Airflow Design for Middle Class Housing in Sierra Leone:
Passively Creating Comfort for Sustainable Housing

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ABSTRACT: The architecture master thesis student along with undergraduate engineering students designed in an office-like collaboration, a comfortable and affordable house for Sierra Leone. Despite conventional knowledge, the collaboration between architects and engineers provided the synergy to explore a wind tower for an atypical location; a mixed hot/humid and hot/dry climate. The architecture student determined the final design outcome based upon his research and IESVE simulations along with knowledge provided by the engineering students. This paper discusses two aspects of this thesis: the pedagogical ideas and the design innovation for housing in this location.

Keywords: ventilation, airflow, energy, comfort, affordable housing, interdisciplinary collaboration

INTRODUCTION

The design of sustainable middle class housing for York Village, Freetown, Sierra Leone was studied by an architecture student for his master thesis project. The thesis project was structured so that the architecture student (AS) engaged with 4th year engineering undergraduate students (ES) on the design of this house through an office like structure with the architecture student in “charge” of the project. Along with professors from both disciplines, ES met every other week with the AS who structured the issues for the students to research and propose solutions. The AS determined the final design outcome based upon knowledge provided by the engineering students, his own research and his IESVE wind simulations.

This research was developed due to the lack of energy efficient building design in Sierra Leone. Like most of the countries in the region, average air temperatures range from around 24 °C (80 °F) to 30 °C (90 °F) and the climate is typically hot and humid all year round (Koch-Nielsen 2002). With global issues like climate change, increased use of fossil fuels and high energy prices, there is a growing need for a more sustainable, economical and less energy dependent lifestyle. It is widely known that most of the countries in the tropical regions of the world are developing countries where the vast majority of the population cannot afford mechanical cooling systems such as air-conditioning or expensive alternatives. Therefore thermal stress (and its impact on health and productivity) should be minimized primarily by appropriate urban and building design that does not involve high cost (Givoni 1988).

The site location for this project is on the west coast of Sierra Leone between the ocean and a mountain range directly to the east. The micro climate of the site creates two distinct seasons – one hot/humid as typically understood for the region, but another season, hot/dry. (Fig. 1) The design incorporated a cooling tower, not typically found in this location, to assist with the natural ventilation of the house especially during periods of little or no air movement. With design experimentation and analyses, an interesting result was uncovered: the cooling tower can act in its traditional role increasing air flow in the hot/dry season, but can also act as a ventilation tower increasing comfort during the hot/humid season. The AS anticipates that the occupants of the designed home will be able to achieve thermal comfort without the installation of air conditioning due to the incorporation of a wind tower in the home design. The study relied on the computer simulation software - Integrated Environmental Solutions Virtual Environment (IESVE) to understand the energy performance and applied CFD to analyse the airflow of the building.

The research outcome will be beneficial to home owners, students, building designers, developers, and governments as well as non-governmental organizations (with little or no knowledge about the subject in tropical regions) of the need for and one approach to achieving sustainable and affordable housing for an emerging middle class. As well, the structure for this master thesis provided a real life architectural – engineering relationship that benefitted both groups of students.
PEDAGOGICAL PROCESS

This architectural thesis was the first attempt at collaboration between engineering and architecture and was thought to be beneficial to both disciplines. Preparing them to understand and celebrate the process of working together was an important aspect of this process as this is what will be required of both in the professional realm. In this process the differences in how engineers and architects are educated from first year to degree completion became a plus for the outcome of the thesis idea. “Engineering faculty and Architecture faculty both address student learning through the prism of Bloom’s taxonomy of the cognitive domain, but do so in diametrically opposite manners” (Saliklis et al. 2009). ES move up the taxonomy starting with acquisition of knowledge while AS start with synthesis and evaluation. Having an architecture master thesis student paired with 4th-year engineering students seemed to provide the right balance of knowledge and synthesis for interaction and invention to occur.

The architecture thesis student was asked to “pitch” his idea to all of the fourth year engineering students along with other outside companies that participate in the Engineering 4th year capstone design experience. The main architectural goal of the project was to create a design which maximizes thermal comfort using the natural and sustainable conditions of the site. ES identified who they would like to work for and created their own engineering companies to meet this role. The project for sustainable middle class housing in York Village, Sierra Leone was enthusiastically received by eight engineering students who formed two companies. Each company was composed of multiple engineering disciplines including mechanical, electrical and computer. A joint time was established to meet every other week, reserving a neutral meeting space, with both engineering teams meeting simultaneously with the AS. The AS prepared the agenda for each meeting and chaired the meetings with the focus on achieving his architecture thesis: Eco – Affordable Housing Project for Sierra Leone’s Middle Class. Both the AS and the team engineering leaders provided meeting minutes. The meetings were lively collaborations to discuss ideas and address the technical challenges of creating a passively sustainable home for a hot humid/dry climate without air-conditioning and with a limited budget of $50,000.00 U.S. dollars. Each engineering company prepared final reports with analysis and results for the requested work for the project. The architecture thesis student had an additional semester to complete his project and prepare his book for final presentation.

The students’ efforts were focused on solutions for the multiple issues concerning livability that would appeal to the emerging middle class of Sierra Leone. A recent study by Deloitte on Africa, The Rise and Rise of the African Middle Class, suggests that the African middle class will grow to 1.1 billion (42%) by 2060 (Deloitte 2012). In Sierra Leone it is common for extended families to live in one house or in an extension built to accommodate changes in family size or income needs. So it is important to plan the site properly to accommodate future development without compromising the initial design. As well, understanding construction, utilities and infrastructure taken for granted in United States versus what exists in an emerging country was a large part of the discussions and design challenges. Thus, the students began discussions with the architecture student sharing his design vision, goals and knowledge of architecture and people in Sierra Leone.

The AS had developed his design to a schematic stage by the first meeting, so the ES were presented with a flexible but well-conceived beginning point for their collaboration of one semester. (Fig. 2) A key approach to achieving thermal comfort in the tropics and in particular the mixed hot/dry is cross-ventilation in the home. Cross-ventilation can be achieved by creating a long narrow design with maximum openings on the longer elevations oriented towards the prevailing winds.
Other multiple issues related to water, energy and waste along with passive cooling were then thoroughly examined by the entire group to create a home design feasible for construction in Sierra Leone.

“Large and small firms working at all scales are increasingly forming collaborative design teams at the initial stages of the design process” (Olsen and MacNamara 2014 p.2). Integrating sustainability and new approaches are best achieved in the early stages of design in a collaborative process. This collaboration requires an understanding of the design process and an ability and willingness to collaborate. Students are rarely prepared to understand the process of collaboration between architect and engineer. This was observed in the early meetings between the students. Learning that once the initial information was understood by the different disciplines and their unique language and approach, it takes multiple interactions to develop and refine information over several months for the best conclusion to be determined. Initially, the students felt that they were inadequate; sometimes blaming the other, not understanding that the process and ultimately the best solution required this iterative approach. The students initially perceived that design was a one-time effort either with an engineer or the architect “calling the shots”. However by the end of the collaborative process how engineer and architect worked together was understood, celebrated and embraced.

“Perhaps one of the most significant outcomes of the technological shift is a growth in importance of both specialization and collaboration… Alliances among disciplinary experts lead to greater innovation and boundary-pushing proposals” (Olsen and MacNamara 2014 p.1). This “office” structure allowed the students to develop an understanding and become comfortable with the collaborative process between architect and engineer. The interrelationships of all of the aspects of designing a sustainable home in another country that provides comfort for that climate and lifestyle was an expansive experience for the students. Engaging multiple engineering disciplines and an AS allowed all of them to understand the value of each of their expertise and the creative outcomes that can occur.

**DESIGN**

The form and orientation of the house is defined by three key factors: to maximize natural ventilation, minimize solar impact and maximize use of a small site area. The intense solar radiation from the equatorial sun is important to understand. The house needs to be oriented so that the amount of solar radiation gained by the building is minimized. In a tropical climate all facades, especially the roof, require great consideration. The roof, the west and east facades of the building mass are the surfaces most affected by the intense radiation. The roof was designed to be perpendicular to the sun, in a saltbox type form, so the intense solar radiation can be easily reflected. Orienting the house east-west helps to minimize the total surface area of the house exposed to the sun when combined with shading techniques. The north and south face of the house can be shaded strategically to reduce the impact of the summer and winter sun respectively. Freetown, Sierra Leone is located at latitude eight degrees above the equator and due to the tilting effect of the sun during the summer months (mostly the rainy season) the sun is in the northern hemisphere at altitude 70 degrees. During the winter months (mostly the dry season), the sun is in the southern hemisphere at altitude 55 degrees. (Fig. 3) Understanding that “buildings… can be viewed as a way to modify the landscape to create more favorable

![Initial architectural design presentation.](image)
microclimates” and that “… at least six new microclimates are created” is crucial in this location (Heschong 1987 p. 8).

In the summer, because of the altitude of the sun the proposed breeze block is sufficient to provide shading to the interior. However, in the winter, the most effective solar shading device will be a louvered screen angled at about 45 degrees. The ventilation/breeze-block is made of cement and are fixed louvered block to allow the constant flow of air in and out of the house. So the breeze-blocks and balconies provide as much shading as possible and they are inexpensive to manufacture in Sierra Leone (Fig. 4).

The large folding doors on the south facade allow maximum ventilation for the living space but also increase the living space size by opening fully to a veranda and the outdoor living area. The double height space in the living area in combination with the cooling tower over the stairs pulls the air from the lower level to the upper level even from the downstairs bedroom and kitchen when necessary. The study on the upper level is also open onto the stairwell and cooling tower. The adjoining second level balcony creates an additional external living area and provides a view of the surroundings.

To help reduce initial costs the kitchen is a single story with a monoslope roof, however an additional bedroom can be provided above the kitchen for expansion. The external kitchen doors provide maximum ventilation, but also allow the kitchen space to be doubled by opening onto the exterior covered verandah space. The kitchen can also be separated from the living space by closing the internal door as required.

Maximizing natural ventilation through the house as well as in the roof space was crucial. (Fig 5) The space between the inner skin of the facade and the screen creates a buffer zone to help cool the air temperature before it enters the internal space of the house and roof.

Solar panels located on top of the cooling tower provide all the needed power to the house and a backup battery storage unit is underneath the staircase. Provision for connection to the national grid along with the location and sizing of the solar panels was a focus of the ES studies. Determining the power load for sizing the solar panels was an important exercise for the students, as cultural issues and expectations became a key part of the discussion in determining the design loads in the home.

The ES also studied the site and climate conditions. They then explored heat transfer through different wall systems: concrete, sand bags, timber, and compressed earthen brick. Because, there is no timber industry in Sierra Leone; the timber being produced and sold by sole traders is not usually well treated to be exposed to heavy rainfall and humidity. A budget estimate for a design of timber was provided by the AS of $100,000. Because this is a tropical area, pests such as termites are a serious concern when using timber. Other options were examined in order to keep the cost down. It was
determined that earthen bricks was the best choice as the material is “cheap, readily available, moderately efficient and have acceptable design flexibility” and maintained the budget. With this type of alternating humid/dry climate, the right choice of materials (where availability is also a factor), and the correct placement of window openings the designer hopes that the occupants will be able to achieve thermal comfort without the installation of air conditioning.

Determining the plumbing system for hot and cold water and the location/size of the water tank was another key discussion, as municipal water and running hot water are not commonly available in Sierra Leone. Traditionally, houses have an independent water tank tower next to the house but in this case the AS chose to place the tank on the roof. Because power and water supply is a major crisis in Sierra Leone, a water tank operated by gravity was considered essential and is the most effective. The ES also designed an in-ground water tank which feeds water into the elevated water tank (s) via a pump and filter. The water tank supplies the faucets through gravity. Water in the lower tank would be considered cold water, thus by pumping the water up into another tank that is stationed on top of the wind tower; water can be heated with the heat of the sun.

Waste is collected via an Ecosan waterless waste collector to be emptied periodically. The alternative was to use a traditional septic tank. Unfortunately with a small site a traditional septic tank cannot be used due to EPA regulations requiring septic tanks to be located at least 50 feet from any drinking water source.

AIRFLOW DESIGN
Passive cooling for thermal comfort is more economical and environmentally friendly than the use of mechanical air conditioning. The lack of a constant breeze and the prevalence of high humidity in the region make passive cooling less effective. It was also understood that the new middle class and most all tropical inhabitants would prefer their homes to be mechanically conditioned to eradicate the high humidity in the atmosphere. Most homes in the region utilize ceiling and or standing fans to enhance passive cooling but their effectiveness also relies on constant air movement. Other passive design strategies discussed for this climate such as the use of shading by trees, large roof overhangs and insulation usually require extra initial cost. Most of the countries in the hot-humid areas are developing countries and this has direct impact on the practicality of some “modern” concepts of urban and building design from a climatic viewpoint. But, the bottom line is that the vast majority of the people in this region cannot afford air
conditioning. The computer simulation software, Integrated Environmental Solutions Virtual Environment (IESVE) was used to understand the energy performance and CFD and airflow of the home with a cooling tower in this climate.

IESVE software was used to simulate the airflow of the house. This was necessary to study the performance of the cooling tower (which is not common in this region) in response to the climatic conditions. It became clear that the wind tower will function both as a cooling tower and as passive stack ventilation system. The study looked at four key periods of the year when wind rose data for the region indicated significant changes in wind patterns. (Fig. 5)

In June and September the tower acts like a stack ventilation system, in March and December the tower functions as a cooling tower. The velocity and temperature keys indicate the approximate wind speed and temperatures in certain areas of the house during a particular season. The simulation indicates that that cooling tower is most effective during the dry season like in typical hot/arid climates where cooling towers are commonly used. However, during the highly humid periods of the year, the tower also assists in the natural ventilation cooling process of the house.

CONCLUSION
Designing a house for the climate of York Village, Freetown, Sierra Leone was an innovative collaboration of ES and AS technical knowledge and an architecture student tenacity to explore an option not typically found in this climate. By using the cooling tower typically found in hot/arid climates for the hot/dry periods of the weather pattern in this location, it was discovered that this passive approach would also have benefits for the occupants during the hot/humid time of the year, hopefully eliminating the use of air conditioning in a house for the emerging middle class. (Fig. 6)

The architecture student learned that listening to ES and keeping “two or more opposing thoughts until an amenable solution arises”, produces productive solutions. “Architects in the coming years will be needed … as facilitators, orchestrators, collaborators and integrators (FOCI)” in creating our built environment. (Deutsch 2014 p.4)

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Figure 6: South façade middle class housing for Sierra Leone.

REFERENCES