Design of a Sustainable Housing Complex in Haiti through Energy Modelling and Simulation Process

Sooleyon Cho, Sedighehsadat Mirianhosseinabadi, Michael Dinka

North Carolina State University, Raleigh, North Carolina
Dewberry, Washington, District of Columbia

ABSTRACT: This paper presents the results of design research for the development of a sustainable housing complex in Haiti using the energy modeling and simulation processes. This study explores architectural and sustainable design strategies to design a prototype sustainable housing complex in a tropical climate that applies specifically to Haiti. In this research, the history, geography, and culture of Haiti are briefly analyzed in the context of family unit, community and economic aspects. The climate conditions are analyzed in the context of residents' comfort, and the general guidelines are presented on how to design sustainable housing in tropical climate. The main research focus of this study is on the effectiveness of natural ventilation in the design of the Haitian housing complex. Due to the consideration of the poor economic situation of Haiti, especially after the massive earthquake in 2010, the design is focused on the passive strategies, not considering active mechanical cooling and heating systems. So, natural ventilation, as the main sustainable strategy of this study, is the key parameter to investigate using the EnergyPlus simulation program. Another following important parameter is the "adjusted comfort zone for Haitians." The energy modeling and simulation technology is extensively used to make design decisions in this regard. The summary of this paper includes the proposed optimal design options and the adjusted comfort zone for Haitians. The effect of natural ventilation is also presented showing the improved indoor temperature and humidity levels of the proposed design compared to those of the conventional construction of Haiti.

KEYWORDS: Natural ventilation, Haitian comfort zone, EnergyPlus simulation, Haitian housing complex

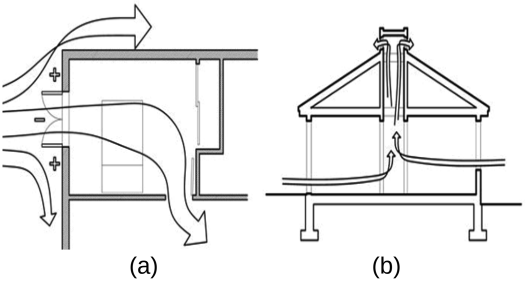
INTRODUCTION

Haiti is one of the poorest and least developed countries in the world with 8.7 million residents. Haiti has struggled with many problems in recent years such as political chaos, severe environmental degradation and an annual barrage of hurricanes. On Jan. 12, 2010, a massive earthquake struck Haiti, changing its capital's face, Port-au-Prince, to wreckage. Even before the shocking earthquake, Haiti had a feeble economy. Haiti has the lowest level among the world's lowest levels of gross domestic product per capita. Public education is not widely available. Infrastructure, health and social services are often worse than in sub-Saharan Africa. 80% of the population is living under the poverty line and 54% of them are living in abject poverty (Central America and Caribbean: Haiti 2013).

Haiti's geographic coordinates are at a longitude of 72° 25′ west and latitude of 19° 00′ north. It is located in the subtropics on the western third of Hispaniola between the Caribbean Sea and the North Atlantic Ocean. The climate is mild-hot and varies with altitude. However, since Haiti is a Tropical Island and surrounded by warm water, temperatures do not vary much over the course of the year. That is why the relative humidity ranges from 75-85% in early morning to 55- 65% during the afternoon. A classic household in Haiti consists of main family members and in some cases young relatives. House style and construction material in Haiti varies from region to region. For example in dry area, most of southern Haiti, houses are constructed of Hollow Block Concrete (HBC) or stone. In wet area, which is most of Northern Haiti, houses are made of Hispaniola pine and local hard woods or wattle and are daub with mud. Haiti also has inadequate energy resources. The country has no petroleum resources, little hydroelectricity potential, and quickly diminishing supplies of wood fuels (CIA 2013). Having virtually no access to electricity, Haiti's poor people depend on the cutting of trees for the production of charcoal. Therefore Haiti government needs to focus on sustainable development that protects the environment and produces local jobs by creating a clean energy economy.

In regard to the poor economic situation of Haiti, especially after the massive earthquake in 2010, the passive strategies are mainly used in the housing design process instead of active mechanical cooling and heating systems. This research focuses on energy saving strategies that reduce the demand for energy in Haiti and emphasizes on the use of natural ventilation, as one of the important sustainable passive strategies in the region during the housing design process. To evaluate the effectiveness of natural ventilation in the design of the Haitian housing complex, two optimized Haitian houses with a slight difference in footprint and zone orientation have been modelled and simulated in EnergyPlus (USDOE 2010). The thermal conditions of the cases are compared to those of the traditional Haitian house.

Natural ventilation generally depends on breeze in the hot seasons to remove heat from the building and provide air movement to cool the occupants. Natural ventilation can be divided in to two categories: cross ventilation and stack ventilation. Cross ventilation drives air through openings in the building using pressures generated on the building by the wind, where air enters on one side of the building, and leaves on the opposite side (e.g. Fig. 1a). Based on natural ventilation principles, the opening of the windward side has to be less than the leeward side to get fresh, comfortable indoor air (Lomas 2007). Stack ventilation also is a passive cooling approach that takes advantage of temperature stratification (e.g. Fig. 1b). When air gets warm, it becomes less dense and rises then ambient air replaces the air that has risen. This natural convection generates an air current, where warmer air is depleted at a high point roof vents, and cooler outdoor air is brought in at a lower level (Kwok and Grondzik 2011). These types of high opening vents collect the hot air near the ceiling and are most useful for night-flush cooling (Lomas 2007).



(a) (b)

Figure 1: Natural Ventilation categories: a) Cross ventilation through Inlets provides air movement in occupant level inside the house, and b) Stack ventilation configuration. Source: (ClimateConsultant 2008)

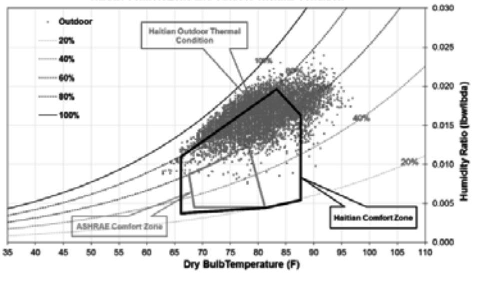


Figure 2: Haitian comfort zone and outdoor condition in comparison with ASHRAE comfort zone. Source: (Authors 2013)

As mentioned, Haiti has a humid tropical climate with hot temperatures throughout the year, so in most of the time Haiti's weather temperature is out of ASHRAE comfort range. ASHRAE Standard 55 specifies conditions in which a specified fraction of the occupants will find the environment thermally acceptable. The revision of Standard 55 includes the addition of the PMV/PPD calculation methods and the concept of adaptation (ASHRAE 55-2004). According to the adaptive hypothesis, contextual factors and past thermal history affect building occupants' thermal expectations and preferences. One of the predictions of the adaptive hypothesis is that people in warm climate zones prefer warmer indoor temperatures than people living in cold climate zones (De Dear and Brager 1998). Moreover, new Adaptive Comfort Standard (ACS) allows warmer indoor temperatures for naturally ventilated buildings during summer (Brager and de Dear 2001). However, based on the above discussion, Haitians have been adapted and strengthened toward harsh climate conditions due to poor living conditions and limited energy resources. Thus, it is reasonable to define a new Haitian comfort range based on the specific conditions in Haiti. Figure 2 shows the Haitian comfort zone on the psychometric chart in comparison with ASHRAE comfort zone. Red points on the psychometric chart show the outdoor condition during the year.

1.0. HAITI WEATHER CONDITION

Haiti has a humid tropical climate with hot temperatures throughout the year, which becomes more mild and fresh with an increase of altitude. The dry season starts from December to March and wet season begins from April to November. Port-au-Prince, ranges in January from an average minimum of 23° C (73° F) to an average maximum of 31°C (88°F); in July, from 25–35°C (77–95°F). The rainfall pattern is varied; however, Port-au-Prince receives an average annual rainfall of 137 cm (54 in). In the study, due to the lack of weather data information about Haiti, the three models have been simulated using the weather data from nearest country, Cuba. Figure 3 shows the outdoor temperature range during the course of the year in Guantanamo bay, Cuba.

2.0. SUSTAINABLE HOUSING COMPLEX DESIGN PROCESS IN HAITI

2.1. Haitian Base-case house (Traditional house)

The majority of Haitian houses have a simple rectangular form for two main reasons: flexibility for future extension and solar heat gain (e.g. Fig. 4a). Building housing in Haiti is a lifetime project which is executed in many phases because of the economic hardship. Consequently, the rectangular shape house gives the owner great flexibility for enlargement and adding rooms to the rectangular shape house whenever needed. Moreover, because of Haiti's geographical proximity to the equator, the sun passes almost directly overhead which makes the maximum heat gains on the east and west sides. The rectangular shape of traditional Haitian houses which is oriented along an east-west axis is a response to reduce solar heat gain. Haitian base–case model in this study is a model of traditional house with four zones based on their orientation. All four zones have some features in common such as: short or no plenum, short room height, minimal window shading, small glazing ratio, hollow block concrete wall, small or no insulation, and no stack ventilation (e.g. Fig. 4b).

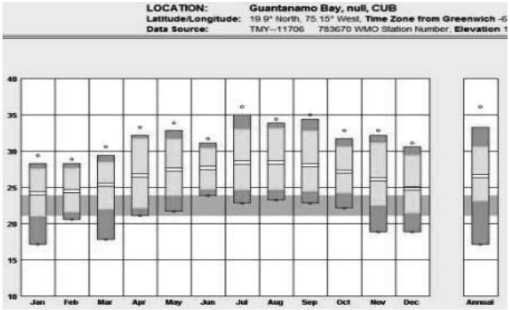
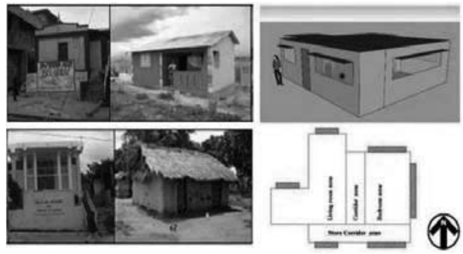


Figure 3: Guantanamo bay, Cuba weather data: Ambient air temperature (° C) range during the course of a year. Source: (Generated using Climate Consultant 2008)



(a) (b)

Figure 4: a) Haitian base-case traditional house, and b) Zoning arrangement in Haitian base-case model. Source: (Authors 2013)

2.2. Design scenarios (Optimized house models)

To achieve sustainable housing design, it is recommended to consider some of the passive strategies in design process of the optimized houses in Haiti to improve energy performance of the buildings. These strategies lead to more sustainable and durable buildings in Haiti and will help the people in poverty to easily handle the poor economic condition. Some of the important strategies which are used in the design of optimized house in this study are mentioned here; Adding window overhangs (Designed for Haiti's latitude) or operable sunshades which reduce summer and fall afternoon heat gain, increasing the north glazing area with vertical shading, increasing the height of the rooms in order to reduce the room temperature, using wall and roof insulation, and using adobe brick as a construction material for walls instead of concrete blocks. Since outdoor air temperature is in the Haitian comfort zone over the course of a year, in the next step, we have provided vertical distance between air inlet and outlet in the *corridor zone* to produce stack ventilation when wind speed is low. Moreover, large well-shaded windows are oriented to predominant breezes, to facilitate the cross ventilation inside the house. The combination of cross ventilation and stack ventilation inside the optimized Haitian houses help reduce air conditioning in hot seasons.

3.0. SIMULATION PROCESS

3.1. EnergyPlus general input parameters (Geometry)

Since EnergyPlus performs a zone heat balance, the first step in preparing a building description is to break the building into zones. Based on the EnergyPlus manual, a zone is a thermal, not a geometric, concept and includes an air volume at a uniform temperature plus all the heat transfer and heat storage surfaces inside of that air volume. The general regulation to specify the number of zones inside of the building without fan systems is to organize the zones based on their location inside the building such as south zone, north zone, west and east zone. In the study, after applying the mentioned sustainable design features to optimize the energy performance of traditional houses in Haiti, two new models (Option-1 and Option-2) were developed and simulated in EnergyPlus, using Cuba weather data with special zoning arrangement and internal gains (people, light, equipment) (e.g. Fig. 5-6) for each option. Tables 1, 2 and 3 show the characteristics of each option used in simulation process.

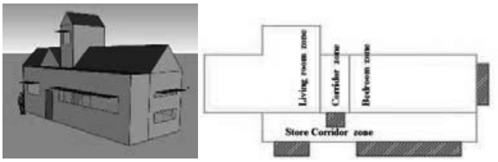


Figure 5: Zoning arrangement in optimized Haitian house (Option-1). Source: (Authors 2013)

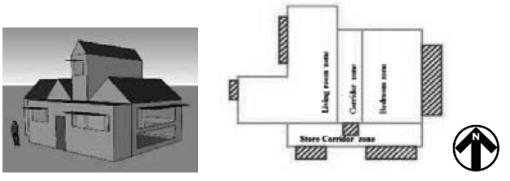


Figure 6: Zoning arrangement in optimized Haitian house (Option-2). Source: (Authors 2013)

Table 1: Geometry characteristics of Haitian base-case, Option-1 & 2 model. Source: (Authors 2013)

Geometry Characteristics	*Area*	*Height of rooms*	*Height of corridor*	*Height of attic*	*Projection Factor*	*Glazing ratio*
Base-case house	77 m^2 (825 ft^2)	2.4 m (8 ft)	2.4 m (8 ft)	-	0.5	0.2
Option-1	65 m^2 (705 ft^2)	3.65 m (12 ft)	6.7 m (22 ft)	1.5m (5 ft)	1	0.2
Option-2	77 m^2 (825 ft^2)	3 m (10 ft)	6 m (20ft)	1.5m (5 ft)	1	0.4

Table 2: Construction characteristics of Haitian base-case house. Source: (Authors 2013)

Construction		***Layer 1 m (in.)***	***Layer 2 m (in.)***	***Layer 3 m (in.)***	***U-value W/m^2.K (Btu/F.ft^2.hr)***
Wall	Exterior Wall	Stucco 0.0254 (1)	Heavy Weight Concrete 0.2 (8)	Gypsum 0.012 (1/2)	2.377 (0.418)
	Interior Wall	Gypsum board 0.019 (0.75)	Wall air space resistance	Gypsum brd. 0.019 (0.75)	–
Roof	Flat Roof	Roof Membrane	IEAD Roof Insulation	Metal Decking	0.358 (0.063)
Floor		Heavy Concrete 0.2 (8)	Carpet pad	_	1.862 (0.327)
Door	Interior and Exterior Door	Wood 0.025 (1)	–	–	–
Window	Normal Window	SHGC=0.25 VT=0.11	–	–	5.84 (1.028)

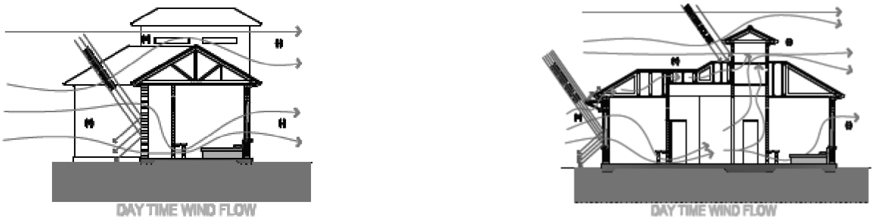
Table 3: Construction characteristics of Optimized Haitian house Option-1 & 2. Source: (Authors 2013)

Construction		*Layer 1 m (in.)*	*Layer 2 m (in.)*	*Layer 3 m (in.)*	*Layer 4 m (in.)*	*Overall U-value W/m^2.K (Btu/F.ft^2.hr)*
Wall	Exterior Wall	Brick 0.1 (4)	Insulation board 0.05 (2)	Wall air space resistance	Gypsum 0.019 (0.75)	0.449 (0.079)
	Interior Wall	Gypsum brd. 0.019 (0.75)	Wall air space resistance	Gypsum brd. 0.019 (0.75)	-	-
Roof	Sloped Roof	Roof Membrane	Metal Decking	-	-	4.035 (0.710)
	Attic Floor	Gypsum 0.012 (1/2)	Attic Floor Insulation	Gypsum 0.012 (1/2)	-	0.3 (0.052)
Floor		Heavy Weight Concrete 0.2 (8)	Carpet pad	-	-	1.86 (0.327)
Door	Interior Door	Wood 0.025 (1)	-	-	-	-
	Exterior Door	Metal surface	Insulation board 0.025 (1)	-	-	1.18 (0.207)
Window		Optimized window	-	-	-	1 (0.176)

3.2. EnergyPlus natural ventilation function (System)

As mentioned, natural ventilation can play a significant role in enhancing the energy performance of the buildings. Moreover, this parameter can be even more efficient in countries such as Haiti with poor economy in the way to achieving the more sustainable buildings. This study examines the natural ventilation effect in an optimized Haitian house design through the whole-building energy simulation using EnergyPlus simulation tool. *Air flow network group* in EnergyPlus includes the airflow network model which provides the ability to simulate multi zone airflows driven by wind and also by a forced air distribution system. Much of the information needed for the air flow calculation is automatically extracted from the building description for thermal modeling. This includes things like the volume and neutral height of the zones, and the orientation and location of the building surfaces that contain cracks or openings through which air flows. In the present study, we have tried to locate the windows and doors in an appropriate place to facilitate the air flow inside the house (e.g. Fig. 7).

The Air flow Network model consists of three consecutive phases: pressure and airflow calculations, node temperature and humidity calculations, and sensible and latent load calculations. (US. DOE 2010).



(a) (b)

Figure 7: Wind flow during day time through: a) Optimized Haitian house Option-1 and b) Optimized Haitian house Option-2. Source: (Authors 2013)

Ventilation control mode is one of the input parameters in air flow network model in EnergyPlus that specify the type of zone level natural ventilation control. Based on the EnergyPlus algorithm for natural ventilation if the zone temperature increases and becomes more than outdoor temperature and set point temperature simultaneously, then ventilation control mode assumes that the operable windows and doors are opened and venting availability schedule allows venting (US. DOE 2010).

4.0. SIMULATION RESULTS AND ANALYSIS

Three whole building simulation models were developed based on passive energy strategies and air flow network in EnergyPlus for traditional Haitian house, optimized Haitian house Option-1, and Option-2. In the present study, we have compared the thermal comfort condition inside of each building zone with natural ventilation and without that, to evaluate the effect of sustainable design features and natural ventilation in enhancing the Haitian building energy performance. In this process we have used psychometric chart which enables us to have a better perception of Indoor temperature and Haitian comfort zone in each building.

Based on the simulation results (e.g. Fig. 8-9) the indoor temperature and humidity ratio for each zone in three different buildings (Base-case house, Option-1 and Option-2) have been illustrated on the psychometrics chart, not using natural ventilation during the day and night. The red points show the outdoor condition and the larger polygon demonstrates the Haitian comfort zone boundary.

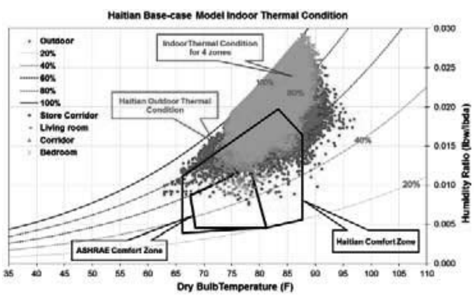
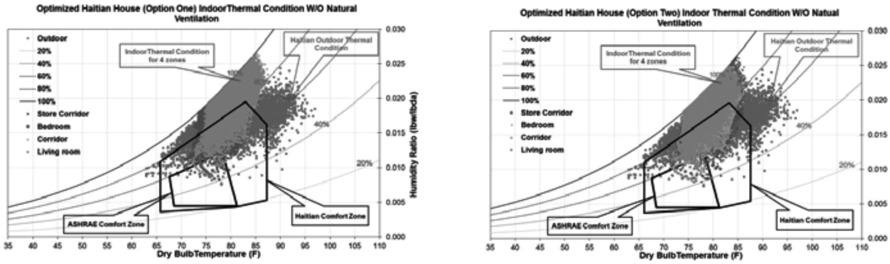


Figure 8: Haitian base-case house indoor thermal condition without natural ventilation. Source: (Authors 2013)



(a) (b)

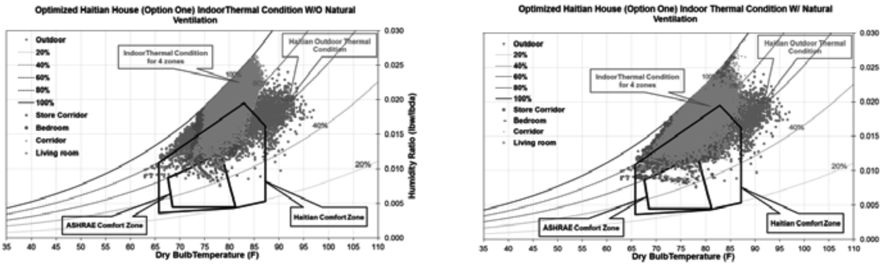
Figure 9: Optimized Haitian houses indoor thermal condition without natural ventilation for: a) Option-1 and b) Option-2. Source: (Authors 2013)

Comparing figure 8 and 9 shows the effect of utilizing passive strategies in the design of two different house plans in Haiti. These passive strategies not only reduce the indoor temperature but also cause to improve the comfort condition inside the houses even without using natural ventilation. Table 4 shows the percentage of hours in the Haitian comfort zone for each building's zone. According to table 4, in optimized Haitian house Option-1, the percentage of bedroom's comfort hours are improved from 21% to 59%, while this amount is from 21% to 49% for optimized Haitian house Option-2 compared to Haitian base-case. Having greater window area in the east and north side of the optimized Haitian house Option-2 might be a good reason for the difference in percentage of hours in Haitian comfort zone between Option-1 & 2. However, the average percentage of hours in Haitian comfort zone for whole building shows that the overall building performance in optimized Haitian houses, Option-1 & 2, has increased in comparison with Haitian traditional house. As mentioned before, Haiti has the relative humidity ranges from 75-85% in early morning to 55- 65% during the afternoon. Adding people and equipment to the EnergyPlus model also increase the latent heat and relative humidity inside the house, thus it is plausible to have higher relative humidity and condensation inside the house during cold days and nights.

Table 4: Percentage of hours in Haitian comfort zone for three cases *without natural ventilation*. Source: (Authors 2013)

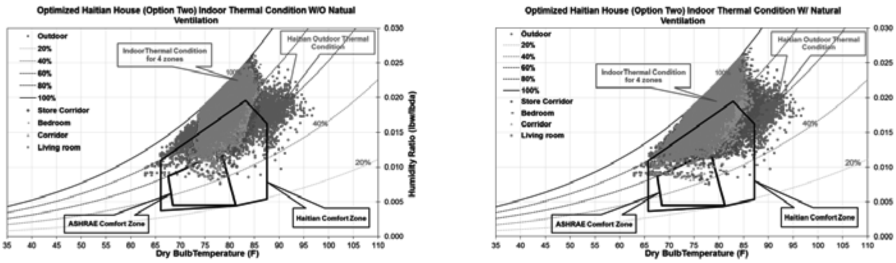
		Store corridor (%)	*Living room (%)*	*Corridor (%)*	*Bedroom (%)*	*Average Percentage of whole building (%)*
1)	*Haitian Base-Case*	38	32	10	21	25
2)	*Optimized Haitian house-1*	85	52	57	59	63
3)	*Optimized Haitian house-2*	69	68	80	49	67

After utilizing passive strategies and evaluating the buildings thermal comfort, natural ventilation was added to the simulation models to examine the effectiveness of natural ventilation on the percentage of hours in Haitian comfort zone for the optimized Haitian houses, Option-1 & 2 (e.g. Fig. 10-11). Figure 10 and 11 respectively shows the optimized Haitian house-Option-1 and optimized Haitian house-Option-2 thermal comfort conditions with and without natural ventilation. It is obvious that considering the natural ventilation in the design causes to increase the percentage of hours in comfort zone.



(a) (b)

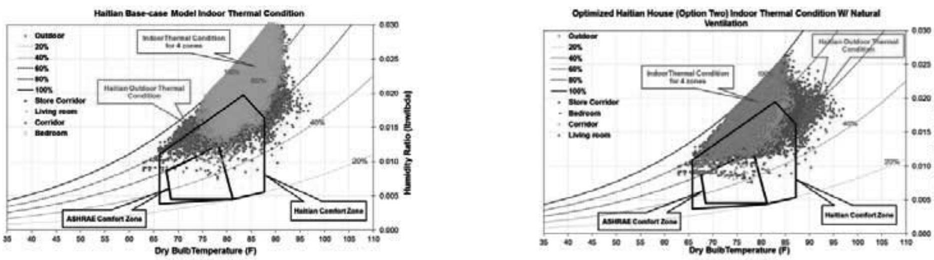
Figure 10: Comparison of Optimized Haitian house Option-1 indoor thermal condition (a) Without natural ventilation and (b) With natural ventilation. Source: (Authors 2013)



(a) (b)

Figure 11: Comparison of Optimized Haitian house Option-2 indoor thermal conditions (a) Without natural ventilation and (b) With natural ventilation. Source: (Authors 2013)

In figure 12 the indoor thermal condition of Haitian base-case house and optimized Haitian house Option-2 have been compared together to illustrate the ultimate effect of considering natural ventilation and passive strategies on the building performance during the design process of Haitian housing complex. Moreover, comparing the percentages of hours in Haitian comfort zone for each zone in two optimized buildings indicates the best configuration of the zones in terms of natural ventilation.



(a) (b)

Figure 12: Indoor thermal condition comparison between (a) Haitian base-case house and (b) Optimized Haitian house Option-2 with natural ventilation. Source: (Authors 2013)

Table 5 briefly compares the average percentage of hours in Haitian comfort zone for Option-1 & 2 Haitian houses in each building zone using natural ventilation. Table 5 shows that zones in the optimized Haitian house Option-2 have better thermal comfort condition than zones in optimized Haitian house Option-1 and it might be because of the larger area for the corridor zone with higher height. Therefore, the effect of stack ventilation increases and in combination with the cross ventilation effect makes a better thermal comfort condition compare to optimized Haitian house Option-1.

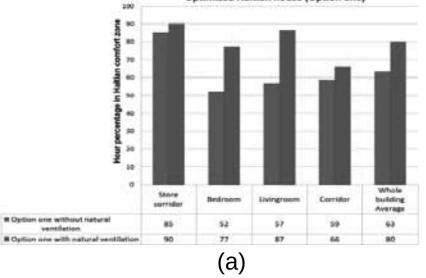
Table 5: Percentage of hours in Haitian comfort zone for optimized Haitian houses, Option-1 & 2 *with natural ventilation* Source: (Authors 2013)

	Store corridor (%)	*Living room (%)*	*Corridor (%)*	*Bedroom (%)*	*Average Percentage of whole building (%)*
Optimized Haitian house (Option-1) with natural ventilation	90	87	66	77	80
Optimized Haitian house (Option-2) with natural ventilation	91	77	85	81	84

Table 6 enables us to compare Haitian base-case house with optimized Haitian houses, Option-1 & 2 to evaluate the natural ventilation effect. As we can conclude from table 6, with the opening of doors and windows to use cross ventilation and stack ventilation, the average percentages of hours in Haitian comfort zone increase in the optimized Haitian houses compare to Haitian base-case house.

Table 6: Average percentage of hours in Haitian comfort zone for three different Haitian houses with and without Natural Ventilation. Source: (Authors 2013)

	Haitian Base-Case (%)	Optimized Haitian house (Option-1) (%)	Optimized Haitian house (Option-2) (%)
Average Percentage of hours in Haitian comfort zone *without Natural Ventilation*	25	63	67
Average Percentage of hours in Haitian comfort zone *with Natural Ventilation*	_	80	84



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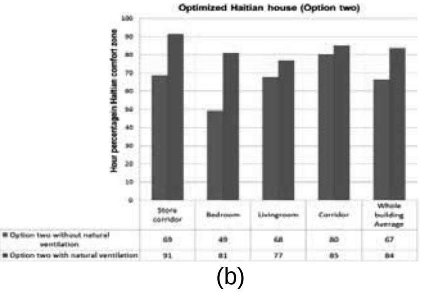

(b)

Figure 13: Comparison between percentages of hours in Haitian comfort zone W/ and W/O natural ventilation for each zone in Optimized Haitian house: (a) Option-1 and (b) Option-2. Source: (Authors 2013)

Figure 13 also shows the improvement of each zone's percentage of hours in Haitian comfort zone in Option-1 and Option-2 houses after adding natural ventilation to the base model in EnergyPlus.

CONCLUSION

Due to the deep economic hardship in Haiti, buildings are required to be more durable with less maintenance and minimal energy consumption, utilizing local labour and materials. Sustainable design strategies, including renewable resources, should be the main approaches for Haiti to be able to achieve the sustainable long term goals. Two different energy models have been developed for this study using EnergyPlus. These models were then optimized by adding some sustainable design features such as increased ceiling heights, operable windows with appropriate shading devices, improved wall insulation, and sustainable construction materials such as adobe bricks instead of concrete blocks for walls. The EnergyPlus simulation results showed that the thermal comfort condition was improved ranging from 25% up to 67% for the optimized Haitian house Option-1 & 2 cases compared to the traditional Haitian house case. These house models do not have mechanical systems. In the optimized Haitian house models, *corridor* zone was placed in the middle of the house with the higher height than other zones and so enhanced the stack ventilation effect besides cross ventilation. Moreover, locating the *store corridor* zone in the south side of the building as an intermediate space prevented the penetration of direct heat and sunshine into living space. In addition, the air flow network object was added to the optimized Haitian house Option-1 & 2 models to evaluate the effect of natural ventilation. The glazing ratio in the north side of the building was increased with proper shading to facilitate the air movement inside the house. New EnergyPlus models were developed to evaluate the influence of natural ventilation on the thermal comfort condition. The results indicated that after adding natural ventilation to the models, the average percentage of hours in Haitian comfort zone substantially increased ranging from 63-67% to 80-84%. To put it in a nut shell, based on the simulation results and graphs, it was concluded that implementing the sustainable features in designing a house in Haiti, using cross ventilation during the day and night and taking advantage of stack ventilation in building, increased the thermal comfort condition inside the Haitian house.

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