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Analyzing the Daylight Performance and its Impact on the Energy Consumption Rate of Selected Yeka Abado Condominium Buildings

Mehret Ayalew

College of Architecture and Civil Engineering, Addis Ababa Science and Technology University

Abstract: ***Adequate daylight is an* implicit element for the indoor environment, which is an asset to health that lowers depression, ensures the occupant's thermal comfort, maintains the room's functionality, creates the desired environment, and reduces the energy consumption rate. The study focuses on *assessing daylight performance and its influence on artificial light usage in buildings. This research-based on survey analysis, building performance simulation, cross-checking method, and secondary data review and analysis. The study was carried out on the sunny season of the location to assess and experience the lighting performance. The study has shown that dominant houses/rooms have daylight complications including insufficient performance, sometimes overpass the acceptance range and confirmed its impact on the electric light consumption. The result also shows that the available daylight in the buildings influenced by the urban context, building form, orientation, and the fenestration design. To improve the natural light performance having a daylight strategy is essential with the evaluation technique at the early designing stage. Appropriate passive and active design strategies are also recommended.***

Keywords: Artificial Lighting, Daylight, Daylight prediction, Energy Consumption, Multistory Residential buildings

1. Introduction

People spend most of their time performing various activities in the environment inside a home [1]. Many researchers have proven that proper and sufficient natural light creates wellbeing and comfort for the indoor space, but in reverse insufficient daylight may cause physiological and psychological problems [2].

2. Problem Definition &Objective

Advanced and adequate daylight relates to the building codes and technologies. In most cases, it is complicated for undeveloped countries to reduce the energy consumption due to the potential to access the reference standards, recommended lighting, recent innovated technologies, and building elements as standard [3]. In most Addis Ababa buildings, windows are designed with improper size, orientation, and arrangement that penetrate inappropriate natural light in the building/room. This makes most building's indoor environments to be tedious and less functional space [4]. As common as other third-world countries, Ethiopia has less access to advanced technologies, advanced materials, and appropriate standards, these affect the goal to provide adequate daylight in the buildings. In such a platform, designers use their thoughts and principles to achieve the desired daylight, and the trend to consider the natural light and able to do daylight performance prediction at the early design stage is rear. So, in the condominium buildings, there are natural light fluctuation and complications, which affects the occupant's visual comfort, thermal comfort, artificial light usage, and energy consumption rate.

The main objective of this study is to investigate the selected Yeka Abado condominium buildings' performance concerning daylight sufficiency and its impact on energy consumption. This helps to recommend a possible solution for the perceived failures and limitations.

3. Daylighting

Sufficient light fits with the task and given area of the building/room. Lighting for an indoor environment needs to be presented as more than just illuminate. Lighting quality doesn't just address an appropriate light quantity but also illuminance uniformity, proper luminance distributions, appropriate light color, minimize glare, and energy-efficient with advanced lighting characters [5]. Basically, it's challenging for the designers to admit the light necessity to distribute evenly and fairly without creating glare or too much heat in the building/room [6]. Light can define and renders the space, form, and indoor bounded area.

The factors affecting the daylight performance are the building orientation, type of windows, type of glass, and position of the sun. Standards have also identified that natural light affects the energy consumption rate of the building by 20% due to the building orientation especially when windows face east or west direction. The window design determines light quality and quantity penetrate in the room. Window types also matter tothe light appearance and the vision in the room and also the energy-performance character. The sun position (true altitude and azimuth angle) and the geographic location decide the available sunlight that directly influences the amount of natural light in the building/ room [7]. Lighting in the multistory residential building has several factors including people's expectations, past experiences of light, and cultural aspect of light [5].

4. Artificial Lighting

The smartest and cost-effective way of utilizing energy in buildings is replacing artificial light with natural light. This contributes to reducing one-third of the energy consumption

[8]. That being said, artificial light and natural light have inseparable relation, which depends on one another. Artificial light mostly consumed during the nighttime and it is also used to create the desired mood in an indoor space. But the artificial light consumption trend sometimes misses the purpose by using the light during the daytime and these most likely happens when the natural light is insufficient in the space. These trend violates the energy efficiency code and lets the building consumes unnecessary energy.

5. Lighting Standards & Measurements

As LEED states, in a computer simulation, the spaces should achieve daylight illuminance levels of a maximum of 50 fc or 540 lux and a minimum of 25-foot candles (fc) or 270 lux in a clear sky condition. Areas with illuminance levels below/above the range do not comply [9].

The recomandeed daylight illuminance level varies based on the room function. Living room, kitchen, bedroom, and Home office function with an average of 300-450 lux is appropriate but the maximum and minimum value can differentiate for general and task purpose. The bathroom, laundry/utility, and hall require less lighting level, which 150-300 lux would be appropriate [10].

As Addis Ababa city municipal construction Bureau revised standard (2010 E.C) specify at 7.2.2.4/ u, the window opening's area should at least be 15% of the room's area, which is the window to area ratio (WTA) [11].

Light can be measured using several instruments and tools, then aphotometer and light meter are the common tools to measure light. Photometry is the science of measuring light by using a photometer, in terms of the perceived brightness by the human eye. A photometer is a tool to measure light intensity [12].Light meter (lux meter) determines the light conditions [13].Since light can be measured through several methodologies, measurements, and tools, then the units in the measurement can be foot candles, candles, lumens, and lux[14]. Light can also be predicted using a building performance simulation system.

6. Methodology Study

a) Description of the case study

The study was conducted on Yeka Abado condominium compound in Addis Ababa, Ethiopia. The compound includes more than 480 buildings including the condominium and communal buildings. The study was focused on two condominium building typologies, which are the S7 and L2 buildings in the compound. The S7 building typology has eight stories and functions as a multistory residential building. The L2 building typology has five stories and function the same as the S7 building. Both building typologies have central circulation and only used staircases for vertical circulation. The finishing materials are the double-glazed window, Hcb block for partitions, and external wall then plastering and painting finish.DSF has the ability to reduce energy consumption by penetrating sufficient natural light and improve internal thermal conditions [15].

b) Study Design

The study is a formative or exploratory study that first analyzes the daylight sufficiency in Yeka Abado condominium buildings and its influence on the energy consumption rate in the houses/buildings toclarify the nature of the problem that can formulate more precise questions that future research answer. This study design used both qualitative (phenomenological paradigm) and quantitative (positivistic paradigm) data collection techniques. The research study focused on the daylight performance considering the local microclimate, building orientation, building form, room arrangement, neighborhood design, and fenestration design.

For this study, the researcher used several assumptions based on the pilot study of the case buildings and literature. There are factors affecting the daylight performance that assumed as similar in the houses by dwellers and the factors include the people's expectations, past experiences of lighting, and cultural aspect[5]. This study conducted with the building form, neighbor design, orientation, and the buildings' fenestration system as a controlled factor

c) Study Population and Sampling

The study population in this paper is the dwellers in the selected Yeka Abado condominium buildings. The case buildings were selected by using stratified and random sampling methods. The researcher categorizes the S7 and L2 buildings using their orientation (as North oriented, East oriented, West oriented, and South oriented buildings), then four buildings selected from each category per typology. So a total of eight buildings were selected using stratified sampling to do the survey analysis. Random sampling was used to select one building from both typologies for the BPS and cross-checking method and also to select the households/occupants for the survey analysis. The finite sampling size calculation method is used to specify the study size for the survey analysis.

A total of 193 occupants/households were selected from the total 348 occupants in the eight selected buildings.

The study period for the survey was selected based on the climate of the location, which is the season that the location receives the highest sunlight throughout the year. The study was conducted from Feb 4-May 28, 2020.

d) Data Collection Tools, Materials, and Methodologies

To carefully investigate the daylight sufficiency in the selected buildings the study used three methodology techniques, which are the Survey analysis, building performance simulation, and the cross-checking method. Data were collected from the selected buildings and the compound. The secondary data collected to use on the theoretical part, building code, standards, and policies regarding the specific topic. The secondary data collected from researches, books, and journals. Architectural drawings and documents have also been collected from the Yeka Abado project office, other governmental, and non-governmental offices.

The survey analysis completed using technology to collect the questionnaire data while preventing the covid 19 spread.

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The questionnaire surveys were used to identify the occupant's overall evaluation of the daylight sufficiency and its influence on the artificial light and energy consumption rate. To do the building performance simulation method architectural drawings and EMP file of Addis Ababa (weather data) has been used. The BPS method also used software to do computer-based simulation system and this method used the standard and recommendation by the software, LEED (2014) and Chris Adams (2014). The cross-checking method used the local standard set by Addis Ababa City Administration Construction Bureau (AACACB).

e) Data Analysis and Interpretation

The data collected from the questionnaire were organized by using Excel software and analyzed by SPSS. BPS used Revit software and Ecotect analysis. The cross-checking method has done by calculating the wall to area ratio of each room in the building.

7. Analysis and Result

a) The daylight sufficiency assessment

The natural light problem has poked by 66.4% of the inhabitants and only 33.6% don't feel the daylight problems. From the occupant that agrees with the existence of the natural light problems, 55.9% of them mention the fenestration design (window opening design) complication for the daylight problems. Other 42.9% and 1.2% inhabitants notify the building orientation problem and the surrounding environment influence (local climate) respectively as shown in Figure 1below.

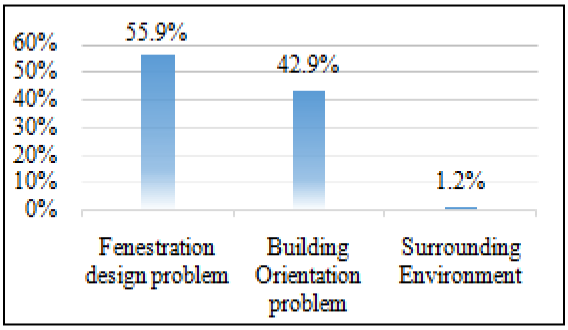

Figure 1: Mentioned reasons for the natural light problem

The daylight sufficiency assessment shows the majority of the occupants, which are 45.3% experience insufficient daylight in their house, the other 33.4% of inhabitants respond as the daylight is sufficient. Neither sufficient nor insufficient, strongly sufficient daylight and no daylight available has responded by 11.2%, 6.9%, and 3.2%occupants respectively. So, the dominant dwellers mention that their house doesn't receive as adequate natural light as it should be (refer to Figure 2).

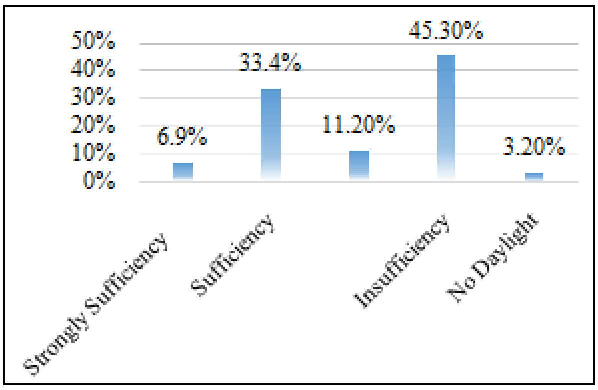

Figure 2: Daylight adequacy assessment

b) Artificial light usage during the daytime

The study has figured out that 52.3% of the occupants use artificial light in one of the rooms in their house during the daytime. Only 47.7% of the occupants don't use artificial light during the daytime. As the analysis shows the occupants in S7 buildings consume more artificial light (refer to Figure 3).

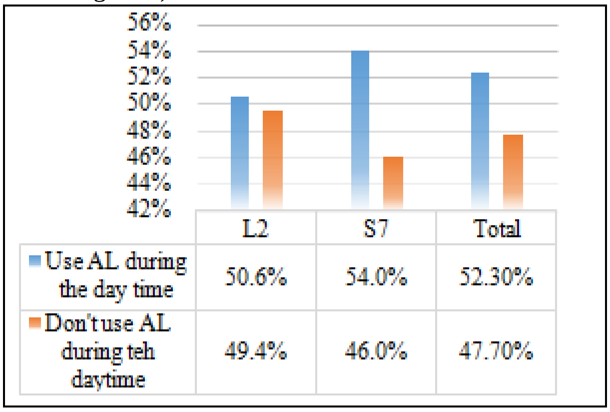

Figure 3: Artificial Lighting usage at day

The occupants consume energy using equipment and utilities, so 43% of the occupants use and consume the dominant energy for lighting primarily, then40.3% of the occupants use a home appliance in second place, in third place by 13% using other technologies that require energy, and only by 3.5% rate the occupants use and consume energy for HVAC (Heating, Ventilation, and Air conditioning) as shown in Figure 4 below. Based on the study done in southern Europe, the energy consumption rate is high due to the extensive use of HVAC and air conditioning devices especially in the summer period [16]. But based on this study, the occupants consume the highest consumption rate for artificial lighting, but using HVAC and other air conditioning is rare due to the trend and the local environment.

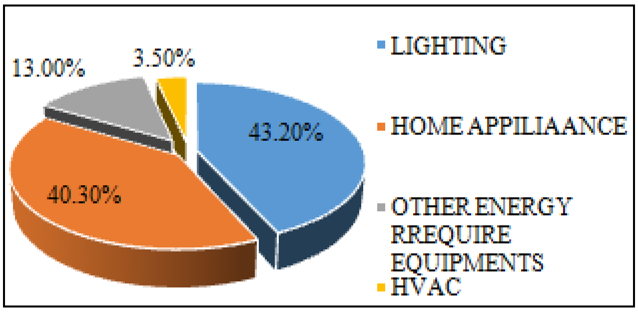

Figure 4: Equipment and Utilities for the dominant energy consumption rate

c) Incidence Solar Radiation of the S7 Building Typology (BPS Analysis)

Building number 280 has been picked to do the building performance simulation analysis. The building Orient at North-West direction at 302º (refer to Figure 5 and Figure 6).

Figure 5: The sampled S7 building's plan and orientation

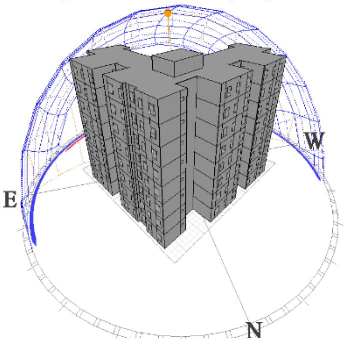

Figure 6: S7 building's 3D with orientation

Due to the building orientation and building form, 40.50% of the windows expos to sufficient sunlight. The dominant fenestration, which is 55.5% of the window openings expose to insufficient sunlight. 4% of the window located inside the building, which is considered as no solar exposure (refer to Figure 7 below).

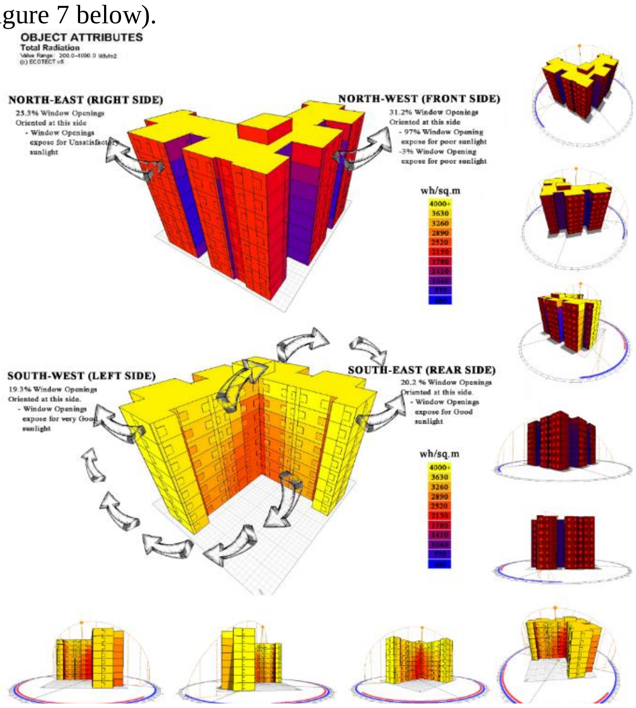

Figure 7: S7 building's incidence solar radiation

On the block that the study has undertaken, the space between the S7 buildings is on average 6 meters but space/gap within other buildings fluctuates slightly. Due to the building form, height (G+7 building), and the spaces between buildings, most buildings are influenced by a shadow effect that has created one to another. Several rooms/houses (especially from the ground until the third floor) expose to less daylight due to that sunlight blockage by the neighbor buildings especially in the afternoon (refer Figure 8 and Figure 9 below).

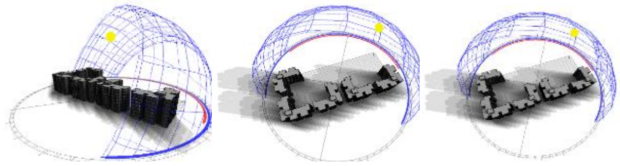

Figure 8: Urban context, building's form and shadow effect on S7 building

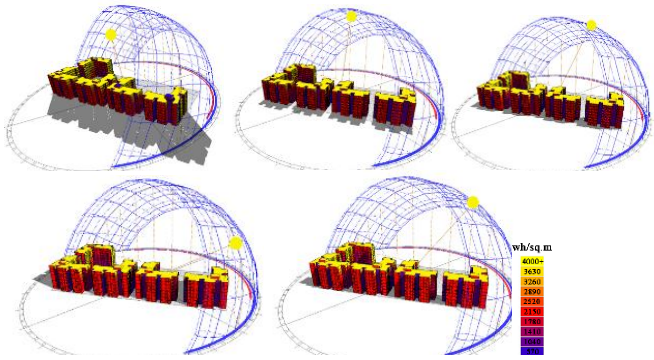

Figure 9: Urban context and shadow effect in the time variation

d) Daylight Analysis of the S7 building typology

Based on the BPS, 39.09% of the rooms get sufficient daylight with 300– 450 lux, and the bathrooms that have 100-150 lux are considered as it experiences sufficient daylight due to the recommended illuminance level (refer to Figure 10 and Figure 11 below). Almost 60.91% of the rooms experience inadequate daylight including the common rooms with less than 300 lux in A.V and the bathrooms with less than 150 lux on average as it gets insufficient daylight based on the standard.

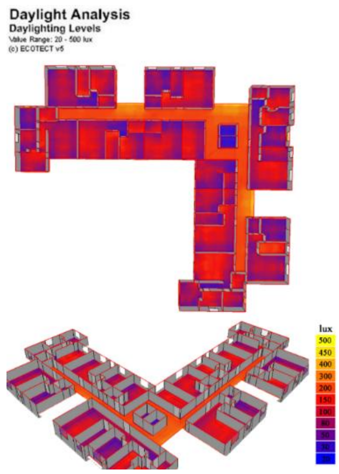

Figure 10: The S7 building's daylight analysis

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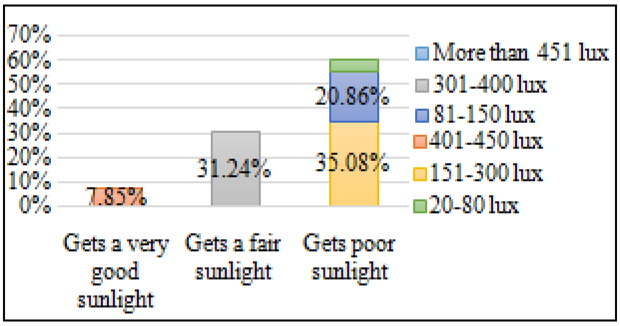

Figure 11: S7 building's illuminance value (lux)

e) Incidence Solar Radiation of the L2 Building Typology

The L2 building selects for the building performance simulation analysis is building number 167. The building was orientated at North -East, 23° (refer to Figure 12 and Figure 13).

Figure 12: Sampled L2 building's plan and orientation

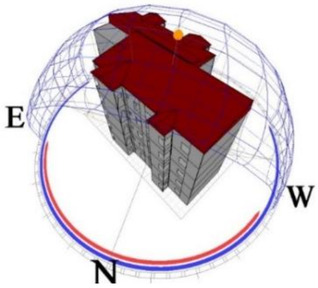

Figure 13 : L2 building's 3D with orientation

Based on the orientation and building form, 61.88% of window openings expose to insufficient sunlight, then only 38.12% of the window openings expose to sufficient sunlight as shown in Figure 14 below.

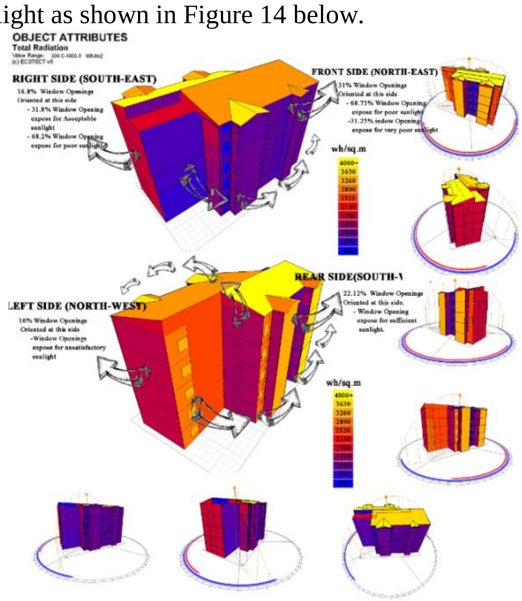

Figure 14: L2 building's incidence solar radiation

The L2 building block selected for this study has an average 12-meter gap/space between the buildings, but the gap/space fluctuates. There is also a room in the building that didn't receive daylight as much as it was supposed to due to the sunlight blockage by the neighbor buildings, but it's much rare compared to the S7 building typology. Somehow, the L2 building has neighbor building's shadow effect, but mainly the buildings face a shadow influence that has created by its own building's surfaces (refer to Figure 15 and Figure 16).

The G+11 building space gap should be 6.1 times larger than the space for the G+4 building [8]. But in the Yeka Abado condominium compound, the space/gap between the S7 buildings (G+7) is smaller than the gap in the L2 buildings (G+4).

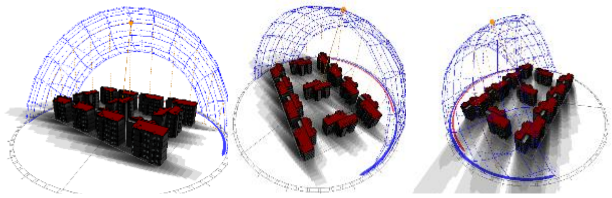

Figure 15: Urban context, building's form and shadow effect on L2 building

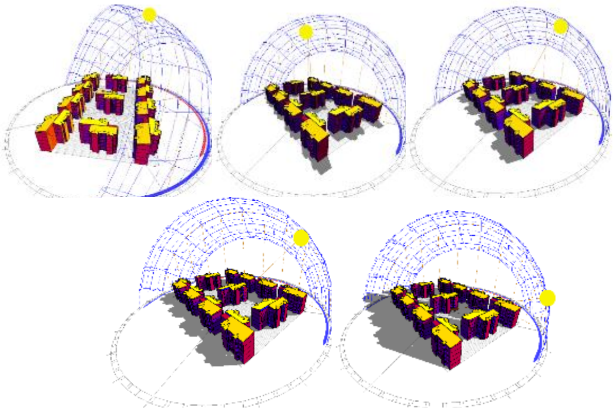

Figure 16: Urban context, building's form and shadow effect in time variation

f) Daylight Analysis of the L2 building typology

The sampled L2 building include 44.17% of rooms that get sufficient daylight, which include the common room with 300-450 lux and the bathrooms that get 100-150 lux. Almost 55.83% of rooms get insufficient daylight including the common rooms with less than 300 lux and the bathrooms with less than 150 lux. Commonly the corridors and the smallest rooms with larger openings get better daylight (natural light). So, the dominant room in the building gets less illuminance level than the recommended illuminance as shown in Figure 17 and Figure 18 below.

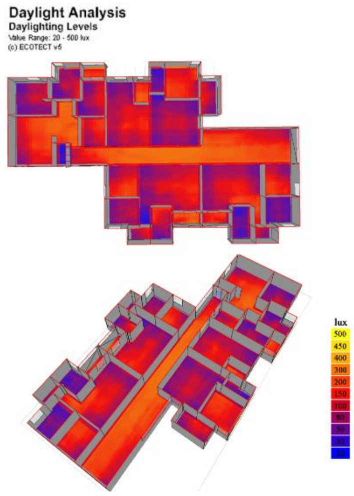

Figure 17: L2 building's daylight analysis

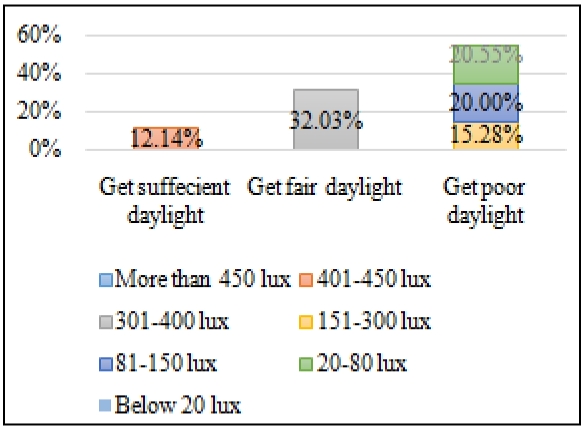

Figure 18: L2 building's illuminance value (lux)

g) S7 and L2 Buildings window to wall ratio

The 62.5% of the room in the S7 building, which is almost 25 rooms per floor or 200 rooms per one S7 building fail to obey the WTA ratio set by AACAB. Only 37.5% of the rooms, which is only 15 rooms per floor or 120 rooms per one S7 building successfully obey the WTA ratio by having the window area as more than 15% of the room area (refer to Figure 19).

Based on the analysis 54.54% of the room in the L2 building, which is almost 12 rooms per floor or 55 rooms per one L2 building fail to obey the window opening standard set by AACAB. The rest 45.45% of the room, which is 10 rooms per floor or 50 rooms per one L2 building pass by successfully obeying the opening standard (refer to Figure 20).

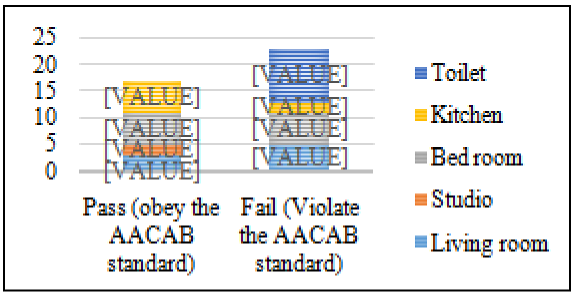

Figure 19: Rooms in S7 building that pass/fail to obey AACAB standard

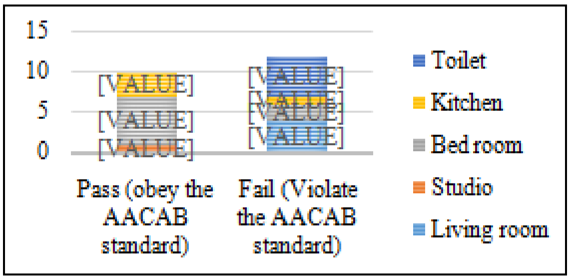

Figure 20: Rooms in L2building that pass/fail to obey AACAB standard

8. Conclusion

From the current study, using a series of field studies carried out for almost 4 months from Feb-May 2020, building performance simulation and cross-checking system using AACACB standard to analyze the building performance, in terms of daylight sufficiency and its impact on the artificial light usage. Basically, the buildings locate in an area that gets 7 hours and 10 minutes sunny hours per day on average throughout the year with 174.32 watts per meter square on average. So, the micro-climate analysis shows that the location is exposed to sufficient sunlight. The field studies and survey result showed that most of the inhabitants found the available daylight not to be sufficient especially the occupant in S7 buildings. The study has figured out that 52.3% of occupants used artificial light during the daytime at least in one of the rooms in their house. In S7 and L2 buildings, only 39.5% and 38.12% of windows exposed to sufficient sunlight respectively, then the rest 56.5% and 61.88% windows have oriented and placed in less sunlight exposed building's surface in S7 and L2 buildings respectively. The daylight analysis has also shown that only 39.09% and 44.17% of rooms get sufficient illuminance level in the S7 and L2 buildings respectively with 300-500 lux for the common rooms and 15-300 lux for the Bathroom. But the rest 60.91% and 55.86% rooms experience insufficient illuminance in S7 and L2 buildings respectively with less than 300 lux in A.V in the common rooms and less than 150 lux in the bathroom. Based on the local standard set by AACACB, 62.5% and 54.54% of the rooms in S7 and L2 buildings respectively violate and don't follow the opening standard. Only 37.5% and 45.45% of the rooms in S7 and L2 building respectively obey the local window opening code.

Generally based on the study analyses result the main finding can be summarized as follows:

- The building has a daylight problem including daylight insufficiency (lighting quantity), light quality (mainly unbalance light distribution), natural light fluctuation through seasons, and sometimes excessive daylight especially in the rooms/houses that orient at the south-west direction.
- The fenestration design in both buildings can be characterized as, some of them set as just an idle, small and inappropriate, exposed for secondary light, large and inappropriate due to the orientation and room's size, and there are also windows that affect by the neighbor building's shadow.
- The window openings has designed in a common arrangement and size in both building typologies and

even in different orientations, these design consideration affect the consistency of daylight in each condominium houses that directly affects the potential to access to sufficient daylight quality and quantity.

- Based on the study, the S7 buildings has more daylight problems than the L2 buildings, which is due to the room arrangement, building form, and space suffocation. The artificial light usage has also noticed more on the S7 buildings.
- The space between buildings fluctuates with unknown concern and also violates the concept of having a large space/gap for buildings with more stories.
- The Yeka Abado condominium building's daylight performance doesn't have a significant influence from the local climate (available sunlight) but instead from the urban context, building form, orientation, and fenestration design.
- Daylight strategy and the building performance simulation doesn't commonly use to achieve the daylight goal, to analyze the building performance, in the early designing stage.
- Based on the study, the daylight performance influences the artificial light usage during the daytime that directly affects the electricity expense and the energy consumption rate of the building.

Abbreviation

AACACB, Addis Ababa city administration construction bureau, A.V, average, BPS, building performance simulation, HCB, hollow concrete block, WTA, wall to area, AL, Artificial light, DSF, double skin façade.

Competing Interests

The author declares that there is no competing interest.

Consent for Publication

Not applicable

Ethics Approval and Consent to Participant

Not applicable

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Author Profile

Mehret Ayalew, Bsc, Addis Ababa Science and Technology University,mersigirma[at]gmail.com.

Daniel Sokido, Ph.D, Ethiopian Civil Service University, (Corresponding Author) danlir2007@yahoo.com,danlirsokido[at]gmail.com.