Energy and System reduction in Uganda Office buildings, through Climate Responsive Design.

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Abstract

A façade is responsible for aesthetic qualities, but also for the overall energy performance of a building. Fully glazed facades are favored for high-rise urban architecture because of the neat and elegant envelopes, that follow an international look associated with success and corporate imagery. However, glass facades in hot and humid equatorial climates facilitate solar heat gains and subsequently, mechanical air-conditioning systems are operated to avoid high indoor temperatures. The overheating associated with solar gains can be mitigated when glass is used in correct proportions.

This research posits that shading elements can mitigate cooling demand for high-rise office buildings. The investigation uses a thermal simulation study to investigate the impact of orientation, solar shading, and thermal mass on cooling loads in office spaces. It is envisaged that lower cooling peak loads (up to 8 times lower) might permit adoption of smaller systems like ceiling fans to replace larger air conditions units. While energy efficiency and energy access are sometimes viewed as competing priorities the two can work in unison to improve overall energy services. Therefore, this investigation also intends to show that a 60% reduction in overall energy demand can merit installation of Photovoltaic panels than sole dependence on diesel generators. Regular power outages and load shedding in Kampala suggest that site specific renewable energy alternatives like PV can support gird supply. At the urban scale an average of $2,500 USD per kW renders hydro generation plants comparatively expensive for local revenue mobilization. However, Photovoltaic installations have better investment potential and can be procured by building owners at a less strenuous $1,500 USD per kW.

KEYWORDS: Energy, Design, Optimisation

1. INTRODUCTION

A vibrant energy sector is critical to a nation's economic development. In Uganda, Mbabazi and Sansa-Otim (2015) found that energy companies are troubled by unreliable supply, inefficient clientele to support generation capacity, deficient maintenance, erratic procurement procedures, and inability to prevent transmission or distribution loses. However, the construction sector has recorded massive growth in the past few decades. National statistical abstract (2017), registered significant increases of 33.1% commercial and 35.7% institutional buildings. Unfortunately, electricity consumption has more than doubled over a 10-year period; a pace that has been strenuous on national electricity supply. As a result, grid electricity for the end user is unreliable, delivered at high tariffs and in many parts of the country still widely inaccessible. Weekly power outages and load shedding continue longer than 3 days for 72% of national grid customers (Mbabazi and Sansa-Otim, 2015). The impact of these blackouts is noticeable across various sectors including education, healthcare, industrial production as well as commercial enterprise. Despite an evident need to assess all possible alternatives, commercial construction has not been considered for energy conservation or on-site generation to feed this national energy deficiency. It is estimated, for instance, that urban buildings in cities alone consume on average 56% of the total generated electricity (Blanco and Muzee, 2016). There is a critical need to innovate with technology to examine the energy potential of urban buildings.

1.1. Problem Definition

The Uganda electricity sector has suffered supply constraints, which now manifest as regular outages, yet high energy demand is still considered unavoidable. Elaborate mechanical ventilation systems are a major driver for this high energy demand. This research focuses on reducing solar gains as a core approach toward energy efficient buildings. Further, promoting conservation and on-site generation as strategy to improve energy supply at the building level. This research fills a knowledge gap on façade functionality and adaptability performance to meet user requirements for humid tropical context.

1.2. Aim and Objective

The main aim of this research is to understand the impact of shading and controlled glazing on cooling energy demand for office building in Uganda.

The objective of the research is to support building owners and designers in making informed decisions on design of office building façades and to show the impact of fully glazed facades in humid tropical climates.

1.3. Scope and Limitation

Scope: This study focuses on fully glazed façades for the humid tropical climate of Kampala, Uganda. The study considers the impact of orientation, solar shading, and thermal mass as treatments to demonstrate that façade design can reduce cooling energy peaks or overall demand.

Limitation: The study focus is narrowed down to a shoe box model of an office in Kampala. The thermal simulation internal load criteria is based on assumed standards of personal space requirements, computer type and artificial lighting; with no additional electrical devices. The investigating also considers the open plan office type which might not be representative of typical office layout in Kampala; where partitioned cubicles are preferred. Comfort indicators like daylighting and visual comfort are not defined for this investigation.

2. BACKGROUD

In 2006 for example, a compact fluorescent light (CFL) distribution program reduced power demand by 32 MW at an investment of US$0.05M per MW, which was more than 50 times cheaper than investing in new baseload hydropower plants. In spite of this success, the currently escalating demand for urban infrastructure building have not yet been considered for their potential to stimulate energy conservation in urban commercial developments. According to MEMD and UBOS (2014), diesel generators supply over 50% of the energy demand for Commercial and Institutional buildings in Uganda, and Knight (2012) posits that depending on load factor (BEFC) and cost of fuel, a diesel generator will make power in the range of USD $1 to $40 per kWh. Therefore, at the current UMEME peak tarrif of USD 0.22$/kWh for commercial customers, and an additional annually increasing generator running costs of USD 0.90$/litre; investment in 10m^2 of a 16% efficiency PV system installed with battery bank at a cost per Watt of USD 1.05$/W, can be recovered in under 3 years. Which could be further improved by energy conservation strategies. At the city scale, PV shared investment can be accommodated by building developers and save government investment of currently unavailable USD $ 3M per MW for hydro dam construction.

3. METHODOLOGY

Energy performance of an office shoebox model 10m x10m area was investigated using TRNSYS 18 which has a transient simulation module used for thermal analysis of buildings. The TRNSYS project model had three main features: weather data reader, solar radiation processor, and TRNBuild. Weather data reader reads the data from standard file format such as IWEC (The International Weather for Energy Calculation) and then links it with the radiation processor. The solar radiation processor calculates the radiation on inclined surfaces. In TRNBuild, a user creates input data for buildings. This data includes building envelope details such as walls, roof, floor, window, and operational behavior of the building such as heating and cooling schedules. The office shoe box for this study was treated as an isolated single zone. Hourly simulations were conducted over one-year period, for a location in Kampala city. This study focused on a single windows type, typical of the region. (including low-e as well as solar control), window area was considered for two scenarios 100% then 50% (expressed as percentage of exposed wall area). Two major orientations considered were West and South. Cooling energy demand was compared for various variant scenarios.

Constants

Room Area	100m^2
Wall type	0.68 W/m^{2}K
typical Glazing	U = 5.8 W/m^{2}K, G = 0.86
Glass area	30m^2 glass
Ceiling/Floor	Concrete with screed

Table 1: 10m X 10m shoebox model base parameters.

3.1 Geometric Model

Variant descripts were selected to display the most direct impact of solar gain on cooling loads. The shoe box represents a typical 100m² office space with a south oriented glass façade exposed to the exterior environment.

Climatic boundary conditions are preset as interior walls, ceiling or floor walls, kept constant to specifically calculate variations due to exposure of exterior façade to the elements.

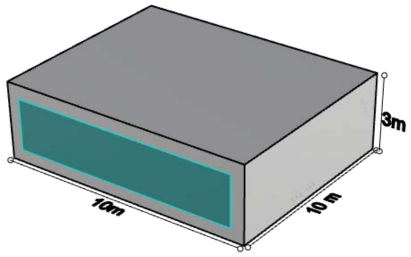

Figure 1: 10m X 10m shoebox model used to simulate office space.

The energy calculation is set as a transient simulation based on hour energy balance, other information is determined from weather data file located in the northern hemisphere at 1190m height above sea level to represent Kampala location.

3.2 Simulated Indoor conditions

A typical office scenario for this kind of modeling is challenging because office vary in area, function as well as internal loads. Therefore, interior loads were depicted as 10m² per person doing light work (75W), 10 computers in the space with PC screen(140W) and filament lamps all to supply 700W maximum heat emission into the space. The schedule for internal loads was set as continuous through the day to accommodate incidental peaks and slumps that might occur in the thermal calculation because of loads from persons or computers suddenly introduced or removed at the start *0800* or end *1800* of a work-day.

4. FINDINGS and DISCUSSION

Orientation	Label	Variant Description	Peak load (W/m²)	Energy demand (kWh/m)
WEST	West	exposed west face	159.34	154.3
South	South	exposed south face	83.7	110.0
South	Double glass	U = 2.8 W/m²K, G = 0.76	61.7	83.6
South	1.5Shade	1.5m Horizontal shade	39.5	80.6
South	1.5Wings	1.5m Vertical Wings	79.7	110.2
South	Shade+Wings	1.5m Vertical wings + Shade	33.8	66.6
South	Half_Heavy	15m² glass	41.8	55.0
South	Half_Shade	15m² glass + 1.5m Shade	17.3	33.9

Table 2: Results for tested variants of shoebox model.

The preliminary results in *Table 2 show* that cooling peak loads reduce by almost 50% when the window is oriented towards the South as opposed to the West. However, a more significant reduction of up to 80% is noticed when combinations of various passive strategies are used. These results correspond to measured data analyzed during a post occupancy evaluation project of classroom buildings in three locations in Uganda. Where Vandermeulen (2018) found that combinations of various passive systems improve indoor ambient temperatures by up to 5°C shown in **appendix 1**.

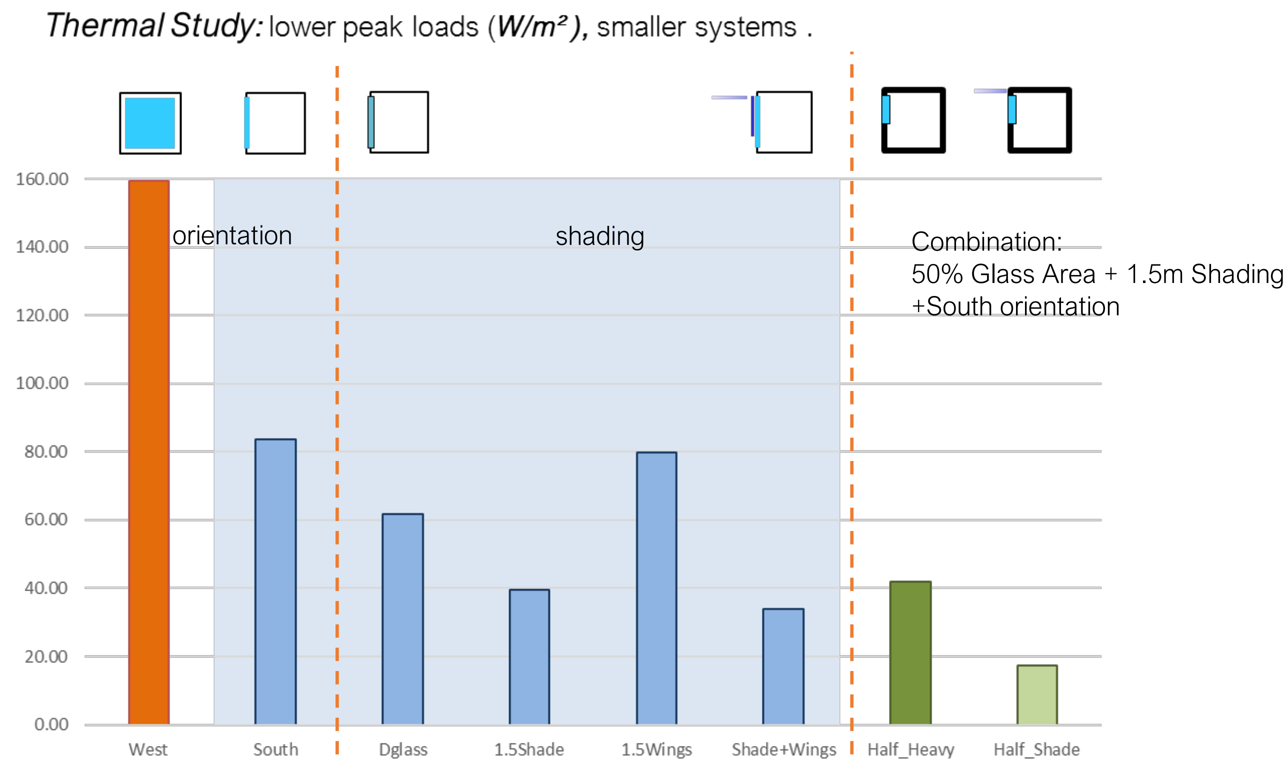

Figure 2: Simulation results for Orientation, Shading and Thermal mass variant

Figure 2 graphs shows that simply changing the orientation improves the energy peak loads and different shading alternatives each offer measurable reductions. However, reducing glass to 50% of initial area offers the most significant energy saving.

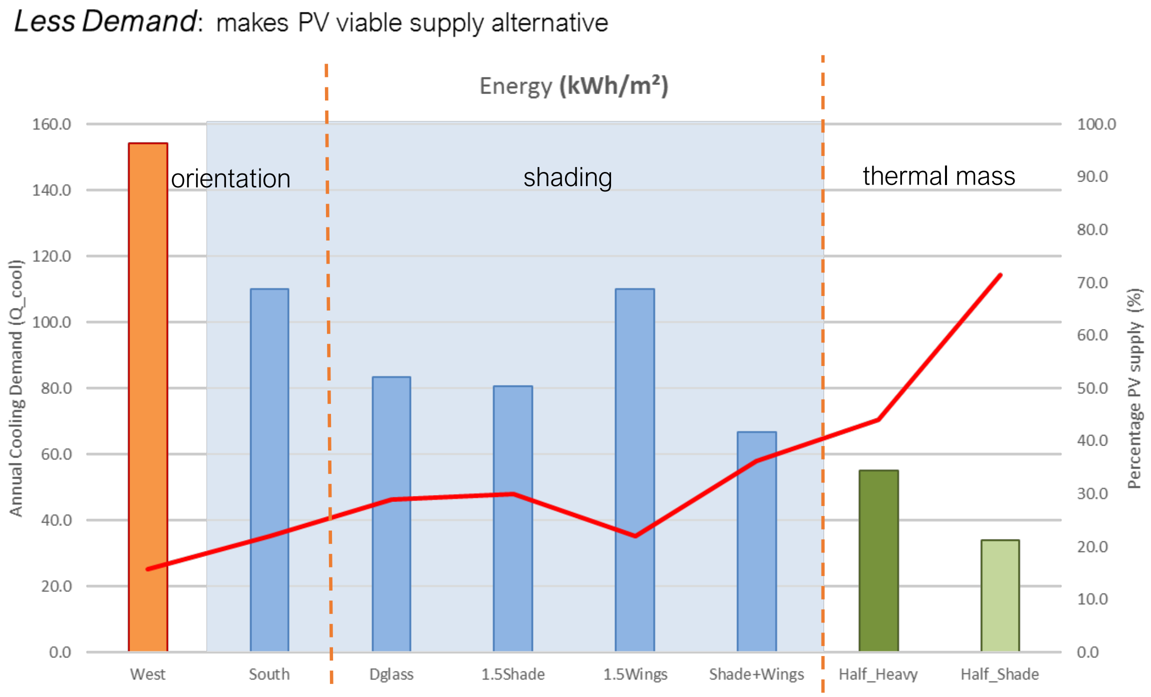

Figure 3: Annual Energy Demand for the variants against potential PV supply.

4.1 Potential PV supply.

These results confirm initial assumptions that optimizing orientation and reducing glass area on facades can offer significant reductions in peak loads. Air conditioning systems can thus be much smaller, then user comfort requirements can then be met by smaller systems like ceiling fans.

Mukwaya and Okidi-Lating (2014) survey revealed that the average EUI for office building in Kampala is 156 kWh/m^2/year, low enough to merit PV supply. The PV potential in the region suggests that from each square meter, a 16% efficiency PV panel can supply 242 kWh/m^2/year as shown in **appendix 2**. A red line in *figure 3* and clearer shown by green line in *Figure 4* shows that proportionally with 25% of Gross floor area PV can supply 100% Net zero energy for an optimized single storey office building. Therefore, a typical 4 storey office building can meet possible 100% Net zero energy demand using photovoltaic systems.

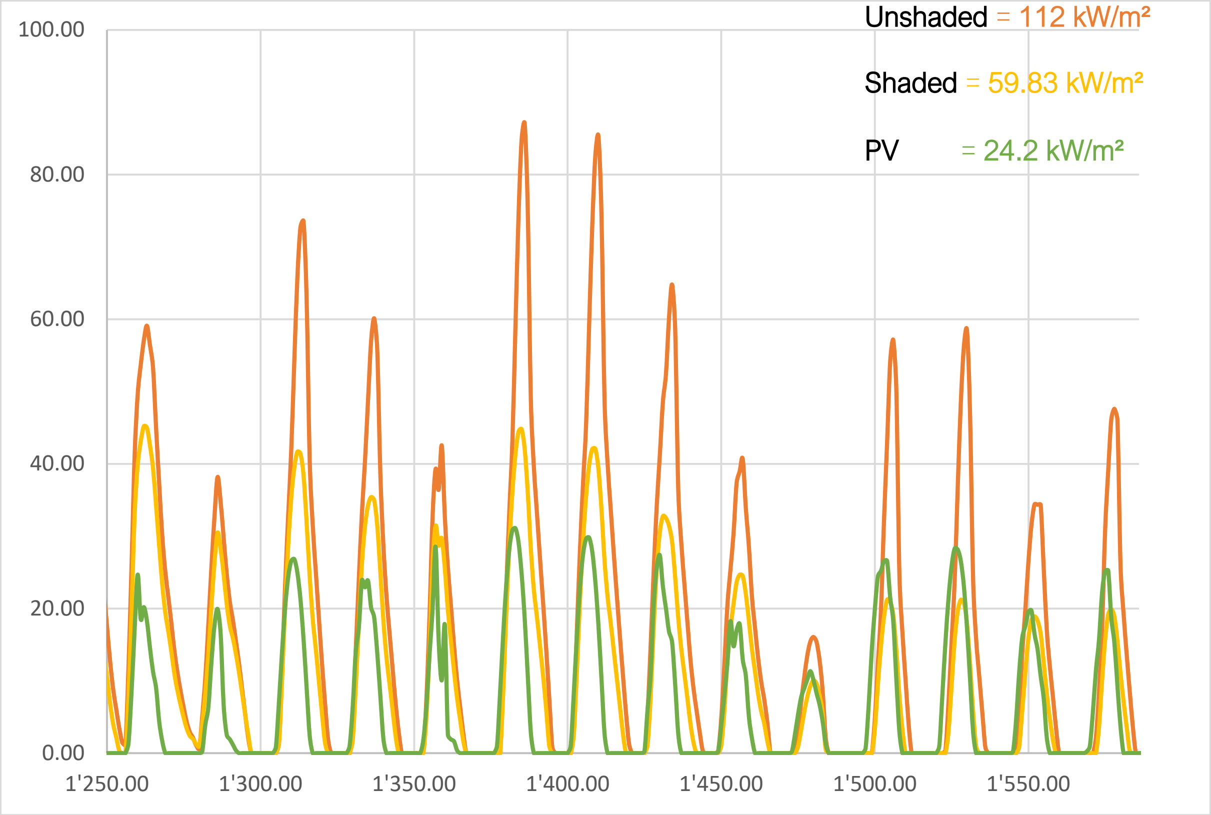

Figure 5: 10% Floor Area PV potential.

5. CONCLUSION

Efficient buildings can play a vital role in the development of sustainable cities for a growing economy like Uganda's where access to electricity is low and the available electricity is unreliable. This simulated study shows that minimising solar heat gains significantly reduces indoor cooling energy demand. Orientation provides the most significant energy reduction. Properly positioning glazing is effective to reduce energy demand. In combination; shading, 50% glazing and avoiding primary solar orientations offers the most beneficial results. Therefore, design optimization is a worthwhile for energy saving in office buildings. Architect and building owners can plan to mitigate the overall energy demand, by designing to minimize the solar heat gains.

6. OUTLOOK

PV potential for commercial buildings in this context is a critical aspect that requires further investigation. This discussion acknowledges that a national sensitisation exercise of this scale would require a strategic implementation plan. A plan that engenders policy adjustments to offer guidance through revised city ordinances for action or enforcement of shading and energy requirements at building approval level. Then a purposeful strategy to coordinated priorities, options and measures of implementation regarding incentives for developers to acquire efficient PV systems and their associated installation equipment. Further, research projects and survey programs could then appraise the implemented energy benchmarks for commercial buildings to aid the future expansions of the entire project. This could meaningfully fuel in local Architects and developers a desire to meet potential island solutions or even Zero Energy solutions.

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