced a reference material (document) for energy measures being taken, which are relevant and appropriate for the Nigerian climatic conditions. This will further contribute to the global effort to combat climate change from the building subsector by improving energy utilization efficiency, thereby resulting in socio-economic development of the country [12].

Meeting the near zero energy (NZE) requirement of buildings is an appropriate area of research with the aim of making near zero energy consumption becoming more achievable due to ongoing development of small scale solar and wind technologies and the emerging development of off-grid energy storage [13]. Near Zero Energy Buildings need to cut 50-70% of energy consumption of an average house to become net zero with on-site energy production or with renewable power from grid [14]. It is possible to achieve zero energy building performance using well known strategies adjusted accordingly to balance climate driven-demand for space heating or cooling, lighting, ventilation and other energy uses with climate-driven supply from renewable energy resources [1]. There are many facets to energy consumption, including the characteristics of the building, status of its electrical appliances, and the behaviours of its inhabitants/occupants. With increasing average temperatures and more frequent extreme weather events because of the influence of human activities on climate change, there is increased pressure on maintaining a comfortable environment for building occupants while minimizing building energy use.

Large scale development of Near Zero Energy Building is seen as a potential solution to deal with future energy challenges in the building sector [2]. Improving energy efficiency requires a different approach to the design and operation of buildings. It starts from the design methodology and goes through to the implementation of regulatory frameworks to allow and enforce energy efficiency (EE) targets [2]. This study is an attempt to use a simple methodology drafted from a systematic re-examination of a grid-tied building project. It will discuss various possible scenarios in the design and decision making of a near zero energy building for an existing/new building.

This study is based on existing concepts and standards of building; it is limited to critical review of a case study project. The work focused only on grid-tied energy-neutral building(s) and not cover off-grid building(s) or any other type of energy conscious building programs. The overall aim of the study is to analyse the design and economic benefits of a near zero energy building; assess and quantify the energy savings potential of NZEB by validating model of building through the collection of real data for existing buildings; evaluate energy performance of a prototype building using building energy simulation tool and assess feasible performance analysis of economic and energy targets of the existing building.

II. MATERIALS AND METHODS

The methodology should not be considered as a “one size fits all” approach to achieve near-zero energy balance in every project due to inherent uncertainties in different aspects of each project.

A typical multi-storey multi-units residential building is analysed. DesignBuilder software, version 6.1.8.021 was used in implementation of the methodology. It is a Simplified Building Energy Model (SBEM) and Dynamic Simulation Model (DSM) tool that helps in the process of building simulation for the purpose of checking the energy usage, carbon, lighting, and comfort performance. It is integrated with EnergyPlus dynamic thermal simulation engine.

The site is located in a residential community of highbrow area of Lagos metropolis (6.43344° Latitude, 3.47658° Longitude). It is a building for residence having 18 units of mini-flats – three floors of six units per floor. The monthly temperatures for Lagos, which was gathered using World Weather Online, is as presented in table 1. This site was chosen because of its location and type. Lekki, Lagos residents are known to be heavy users of energy because majority of them are upper middle-class. Lekki is a mixture of commercial and residential buildings interwoven in its fabric. The nature of the building, multi-storey and multi-family residential building, implies that the building will require as much energy as most commercial buildings within the vicinity. This building also has the potential of being used as both commercial and residential or mainly for commercial activities in the future.

S/N	Month	Temperature (°C)		
		Average	Minimum	Maximum
1	January	31	21	38
2	February	31	23	36
3	March	29	24	35
4	April	29	24	34
5	May	28	23	33
6	June	26	22	31
7	July	24	22	29
8	August	24	21	28
9	September	24	22	29
10	October	26	22	32
11	November	29	22	35
12	December	29	22	37

Table 1: Annual monthly temperature distribution for Lagos, Nigeria

III. THEORY AND CALCULATIONS

A. *Benefits of NZEB*

The benefits of near-zero energy building (NZEB) can be evaluated with respects to its economic advantages and environmental benefits. The economic advantage is evaluated on the total energy consumed by the building, for cooling, lighting, and powering of the electrical equipment. In order to evaluate the environmental benefits, the carbon dioxide emission is evaluated. The total carbon dioxide generation rate (G_{CO_2}) for a space is given in equation (1).

Carbon dioxide is one of the greenhouse gases (GHGs) that its emission to the atmosphere needs to be minimized.

$$G_{CO_2} = N_p \times S_p \times A_c \times R_{CO_2} \quad (1)$$

Where N_p is the number of people, S_p is the schedule of the people, A_c is the activity of the people and R_{CO_2} is the carbon dioxide generation rate per person. The recommended value is $3.82 \times 10^{-8}\ m^3/sW$

B. *Energy Savings Potential*

To evaluate the energy savings potential, the purpose of the building must be defined as either residential, commercial, or industrial. This will help in predicting the activities of the occupants, and choice of construction materials.

a) Occupants Activities

The building has three floors with six units of flats per floor. Each floor is divided into two: front row and back row of three units each. The total floor area of the building is 2,733.2 m^2. A total of 2,008.2 m^2 is occupied while 725 m^2 is unoccupied. The unoccupied floor area are the three passages on each floor that leads to each of the flat units. The average occupancy rate is 50 m^2 per person. The Nigerian holidays are New Year's Day (one day), Good Friday (one day), Easter Monday (one day), Labour Day (one day), Eid al-Fitr (two days), Democracy Day (one day), Eid al-Adha (two days), Independence Day (one day), Prophet's Birthday (one day), Christmas Day (one day) and Boxing Day (one day). This equals a total of 13 holidays of 365 days per annum. Also, it is assumed that an average person takes a personal leave of 27 days. Therefore, a total of 40 holidays is accounted for. The percentage occupancy of the building for different hours of the day for both the weekdays (Mondays through Fridays) and weekends (Saturdays and Sundays) and Holidays are presented in table 2 and table 3, respectively.

S/N	Time Period	Percentage of Occupancy (%)
1	12 midnight – 5am	100
2	5am – 6am	80
3	6am – 8am	75
4	8am – 9am	50
5	9am – 3pm	43
6	3pm – 6pm	50
7	6pm – 9pm	75
8	9pm – 12 midnight	80

Table 2: Percentage occupancy on weekdays

S/N	Time Period	Percentage of Occupancy (%)
1	12 midnight – 7am	100
2	7am – 8am	80
3	8am – 9am	75
4	9am – 10	50
5	10am – 3pm	43
6	3pm – 6pm	50
7	6pm – 9pm	75
8	9pm – 12 midnight	80

Table 3: Percentage occupancy on weekends and holidays

It is assumed that each flat unit is occupied by a family of one adult male (the father), one adult female (the mother) and two children.

Clothing reduces the body's heat loss and are classified according to their insulation value. The insulation value for individual clothing material can be found in ISO 7730. The cooling temperature is set to 26 °C when it is occupied during the day. However, the temperature level is set to 32 °C in the night when the body metabolism is low and when the building is unoccupied.

The convected fraction (F_c) is defined as the fraction of the heat from electric equipment convected to the air and it is calculated as shown in equation (2).

$$F_c = 1 - (F_l + F_r + F_{lost}) \tag{2}$$

Where F_l is the latent fraction which characterizes the latent heat given off by an equipment; F_r is the radiant fraction which characterizes the amount of long-wave radiant heat being given off by an equipment; and F_{lost} is the fraction lost which characterizes the amount of lost heat being given off by an equipment.

b) Construction Materials

The construction materials determine the conduction of heat through walls, roofs, ground, and other opaque parts of the building. The walls and roofs are uninsulated. The walls are made of bricks with the internal partitions plastered at a thickness of 115 mm on both sides. The internal floor is made of 300 mm concrete slab. The external doors are made of metallic structure while the inner doors are made of wooden structures.

The design infiltration rate is defined as the rate of entry of unintentional air from outside through cracks, holes and through the porosity of the structures. Infiltration airflow can also occur through the cracks between windows, vents and doors and the main wall or roof surface. The design infiltration rate is assumed to be a constant value in this study, and it is measured in air changes per hour (ac/h). The air flow rate (Q_{air}) (m^3/s) at standard pressure can be calculated from equation (3).

$$Q_{air} = Q_{infiltration} \times \frac{V_{space}}{3600} \tag{3}$$

Where $Q_{infiltration}$, is the infiltration rate measured in air changes per hour (ac/h); and V_{space} is the total air volume of the space including the volume of floor and ceiling, any raised floor and suspended ceiling voids, and half of the volume of partition walls within the building in cubic metre (m^3).

C. Energy Performance of a Building

To determine the energy consumption of a building, the energy consumption of each unit of the building must be known. Also, the heat gains by various structures of the building such as the windows, roofs and walls. The building has three floors. Each floor has six units of apartments divided into three on each side and separated by breezeways as shown in Figure 1 and Figure 2.

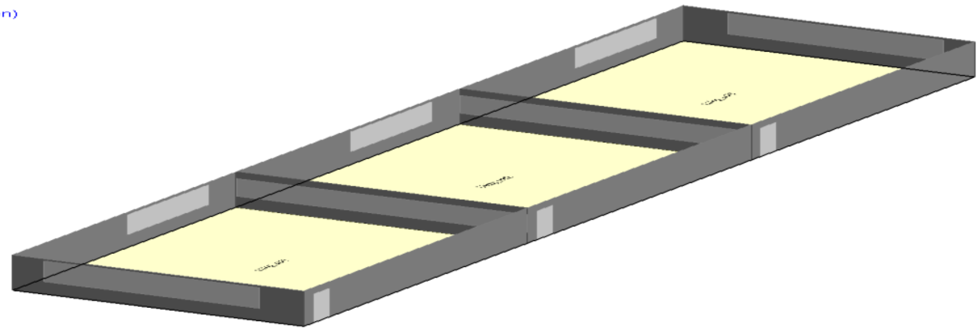

Fig. 1: Axonometric view of last floor and one row consisting of three-units of mini-flats

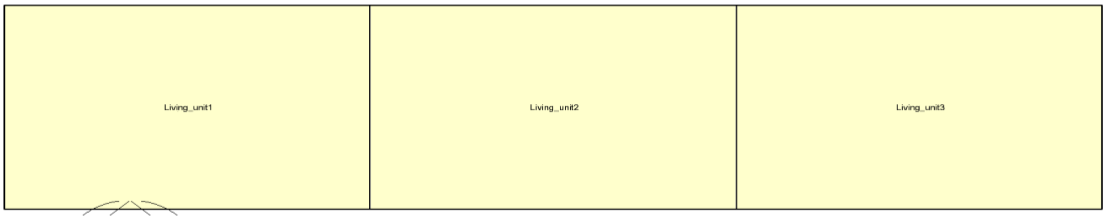

Fig. 2: Plan view of the last floor and one row consisting of three-units of mini-flats

The ground floor has an area of 111.569 m^2 (12.18 m by 9.16 m). It is made of three layers. The first layer is cast-in-place concrete of 100 mm thickness. Then floor screed of 70 mm is applied as the second layer and then finishing with 30 mm timber flooring. The transfer of heat between the ground surface and the enclosed air is calculated using Thermal Analysis Research Program (TARP) convection algorithm [15] as presented in equation (4).

$$h_{ci} = \begin{cases} \dfrac{9.482|\Delta T|^{1/3}}{7.283 - |\cos\varphi|} & \Delta T < 0.0 \\ \dfrac{1.810|\Delta T|^{1/3}}{1.382 + |\cos\varphi|} & \Delta T > 0.0 \end{cases} \qquad (4)$$

where ΔT is the temperature difference between the ground floor surface temperature and the room air temperature and φ is the ground floor surface tilt angle.

The transfer of heat between the ground floor external surface is based on Rowley's formulas which combine the convective and radiative heat transfer for smooth and rough surfaces as shown in equation (5).

$$h_{co} = \begin{cases} 8.23 + 3.83V - 0.047V^2, & \textit{for smooth surfaces} \\ 11.58 + 6.806V, & \textit{for rough surfaces} \end{cases} \qquad (5)$$

The ceiling has the same dimension as the floor. It consists of 100 mm concrete slab which is finished with 35 mm of wood. The partition between units of apartment is 23.724 m^2 area (9.16 m by 2.59 m). It has a subsurface which is 9.13 m^2 in area (9.13 m by 1.298 m). It is made of 115 mm single leaf bricks plastered on both sides using Gypsum plastering of 13 mm thickness. The subsurface is made of 100 mm concrete slab and 35 mm of wood. The external walls are made of 100 mm brickwork either side of 50 mm air gap. They are then plastered with Gypsum plastering of 13 mm thickness on the inside. The external door is 1.938 m^2 in area (0.91 m by 2.13 m). It is made of 3 mm thick steel on either side of 10 mm air gap.

Like the inside and outside convection algorithms used for the ground floor surface, TARP and Rowley's formulas are also used for the vertical walls. However, the TARP algorithm equation changes for the vertical walls as shown in equation (6).

$$h_{ci} = 1.31|\Delta T|^{1/3} \qquad (6)$$

The windows use double glazing of 6 mm on each side of 13 mm air gap. The frame is made of 20 mm painted wood.

On each row, the middle apartment unit has two partitions and two external walls, one 6.84 m^2 window and one 1.938 m^2 door while the other two units on either side of the middle unit has three external walls and one partition, a 6.84 m^2 and a 10.26 m^2 windows, and a 1.938 m^2 door as shown in Fig..

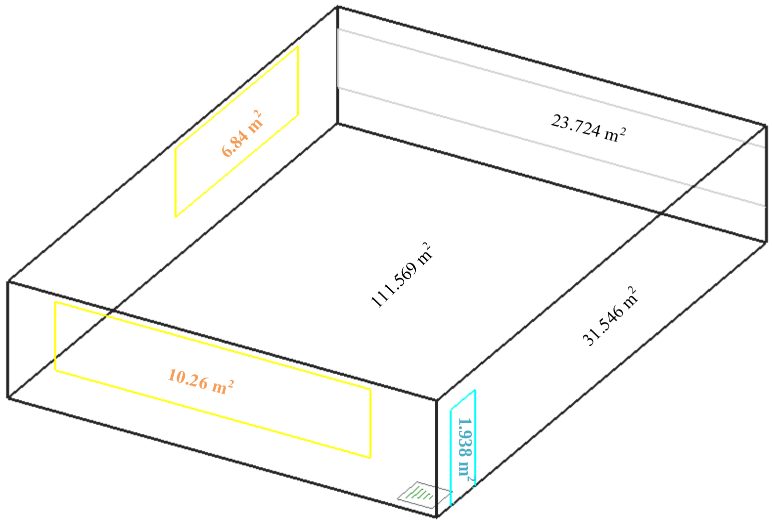

Fig. 3: Axonometric view of a single unit in the building

The roof has internal glazing, block walls and roofing sections. The internal glazing is single, clear with 3 mm thickness. The roofs are pitched at an angle of 23°. The roofing material is a three-layered one with the outermost made of 25 mm clay tile and the innermost made of roofing felt with 20 mm air gap sandwiched between the outermost and the innermost materials. The internal and external heat exchange methods used are based on TARP algorithm and Rowley's formulas, respectively. The external walls of the roof are made of the same construction materials as the vertical external walls.

IV. RESULTS AND DISCUSSION OF RESULTS

The results of applying the proposed methodology as a means of achieving energy efficient building on the 18 units of apartments is here presented.

The condition of Lekki, Lagos on January 15th is presented in figure 4. It can be seen that the dry-bulb temperature is much higher than the dew-point temperature between 8 am and 9 pm. This indicates low relative humidity. Also, the sun rises at 7am and rises to its maximum irradiance at 11 am. It maintains this maximum value till 3 pm and starts decreasing until it gets to 0% at 7 pm.

A. *Essence of NZEB*

In figure 5, the relative humidity is less than 50% from 8 am. It goes beyond 50% from 3:15 pm to 4 pm before decreasing to below 50% for the rest of the day. The internal air temperature is higher than the outside dry-bulb temperature between midnight and 5:30 am. Hence, there will be a need for cooling. However, the internal air temperature decreases below the external air temperature between 5:30 am and 10:30 am. The internal air temperature is now higher than the outside dry-bulb temperature between 10:30 am and 3:30 am. The major influence on the temperature difference can be traced to the infiltration rate which varies linearly with the difference in temperature between internal and outside air temperatures.

B. *Energy Savings Potentials of the NZEB*

In Fig.6, cooling started from 5 am to 10:30 am. The cooling can be divided into two; namely sensible cooling which maintains the set temperature for the internal air at 26 °C and the latent cooling which maintains the relative humidity below 60%. The infiltration rate which maintains the internal air temperature at 22 °C was sufficient between 10:30 am and 3 pm, and hence, less cooling is needed to maintain the set relative humidity. More cooling energy will be consumed beyond 3 pm to maintain the set temperature.

C. *Performance of the NZEB*

Fig.7 shows the heat balance – heat gained and lost – between the structures and the infiltration (air change per hour). It can be seen that the glazing gain varies directly with the irradiance of the sun. Also, some heat was emitted through the glazing in the night between midnight and 7 am.

These results are summarized as comfortability data in Table 4 and heat gains in Table 5.

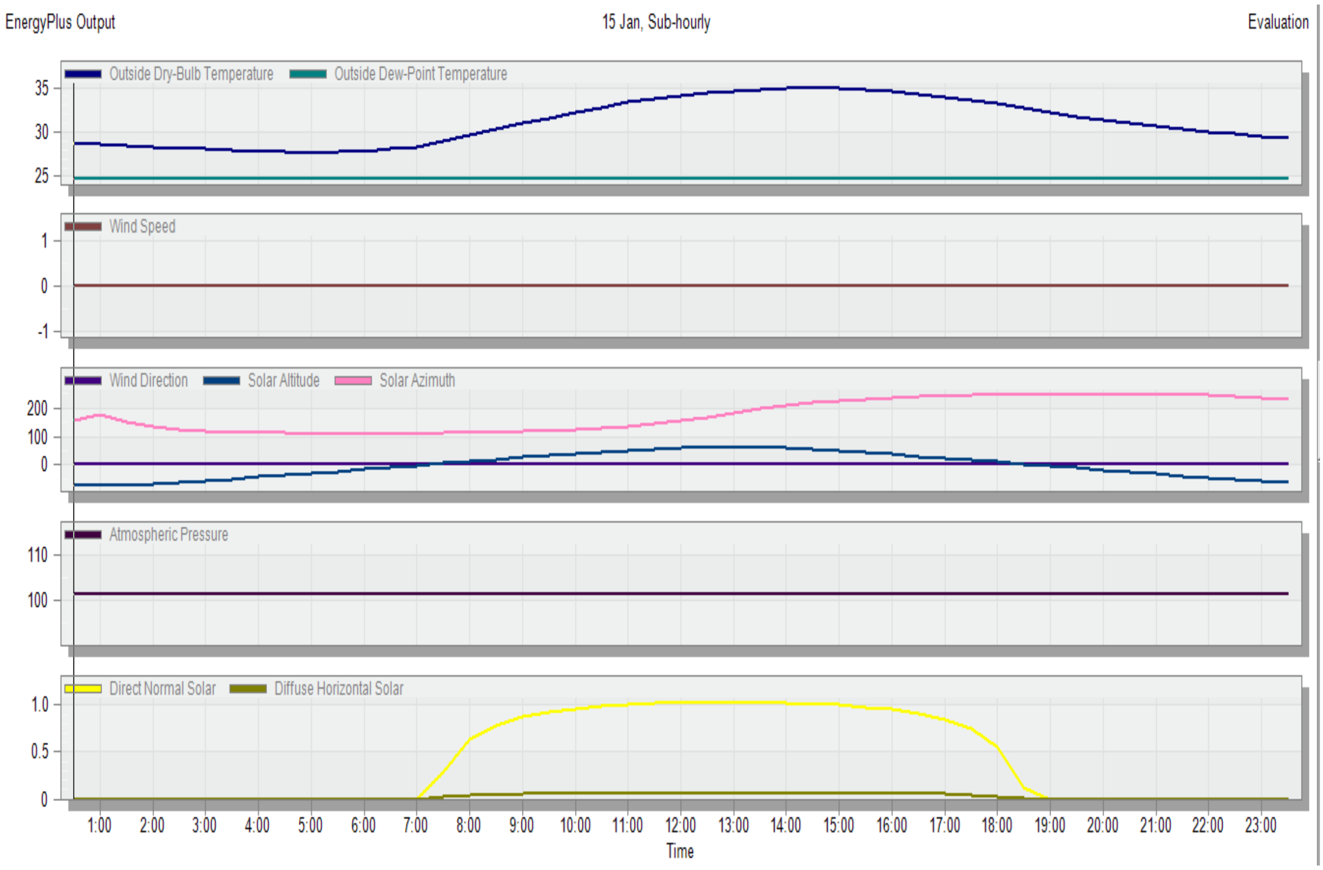

Fig. 4: Lekki-Lagos site data where the 18 units of apartments is located

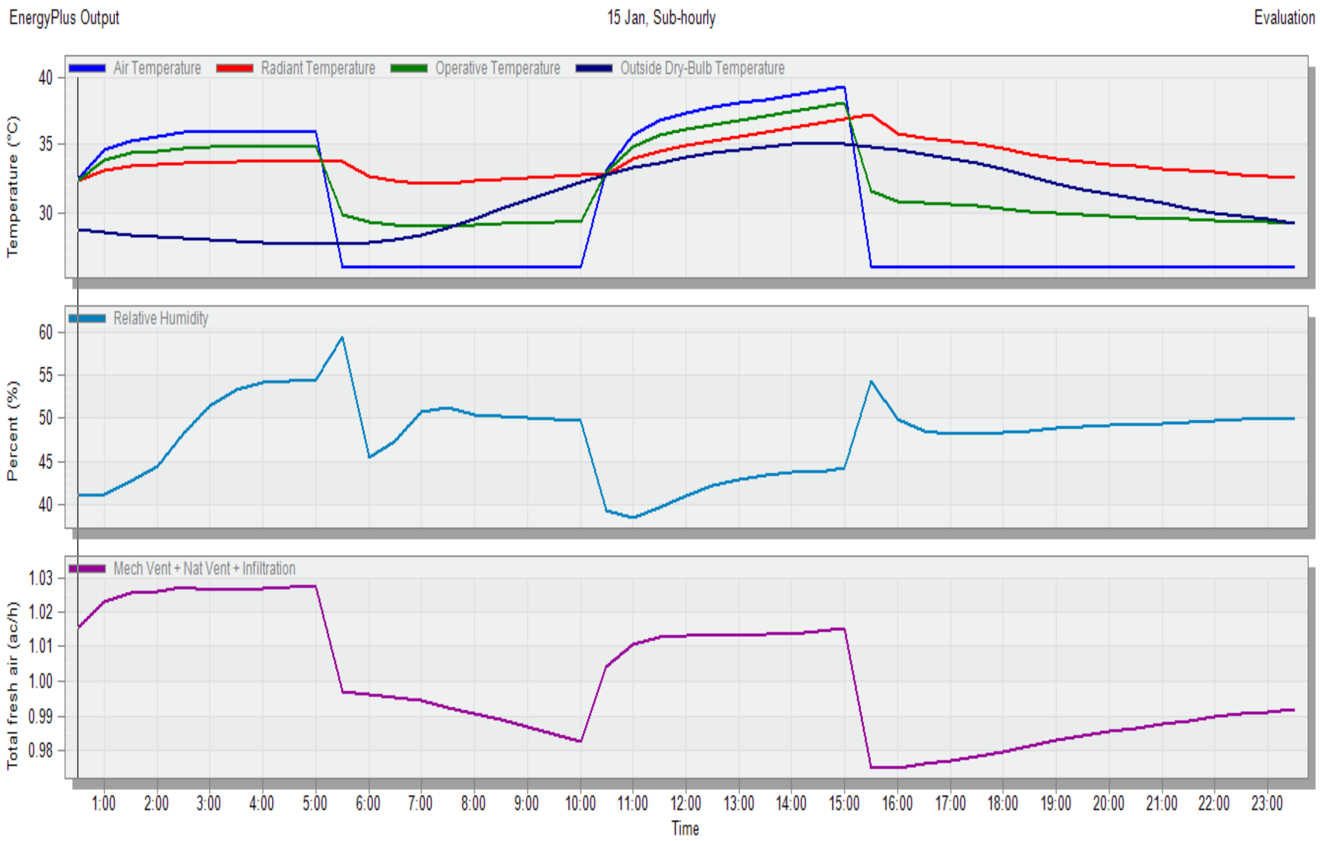

Fig. 5: Measure of comfortability for occupants of the building

Fig. 6: Energy usage by the electrical loads

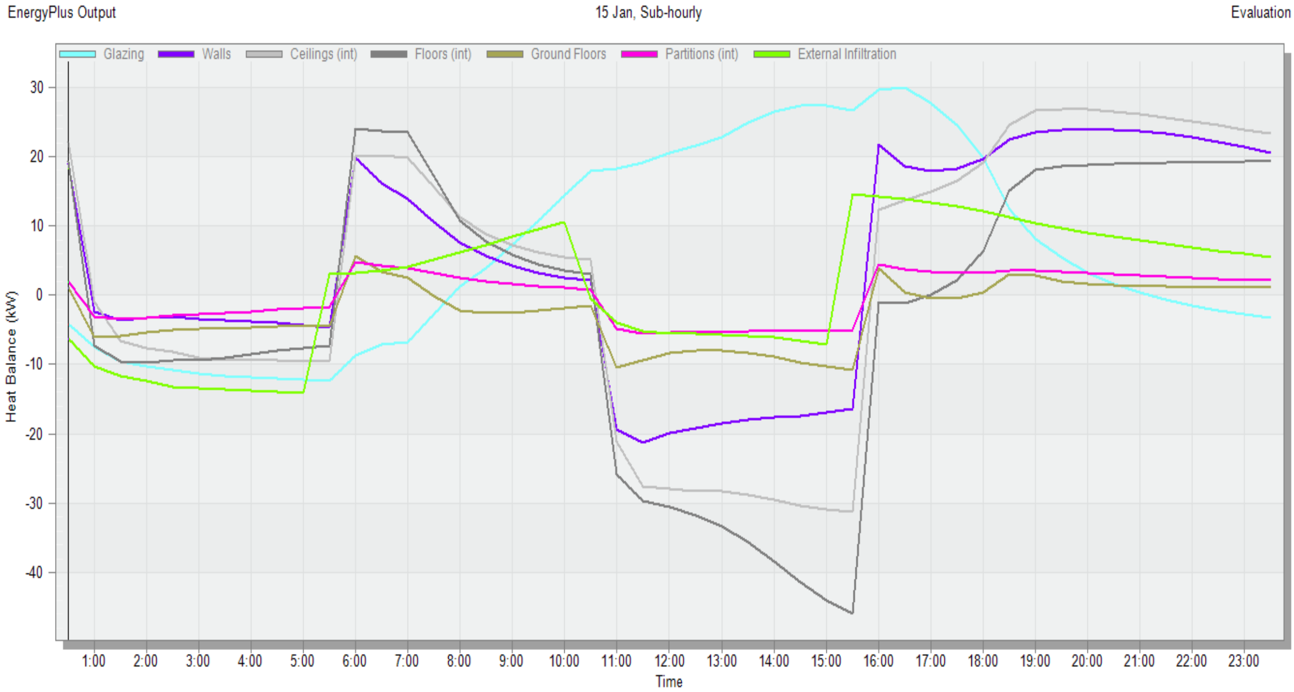

Fig. 7: Heat balance from structures and infiltration

Space	Design Capacity (kW)	Design Flowrate (m^3/s)	Total Cooling Load (kW)	Sensible (kW)	Latent (kW)	Air Temp (°C)	Max Op Temp in Day (°C)	Time of Max Cooling
Front Row, Bottom Floor 1	24.92	0.904	21.67	13.43	8.24	26.11	38.67	Jan 15:30
Front Row, Bottom Floor 2	22.98	0.811	19.98	12.01	7.97	26.08	37.25	Jan 15:30
Front Row, Bottom Floor 3	24.19	0.869	21.04	12.9	8.14	26.1	38.39	Jan 15:30
Back Row, Bottom Floor 1	22.64	0.795	19.69	11.78	7.91	26.07	36.58	Jan 15:30
Back Row, Bottom Floor 2	20.26	0.685	17.62	10.11	7.51	26.03	35.03	Jan 15:30
Back Row, Bottom Floor 3	21.74	0.753	18.91	11.14	7.76	26.06	36.32	Jan 15:30
Front Row, Middle Floor 1	24.6	0.889	21.39	13.2	8.19	26.1	38.12	Jan 15:30
Front Row, Middle Floor 2	22.77	0.801	19.8	11.87	7.93	26.08	36.97	Jan 15:30
Front Row, Middle Floor 3	23.99	0.859	20.86	12.75	8.11	26.1	38.1	Jan 15:30
Back Row, Middle Floor 1	22.38	0.783	19.46	11.6	7.86	26.07	36.27	Jan 15:30
Back Row, Middle Floor 2	20.26	0.685	17.62	10.11	7.5	26.03	34.98	Jan 15:30
Back Row, Middle Floor 3	21.73	0.752	18.9	11.14	7.76	26.06	36.27	Jan 15:30
Front Row, Top Floor 1	26.81	0.994	23.32	14.81	8.51	26.16	41.49	Jan 15:30
Front, Row, Top Floor 2	25.28	0.918	21.99	13.66	8.32	26.14	40.56	Jan 15:30
Front Row, Top Floor 3	26.14	0.96	22.73	14.31	8.43	26.15	41.4	Jan 15:30
Back Row, Top Floor 1	25.03	0.907	21.77	13.49	8.28	26.12	39.86	Jan 15:30
Back Row, Top Floor 2	23.3	0.823	20.26	12.21	8.04	26.1	38.83	Jan 15:30
Back Row, Top Floor 3	24.33	0.873	21.15	12.97	8.19	26.12	39.8	Jan 15:30
Roof	0	0	0	0	0	-	52.32	Jan 15:00
Total	423.37	15.062	368.15	223.5	144.65	20.26	52.32	Jan 15:30

Table 4: Tabular presentation of occupancies comfortability

Space	**Glazing Gains (kW)**	**Wall Gains (kW)**	**Floor Gains (kW)**	**Roof & Ceiling Gains (kW)**	**Infiltration Gains (kW)**	**Electric Equip Gains (kW)**	**Lighting Gains (kW)**	**Solar Gains (kW)**
Front Row, Bottom Floor 1	1.09	-1.43	-3.07	-3.7	0.81	1.45	1.67	4.96
Front Row, Bottom Floor 2	0.54	-0.68	-1.61	-2.5	0.81	1.45	1.67	1.63
Front Row, Bottom Floor 3	0.36	-0.65	-1.78	-2.48	0.81	1.45	1.67	2.07
Back Row, Bottom Floor 1	0.79	-1.45	-2.39	-3.02	0.81	1.45	1.67	3.71
Back Row, Bottom Floor 2	0.21	-0.75	-0.89	-1.79	0.81	1.45	1.67	0.37
Back Row, Bottom Floor 3	0.06	-0.66	-1.1	-1.81	0.81	1.45	1.67	0.82
Front Row, Middle Floor 1	1.07	-1.11	-4.34	-2.85	0.8	1.45	1.67	4.97
Front Row, Middle Floor 2	0.51	-0.51	-2.39	-1.92	0.81	1.45	1.67	1.68
Front Row, Middle Floor 3	0.35	-0.51	-2.4	-2.01	0.8	1.45	1.67	2.09
Back Row, Middle Floor 1	0.78	-1.2	-3.49	-2.27	0.81	1.45	1.67	3.71
Back Row, Middle Floor 2	0.19	-0.64	-1.5	-1.3	0.81	1.45	1.67	0.4
Back Row, Middle Floor 3	0.05	-0.59	-1.54	-1.43	0.81	1.45	1.67	0.83
Front Row, Top Floor 1	3.57	-2.23	-6.72	-1.06	0.8	1.45	1.67	5.11
Front, Row, Top Floor 2	3.49	-1.63	-4.86	-0.69	0.8	1.45	1.67	1.82
Front Row, Top Floor 3	3.12	-1.58	-4.71	-0.74	0.8	1.45	1.67	2.23
Back Row, Top Floor 1	3.7	-2.35	-5.95	-0.8	0.8	1.45	1.67	3.85
Back Row, Top Floor 2	3.62	-1.79	-4.07	-0.41	0.8	1.45	1.67	0.55
Back Row, Top Floor 3	3.22	-1.68	-3.95	-0.48	0.8	1.45	1.67	0.97
Roof	-20.59	-4.74	-18.06	48.13	-7.76	0	0	2.08
Total	6.12	-26.17	-74.79	16.89	6.73	26.17	30.12	43.86

Table 5: Tabular presentation of heat exchange among the structures and due to infiltration

D. Dry Season (Nov 1st – Feb 28th)

Fig.8 shows that the period under consideration is in the same season as the difference between the dew-point temperature and the outside dry-bulb temperature is constant.

a) Benefits of NZEB
Fig.9 and figure 10 shows the total energy consumed from the grid for the period considered and the associated CO_2 emitted as a result of the energy consumed. It can be seen that the total CO_2 emitted varies directly with the total energy consumed. This is because 100% of the energy is assumed to come from the grid

6 shows the total energy consumed by different categories of electrical loads between November 1 and February 28. This implies that 30.07 kWh/m^2 was used for lighting, 115.4 kWh/m^2 was used for cooling for the dry season period considered.

b) Energy Savings
The infiltration rate varies from 1.02 to 1.045 air changes per hour as shown in Fig.11. This implies the infiltration rate is high during this period being considered. Fig.12 shows that the cooling energy required is greater than the energy require for lighting on all days within the period considered. Fig. 13 shows that the latent load varies between 3.6 kWh and 4.2 kWh per day between 1 November and 28 February to maintain the set relative humidity.

c) Performance Evaluation

Fig. shows that occupants will need cooling as the inside air temperature is higher than the outside dry-bulb temperature. The relative humidity is less than 60%. Fig.15 shows the total energy consumed as a result of cooling the building for the comfortability of the occupants to meet the set temperature of 26 °C and the relative humidity of less than 60%. It can be seen that some energy was consumed to maintain the set moisture level of the building.

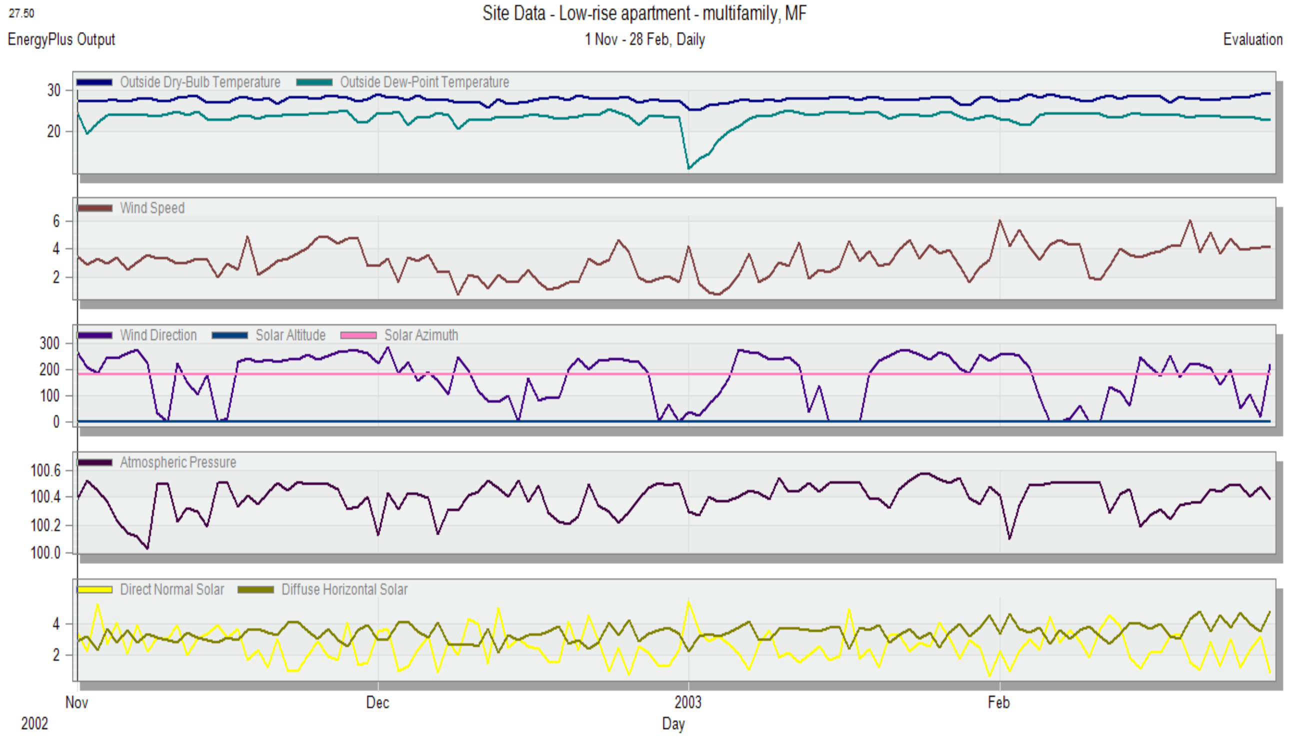

Fig. 8: Lekki-Lagos site data from 1 Nov. to 28 Feb

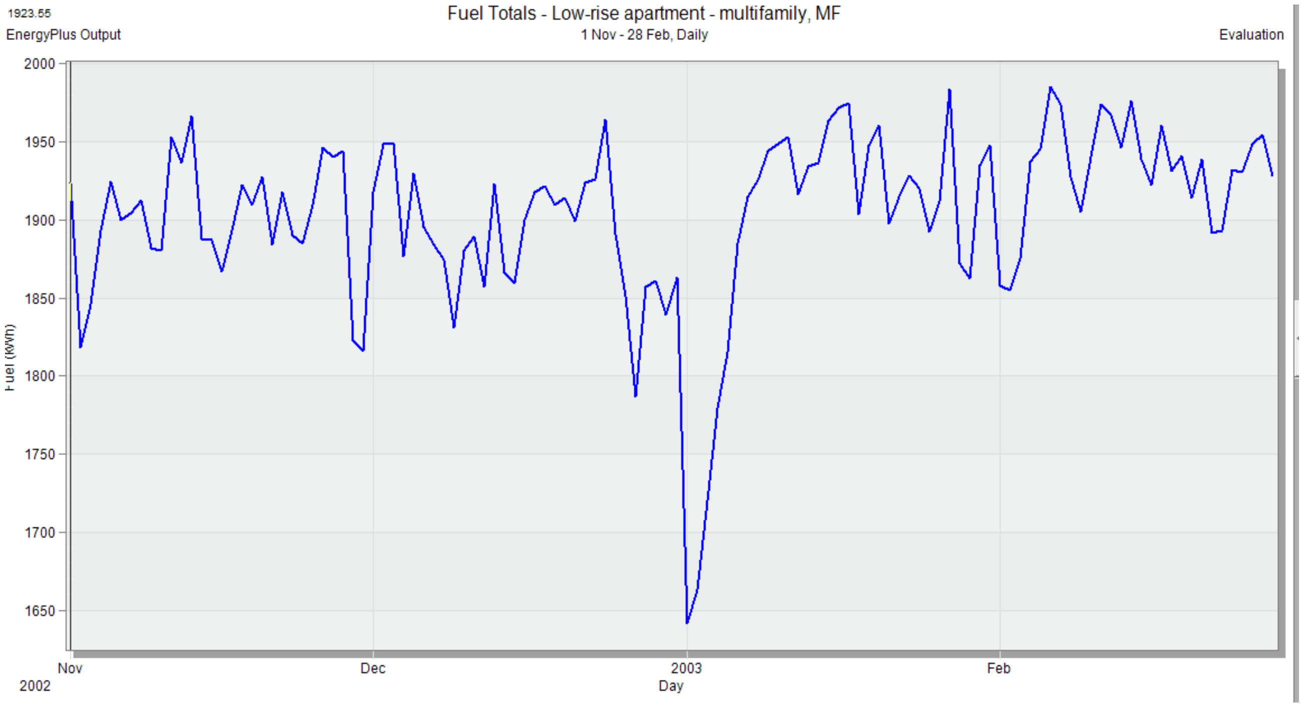

Fig. 9: Total energy used as a result of lighting, cooling and other equipment

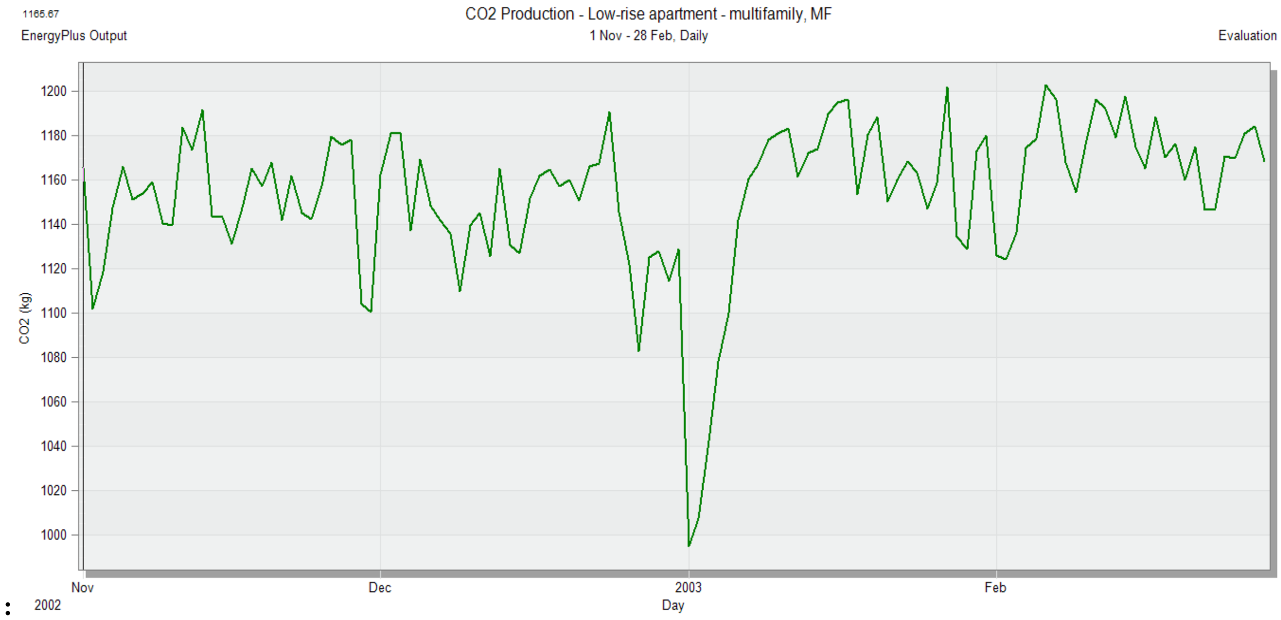

Fig. 10: Carbon dioxide emitted as a result of energy consumed from the grid

Category	Cooling	Interior Lighting	Exterior Lighting	Others	Total
Energy Used (kWh)	231,758.82	60,247.15	145.95	75,361.96	367,513.88

Table 6: Energy consumed by different categories of electrical loads

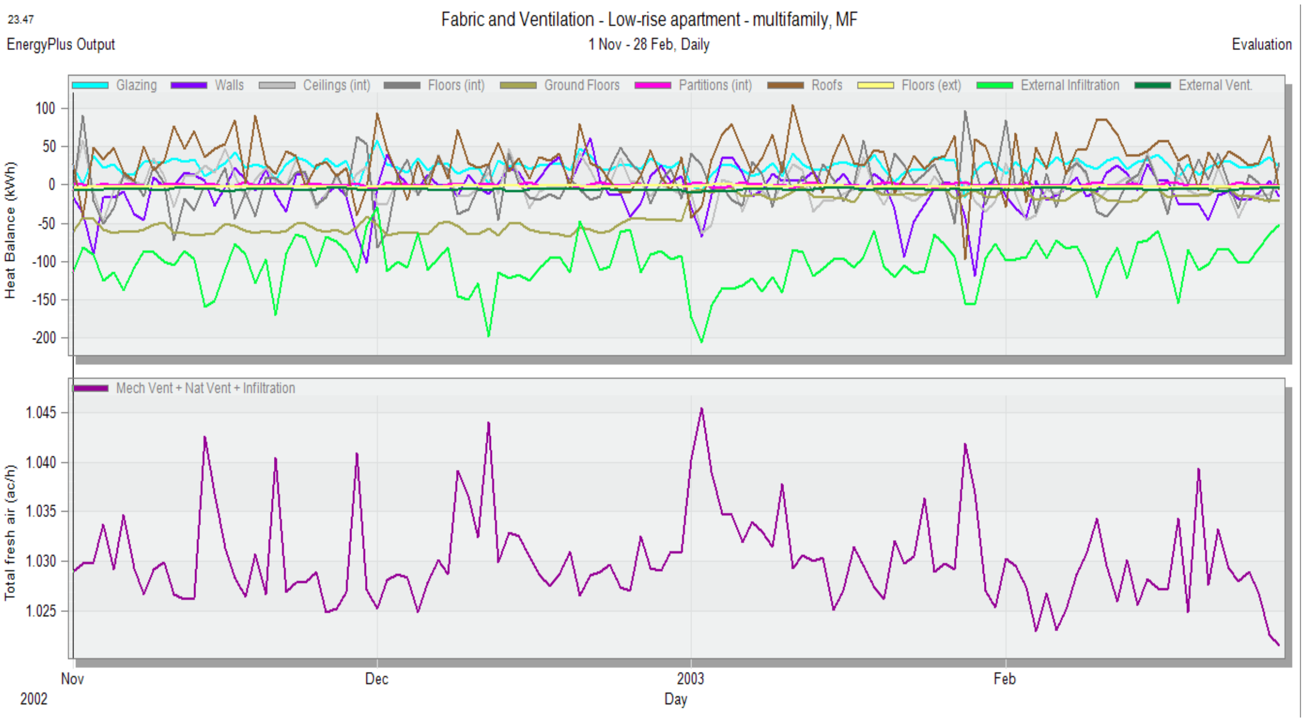

Fig. 11: Heat balance through the structures and ventilation

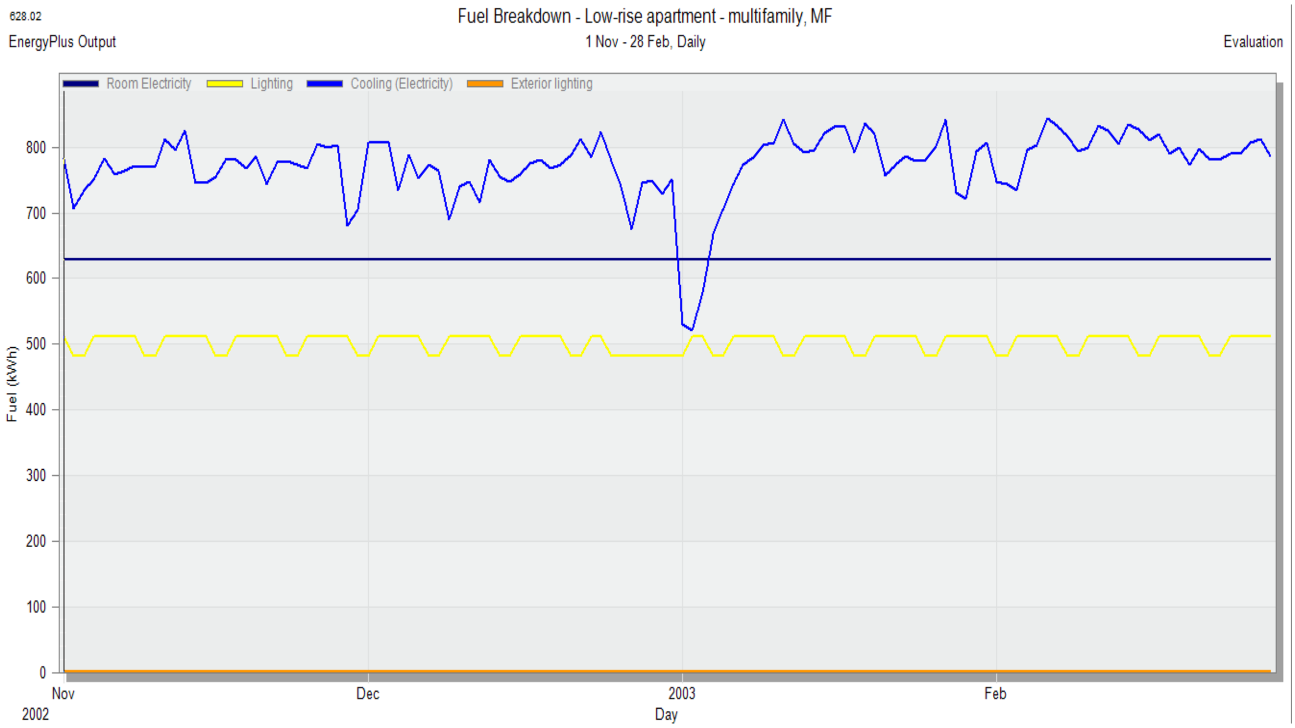

Fig. 12: Energy usage by lighting and cooling

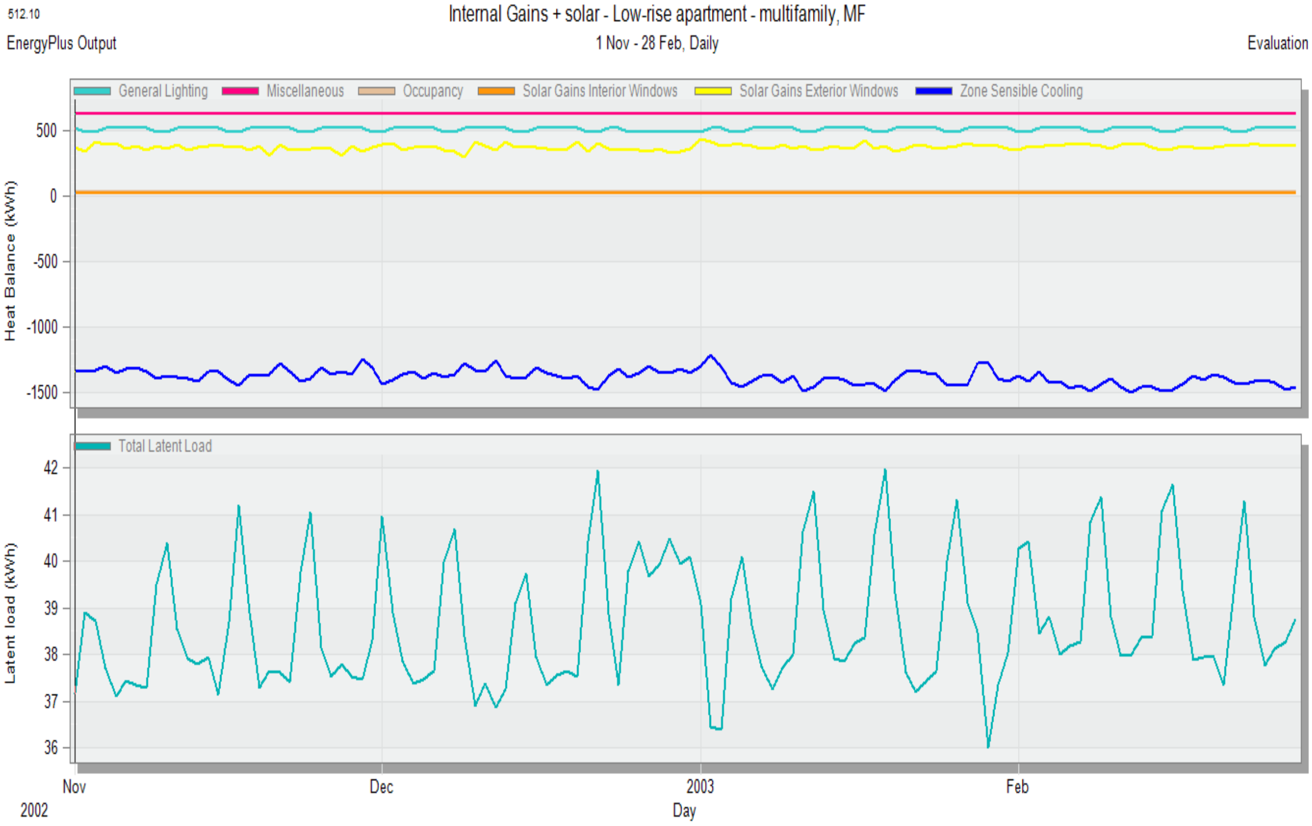

Fig. 13: Internal and solar gains

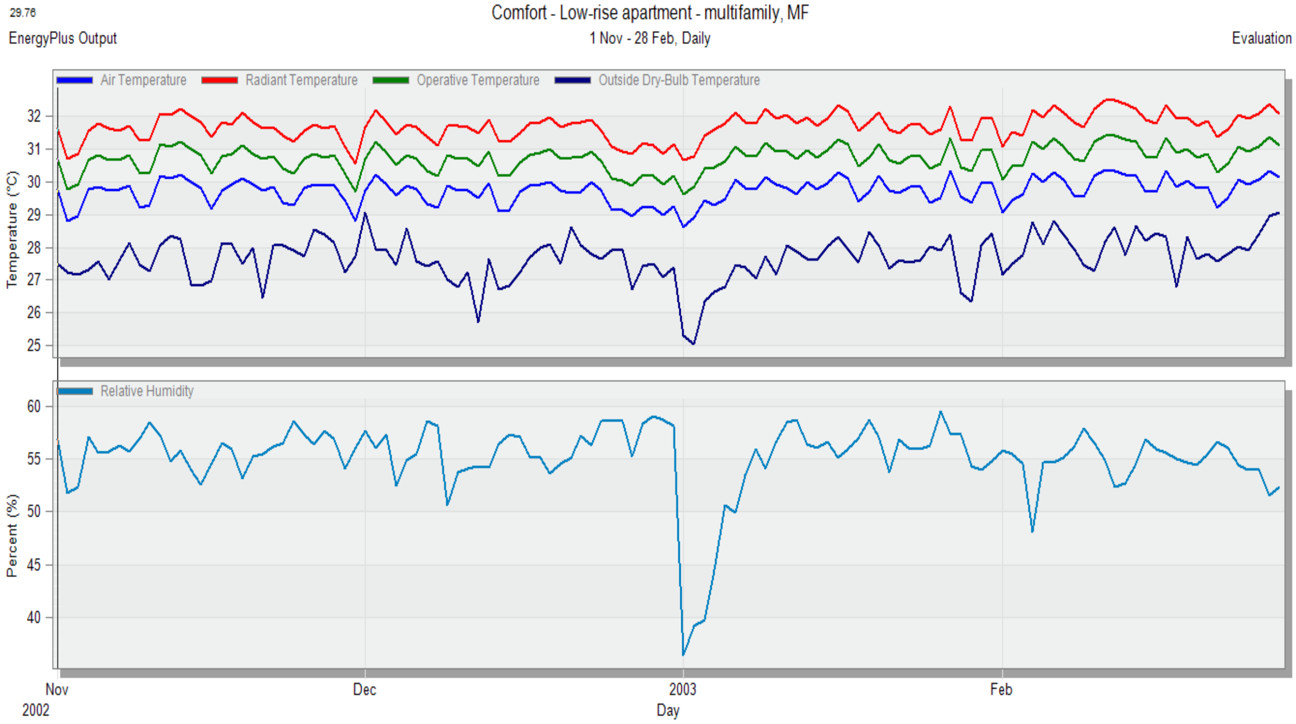

Fig. 14: Comfortability of occupants

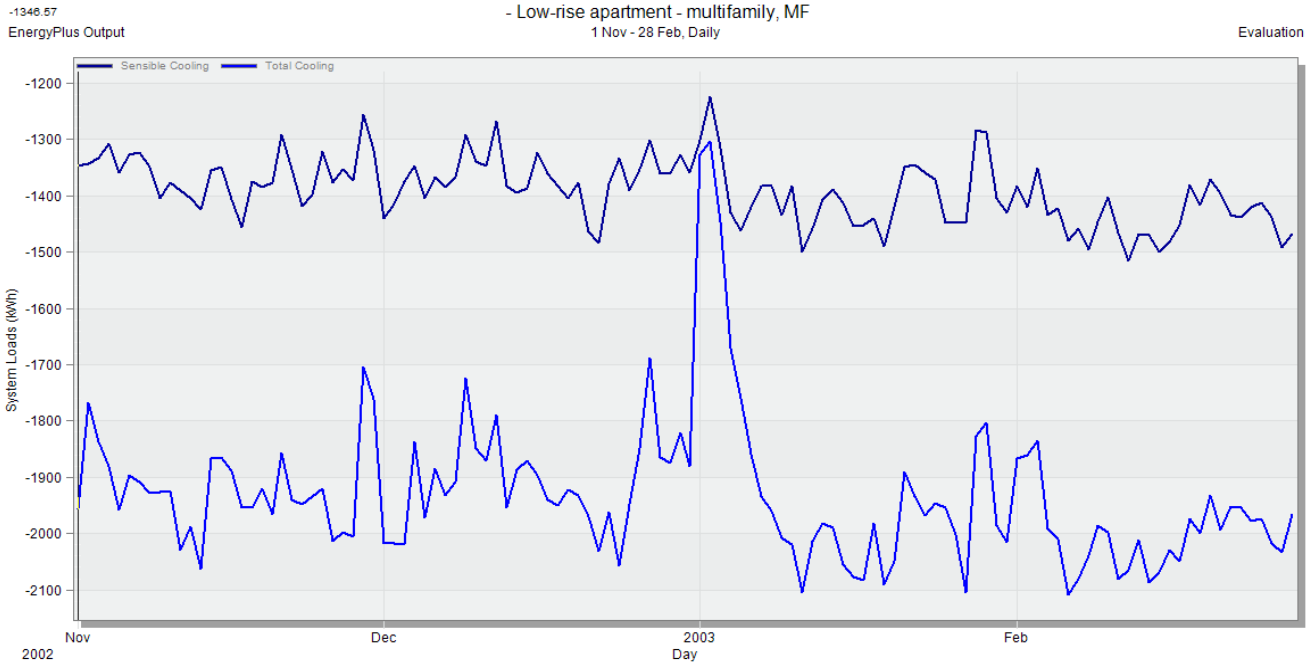

Fig. 15: Cooling energy consumed to maintain the set temperature (sensible cooling) and the set relative humidity (latent cooling)

E. Rainy Season (May 1st – August 31st)

Fig.16 shows that the difference between the dew-point temperatures and the outside dry-bulb temperature is lower than the dry season. Also, it is more likely to rain between June and August than May as shown by the temperature graphs. The outside air-bulb temperature is about 30 °C and the dew-point temperature is about 24 °C in the dry season period considered. Whereas the outside air-bulb temperature is about 25 °C and the dew-point temperature is about 22 °C in the rainy season considered.

a) Benefits of NZEB

Fig.17 shows the total energy consumed in the rainy season from 1st of May through 31st of August. The aggregate energy consumed consist of the energy used for lighting, cooling and powering of electrical appliances. Fig.18 shows the associated carbon dioxide emission. It can be seen that the energy consumed is directly proportional to the carbon dioxide emitted to the atmosphere.

The total energy consumed for this period is shown in table 7. This implies that 30.61 kWh/m^2 energy was consumed on lighting, 99.04 kWh/m^2 was consumed on HVAC system, predominantly for cooling. The higher energy used for lighting during the rainy season is due to extra three days in raining season period considered compared to the dry season. The major difference is observed in the energy used in cooling, about 16 kWh/m^2 difference.

b) Energy Savings

Fig.19 shows that the roof structure is the highest gainer of heat. This heat is balanced by the air ventilation and the emission of heat from the indoor to outside by the walls. Fig.20 shows that the energy consumed by cooling the building as the rate of ventilation increases. Also, figure 21 shows that the energy consumed to maintain the set temperature (sensible cooling) is directly proportional to the energy consumed to maintain the set relative humidity (latent cooling).

c) Performance Evaluation

Fig.22 shows that the comfortability of the occupants is not compromised despite using less energy as a result of choice of construction materials, glazing, air ventilation and roofing materials. This is shown through the operative temperature of the building's indoor. Fig.23 validates that the energy consumed to keep the indoor set temperature is directly proportional to the energy consumed to keep the set relative humidity of the buildings indoor. The energy consumed by the latent cooling is the difference between the energy consumed for total cooling and the energy consumed to maintain the building's internal temperature at a set value range.

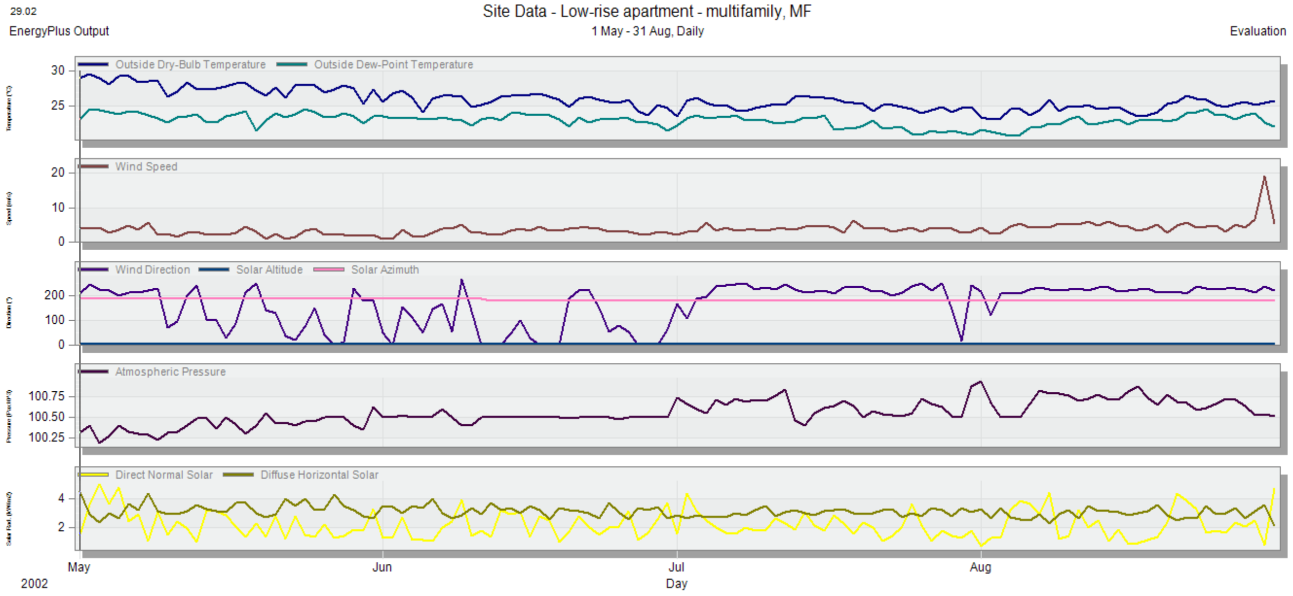

Fig. 16: Site data for the rainy season

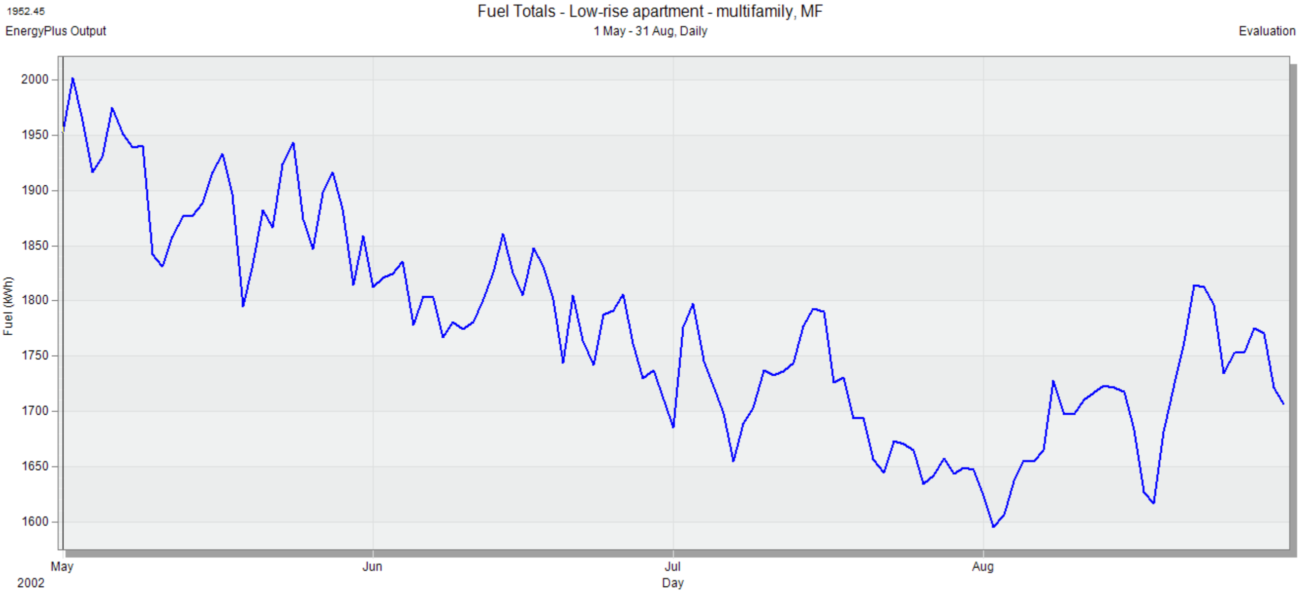

Fig. 17: Total energy used during the raining season

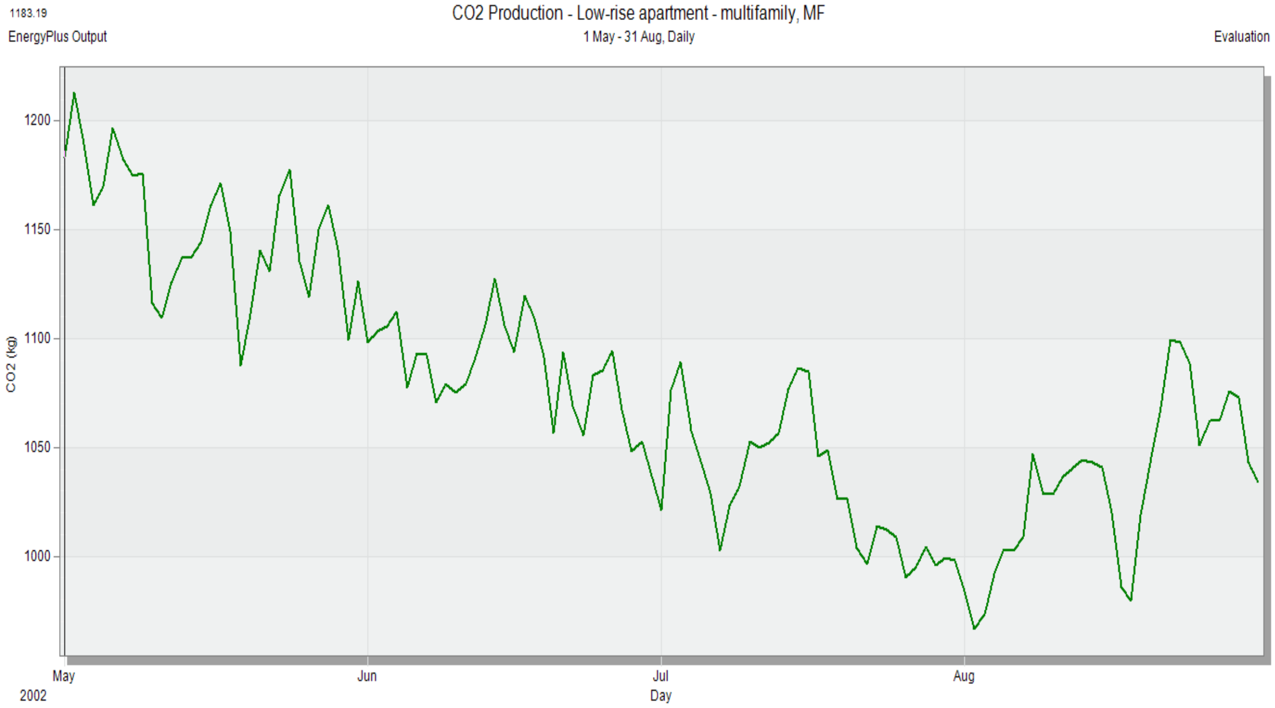

Fig. 18: Associated CO_2 emitted as a result of energy consumed from the grid

Category	Cooling	Interior Lighting	Exterior Lighting	Others	Total
Energy Used (kWh)	198,900.49	61,331.6	141.45	77,246.01	337,619.55

Table 7: Categories of energy consumption

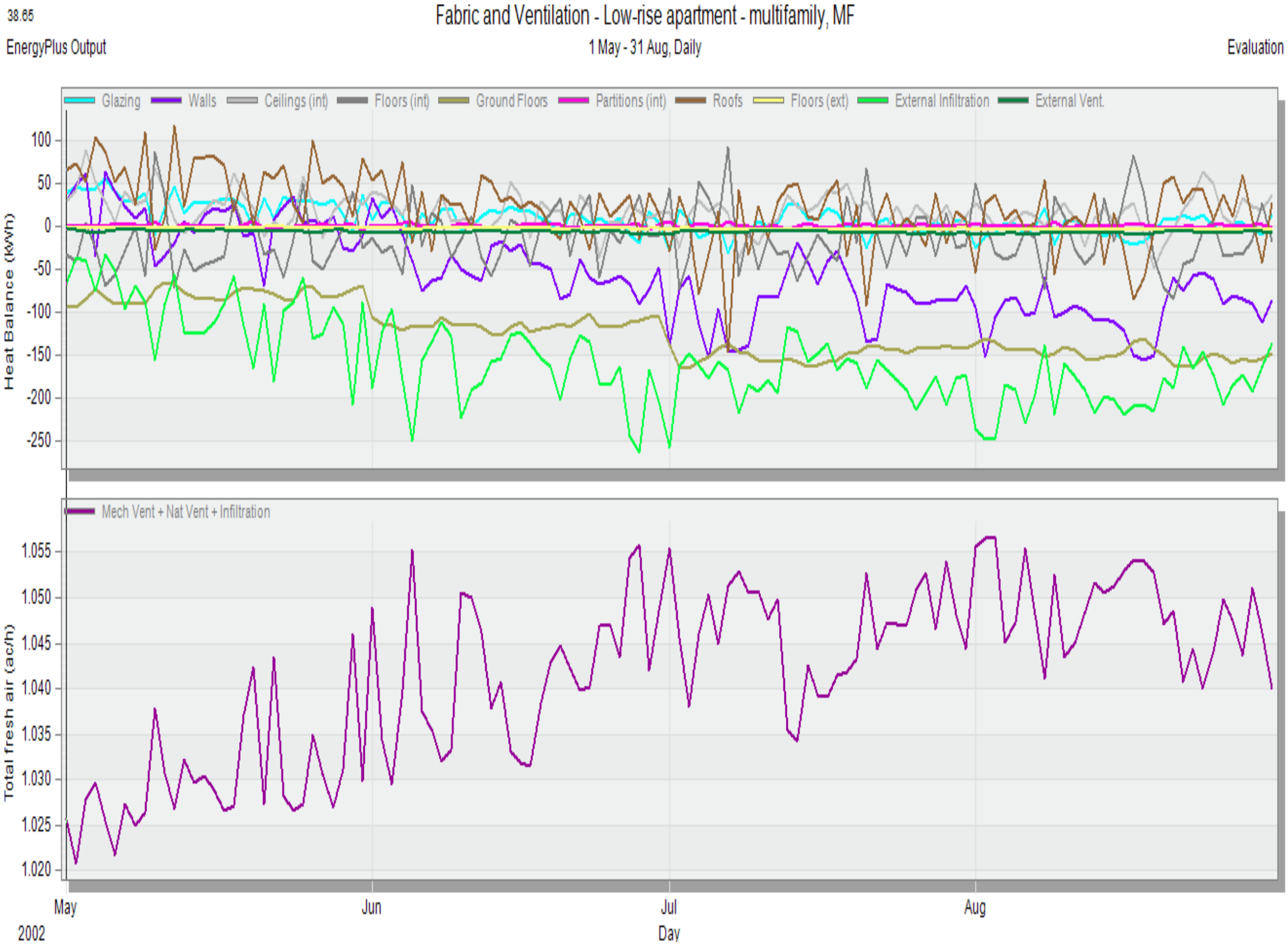

Fig. 19: Heat balance and infiltration rate during raining season

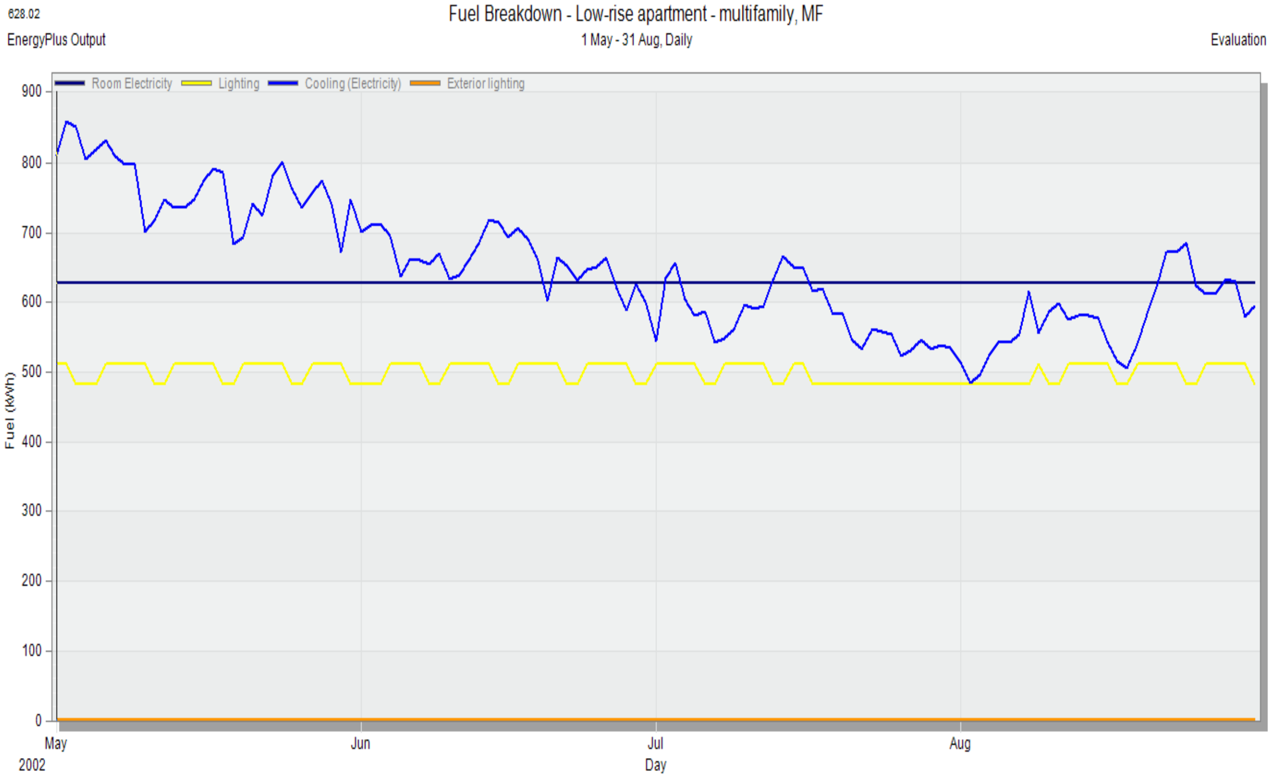

Fig. 20: Energy consumption by different categories of electrical loads during the raining season

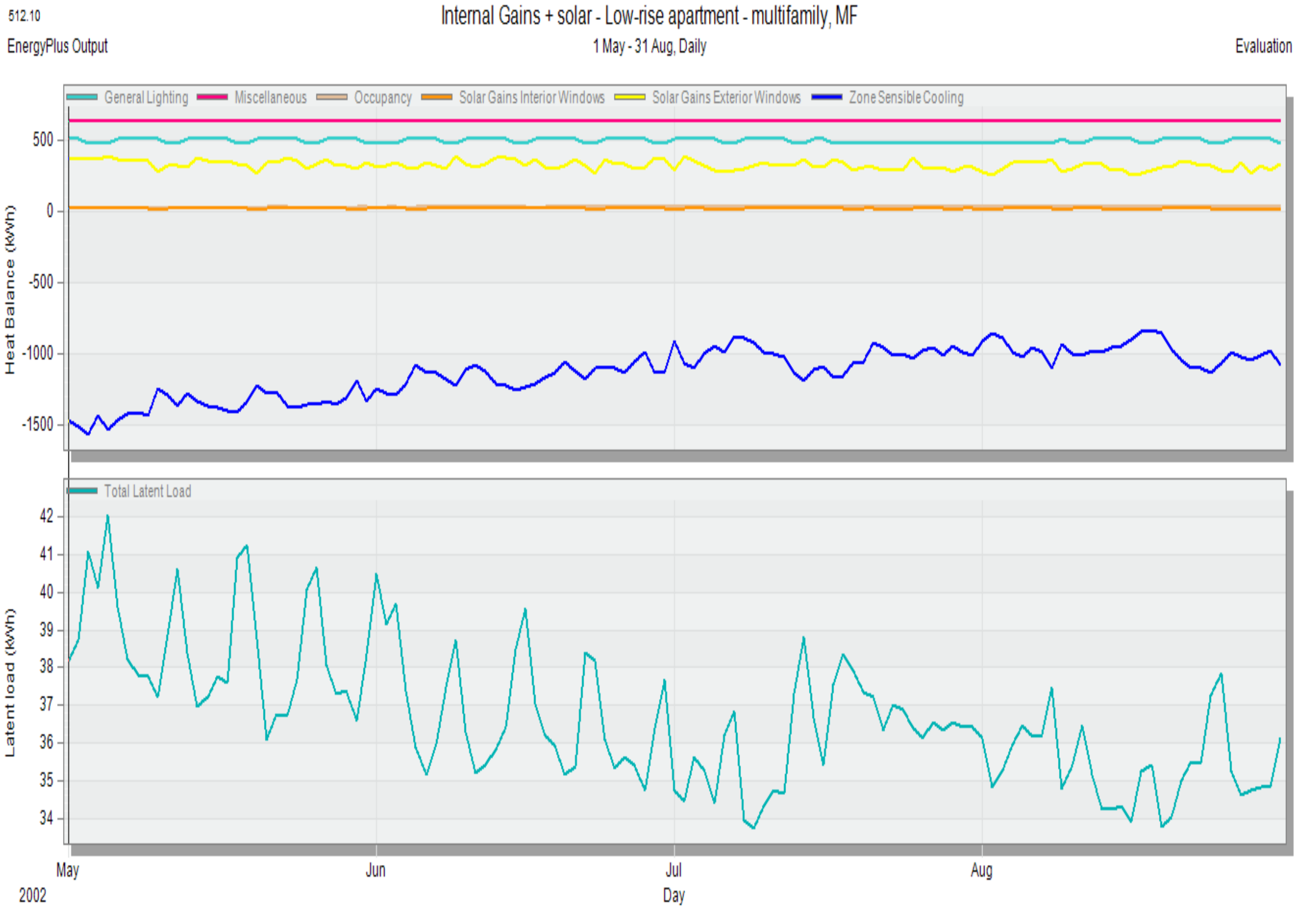

Fig. 21: Latent load and heat balance

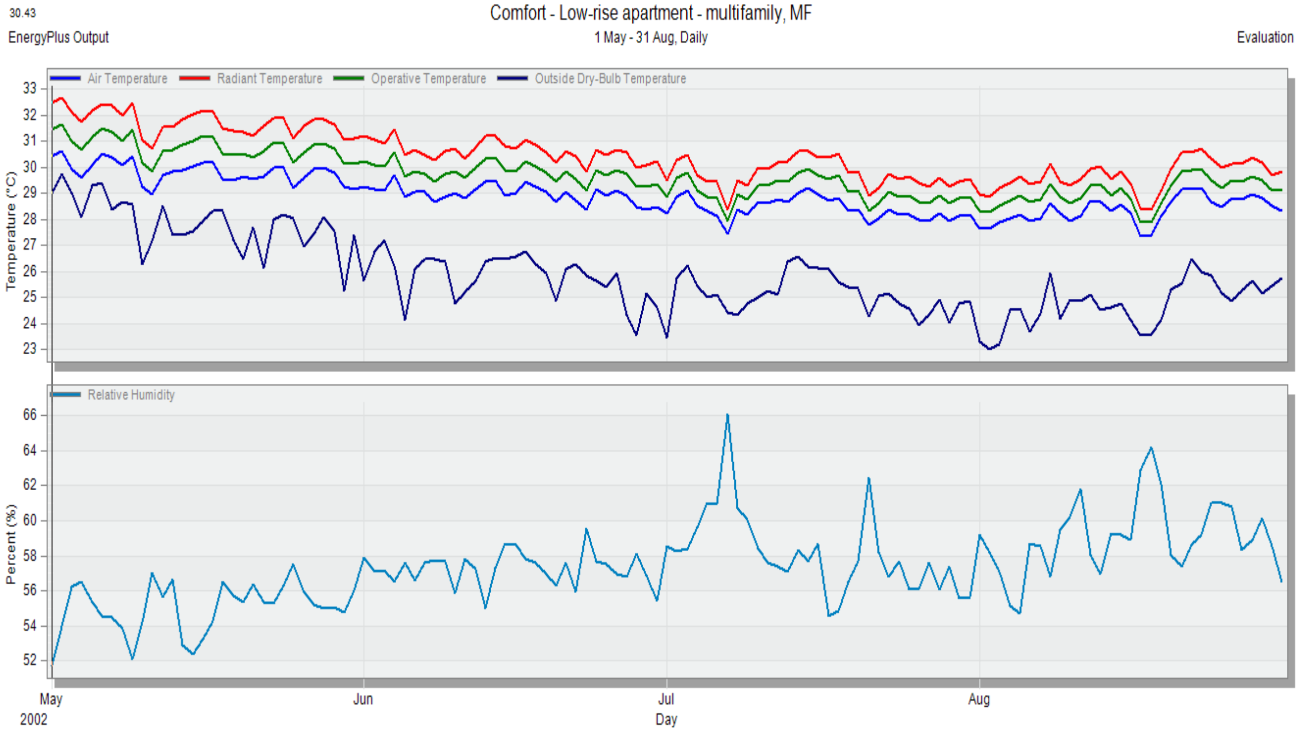

Fig. 22: Comfortability of the occupants during the raining season

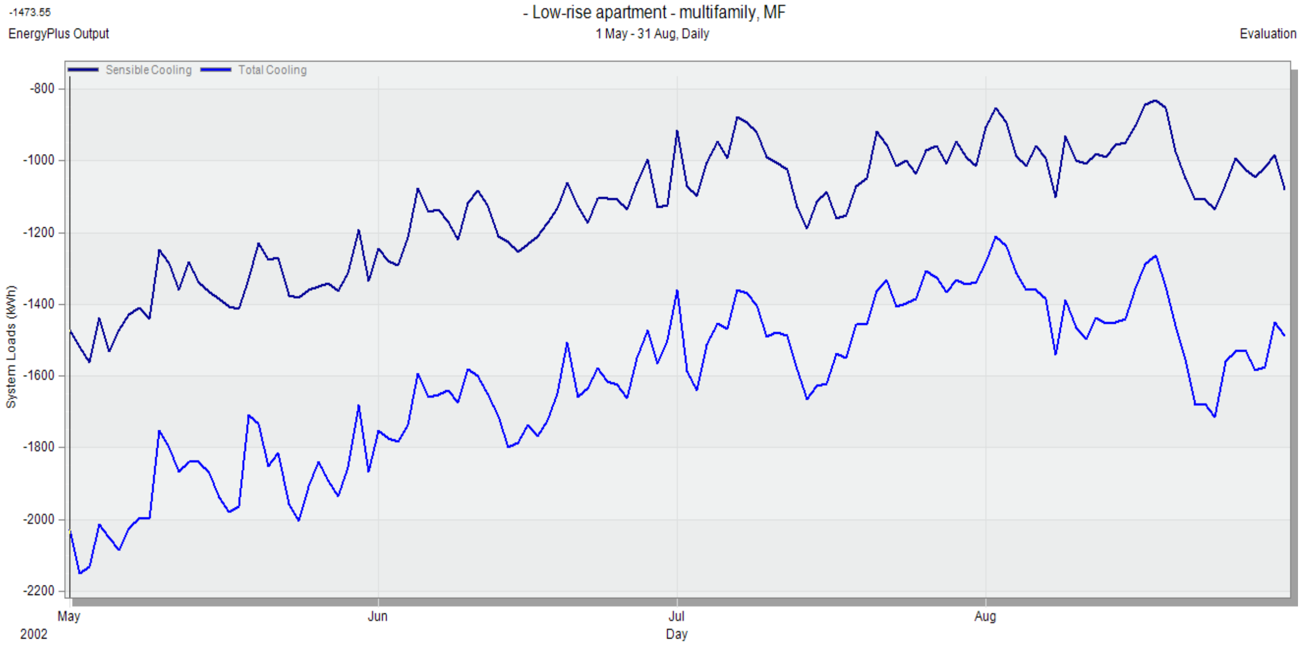

Fig. 23: Cooling energy consumed for both sensible and latent load

V. CONCLUSIONS

It was found that the near zero energy building (NZEB) protocol developed in this study consumes less energy than the existing conventional building. The total energy usage for the dry season is 367,513.88 kWh. This implies that the energy consumed by the building is 182.98 kWh/m^2 for this period between November 1st and February 28th. This means about 1.52 kWh/m^2/day for this period. Similarly, the total energy consumed during the rainy season of May 1st through August 31st is 337,619.55 kWh. This is equivalent to 168.10 kWh/m^2 for this period. Hence, 1.37 kWh/m^2 was consumed per day in the rainy season. The average energy consumed per day by the building is 4,000 kWh/day. This is equivalent to 1.99 kWh/m^2/day.

The main reason for the difference between current building energy utilization and the proposed near zero energy building concept indicates the achievement of this idea. This building energy reduction has a very strong nexus with the energy utilized for the cooling purpose in the NZEB which is equivalent to the set temperature and set relative humidity of the building ambience. This is achieved through the replacement of the partition hollow brick walls with insulated walls, re-orienting majority of the windows to improve ventilation and the use of double glazing instead of the existing single glazing. The double glazing of the window reduces the heat gain through them. Consequently, less carbon dioxide is emitted to the atmosphere, as energy consumed is directly proportional to the carbon dioxide emitted. Hence, the NZEB prototype is more environmentally friendly.

Energy savings is principally due to the reduced need for active cooling through air conditioners (ACs). It is affected through the location of the windows with respect to the air flow, the size of the windows, the choice of construction materials, solar gains, roof design, choice of roof materials, glazing materials, and door materials.

The comfortability of the occupants of the building is not sacrificed as it was shown that the operative temperature of the building is within range for both the set temperature and set relative humidity.

It can therefore be concluded that near zero energy building (NZEB) results have more environmental benefits through lower carbon dioxide emission, more economic benefits through lower energy consumption while the comfortability of the occupants is not compromised.

In particular, for an existing urban residential building, attention should be paid to reducing the energy consumed by the air conditioners by taking advantage of ventilation. This can be done by locating the windows such that they face north or south of the air movement. Also, double glazing and solar shadding should be used to reduce heat gained through the window.

Following this study, it is recommended that the Nigerian Government should empower the Building Control Agencies in federating states to make Nigerian building energy efficiency code a paramount aspect of building approval processing documents. This will ensure that new buildings follow NZEB design procedures (detailed in this study) in order to minimize energy consumed by the buildings. Thus, this will reduce the gap in energy demand but not supplied. In other words, this study reduces the cooling load consumption without necessarily reducing the comfort from the cooling units. However, to achieve same results as above for the existing buildings, it is suggested that retrofitting of the roof design and material, windows glazing, relocation of windows and their sizes could be considered.

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