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Thermal Comfort in a Residential House in Kampala

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Abstract: Global warming and climate change has been a challenge in the last decades. Buildings are major contributors to energy consumption. This is due to the rise in human comfort needs and services. The residential sector consumes a significant amount of energy worldwide. A NZEB strategy emphasizes closing the gap between energy demand and renewable energy supply. Despite some of the roles that NZEBs significantly contribute to smart cities on the energy efficiency, the potential contribution of NZEB to the residential sector of Uganda has not been documented in literature. The objective of this study was to develop a thermal comfort model in a residential house through an envelope design. CBE tool was used and results indicate; PMV with elevated air speed of residential houses during resting hours in Kampala; at night: -0.75. DBT as 24.1°C, PPD as 17%, the Cooling effect as 2.7°C and SET = 26.3°C. The study realized factors to be considered while building like; air temperature, average radiant temperature, air speed, air humidity. The model developed in this study enables a building to heat up during cold hours and cool down during hot hours by the help of the water pool collected during rainy days. This water cools down the house during the day time while absorbing heat that can be released during the night hours that are somehow cold in Kampala. However, if this isn't considered, then heat pumps have to be employed to pump heat into rooms to reduce heating in rooms. Recommendations should be put in raising thick walls and ceilings to maintain building temperatures.

Keywords: Net Zero, Energy, Buildings, Predicted Mean Vote

1. Introduction

Global warming and climate change are increasing issues since the last decades. Commercial and residential buildings are major contributors to energy consumption [42]. Energy consumption significantly increases on a yearly basis due to the rise in human comfort needs and services [56]. The residential sector therefore, consumes a significant amount of energy worldwide. By the year 2030, the energy demand in buildings is expected to increase up to 50% [54]. There is need to use net zero energy strategies for the residential sector in order to close the gap between energy demand and renewable energy supply [46]. Net Zero Energy entails that the total amount of energy used by a building is equal to or less than the amount of renewable energy created on-site. Net zero energy does not increase the amount of greenhouse gases in the atmosphere [44]. The wording "Net" emphasizes the energy exchange between the building and the energy infrastructure [47]. By the building-grid interaction, the National Nearly Zero-Energy Buildings (NZEBs) become an active part of the renewable energy infrastructure. According to the US department of education 2015, the main advantages of Nearly Zero Energy living (NZE) at the beneficiary level is the low cost of utilities, whereas the strategic advantage is obviously related to the much lower environmental impact. Additionally, when implemented at the community level, the NZE concept improves energy security and resilience against power outages and natural disasters. NZE plays a vital role for sustainable energy utilization, energy security and being environment friendly [31].

Wide acceptance of zero energy technology may require more government incentives or building code regulations [15]. The Canadian R-2000 and the German passive house standards have been internationally influential. Using standard building techniques and energy cost modelling, zero energy homes can be very affordable to build [13]. Zero net energy has unprecedented potential to transform the way buildings use energy. This ultra-efficiency goal is one that the owners can define and design teams to reach occupants desires. An increasing number of buildings are meeting this standard, raising confidence that a ZNE goal is realistic given current building technologies and design approaches [67].

Net Zero Energy buildings are common for commercial and residential sectors with different applications from the energy generated in each sector. Productive use of energy can be defined as the processing of energy generated as an input so as to effectively be used and stored as electrical energy. The productive uses in the commercial sector are predominantly lighting, air-conditioning and powering office machines and devices. Net zero energy offers a range of productive uses to the household sector ranging from heating of domestic water, heating and cooling to achieve thermal comfort of people, powering electrical appliances and laundry [36]. However, the role of Net zero energy building on such productive uses in the household sector of Uganda has not been quantified. It is therefore important to study, analyse and implement the net zero energy strategies that contribute to the reduction of subsequent energy costs arising from grid consumption which inhibit the productive uses of energy in the household sector.

2. Methods in Data Collection

2.1. Thermal Comfort

Understanding thermal comfort is important to architecture, as it does not only lay the foundation for building design but also affects the field of sustainable design. Contemporary Models of thermal comfort recommend that a narrow temperature range be applied equally across all building types, climate zones and populations [32]. Research shows that comfortable occupants are more alert, have better energy levels and use fewer sick days, which translate to more productive and satisfied employees [45]. The six variables that drive occupant thermal comfort are illustrated in figure 1;

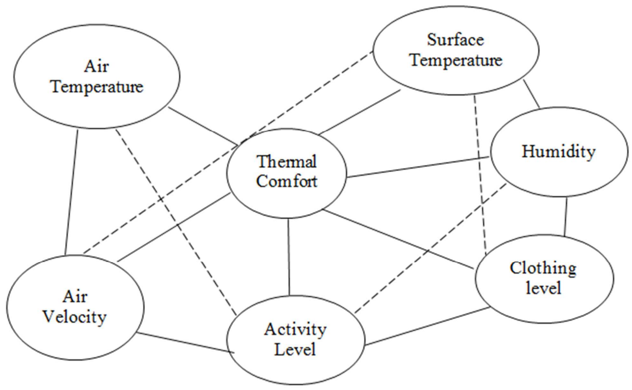

Figure 1. *Six Variables in thermal comfort.*

2.1.1. Physiological Basis of Thermal Comfort

The human body continuously produces heat. This heat is due to metabolism and divided into two kinds; Basal metabolism, which is due to biological processes which are continuous and non-conscious, plus muscular metabolism, which is consciously controllable (except shivering) [8]. Balbis et al studies indicate that a suitable thermal environment for classrooms in colleges and universities impact thermal comfort, learning performance and the building energy consumption [12]. [8] studies indicate the metabolic rates for the different activities of persons as highlighted in table 1.

Table 1. *Metabolic rates for different activities of persons.*

S. No	Activity	Met	W/m^2	W (av)
1	Sleeping	0.7	40	70
2	Reclining, lying in bed	0.8	46	80
3	Seated, at rest	1.0	58	100
4	Standing, sedentary work	1.2	70	120
5	Very light work (shopping, cooking, light industry)	1.6	93	160
6	Medium light work (house, machine tool)	2.0	116	200
7	Steady medium work (jackhammer, social dancing)	3.0	175	300
8	Heavy work (sawing, planning by hand, tennis)	6.0	350	600
9	Very heavy work (squash, furnace work)	7.0	410	700

The heat produced is dissipated to the environment, or a change in body temperature will occur.

The body's heat balance can be expressed as;

$$M \pm R \pm C_v \pm C_d - E = \Delta S \text{ (W)} \quad (1)$$

Where M is the metabolic rate, R is the net radiation, E is the evaporation heat loss, C_v is the convection, C_d is conduction, ΔS is the change in heat stored.

2.1.2. Individual Dissatisfaction

The occupant comfort (satisfaction) is modelled by a method inspired by Fanger's PMV and PPD [10]. The degree of Individual Dissatisfaction (DID);

$$\text{DID (vote)} = \frac{1+\tanh(2|\text{vote}|-3)}{2} \quad (2)$$

Where an individual's vote is a function of the surrounding indoor temperature (T) and two parameters describing the individual's preferences; T_0 , the desired individual temperature, and ΔT, the individual's temperature tolerance, namely: [9]

$$\text{Vote(T)} = \begin{cases} +3, T > T_0 + 2\Delta T \\ -3, T < T_0 - 2\Delta T \\ 1.5\frac{T-T_0}{\Delta T}, \text{otherwise} \end{cases} \quad (3)$$

2.1.3. Sensible Heat Loss

Heat transfer from the skin surface to the surrounding air is treated in two sections, i.e. from the skin through the clothing and from the clothing to the environment. The convective heat loss can be expressed in terms of a heat transfer coefficient and the difference between the mean temperature of the outer surface of the clothed body and the environmental temperature;

$$C = f_{cl}\, h_c\, (t_{cl} - t_a) \quad (4)$$

Where C – convective heat loss, W/m^2, f_{cl} is the clothing area factor $= \frac{A_{cl}}{A_D}$, h_c is the convective heat transfer coefficient at clothing surface, W/m^2K, t_{cl} is the mean temperature of the outer surface of the clothed body, °C, t_a is the air temperature, A_{cl} is the surface area of clothed body, m^2 and A_D is DuBois surface area nude body, m^2 [28]. f_{cl} can be found in Table 2 for various clothing ensembles as per [53] studies.

Table 2. *Typical values of clothing area factor.*

Ensemble description	f_{cl}
Walking shorts, shorts-sleeve shirt	1.10
Trousers, short-sleeve shirt	1.15
Trousers, long-sleeve shirt	1.20
Same as above, plus suit jacket	1.23
Trousers, long-sleeve shirt, long sleeve sweater, t-shirt	1.28
Sweat pants, sweat shirt	1.19
Long-sleeve, pajama top, long pajama trousers, short $^3/_4$ sleeve robe, slippers	1.32
Knee-length shirt, short-sleeve shirt, panty hose, sandals	1.26
Knee-length shirt, short-sleeve shirt, half-slip, panty hose, long-sleeve sweater	1.46
Same as above, replace sweater with suit jacket	1.30
Ankle-length skit, long-sleeve shirt, suit jacket, panty hose	1.46

2.1.4. Measures of Comfort

(i). Operative Temperature (OT)

Operative temperature of a uniform, isothermal black enclosure in which man would exchange heat by radiation and convection at the same rate as in the given non-uniform environment, or as the average of MRT and DBT weighted by their respective transfer coefficients [8], i.e.;

$$OT = \frac{h_r MRT + h_c DBT}{h_r + h_c} \quad (5)$$

Where, h_r and h_c are radiation and convection coefficients.

(ii). Dry Bulb Temperature (DBT) and Wet Bulb Temperature (WBT)

DBT is the air temperature determined by an ordinary thermometer. DBT is given in weather reports. Its scale is located at the base of the psychometric chart. WBT reflects the cooling effect of evaporating water. This effect is often used to cool livestock buildings and some homes, and is the cooling process when we perspire. WBT can be determined by passing air over a thermometer that has been wrapped with small amount of moist cloth [57].

(iii). Mean Radiant Temperature (T_{mrt})

T_{mrt} is defined as the uniform surface temperature of an enclosure in which an occupant would exchange the same amount of radiant as that in the actual non-uniform enclosure. This is the most important metrological parameter governing human energy balance. T_{mrt} can be calculated as per Eqn (6) [64].

$$T_{mrt} = \sqrt[4]{S_{str}/a_1\sigma} - 273.15 \quad (6)$$

But

$$S_{str} = a_k \sum_{i=1}^{6} k_i F_i + a_1 \sum_{i=1}^{6} L_i F_i \quad (7)$$

Where S_{str} = mean radiant flux density, k_i= short-wave radiation fluxes (i=6), L_i= long wave radiation fluxes (i=6), F_i= angle factors between a person and the surrounding surfaces ((i=6), a_k= absorption coefficient for long-wave radiation (standard value 0.97) and σ= Stefan Boltzmann constant (5.67 x 10^{-8} $Wm^{-2}K^{-4}$), F_i depends on the position and orientation of the person [23].

(iv). Passive Design, Energy Efficiency, Thermal Dynamics and Comfort

It is important to note the principle categories of building solar heating and cooling systems, i.e. passive and active. Passive systems integrate into the structure of the building technologies that admit, absorb, store and release solar energy, thereby reducing the need for electricity use to transport fluids. On the other hand, active systems include fans and pumps controlled to move air and heat transfer fluids respectively for space heating and cooling as well as domestic hot water heating [8].

2.2. Thermal Identification and Localization

It is important for the design of thermal devices to know how much thermal stimuli need to differ in order to be distinguishable [34]. Studies indicate that the concept of outdoor thermal comfort has been treated as a purely physiological concept for a long time. Thermal comfort is defined as well as the human satisfaction with its thermal environment [41]. Nikolopoulou et al studies questioned this purely physiological approach and opted for a more inclusive, phenomenological approach to the concept of thermal comfort. Nikolopoulou et al work on outdoor thermal comfort showed that other factors like, thermal history, expectations, presence of company and other non-physical factors influence thermal comfort perception [50].

2.2.1. Thermal Comfort Tools

Some of the tools that perform thermal comfort calculations, two of which are also able to visualize comfort conditions; *Climate Consultant;* is an excellent graphics-based, free, stand-alone computer program that helps users understand weather data used for building performance software. *Autodesk Ecotect Weather;* the Ecotect Weather is a flexible and interactive add-on for Autodesk Ecotect that provides the user with visualizations of weather data depending on the location and the 3D model of the building, imported into or created in Ecotect [62].

2.2.2. Classification of NZEBs

Although all attempts to achieve a NZEB are valuable, a NZEB can be classified based on the Renewable Energy supply options used and definitions met [73]. A building that offsets all its energy use from a renewable resource available within the footprint is at the top of the NZEB classification system at a NZEB [74]. A building that achieves a NZEB definition through a combination of onsite renewable and off-site purchases of renewable energy credits is placed at the lowest end of the NZEB classification at a NZEB: D [65]. The classifications system starts with the premise that all NZEBs must first reduce site energy use through energy efficiency and demand side renewable building technologies, including such strategies as daylighting, insulation, passive solar heating, high-efficiency HVAC equipment, natural ventilation, evaporative cooling, and ground-source heat pumps. Classification system breaks down NZEBs into two groups as reported by [16].

2.3. Quantification of Thermal Comfort Needs of the Residential Buildings

Thermal comfort of the people in this study was measured to help offer advice to the various architectural engineers and house designers and enable develop structures that are favourable to the users in the areas of Kampala that later could be adopted as well by other cities and municipals in Uganda. PMV index was used to determine thermal comfort levels of the people of Kampala. The PMV index depended on six factors as noted in chapter two, i.e. the metabolic rate, clothing insulation, air temperature, humidity, air velocity and mean radiant temperature. These key parameters were analyzed to help come up with the overall thermal comfort model which later gave the final value.

2.4. Development of a NZEB Model for a House in Kampala and Improve Its Thermal Comfort

The NZEB model for Kampala was developed through reviewing of literature for successful models developed by [70] and [2] then relating it to the situation in Kampala. The approach included as many energy-reducing techniques as are economically and technically feasible and suitable for this study, then an energy-use analysis for the selected buildings in Kampala was also done to determine consumption, so as to make adjustments needed to get the energy demands as low as possible.

3. Results and Discussion

3.1. Data Analysis

The data analysis of the inputs collected during the energy need assessment was conducted in order to process input data coming from different sources by using a weighed analysis. The analysis considered appropriate sampling weights for the estimated parameters to reflect the probability of sampling households from different sources as well as adjustments for non-response. The data was cross-checked in order to find out discordance for the data.

The different data sources were managed separately to observe dis-aggregate data, then aggregated to obtain final results. The process consisted of four phases as follows;

Data entry and processing: was done to get raw data organized into different data sources, Analysis of raw data, Cross-checking, Aggregation, Thermal needs assessment output for model design.

Table 3*. Energy demands and consumption.*

Respondents	Expenditure on Energy rank (1-4)	Main source of energy (National grid-1, Solar-2, Biomass-3, Gas-4)	Is it easy to access Energy	Most important (cost of energy-1, convenience-2, cost of appliancies-3, health & environment-4)	Expenditure on National grid (UGX)
A	2	1	Yes	2	50000
B	1	1	Yes	1	50000
C	2	1	No	1	50000
D	3	4	Yes	1	10000
E	3	1	Yes	4	100000
F	4	1	Yes	2	50000
G	2	1	Yes	1	100000
H	1	1	Yes	2	10000
I	3	3	Yes	1	50000
J	4	1	Yes	1	50000
K	3	1	Yes	4	50000
L	4	1	Yes	2	50000

Respondents	Expenditure on Energy rank (1-4)	Main source of energy (National grid-1, Solar-2, Biomass-3, Gas-4)	Is it easy to access Energy	Most important (cost of energy-1, convenience-2, cost of appliancies-3, health & environment-4)	Expenditure on National grid (UGX)
M	1	1	Yes	1	50000
N	4	1	Yes	4	50000
O	4	1	Yes	2	50000
P	3	1	Yes	1	50000
Q	3	1	Yes	1	50000
R	3	4	Sometimes difficult	1	50000
S	2	1	Yes	4	100000
T	2	1	Yes	1	10000

Each respondent was asked to fill the questionnaire through an online system and responses were compiled as seen in table 3, Energy expenditure priority ranks third in comparison to other personal needs such as food, education, clothes, health care, religious functions and entertainment of respondents. The main source of energy for the people of Kampala is grid power in comparison to solar that no respondent around Kampala opted for, some respondents consider gas and a few opt for biomass. Most of the respondents have access to grid power, they are more affected by costs of energy followed by convenience of the energy source, health & environment and finally the cost of appliances and most people spend between UGX 10000 to UGX 50000 on power, though other spend less than UGX 10000 and others above UGX 50000.

The graph of consumption choice against the main source of energy used was plotted and it shows that more people in Kampala are connected to the main grid. This is as illustrated in figure 2.

Table 4. *Extract from Energy demands and consumption for the people of Kampala (from table 3).*

Rank of main source of energy	Number of consumes out of 20 respondents
National grid	17
Solar	0
Biomass	1
gas	2

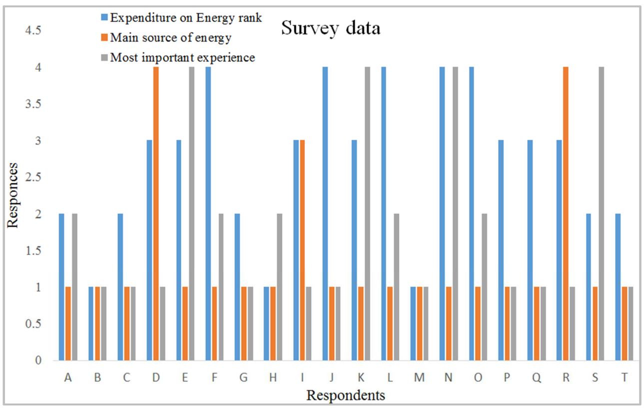

Figure 2. *Expenditure on Energy rank, main sources of energy people use, most important experience and expenditure on national grid against Respondents.*

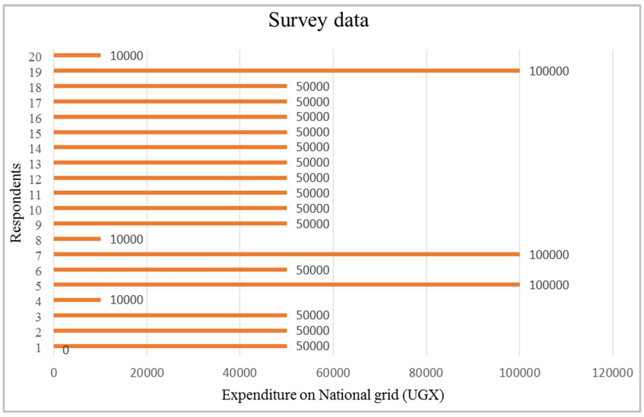

Figure 3. *Expenditure on Hydro power.*

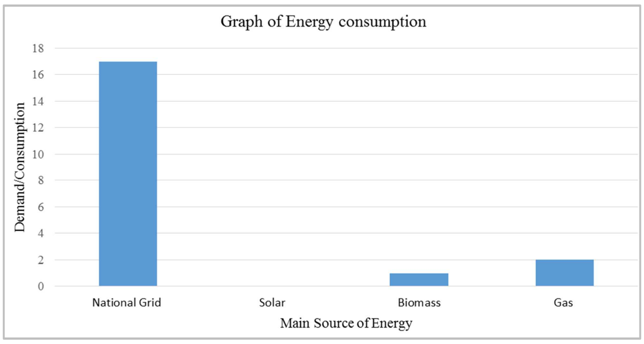

Figure 4. *Energy consumption of the people of Kampala.*

Figure 4 of energy consumption indicates how Kampala residents are connected to the National grid and prefer using this form of energy as compared to other sources of energy available. The people of Kampala do not use solar energy for any of their consumption, but some use biomass for their energy needs like cooking and heating. Other residential consumers of energy in Kampala prefer using gas for their cooking and other heating purposes.

Table 5. *Consideration in energy consumption decisions extracted from Energy demands and consumption for the people of Kampala (from table 3).*

Most important	Rank of considerations
Cost of energy	11
Convenience	5
Cost of appliances	0
Health and environment	3

A graph of different parameters that the people of Kampala consider in choosing a given energy source is indicated in figure 5.

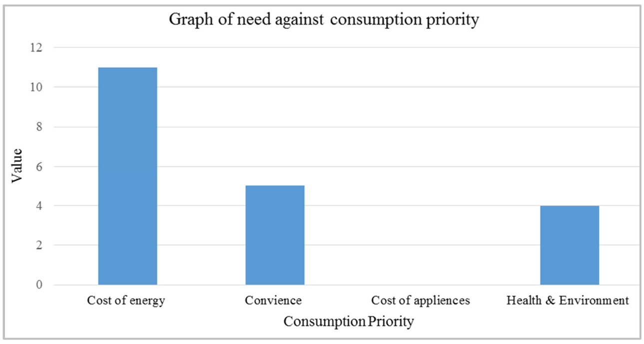

Figure 5. *Priority in consumption by the people of Kampala.*

Figure 5 indicate what the people of Kampala consider as a priority in comparison to others. Cost of energy takes a high part of an individual attention when using any form of energy. This means that the people of Kampala are willing to spend their money on energy though putting much attention on the amount of money they incur in using that form of energy. The convenience of the using a given form of energy also determines how the people of Kampala use given energy. Cost of appliances is not so much considered when prioritizing consumption according to the several respondents of this study. Finally, the people of Kampala are so much sensitive when it comes to their health and the environment they stay in. they are so much concerned with an energy form that is able to conserve the environment where they stay.

3.2. House Hold Energy Consumption in Kampala

The survey results showed: 35% of the interviewed people in Kampala do not support the use of a fan in their houses for thermal comfort, 30% use fans to meet their thermal comfort needs while 35% are not sue whether they need a fan or don't need for their thermal satisfaction. This is demonstrated in the second column of table 6 100% of the respondents support the use of energy saving bulbs to reduce on wastage of power. If electricity bills are reduced, 50% of the respondents believe there will be an increase in consumption, 30% think reduction in power bills won't change their consumption behaviour and 20% were not sure of what will happen in case there is a reduction in the electricity bills.

Table 6. *House-hold Energy consumption in Kampala.*

Respondent	Need a fan? Yes/No	Users of energy savers bulbs, Yes/No	Time when bulbs are on (Nights only-1, night & day-2)	Increase in consumption if electricity costs are reduced, Yes/No	Use of electricity for other purposes (not necessary-1, low extent-2, necessity-3, large extent-4)
A	No	Yes	1	No	3
B	Yes	Yes	2	Maybe	3
C	No	Yes	1	Yes	3
D	Sometimes	Yes	1	Maybe	2
E	Sometimes	Yes	1	No	2
F	Sometimes	Yes	1	Yes	2
G	No	Yes	1	Maybe	2
H	No	Yes	1	Yes	2
I	Sometimes	Yes	1	No	2
J	Yes	Yes	2	Yes	2
K	Sometimes	Yes	2	Yes	3
L	Sometimes	Yes	1	No	3
M	Yes	Yes	2	Yes	2
N	No	Yes	1	No	1
O	Yes	Yes	1	No	2
P	Yes	Yes	1	Yes	2
Q	Sometimes	Yes	2	Yes	3
R	Yes	Yes	1	Maybe	3
S	No	Yes	1	Yes	3
T	No	Yes	1	Yes	3

Extracts from the House-hold Energy consumption in Kampala are as shown in tables 7 and 8.

Table 7. *Time when bulbs are on.*

Time of the day	Rank
Nights only	15
Nights and days	5

Table 8. *Use of electricity for other purposes.*

Purpose level	Rank
Not necessary	1
Low extent	10
Necessity	9
Large extent	0

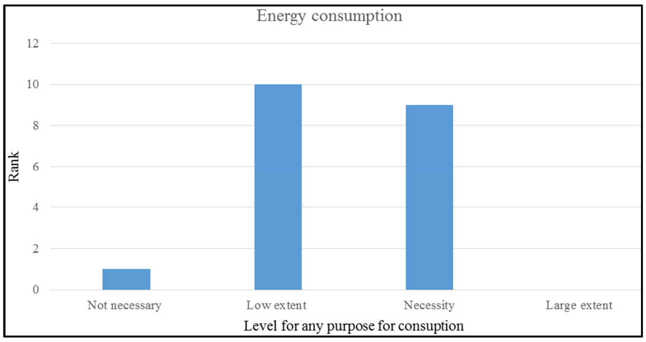

Figure 6. *Energy consumption.*

Majority of the residences of Kampala find it somehow important to use electricity for other purposes other than home consumption (lighting, cooking and running appliances). About 50% of the survey respondents support this, however, 45% see it necessary to use electricity for other applications other than home use. 5% of the respondents do not support the idea of using electricity for other purposes. None of the respondents fully supports this idea.

Quantification of thermal comfort needs of residential buildings in Kampala using Predicted Mean Vote (PMV) index.

Scales for PMV index were established to quantify thermal perception as highlighted in table 9.

Table 9. *PMV index scale and the corresponding thermal perception.*

Thermal perception	Scales
Hot	3
Warm	2
Slightly warm	1
Neutral	0
Slightly cool	-1
Cool	-2
Cold	-3

The thermal comfort index PMV, corresponds to [23] scale and the difference between the heat generated and the heat released by the human body, which corresponds to eqn. (1). However, the model, according to [29] predicts thermal sensations; but, it is tedious to take into consideration all PMV parameters such as clothing insulation, metabolic rate, and the four classical environmental parameters like air temperature, mean radiant temperature, air speed and relative humidity. However, the conditions to help in calculating PMV of Kampala were as per table 10 clothing insulation with an assumption that people in Kampala occupy their residential houses in the night to rest which is derived from table 2 and they sleep in trousers and long-sleeved shirts, the metabolic rate (met) was obtained from table 1 while sleeping as 0.7, and $M(W/m^2) = 58$, while relative humidity of Kampala obtained from [35] studies, the radial temperature of Kampala was obtained from [49].

Table 10. *Climatic conditions of Kampala.*

Month	Relative Humidity at 6 am	Clothing Insulation	Air speed m/s	Air temperature (°C)	Radial temperature (°C)
January	78.27	1.2	2.05	26.78	26.78
February	75.69	1.2	2.05	27.56	27.56
March	79.96	1.2	2.5	27.13	27.13
April	80.63	1.2	2.5	26.20	26.20

The model used in coming up with PMV is illustrated in figure 7.

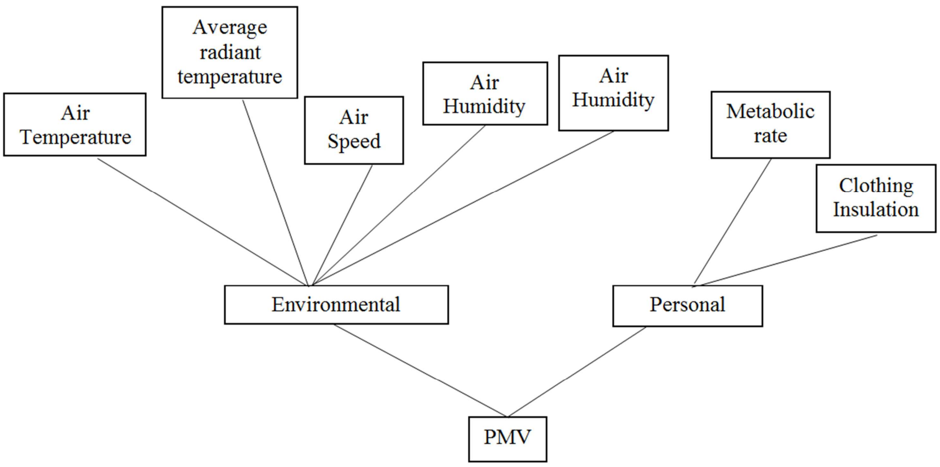

Figure 7. *Parameters used in determination of PMV in relation to thermal comfort.*

3.2.1. Assumptions

1) People spend more time in residential houses at night resting,

2) Wearing trousers and long sleeved shirts.

$$PMV = (0.303\ e^{-2.100M} + 0.028).\ [(M - W) - H - E_c - C_{res} - E_{res}]$$

Where, M – the metabolic rate (W/m^2), W – the effective mechanical power (W/m^2), H – the sensitive heat losses, E_c – the heat exchange by evaporation on the skin, C_{res} – heat exchange by convection in breathing, E_{res} – the evaporative heat exchange in breathing.

The terms H, E_c, C_{res}, and H_{res}, corresponds to the heat exchange between the body and the surrounding environment and are calculated as;

$$H = 3.96 \text{ x } 10^{-8} \text{x } f_{cl} \text{ x } [(t_{cl} + 273)^4 - (t_r + 273)^4] - f_{cl} \text{ x } h_c \text{ x } (t_{cl} - t_a) \quad (8)$$

$$E_c = 3.05 \text{ x } 10^{-3} \, [5733 - 6.99 \text{ x } (M - W) - P_a] - 0.42 \text{ x } [(M - W) - 58.15] \quad (9)$$

$$C_{res} = 0.0014 \text{ x } M \text{ x } (34 - t_a) \quad (10)$$

$$E_{res} = 1.7 \text{ x } 10^{-5} \text{ x } M \text{ x } (5867 - P_a) \quad (11)$$

Where;

l_{cl} – is the clothing insulation, (m^2K/W), f_{cl} – is the clothing surface area factor, t_a – the air temperature (°C), t_r- the mean radiant temperature (°C), V_{ar} is the relative air velocity (m/s), P_a is the water vapour partial pressure (P_a), $t_{cl}$is the clothing surface temperature (°C).

The CBE took this complex formula and translated it into an attractive, graphical tool. By varying the inputs for every variable, a user can find not only the predictive PMV, but also where those conditions fall in the range of comfortable conditions. This tool is key during the design process for the client and design team to experiment with different conditions and get a better feeling for the implication of the design decisions [45].

Therefore, this study utilized the CBE tool developed by ASHRAE for the PMV and generating thermal comfort graphs used in the analysis as recommended by [62]. Results from the tool are as follows, Parameters as shown in table 10 for Kampala were used. Taking February as a reference month when most parts of Kampala experience high temperatures of 27.56°C, the results were run on the CBE tool and results are as per figures 8, 9, 10 & 11.

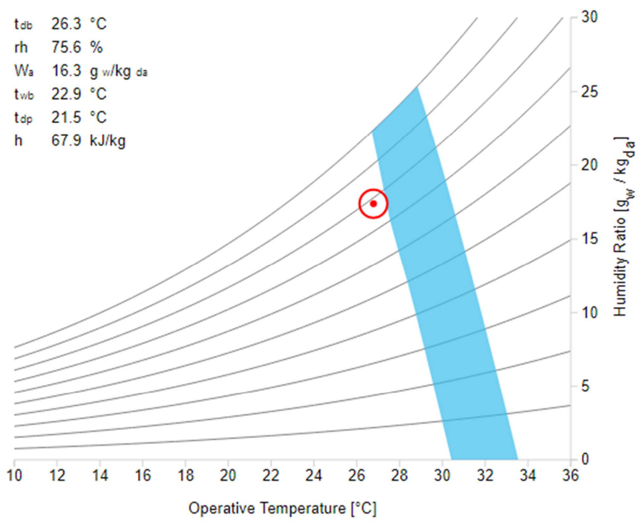

Figure 8. *The psychometric chart (operative temperature °C).*

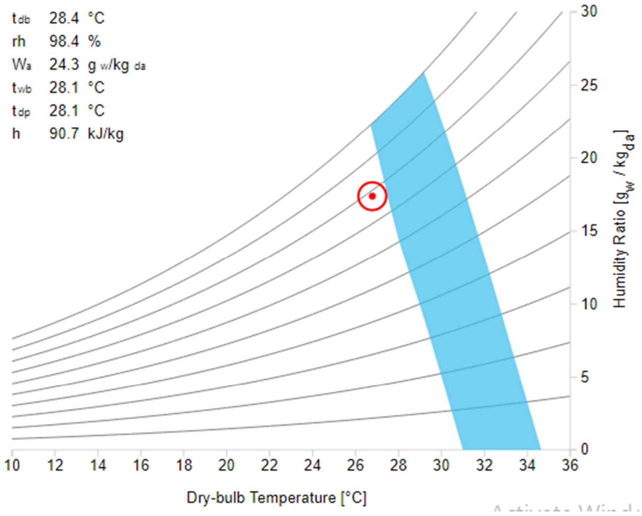

Figure 9. *The psychometric chart (Dry-bulb temperature °C).*

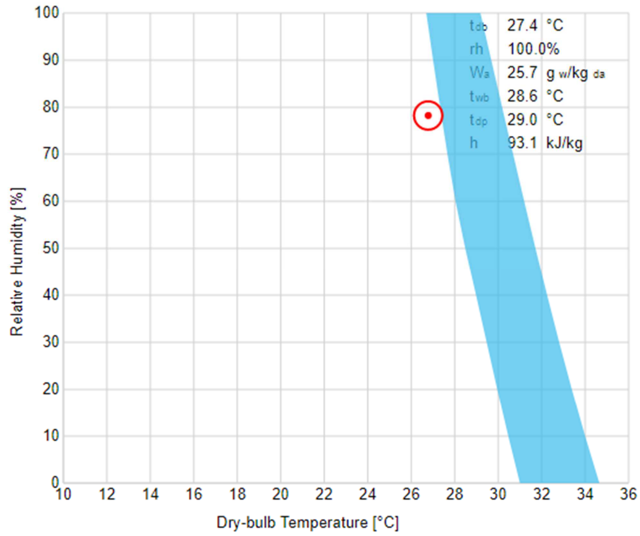

Figure 10. *Relative humidity against Dry-bulb temperature.*

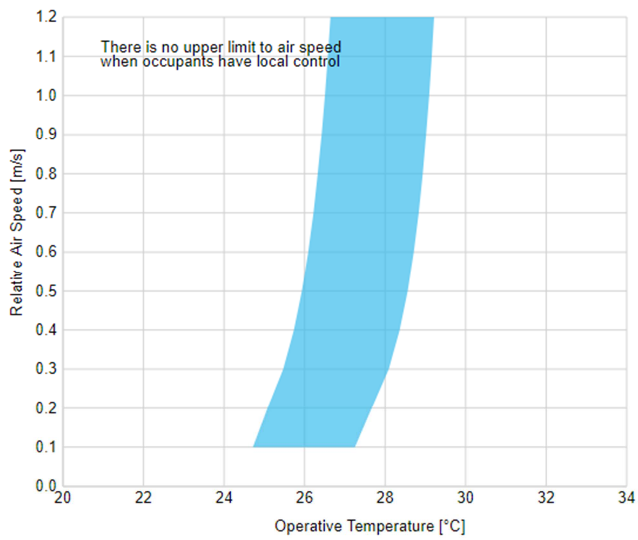

Figure 11. *Air speed against operative temperature.*

3.2.2. Summery

1) PMV with elevated air speed = -0.75
2) Sensation is slightly cool
3) Dry-bulb temperature at still air =24.1°C
4) PPD with elevated air speed = 17%
5) Cooling effect = 2.7°C
6) SET = 26.3°C
7) Since the PMV is between -1 and 1, this means that people feel comfortable leaving in these conditions [22].

3.3. Development of a NZEB Model for a House in Kampala So as to Improve Its Thermal Comfort

Due to the reason of improvement/ reduction in the use of non-renewable energy, the study with theoretical and experimental approaches operated on;

Development of innovative solutions aimed at reducing the energy requirements of the building envelope.

Increase of the efficiency of active energy systems and Supply of energy from renewable sources.

3.3.1. Energy-Use Analysis for Some Buildings in Kampala

As noted in section (3.4), energy use analysis was done to determine energy consumption by these buildings in order to reduce on the demand. In reference to studies conducted by [71] on ZEB, technologies employed in this model included;

1) Smart double skin cladding system by adaptively movable louvers,
2) Portable water saving including rain water utilization,
3) Natural ventilation by window louvers and clay ventilators effect,
4) Integrated building operation system,
5) Thermal mass utilization and,
6) Radiation cooling and heating panel system.

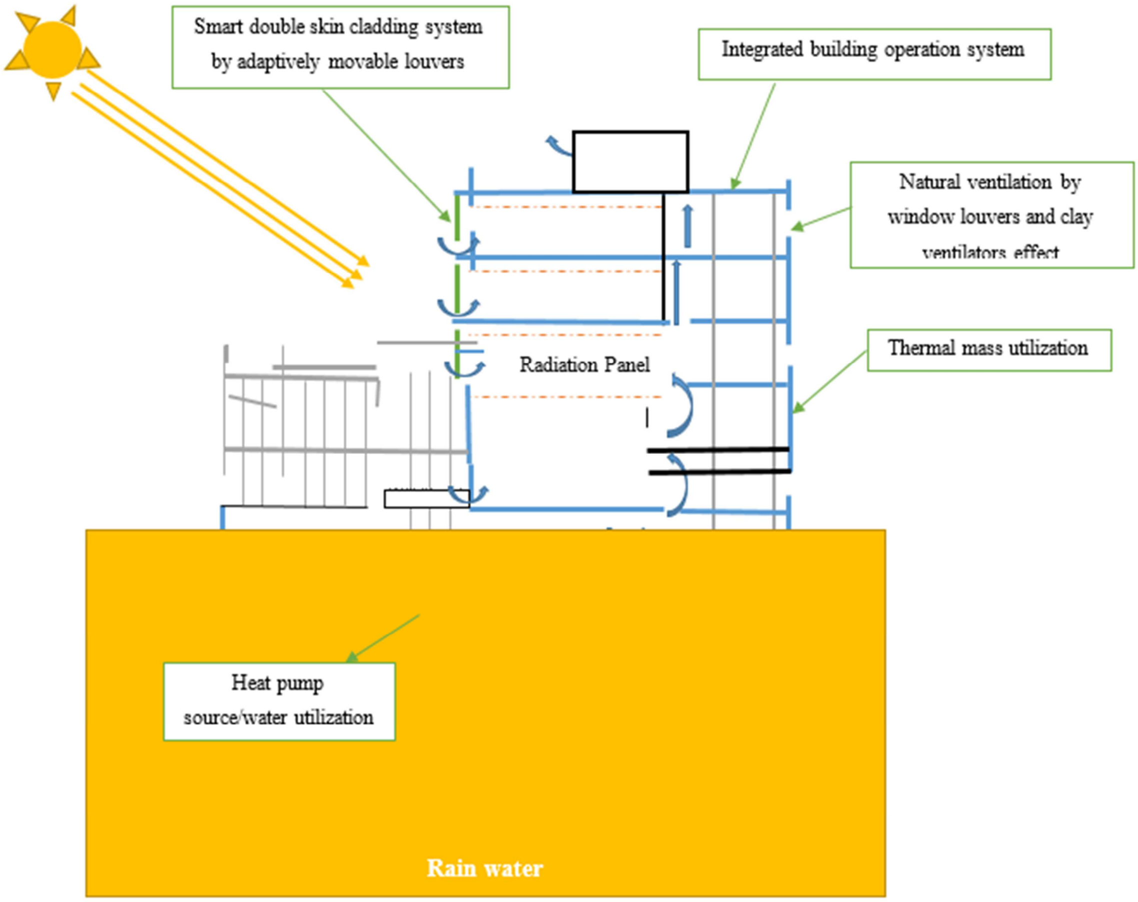

Figure 12. Developed technologies.

3.3.2. Smart Double Skin Casing System by Adaptively Movable Louvers

East and west elevations on the building's windows provide considerable thermal load as well as an opportunity to utilize natural ventilation, natural light and heat radiation from sunrays in the morning and evening. The smart double skin casing helps to solve contradict requirements on selective control of light heat and airflows. The system is made of movable vertical louvers and their frames. Each vertical louver unit is composed of double layered slat panels and a double glazed panel. This unit can be able to be rolled around vertical axis as shown in figure 12 for the different scenarios depending on the weather conditions;

Kampala and Uganda generally experiences high temperatures during its dry season. This is associated with a lot of discomfort to the occupants of most buildings. To solve this issue, buildings require being designed to handle such severe conditions. In this context, the white coloured side of the panel in movable louvers faces outside and the angle of louvers follows daylight position to prevent high sunrays to the inside of the building.

3.3.3. Scenario B (at Night Hours)

In Kampala and generally Uganda, night hours are mostly cold and somehow may cause discomfort to the occupants of buildings. In this scenario, movable louvers are opened to the outside to maximize natural ventilation since this is the time when most residential buildings in Uganda have got the biggest numbers of occupants. The outside temperatures are also lower than the inside, therefore natural ventilation is introduced through inlet within slat panels to facilitate night purge effect.

3.3.4. Scenario C (Rainy Seasons)

Cold seasons in Uganda are too uncomfortable for most occupants of buildings, this is always accompanied with shivering and sneezing. Buildings therefore require much attention during design thinking. In this scenario, the black coloured side of the movable louvers faces outside in order to collect radiated heat from the sun and to stock them in upper floor slabs by utilizing its thermal mass. Even when the time when louvers are shut, visibility from inside is assured by deliberate detailing of punching metal shape of slats.

3.3.5. Portable Water Saving Including Rain Water Utilization

This water is collected when it rains and preserved as shown in figure 13 during hot periods of the day, it cools the base of the house while absorbing heat. This heat is dissipated to the house walls during periods of coldness.

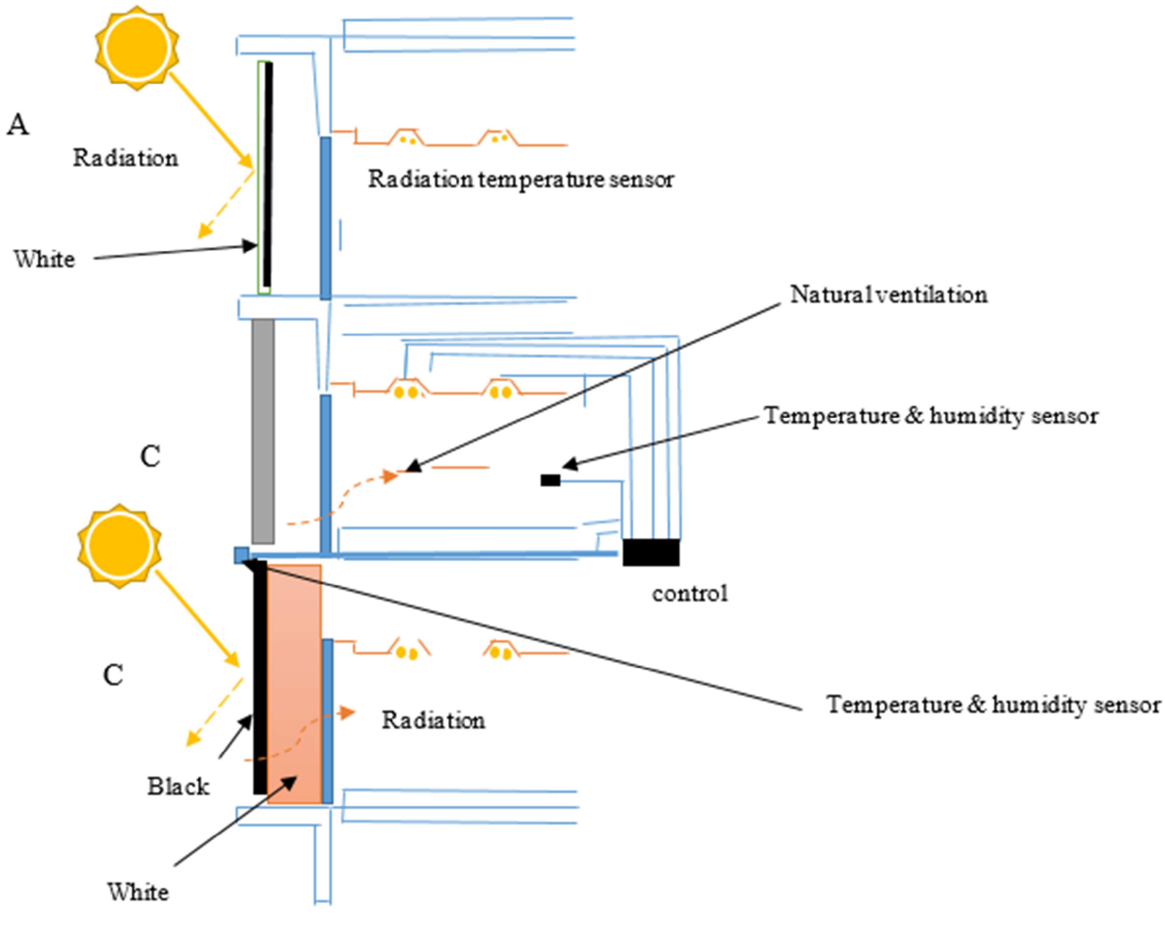

Figure 13. *Scenario A (During dry seasons during daytime).*

3.3.6. Natural Ventilation by Window Louvers and Clay Ventilators Effect

Natural ventilation is very important for every building, as it helps in reducing the need for energy to induce favourable thermal conditions into the building. For this model, ventilation was achieved through building's windows and traditional ventilators. The traditional ventilators and window louvers are made to be utilized in the night hours when building occupants are resting since windows may not be left open.

3.3.7. Integrated Building Operation System

The building is controlled by an energy monitoring system based on the idea of information embedded into the building, which consists of; sensors of energy use, temperature, humidity, indoor air quality, illumination intensity etc. this system controls these parameters through regulating them to the set standards by the occupants of the buildings. This system operates on the flow chart demonstrated in figure 14.

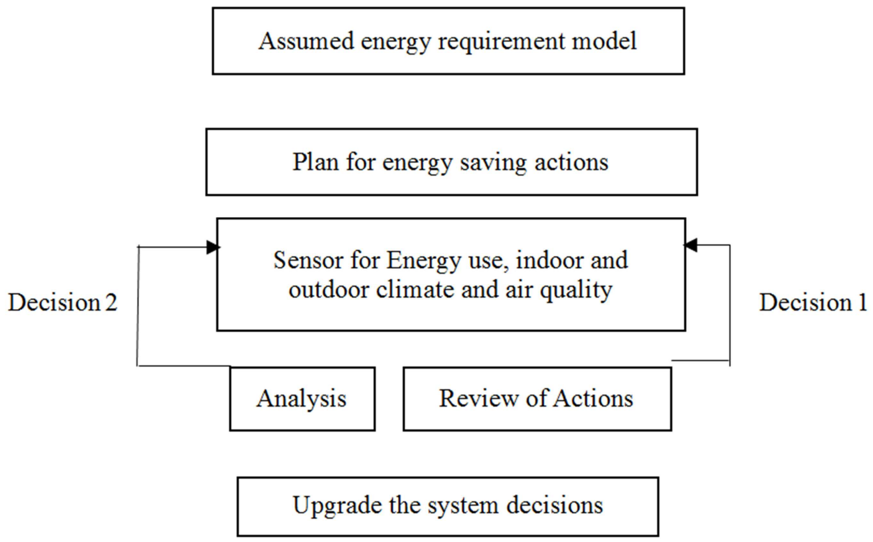

Figure 14. *A proactive demand control system using real time energy monitoring.*

3.3.8. Thermal Mass Utilization

The model emphasis the building design to have capacity of stocking heat in floor slabs through utilization of thermal mass. The heat generated by home appliances internally is as well preserved by thermal mass of the building for use during cold periods. You realize for this model that structural members and spaces between ceiling and floor panels are cooled by natural ventilation in the night in order to minimize cooling load that may call for energy to run mechanical coolers during daytime.

3.3.9. Radiation Cooling and Heating Panel System

In the traditional buildings commonly constructed in Kampala use conventional air conditioning methods to change air temperature to either warm or cold for human body utilization. This indirect warming and cooling involves a lot of energy wastage and inefficiency in energy use. Radiation panel heating and cooling is a direct method to warm or cool human body with no energy consumed in bringing air and activating fans. In this model, the panels are installed on the ceilings of the buildings to be able to provide the thermal comfort requirements by each individual occupants of these buildings as seen in the figure 15.

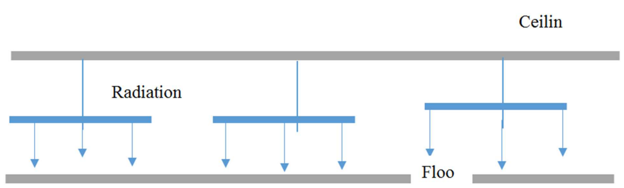

Figure 15. *Radiation cooling and heating panel system.*

4. Conclusion and Recommendations

4.1. Conclusion

The study realized a number of important factors that required consideration while raising buildings in Kampala. Among which included; air temperature, average radiant temperature, air speed, air humidity, and others as highlighted in table 10. while raising a house, designers are advised to follow comfort models in order to enable comfort of all occupants in these buildings. The position of a given building determines the amount of energy required to give light, warm rooms or cool rooms. In Kampala, by studying table 10, you realise that temperatures are moderate and do not go so extremely low or high. The model developed in this study enables a building to heat up during cold hours and cool down during hot hours by the help of the water pool collected during rainy days. This water cools down the house during the day time while absorbing heat that can be released during the night hours that are somehow cold in Kampala. However, if this isn't considered, then heat pumps have to be employed to pump heat into rooms to reduce heating in rooms.

4.2. Recommendations

To have the people of Kampala enjoy staying in their houses, there is need to review the considerations taken into account while developing these structures. The study realises better design techniques of buildings but does not take into consideration the number of occupants on average houses in Kampala hold. This calls for a study based on the occupants of these buildings as they are the part of the main sources of heat generated in buildings. The study emphasises on maintaining thermal comfort in buildings through ventilations, providing water pool in the basement, using sensors and so on but does not consider the size of walls. This determines how much temperature loss and gain the house emits or receives at particular moments. Therefore, recommendations should be put in raising thick walls and ceilings to maintain building temperatures.

Abbreviations and Acronyms

ASHRAE – American Society of Heating Refrigeration, Air-Conditioning Engineers, HVAC - Heating Ventilation and Air Conditioning, IREA - International Renewable Energy Agency, NZE - Net Zero Energy, NZEB - Net Zero Energy Building, REC - Renewable Energy Credits, RES - Renewable Energy Supply, DBT - Dry Bulb Temperature, MRT - Mean Radiant Temperature, and SET - Standard Effective temperature.

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