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Towards Achieving Sustainable Development Goal-2030 Agenda-Thirteen: Selective Treatment of Sun-Facing Residential Window Fabrics in the Tropical Building Design

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ABSTRACT: High solar gains associated with the Tropical climate result in high indoor temperature, the consequence of which induces indoor thermal discomfort. Particularly, both the East and West facing component building envelope receive more solar gains through early morning sun rise and late afternoon sun set respectively, thereby raising the indoor temperature of the affected spaces within the periods. However, the need to optimize indoor thermal comfort through mechanical installations among others, increases carbon emissions into the atmosphere, as buildings account for about 40% of global emissions through their construction, operation and maintenance. Due to its importance at the global level, Climate Change induced mitigation has resulted into promulgation of seventeen-pronged (17) United Nation's Sustainable Development Goal 2030 (SDG-2030) Agenda. Of particular relevance within the precinct of built environment is the Agenda thirteen (Agenda-13) which encompasses the need for urgent action to combat Climate Change and its impacts across various areas of human engagements. It is on this basis that this research work explored beneficial impacts of selective treatment of East and West-facing residential building window fabrics, in the tropical city of Ogbomoso, Nigeria. In its approach, comparative evaluations of indoor solar gains using single-glazed and double-glazed virtual building models was carried out through *DesignBuilder* based simulations. The results indicate 8.5%, 8.5% and 8.6% annual reductions in the indoor solar gains in the whole building, East-end apartment and West-end apartment respectively, with the adoption of the double-glazed windows. Focusing specific individual sun-facing functional spaces (bedrooms in this case), more significant reduction in the indoor solar gains (i.e., about 28%) was recorded in each case. This research output may influence subsequent design and composition of the sun-facing window fabrics at this local level, thereby leading to reduced mechanical installations, for optimum indoor thermal comfort. This is an attempt to contribute towards achieving SDG-2030 Agenda-13 individually at this level, for overall collective realization at the global level. This endeavour aims at reducing carbon emissions at the building micro level in the study area, for overall clean, safe and sustainable global environment. This submission is part of an ongoing research work scheduled to be validated with life prototype/physical models subsequently.

KEYWORDS: Building Design, Carbon Emission, Climate Change, Simulation, Sustainable Development, Thermal Comfort, Tropical Region

I. INTRODUCTION

Buildings account for about 15% of carbon emissions, with transport and industry being responsible for 14% and 21%, respectively, and the remainder is due to other activities (Karyono and Bachtiar, 2017). Thus, there is the need for efficient and sustainable utilization of energy to conserve the fast-depleting resources, and protect the built environment from avoidable carbon emissions. However, concerns for the Climate Change induced impacts have become a global issue as the need to address it has featured in the policy frameworks of many countries (Valizadeh et al. 2020; Karimi et al. 2018). The threat of climate change has brought the international community together, to devise mechanisms to address it particularly, to keep the global warming below 2 °C (Indukuri, 2022). This is premised on the Stockholm Conference of 1972, Vienna Convention of 1985, Montreal Protocol of 1987, establishment of IPCC in 1988, Earth Summit of 1992, adoption of the United Nations Framework Convention on Climate Change (UNFCC) in 1992, regular Conference of Parties (COP) and other related conferences, promotion of the 'Millennium Development Goals' in 2015 (MDGs-2015 Agenda) and subsequent adoption of a fifteen-year Sustainability programme, Sustainable Development Goals (SDG – 2030 Agenda) in 2015, among others. This particular Agenda (SDG – 2030 Agenda) is composed of 17 comprehensive objectives (known as SDGs), 169 targets, separate ways of executions, and follow up actions. Of the seventeen (17) goals, the first one, Goal 1, addresses 'Poverty eradication' as the last one, Goal 17, emphasises 'Partnership for goals' (Olaniyan, 2023; Indukuri, 2022; Yu et al., 2020; IPCC, 2018; Attoye, Aoul and Hassan, 2017; United Nations, 2015). Within the context of Built Environment, the focus of this submission is the Goal 13, which encompasses the need for urgent action to combat Climate Change and its impacts particularly, on the tropical design, through reduced carbon emissions. Thus, this submission dwells on the efforts towards achieving this important Goal-13 of the SDG-2030 Agenda, from the standpoint of relevant professionals (i.e. Architects, Engineers, etc.) within the precinct of the built environment in the tropical region.

Tropical region is characterized by elevated outdoor temperature, relative humidity, and solar radiation with its attendant influence on the indoor energy performance of buildings (Kirimtat, Koyunbaba, Chatzikonstantinou, & Sariyildiz, 2016; Kirimtat, Krejcar, Ekici, & Tasgetiren, 2019}. In particular, sunny climate presents an excess of solar gains that cause high energy consumption due to the interior cooling needs, and thus, proper management of sunlight impinging onto building facades is an important issue in the design of energy-efficient buildings (González-Pardo, Rodríguez, González-Aguilar, & Romero, 2014}. Mechanisms for Solar control system should therefore be considered for all glazed openings exposed to direct sunlight particularly, on the East (through South) to West-facing facades since the solar gains within, coincide with the hottest part of the day (Kirimtat, Koyunbaba, Chatzikonstantinou, & Sariyildiz, 2016). This would enable control of incoming sunrays, thereby reducing HVAC (Heating, Ventilating and Air-Conditioning) loads, decreasing the energy consumption and minimizing the energy costs (Kumar, 2016; González-Pardo et al, 2014).

Glazing units inclusive of windows, glazing façades and glazing roofs constitute important parts of buildings necessary for provision of vision, daylighting, air ventilation and passive solar gain. Beside facilitating aesthetic look of the building, glazing units are in place to serve as physical and visual connection to outsiders (Li et al, 2020; Chaiyapinunt et al, 2005). However, glazing units are generally poor in thermal resistance relative to other building components. They therefore occupy a critical position in the energy demand of buildings and the overall indoor thermal comfort. It is established that 30% of the energy consumption through heat loss in a building as well as huge energy consumption of cooling-dominated room in hot climates arising from excessive heat gain are attributed to windows (Li et al, 2020; Ozel, 2022; Arıcı and Karabay, 2010). Thus, in view of the critical role of window units on the energy demand of buildings, efforts should be intensified to reduce the energy consumption without affecting the level of indoor thermal comfort in a wide range of climatic conditions particularly, the tropical region.

Sequel to the above, previous researchers have investigated different mechanisms to reduce solar gains through direct incoming sunrays into the building. On the one hand, impacts of various forms of shading devices mounted on the building envelopes to reduce overheating time of the building for improved energy efficiency within, were demonstrated by various researchers (Kirimtat, Krejcar, Ekici, & Tasgetiren, 2019; Valladares-Rendón, Schmid & Lo, 2017; Jayathissa et al., 2017; Al-Obaidi et al., 2017, Xiong and Tzempelikos, 2016, and Li et al., 2016; Chou et al., 2016; Bunning and Crawford, 2016; Goldman, 2016; Rodriguez-Ubinas et al., 2014; Sanati and Utzinger, 2013; Almusaed 2011; Rogers and Goldman, 2006; Beltran, Lee, and Selkowitz 1997; Littlefair, Aizlewood, and Birtles 1994;). In this case, solar radiation incident on the building was inhibited as the shading devices were placed internally or externally or in-between the internal and external building spaces. Shading devices were positioned to take the forms of dynamic facades, projections (chajja), cantilevers, louvres, fins, grating, light shelf, jaalis or even textiles. They can be fixed permanently or remain flexible for control, manually or automatically (Kumar, 2016). Plants are also used for shading the buildings as vegetation near a window can provide shading effect, and reduce sunlight's direct radiation (Faisal & Aldy, 2016). On the other hand, introduction of multilayer glazing and coating glass surfaces with low emissivity materials (Li et al, 2020; Chaiyapinunt et al, 2005) can be considered. In this case, thermal resistance performance of glazing units is improved by introducing double or triple glazing with inert gas infill (such as argon, krypton or xenon) between the glass panes (Chaiyapinunt et al, 2005). The gas acts as a stationary air layer which enhances thermal insulation performance of the window due to the low gas thermal conductivity, thereby decreasing the conduction heat transfer between the glass panes (Arıcı & Karabay, 2010). It is established that the heat transfer rate of a single-glazed window is about 2.5 times higher than that of a double-glazed window (Arıcı & Karabay, 2010). Consequently, installing double-glazed windows can reduce both significant amount of energy and environmental pollution. This study therefore compared energy saving capabilities between different window glass fabrics, with a view to inhibiting solar gains into the building. This is to improve on the energy efficiency of the building, and enhance realization of Sustainable Development Goal-2030 Agenda-Thirteen particularly, in the Tropical city of Ogbomoso, Nigeria.

II. METHODOLOGY

The study area, Ogbomoso, which lies on 8° 10' North of the equator and 4° 15' East of Greenwich Meridian, exists within the transition zone of rainforest and the savannah. It is situated within the derived savannah region, and serves as a gateway to the Northern part of Nigeria, from the South. Using Köppen-Geiger climate classification, the climate is considered to be 'Aw' and has tropical wet and dry climates with the highest (24.70 days) and lowest (0.73 days) number of rainy days in July and December respectively (En.climate, 2022; Olaniyan, 2012). While its wet season is usually experienced between April and October, the dry season on the other hand usually falls between November and March. It has a mean annual rainfall of about 1200mm and precipitation variation of 178 mm between the driest and wettest months. It experiences lowest and highest Relative Humidity in January (42.54%) and September (85.18%) respectively. It has an average of 76.53 hours and 2323.51 hours of sunshine per month and annually respectively. More importantly, the climate is characterized with high solar radiation (with radiation value of over 10KJ/m2/day for some months) which often leads to indoor thermal discomfort in most part of the year (En.climate, 2022; Olaniyan, 2012). This necessitates the need for thermal analyses for proper design interventions in the area.

This research primarily depends on simulating building performance via *EnergyPlus* integrated software, *DesignBuilder*. This is to explore comparative impacts of changing window fabrics (i.e., single-glazed and double-glazed window fabrics) on the indoor solar gains (through exterior windows) in respect of Sun-facing East and West residential building walls, in the tropical city of Ogbomoso, Nigeria. *DesignBuilder* is an hourly energy simulation engine for modelling building's heating, cooling, lighting, ventilating and other energy flows. Its integration with *Energplus* allows complete simulations within the same interface. This ensures ease of comprehensive simulation process. *DesignBuilder* uses construction components to model the conduction of heat through walls, windows, roofs, ground and other opaque parts of the building envelope as the physical properties of each element have been pre-defined for broad simulation processes (*DesignBuilder* 2023; Abdullah et al, 2022). These simulations are made to run for the whole year (i.e., 12 months) as outputs are obtained in forms of hourly, daily and monthly data, for ease of result analyses.
Virtual model of a three-bedroom twin apartment-building (comprising of both East-End and West-End apartments) occupying a total area of 255.75 square metre, subjected to energy performance simulation analysis for this study is illustrated in Figure 1 (i.e., the Floor Plan). The model as obtained on the *DesignBuilder* interface (i.e., three-dimensional drawings) is shown in Figure 2. As prevalent in the study area, the wall of the modelled building is constructed of 225mm hollow sandcrete block, finished with 12mm thick sand-cement mortar on both internal and external surfaces. The window is of 6mm thick clear glass, and the building is complemented with 40mm thick wooden panel doors. The roof is of 0.45mm thick long span aluminium sheet on timber roof carcass, finished underneath with 6mm thick Asbestos ceiling sheets. This building description represents the first of the two variants of the building models adopted. In line with the research focus, this model serves as the basic model tagged the Control Model. The other variant of the Control Model tagged the double-glazed model, consists of double-glazed windows (i.e., composed of two layers of 6 mm thick clear glass separated by 13 mm air gap) on the sun-facing sides (i.e., East and West facing walls). Each of these models is subjected to numerical simulations in turn, to analyse the influence of changing window fabrics (i.e., single-glazed, and double-glazed window fabrics) on the indoor solar gains (through exterior windows) in respect of selective Sun-facing East and West residential building walls, in the tropical study area. This is useful for informed analytical design decisions to improve building energy performance in respect of the building envelope particularly, window fabrics in this context.

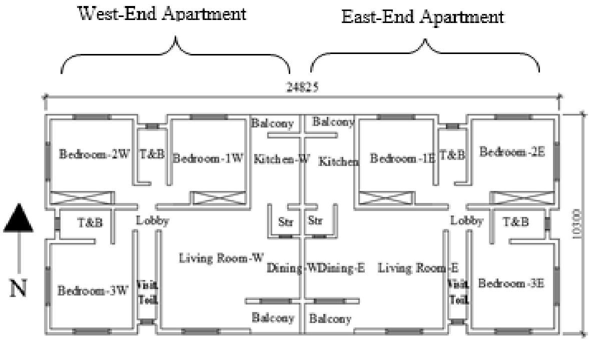

Figure 1: Floor Plan of the twin-apartments (as captured in AutoCAD-2020 version)

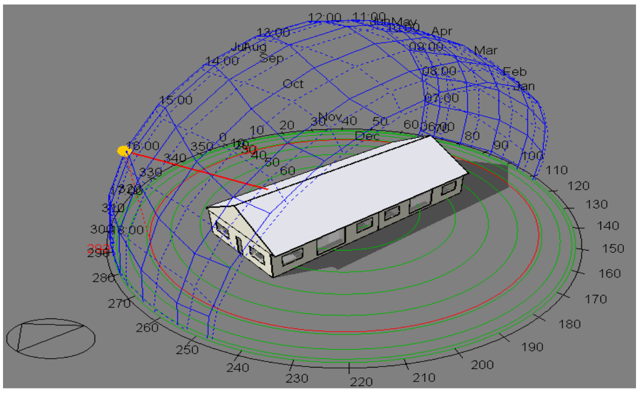

Figure 2: Virtual model of a three-bedroom twin apartments-building model as obtained on the DesignBuilder interface

III. RESULTS ANALYSIS AND DISCUSSION

A. Prevalent Solar Radiation vis-à-vis Building Indoor Thermal Experience in the Study Area

Based on the geographical location of the study area, simulation outputs for the relevant climatic data indicate high solar radiations particularly, between October and May, with each month experiencing almost 100 kwh/m2 area of Diffuse Radiation. Highest value of 114.13 kwh/m2 was recorded in the month of March. The trend is also similar for the Direct Radiation over the same period as the highest Direct Radiation of 84.45 kwh/m2 was also recorded in March.

Outside Dry Bulb Temperature ranges between 24.8 °C (in August) and 28.6 °C (in April) over the same period. Details of these simulation outputs are as graphically illustrated in Figure 3. The actual simulation output as captured directly from *DesignBuilder* interface is as shown in Appendix I for referencing and verification. These radiations form the basis for the indoor solar gains through the walling fabrics, windows, among others (Figure 4) from which indoor thermal discomfort is experienced.

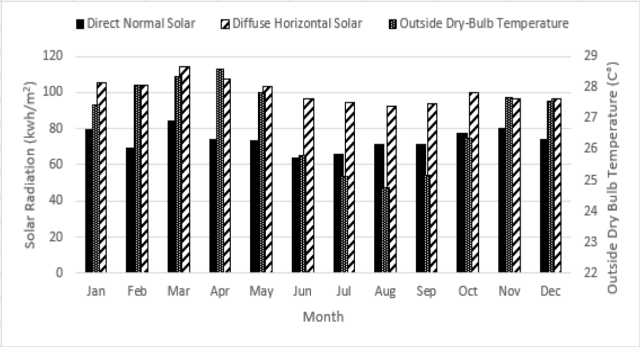

Figure 3: Simulation Output showing Relevant Climatic Data of Outside Dry Bulb Temperature and Solar Radiations (involving both Direct and Diffuse) of the Study Area.

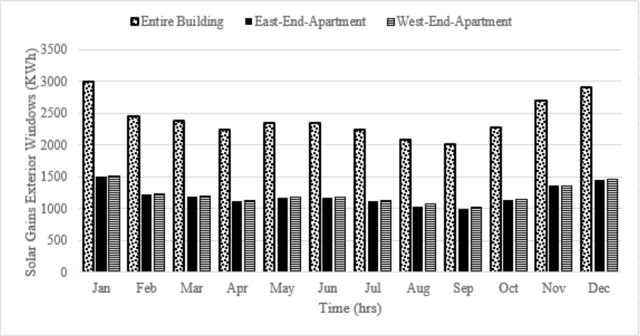

Figure 4: Monthly Building Solar Gains through the Exterior Glazing

Based on the observed solar radiation in the study area (as illustrated in Figure 3), annual solar gains through the exterior windows of 28991.08 KWh, 14421.25 KWh and 14569.84 KWh were recorded for the whole building, East-end apartment and West-end apartment respectively. Details of these on monthly bases are as graphically illustrated in Figure 4 with the maximum value for each unit (i.e., the whole building, East-end apartment and West-end apartment) recorded in the month of January. Further details indicate that the West-end bedrooms experienced more solar gains through the exterior windows (i.e., Bedroom-2W: 2340.52 KWh; Bedroom-3W: 2165.39 KWh) than the East-end (i.e., Bedroom-2E: 2290.71 KWh; Bedroom-3E: 2115.36 KWh). These are attributable to the radiations arising from both evening sun setting and early morning sun rising respectively. However, each of the adjoining central bedrooms (i.e., Bedroom-1E, and Bedroom-1W) experienced far less annual solar gains in this regard (i.e., 885.98 KWh). This is a reflection of their relative (sandwiched) positions within the building in view of the daily changing sun's azimuth. Details of these solar gains are further analysed on their daily patterns as illustrated in Figure 5

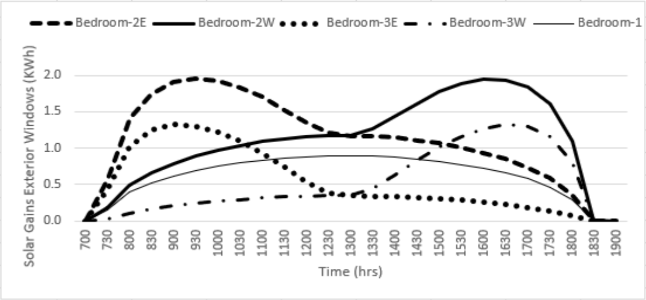

Figure 5: Daily Solar Gains into the individual Bedrooms through the Exterior Glazing

From Figure 5, the impacts of the morning solar gains can be seen in the values attributed to the East-End windows in the morning as the sun rises from the East (i.e., solar gains between 700 and 1100 hrs particularly, around 930 hrs). This trend declines as the day progresses with the changing positions of the sun. The reverse is the case as the solar gains on the West-End windows also rose in the evening due to the solar gains arising from the sun setting in the West in the evening (i.e., between 1530 and 1800 hrs particularly, around 4300 hrs). However, the changes experienced in the central bedroom (typical Bedroom-1 i.e., Bedroom-1E, and Bedroom-1W) were very minimal, due to their relative locations in the building

B. Building Indoor Thermal Experience After the Interventions

Based on the impacts of the regular indoor solar gains through the components of the building envelope (such as the walling fabric, window, roof, etc.) with its attendant indoor thermal discomfort regularly experienced in the study area, the aim of this study is to evolve an intervention through construction approaches whereby modifications are effected on the window component. In this case, ordinary single layer window predominantly used in the study area was replaced with double glazed window (with argon gas infill between glass panes that are 13 mm wide apart), and annual simulations were run again. The results of the simulations indicate significant overall reductions in the indoor solar gains as shown in Figure 6

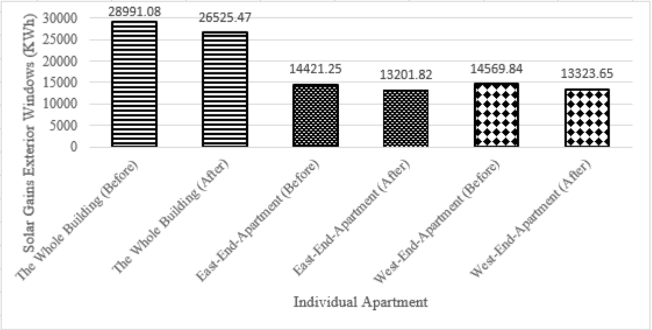

Figure 6: Comparative Overall Indoor Solar Gains before And after the Intervention

Based on the double-glazed window intervention on the sun-facing walls, simulation outputs shown in Figure 6 indicate 8.5%, 8.5% and 8.6% annual reductions in the indoor solar gains in the whole building, East-end apartment and West-end apartment respectively. Further analyses on the individual sun-facing bedrooms (East-end and West-end bedrooms i.e., bedrooms 2 and 3) show similar reductions in indoor solar gains, as shown in Figures 7 and 8.

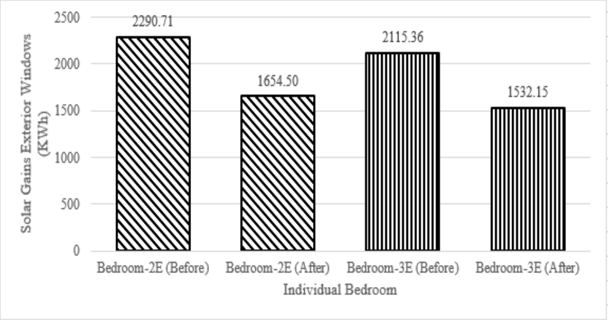

Figure 7: Comparative Annual Indoor Solar Gains into Individual East-facing Bedroom before and after the Intervention

From Figure 7, 27.8% and 27.6% annual reductions in the indoor solar gains in the East-end bedrooms 2 and 3 were recorded respectively. Daily analyses of the bedrooms based on the peak summer day (01 April) thermal conditions were also examined as shown in Figure 9.

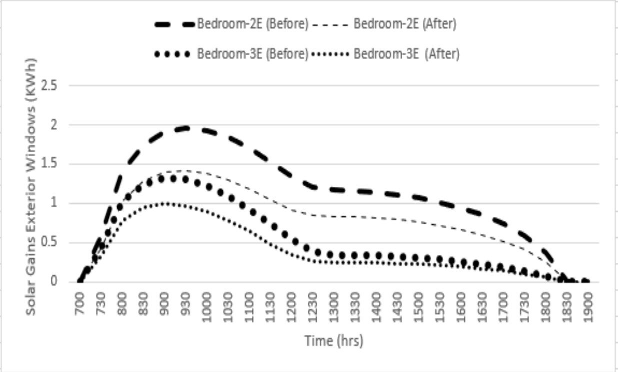

Figure 8: Comparative Daily Indoor Solar Gains into Individual East-facing Bedroom before and after the Intervention

From Figure 8, beneficial impact of the intervention on the early morning solar radiation gains into each of the East-facing bedrooms 2 and 3 could be observed in their reductions, as the individual highest initial value (before the intervention) of 1.95 KWh in Bedroom 2 and 1.30 KWh in Bedroom 3 at 930 Hrs dropped to 1.42 KWh and 0.97 KWh respectively (after the intervention).

Similarly, 27.8% and 27.6% annual reductions in the indoor solar gains in the West-end bedrooms 2 and 3 respectively, were also recorded (as shown in Figure 9).

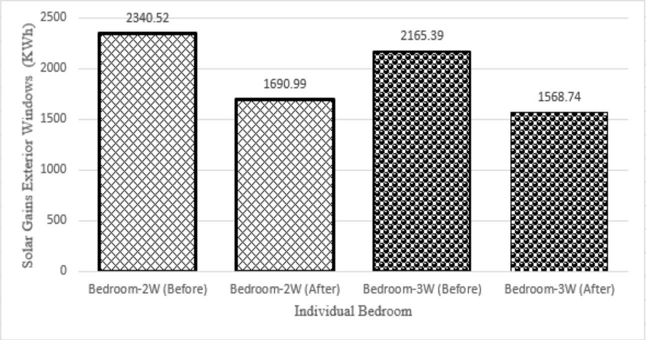

Figure 9: Comparative Annual Indoor Solar Gains into Individual West-facing Bedroom before and after the Intervention

Daily analyses of the bedrooms based on the peak summer day (01 April) thermal conditions were also examined as shown in Figure 10.

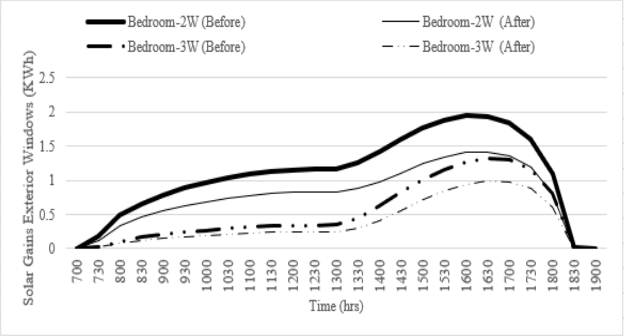

Figure 10: Comparative Daily Indoor Solar Gains into Individual West-facing Bedroom before and after the Intervention

From Figure 10, beneficial impact of the intervention on the evening solar radiation gains into each of the West-facing bedrooms 2 & 3 could be observed in their reductions, as the individual highest initial value (before the intervention) of about 1.94 KWh in Bedroom 2 and 1.32 KWh in Bedroom 3 at 1630 Hrs dropped to 1.41 KWh and 0.99 KWh respectively (after the intervention)..

C. Overall Results Implications

Based on the elevated outdoor tropical temperature arising from the high solar gains in the region, simulation results indicate early morning and evening indoor solar gains through the East and West facing windows respectively. As a pre-emptive step at the building design stage, adoption of double-glazed windows in this case has reduced the impacts of the identified indoor solar gains in the morning and evening, on the indoor thermal condition of the building. These research results align with the findings of Ozel (2022), Ishac & Nadim (2021), Valladares-Rendón, Schmid, and Lo (2017), Faisal and Aldy (2016), Valladares-Rendón, & Lo (2014), Arıcı and Karabay (2010), Chaiyapinunt et al (2005), Chaiyapinunt (2009), Chapman and Sengupta (2004), among others. This research efforts would contribute to the United Nations’ Sustainable Development Goal-2030 Agenda-Thirteen at this local, individual level, as the amount of active energy needed to expend on attaining future indoor thermal comfort with its attendant carbon emissions would be reduced. This is in agreement with the global priority for the compelling need to reduce the effects of global warming through reduction in the greenhouse gas emissions at local individual level, and collectively at the global level (Kirimtat et al., 2016: EU, 2013). By focusing on energy efficiency in buildings, energy consumption can be reduced. This is also applicable to the amount of CO2 emissions into the atmosphere as each kWh of energy saved prevents the emission of 680.39 g of carbon dioxide, 5.67 g of sulfur dioxide, and 2.27 g of nitrogen oxide ((Littlefair, Ortiz & Bhaumik, 2010; Dubois, 2001; Lancashire and Fox, 1996). In accordance with the set European Union target, a reduction of at least 20% below 1990 levels in domestic greenhouse gas emissions must be achieved by 2050 (EU, 2013; Kirimtat et al., 2016). Hence, the need to direct efforts towards reducing greenhouse gas emissions at every relevant level of building construction process. Thus, in view of the critical role played by window units on the energy demand of buildings, efforts should be intensified to reduce the building energy consumption (through the window) without affecting the level of indoor thermal comfort in a wide range of climatic conditions particularly, the tropical region in this context.

IV. CONCLUSIONS

Tropical buildings consume large quantities of energy particularly, towards cooling interior spaces, consequent upon solar gains through the fabrics of the building envelope (inclusive of the wall, window, door. roof, etc.). In particular, it is established that 30% of the energy consumption through heat loss in a building as well as huge energy consumption of cooling-dominated rooms in hot climates arising from excessive heat gain are attributed to windows. These have consequential impacts on the building energy efficiency. Thus. one of the approaches to address this challenge is through proper building design, and selection of building envelope and its components. Apart from the location and proper orientation of the building, the issue of thermal comfort could be costly to handle at a later stage, if attention is not paid to the choice of the appropriate material selection at the building design stage. Thus, this study, through simulation-based approach has demonstrated the beneficial impacts of adoption of double-glazed windows (as an appropriate building envelope component) in reducing both early morning and evening indoor solar gains into the building, which otherwise induce indoor thermal discomfort. This is a sustainable approach at the design stage which minimizes future active energy sources necessary to attain additional indoor thermal comfort for the potential occupant. This research aligns with the United Nations Sustainable Development Goal-2030 Agenda-Thirteen (13) which emphasizes the need to reduce carbon emissions, for sustainable healthy, safe and comfortable global environment.

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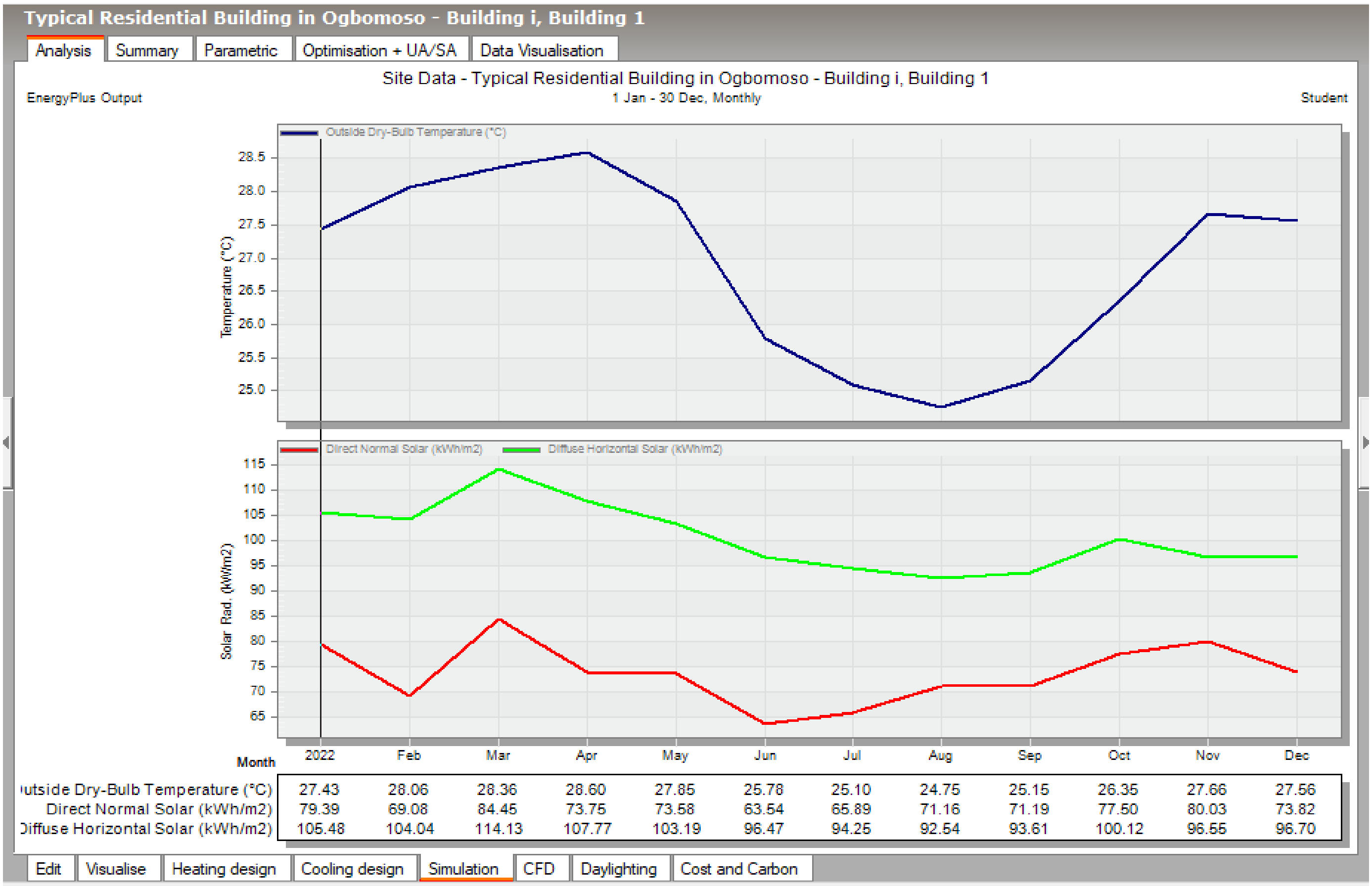
APPENDIX I:

Details of the Site Data simulation output (including Outside Dry Bulb Temperature and Solar Radiation (involving both direct and diffuse) as obtained directly from *DesignBuilder* interface



Site Data - Typical Residential Building in Ogbomoso - Building i, Building 1
1 Jan - 30 Dec, Monthly

Month	2022	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
utside Dry-Bulb Temperature (°C)	27.43	28.06	28.36	28.60	27.85	25.78	25.10	24.75	25.15	26.35	27.66	27.56
Direct Normal Solar (kWh/m2)	79.39	69.08	84.45	73.75	73.58	63.54	65.89	71.16	71.19	77.50	80.03	73.82
iffuse Horizontal Solar (kWh/m2)	105.48	104.04	114.13	107.77	103.19	96.47	94.25	92.54	93.61	100.12	96.55	96.70