

ANALYSIS FOR THE DESIGN OF A SUSTAINABLE HOUSING COMPLEX IN HAITI

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ABSTRACT

This paper presents sustainable strategies for the design of a prototype sustainable housing complex in tropical climate that applies specifically to Haiti. The tropical climate zone is hot and humid with abundant rainfall and luxuriant vegetation growth. Despite its beautiful environment most of the countries in this zone are undeveloped and poverty manifests itself in different faces especially in poor housing condition.

In this study, the history, geography, and culture of Haiti are analyzed in the context of family unit, community, and economic aspects. The climate conditions are also investigated in the context of residents' comfort and energy savings. The construction materials appropriate for Haiti climate are explored. Rainwater harvesting and gray water reuses are discussed.

Finally, sustainable design principles are proposed. Sustainable housing design refers to a strategy to plan and build a housing complex that uses efficient energy and water management while minimizing the overall adverse health and environmental problems. This means keeping the conventional comfort and environment conditions in housing by using natural sources of energy, like sun and wind, to provide natural heating, cooling, ventilation, lighting, and water management while contributing to a responsible natural resources use.

The proposed guiding principles target to be utilized for the design of sustainable housing complex in Haiti located in a tropical climate.

BACKGROUND

Haiti is one of the poorest and least developed countries in the world with 8.7 million residents nearly all African descent and who speak Creole and French. Haiti in recent years has struggled with problems ranging from constant political turmoil, severe environmental degradation and an annual barrage of hurricanes.

On Jan. 12, 2010, a massive earthquake struck Haiti, reducing much of its capital to rubble. It was the worst earthquake in the region in more than 200 years^[1]. A huge part of the capital city, Port-au-

Prince, lay in ruins and thousands of people were trapped in the rubble of buildings. Schools, hospitals and residential buildings collapsed and killed about 200,000 to 250,000 people^[2]. Even before the devastating earthquake, Haiti had a distressed economy.

Severe deforestation had crippled the agricultural economy and left the country's residents vulnerable to hurricanes, floods, and landslides. Since 2008 hurricanes and Tropical storms devastated crops and caused one billion dollars damage, 15 percent of the gross domestic product for Haiti. The disaster left 800 dead, which is relatively small compared to the tropical storm and mud slide of 2004 when 3,000 perished^[3].

Its long history of political instability and corruption has added to the turmoil. Haiti has 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. Eighty percent of the population is living under the poverty line and 54% of them are living in abject poverty^[4]. More than two-thirds of the labor forces do not have formal jobs, and just 52.9% of adults over age 15 are literate^[5]. Despite the destruction wreaked by multiple tropical storms and the catastrophic earthquake, Haiti has and will struggle to pull itself out of poverty. The people of Haiti have sustained numerous disasters in recent years and they persevere.

With the help of the international community Haiti can put things back together again. However, building rickety houses, getting water flowing again, or fixing the presidential palace doesn't do any good as long as a sustainable path out of poverty doesn't exist. Haiti needs to focus on sustainable development that protects the environment and spurs local jobs by creating a clean energy economy. This is an extraordinary opportunity to start over and recreate sustainable development in Haiti. In this study sustainable design strategies are proposed to create a sustainable housing complex in the devastated city of Port-au-Prince.

MISSION AND VISION

This study is to explore the major issues that surround sustainable housing complex in Haiti and to provide guiding design principles that can be used. It explores key principles on how to design sustainable housing that is going to save energy, environment, and strengthen community life. It focuses on energy saving strategies that reduce the demand for energy in Haiti and encourage local innovation that have a positive impact on the environment. As a result it improves the economies of low-income families as the country reduces the need for investment and subsidy in energy infrastructure. The project also focuses on how to create a livable and walkable strong sustainable community with a better quality of life for the residents. The project includes but not limited to housing, local markets, and social services that promote local community development. At the end, these developments will help create an exemplary sustainable community that has local innovative green jobs, and assist the region to become more competitive on a national scale.

ABOUT HAITI

“Give me Liberty or Death” Haiti Declaration of Independence, January 1, 1804.

History: In 1492 Columbus landed in Hispaniola Island by accident in search of new and better routes to India. In the following years of Spanish settlers, the native people of the island – Arawak Amerindians suffered near-extinction, presumably due to oppression by the Spanish. After three decades Spanish interest in Hispaniola began to wane as more lucrative gold and silver deposits were found in Mexico and South America. In 1670 the French took control over the western portion of the island to establish a permanent settlement and in 1697 Spain officially ceded the western third of Hispaniola to France. The French colony was based on forestry, tobacco, cotton, sugar and coffee on the fertile northern plain of Hispaniola and exporting them to Europe. The expansion of plantation prompted heavy importation of African slaves.

After a century of brutal slavery by French settlers, the outbreak of revolution in France in 1789 inspired the 500,000 African decedent slaves to fight for their independence. On January 1, 1804 the western Hispaniola led by Jean Jacques Dessalines declared independence reclaiming the indigenous Taino Indians name Haiti which means Land of mountains. Haiti is the world’s oldest black republic and the second-oldest republic in the Western Hemisphere, after the United States. Today 95% of Haiti’s population is black African decedents and

known for their strong nationalist movement across the political spectrum^[6].

Geography: Haiti is located in the subtropics on the western third of Hispaniola between the Caribbean Sea and the North Atlantic Ocean. Haiti’s geographic coordinates are 18 32 N, 72 20 W. Haiti covers 10,714 square miles, slightly smaller than the size of the state of Maryland. Three-quarters of Haiti’s terrain is mountainous. The climate is mild-hot and also varies with altitude. The mountains are calcareous rather than volcanic and give way to widely varying microclimatic and soil conditions. There is also a tectonic fault line that runs through the country, causing occasional and sometimes devastating earthquakes. The island is also located within the Caribbean hurricane belt^[7].

As a result of geographical location (Figures 1&2), building construction in Haiti should incorporate systems that resist hurricane and earthquake.



Figure 1. Haiti Geographical Location in Central America



Figure 2. Haiti Map (“Behind the mountains are more mountains” Haitians’ proverb)

Culture: A typical household in Haiti is made up of nuclear family members and in some cases young

relatives. The husband is thought of as the owner of the house and is not expected to bring bride price or dowry; therefore, in most cases the men must provide house, garden plots, and livestock. The house typically is associated with the woman, and she is thought of as the manager of the property and the decision maker regarding use of funds from the sale of garden vegetables and household animals.

Although it is not legal, a minority of the men population has more than one wife, and these relationships are acknowledged as legitimate by the community^[8].

The official state religion is Catholicism; however, Haiti is famous for its popular religion, known to its practitioners as "serving the lwa" but referred to by the literature and the outside world as Voodoo (Figure 3). This religious complex is a syncretic mixture of African's native religious rituals and Catholic beliefs, and its practitioners continue to be members of a Catholic parish^[9].

People feel very strongly about greetings, men shake hands on meeting and departing, and men with women kiss on the cheek when greeting. Women and especially men commonly hold hands in public as a display of friendship. In general, Haitian people have kept a strong African culture with their collective society that trades privacy for intimacy.



Figure 3. Voodoo Ceremony

Economy: Haiti is one of the poorest countries in the Western Hemisphere and the least developed country in the world. About 80% of the population is estimated to be living in poverty. Heavy migration from rural areas to towns and cities occurring over the past decade has adversely affected the distribution of the water supply. Access to water and sanitation facilities are inadequate, contributing to poor living conditions, disease, and a high child mortality rate. The population has already outstripped domestic food production and most Haitians live on \$2 or less per day and suffer from malnutrition. Poverty has forced at least quarter of a million Haitian children to work

as "restavecs", unpaid household servants, which is considered to be a modern day form of slavery by the United Nations^[10].

Haiti also has limited energy resources. The country has no petroleum resources, little hydroelectricity potential, and rapidly diminishing supplies of wood fuels. Wood accounts for 75 % of the nation's energy consumption (Figure 4) while petroleum accounted for 15%, and hydroelectric power for 5%. Having virtually no access to electricity, Haiti's poor depend on the cutting of trees for the production of charcoal.



Figure 4. Haiti Woman Carrying Wood for Cooking



Figure 5. Haiti & Dominican Republic Border.

Similarly, many rural small businesses use wood as a fuel in powering their operations which is the main factor for deforestation that has felled 98% of Haiti's tree cover with the remaining 2% disappearing fast^[11]. The violence done to the environment due to an unmet basic energy demand is the main problem haunting Haiti now. Looking at the satellite map (Figure 5) of the borders of Haiti (on the left) and Dominican Republic (on the right) highlights the relative deforestation of Haiti.

Deforestation, with its devastating environmental consequences, is a serious problem in Haiti. For

example, Lac de Peligre, the only major reservoir in the country, has lost 30 percent of its storage capacity due to sedimentation caused by deforestation^[12]. Deforestation accelerates soil erosion, decreases the amount of recharge to aquifers by increasing surface runoff, and damages barrier reefs and ecosystems. As a result, it reduces agricultural production and creates food shortage (Figure 6).



Figure 6. Woman in Haiti Making Cookies from Dirt

This deep economic hardship requires buildings in Haiti to be durable, that require less maintenance and energy, and more local labor and local material. Using renewable clean energy resources through a sustainable design strategy is the best and only way for Haiti to claim sustainable long term prosperity.

“Women are the center post.” Haitian proverbs

Social Organization: Haiti has a strong social interconnected system that provides mutual responsibility among the members of extended families called Lakou (Figure 7). Lakou refers to cluster of homes in which families, as well as extended and multiple-generation families reside. These prominent Haitian’s communities were started by runaway slaves during the French occupation and War of Independence. Once escaped, they fled to the mountains or remote areas and lived together with other slaves in hidden locations. Lakou is the creation of free people living cooperatively on their own property as opposed to slaves living on a master’s plantations^[13].

Initially, the members of a Lakou worked cooperatively and provided for each other through financial and other forms of support. Moreover, the original Lakou was based on the African tradition that raising children was too great a responsibility for only one or two people to bear, and that it was healthier for children and mothers to have contact with a wide circle of people and share parenting responsibilities.



Figure 7. Lakou, Community in Rural Area

However, the original Lakou system has changed due to the increased pressures of poverty and landholding fragmentation. As a result, the Lakou shared parenting system shifted to a typical nuclear family system and fallen largely on the shoulders of individual Haitian mothers. With the backdrop of ongoing poverty, gender discrimination, and embedded male dominance; the Haitian women have yet been the stabilizing center of the majority of rural households.



Figure 8. Street Vegetables Market in Port-au-Prince

In today’s typical Haitian nuclear family, husband and wife have a complementary responsibility role both in urban and rural area. The heavy work like farming and tilling are the responsibility of men and often women assist in weeding.

On the other hand women are also responsible for cultivating garden vegetables and selling agriculture products. Women participate in the labor force in much greater extent and Haiti’s culture values her contribution by allowing her to have equal share of the income generated through agriculture. Furthermore, the income women earned from non-farm business activities is recognized as their own^[14]. As a result they often acquire sufficient capital to become full-time market traders and economically

independent. The culture of Haiti allows women to grow. This is where Non Governmental Organizations (NGOs) can help Haiti's economy by empowering women with programs like micro-lending and family planning.

Urban/Rural Neighborhoods Organization: In most of the urban areas the houses are built without a strong organizational system but instead in random chaotic organization following the topography of the land. However in some of older urban areas the houses are constructed in centralized organization. They have often an open space at the center. Grid system is the general underlined geometry of the city planning^[15].

Figure 9 shows the organization of the space in Jacamleo city, and Figure 10 is an example of how chaotic the cities in Haiti. Figure 11 shows a grid system in Jacamleo city. Figure 12 is a picture of a city showing the landscape of the buildings.



Figure 9. Open Space Organization, Jacamleo City

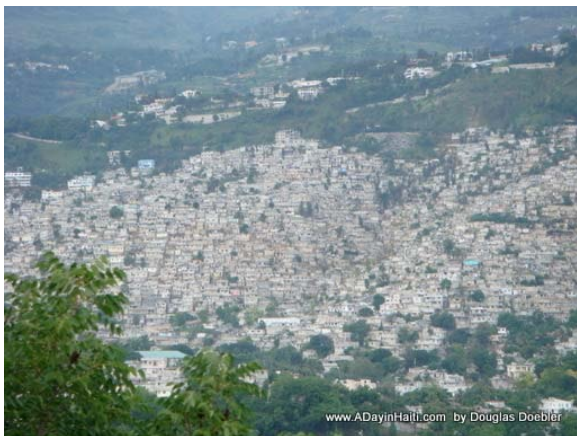


Figure 10. Chaos, Port-au-Prince City



Figure 11. Grid System, Jacamleo City

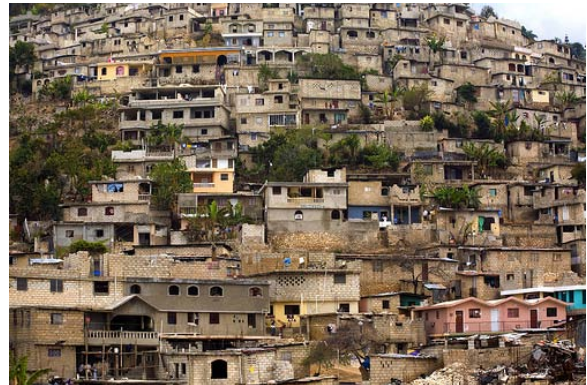


Figure 12. Housing Built Following Topography, Port-au-Prince City

The Vernacular House: Typical Haiti houses are rectangular shape, single-story, and two rooms shake with a front porch. 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 (Figure 13).

Rationale for material selection

- HBC affordable
- Locally manufactured
- High skilled labor not required
- Relatively short time of construction process
- Durable and sign of modernity

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 (Figure 14).

Rationale for material selection

- Cheap wood due to illegal deforestation
- Free mud
- High skilled labor not required
- No transportation cost



Figure 13. HBC House, Southern Haiti



Figure 14. Local Hard Wood House, Northern Haiti

DESCRIPTION OF THE STUDY

The goal of this study is to design eco-friendly housing complex that is walkable, livable, and sustainable.

Site: The project site is located in Port-au-Prince, the capital city of Haiti.

Context: The housing complex size and concept is inspired by the traditional Haiti community organization, Lakou, an independent cluster of homes made up of immediate and extended families.

Size of occupants: Haiti has a life expectancy of 52 years and an infant mortality rate of 8% due to malnutrition. As a result, having a lot of kids in an early stage of life is one of the traditional ways to keep your bloodline going. Today, the average Haitians nuclear family size is six. The housing complex will be designed for three generation of ten modest size families or a total of 160 inhabitants by the calculation below (Figure 15).

Average family (three generations) = 16 members * 10 households = 160 inhabitants.

Facilities: The project has four major components; residential, shopping, service, and workshop.

Residential: This area will be secured for residents only. It incorporates residence buildings, gardens, open spaces and playgrounds.

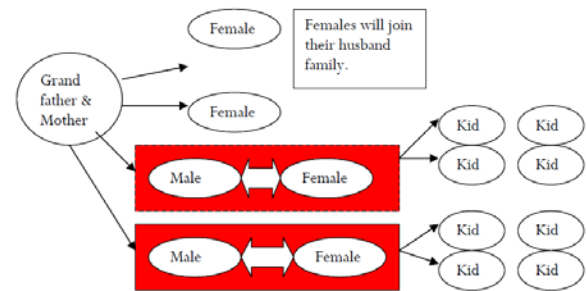


Figure 15. Average Haiti Family Members (Three Generations)

Shopping: This area will be accessible for public. It incorporates vegetable markets, a laundry, shoes repair (alteration), a clinic and a micro-lending services area.

Service: This area will be partially accessible to public. It incorporates a library, a place of worship place, and a family planning education area.

Workshop: This area will be partially accessible to public. It incorporates training areas for green jobs. It includes but not limited to;

- Solar panel and wind mill installation
- Rainwater and grey water harvesting
- Sustainable construction material selecting
- Tree planting, advocacy, and conservation

CLIMATE

Haiti has a humid tropical climate with hot temperatures throughout the year, which becomes more mild and fresh with an increase of altitude. Haiti has two main seasons, dry season (December to March) and wet season (April to November) (Figure 16).

Dry Season (December – March): There are three main players in the climate of Haiti; the Bermuda/Azores high, the easterly trade winds, and the terrain of Haiti. The Bermuda high shifts north and south as it expands and shrinks with the seasons, which slightly alters the direction of the easterly trades. The easterly trades extend above 15,000 feet and are divided by the trade wind inversion created by circulation around the Bermuda high (Figure 17).

Air below the inversion is moist and unstable while the air above is conditionally unstable but dry. Although the easterly trades persist year-round, Haiti is actually under northeasterly flow because of the Bermuda high. The trades turn northeasterly and bring moist air to the windward (northern and northeastern) slopes and mountains.

Port-au-Prince, Haiti

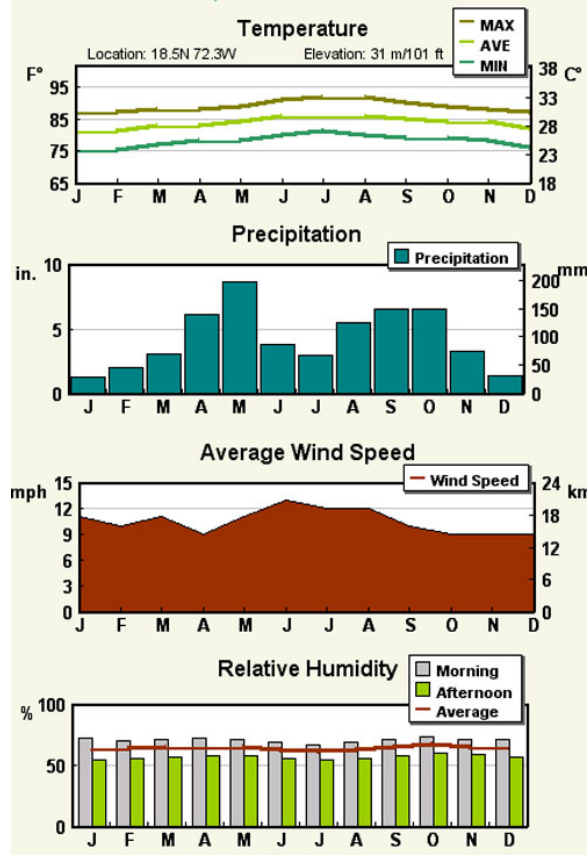


Figure 16. Climate Data of Port-au-Prince (Capital City of Haiti)

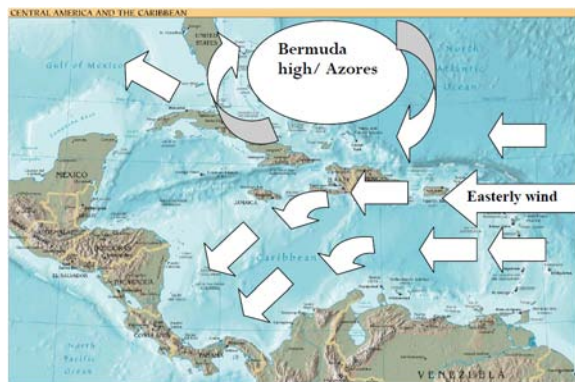


Figure 17. Dry Season (December – March) Wind Flow Direction Changes to NE. Bermuda High/ Azores Easterly Wind

This brings increased rainfall to those areas and decreased rainfall in leeward locals which are the south and southwestern areas where the capital city Port-au-Prince is located (Fig. 4.2).

Wet Season (April – November): In this season the easterly trade winds are predominant. The

Bermuda high expands and migrates over the Caribbean during Jun and July. This is when the average pressure over Haiti is the highest of the year. During September and October, the atmospheric pressure is lower because the Bermuda high retreats. The trade wind inversion weakens and allows convection to develop more often.

In general, due to Haiti’s geographical location as 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. The term dry season in Haiti is more about less rainfall relative to the wet season than an actual dry period. That is why we see precipitation in all Haiti regions all year long^[16] (Figure 18).

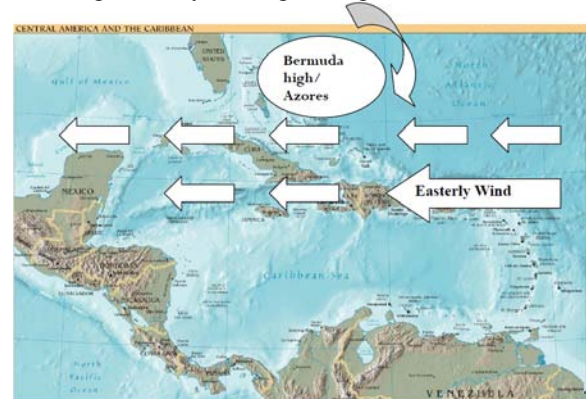


Figure 18. Wet Season (April - November) Wind Flow Direction Persists in East Direction. Bermuda High/ Azores Easterly Wind

Key Climatic Design Priorities: (1) Open the building to the outdoors since temperatures are comfortable much of the year.

- Create outdoor spaces with different orientations for uses at different times of the year: South side for winter and North side for summer.
- Create Verandah or living areas that are sheltered from the hot summer and cool winter
- Create a non-compact building designed for maximum contact with the outdoors. Include spaces that are used as a transition.
- Create area with large operable windows and minimum exterior walls that have few interior partitions.

(2) Protect from the summer sun.

- Avoid building on east and especially west slopes. North slopes are best because solar heating is not required a lot in the winter.
- Use plants for shading
- Use low albedo ground covers around the building to minimize reflected light entering windows.

- Avoid east and especially west windows if at all possible.
 - Use only vertical glazing. Horizontal or sloped glazing (skylights) should be shaded on the outside during summer.
- (3) Avoid creating additional humidity.
- (4) Allow natural ventilation to both cool and remove excess moisture most of the year.
- Orient the building to capture the prevailing wind.
 - Create “night flush cooling” and “comfort ventilation”.

BUILDING COMPONENTS AND SYSTEMS

Comfort level in building interiors in tropical climates are affected by the external environment levels of air temperature, level of solar radiation, air movement and humidity. As a result, all three heat transfer mechanisms (conduction, convection, and radiation) affect the building. The solar radiation coming into the outer elements of the building will be absorbed as heat and transmitted to the building by conduction.

At the same time, convection occurs due to the temperature difference between outdoor temperature and indoor temperature. Convection thermal transmission occurs from outdoor hot air to the exterior surface of the building element and then to the indoor surface of the building element and finally to the indoor air. As a result the indoor temperature and relative humidity will fluctuate according to the outdoor temperature and create discomfort to the residents.

Building in the tropics therefore requires a high degree of thermal inertia that makes the room temperature and relative humidity remain reasonably stable and unaffected by fluctuations of the outdoor conditions. Controlling heat transfer mechanisms is the key to achieving a high degree of thermal inertia. These controlling methods are discussed below in the context of orientation and major components of the building like roof, wall, opening, and landscape.

Orientation: The majority of houses built in Haiti have a basic rectangular shape for two major reasons: flexibility and solar heat gain.

Flexibility: Due to the economic hardship, building housing in Haiti is a lifetime project to be executed in a number of phases. As a result, the rectangular shape house gives the owner and the local craftsmen great flexibility for expansion whenever necessary. Adding rooms to the rectangular shape gabled roof house does not require major change on the existing structure.

Solar heat gain: Due to 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 (Figure 19). The rectangular shape of traditional Haitian houses oriented along an east-west axis is a response to reduce solar heat gain^[17].

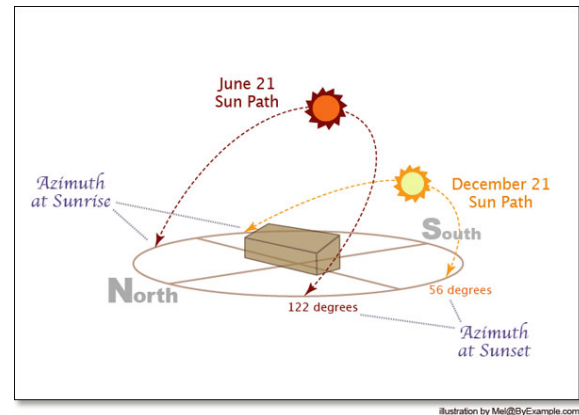


Figure 19. Sun Path Diagram of Summer/Winter

Roof: Due to Haiti’s geographical proximity to the equator, the near vertical sun during the hottest hours of the day heats the roof with great intensity. Metal roof, widely used in Haiti, are made from aluminum, zinc, copper or stainless steel and has the disadvantage of being a very effective heat conductor rather than heat reflectors. As a result the indoor air temperature is highly affected.



Figure 20. Metal Roofs Corrosion, Port-au-Prince

Metal roof is also a weak sound insulator. In wet season, noise due to high precipitation on metal roof is a major problem for residents. Metal roof also suffers from corrosion caused by contact with sulphur dioxide in the atmosphere (Figure 20).

However the accustomed big eaves and pitched or sloping roof design is working very well for Haiti’s climate in creating plenty of shade around the building and standing to heavy tropical showers. Selection of roof material and construction system in

hot tropical climate has to consider roof solar shading, solar reflection and thermal insulation.

Roof solar shading: Appropriate external shading devices can control solar radiation admitted into the indoor environment. This reduces cooling loads and improves thermal comfort.

For example, when deciduous plants or creepers cover the building the evaporation from the leaf surface lowers the temperature of the covered area at daytime and nighttime.

Roof solar reflection: If the roof is painted with a color that reflects solar radiation it minimizes heat absorption and reduces the heat flux transmitted into the building.

Roof thermal insulation: Roof thermal insulation can be used in two major ways; green roof and double roof system. Green roof can be used as a high quality insulation device in the summer. It insulates the roof from direct solar radiation which reduces the heat flux through the roof. The thickness of the soil layer, its density, and its moisture content are the main factors for the soil thermal diffusivity.

Green roof (Figure 21) is more effective in reducing heat gain than heat loss and therefore performs better in hot and humid areas^[18]. Green roof cultivation is an easy way to insulate the building effectively in a climate like Haiti where the annual average precipitation is 54 inches and available all year long, Double roofing is creating layers of surfaces to control heat transmission through conduction.

The construction of secondary roof with a gap of several inches difference from primary roof surface (roof cavity) allows ample airflow in-between reduces heat transmission through conduction and prevents moisture build-up. This thermal conduction can also be achieved using false ceiling too.

For sloping roof (Figure 22) applying roof insulation has the same thermal insulation effect as flat green roof construction. Ventilation of attic and attic height makes the sloping roof much more effective roof design in controlling heat transmission^[19].

Roof Summary: To optimize the roof thermal performance the following criteria have to be considered in selecting and detailing of roof system.

- Low thermal conduction roof material (like white concrete tile, cement shingles or clay tile)
- Roof shading
- High albedo material (exterior surface paint)
- Use of green roof or double roof system
- Geometry of ceiling and the size of attic
- Ventilation of attic

Wall: The construction material and design details of wall are the two major factors that contribute in creating high degree thermal inertia for

the wall so that the indoor temperature and relative humidity remain reasonably stable despite the outdoor condition. As a result, high thermal mass construction materials or insulation are required to slow down the rapid heat transfer that occurs in hot climate. Construction materials such as brick, cement block, concrete and solid masonry materials are considered high thermal mass due to their properties to absorb heat from solar radiation at a slower rate than light material like metal sheet, and timber.

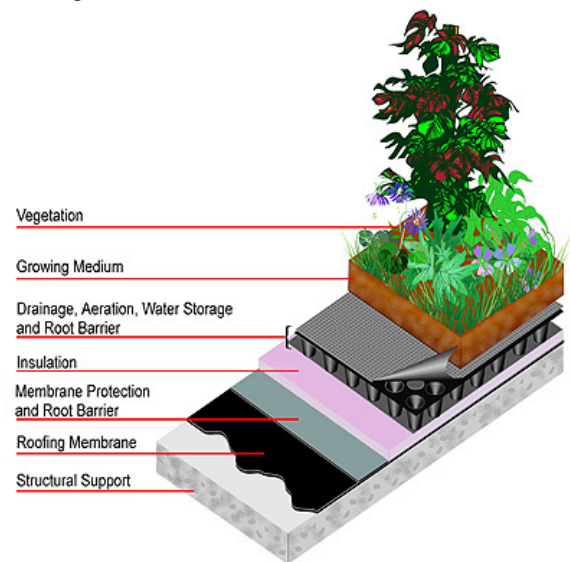


Figure 21. Green Roof Structure

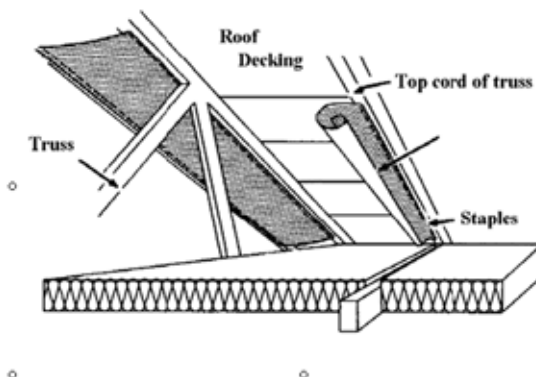


Figure 22. Sloping Roof Insulation Details

Metal sheet and timber wall systems, widely used in Haiti, absorb heat quickly and conversely cool down quickly. As a result, indoor heat flux and humidity increase and creates discomfort to the residents. When selecting wall material and construction systems in a hot tropical climate it is necessary to consider wall solar shading, solar reflection and wall thickness and thermal insulation.

Wall solar shading: The most important wall surfaces that need shading are those exposed the most.

In Haiti's case, the eastern and western side wall get high solar radiation and as a result need more shading; however, the northern and southern wall surfaces also need less shading. Wall shading can be achieved by longer roof eaves and planting trees.

Wall solar reflection: To avoid solar gain the exterior side of wall has to use a white reflectance surface or has to be painted a similar color. Researchers indicate that using white reflective surface reduces solar heat gain and minimizes the need for insulation.

Wall thickness: Thermal transmission in materials depends on thermal conductivity and thickness of that material. Mostly lower value thermal conductivity will have less thermal transmission. That is why rooms with thick walls and high thermal mass tend to be more comfortable in hot temperature.

However in Haiti, most of the traditional material used for wall is considered to be low-mass material like wood with mud (wattle and daub). Due to the material low thermal conductivity, the indoor temperature drops rapidly in the evening when winds usually subside. High mass buildings usually cool down more slowly during the night which creates a feature of discomfort during sleep. But on day time bases the high mass walls have far more advantage than low mass walls^[20]. If high mass material is selected to slow the heat gain at day time Table 1), well designed ventilation is mandatory to encounter the high mass wall's adverse effects and keep sleep comfort at night.

Table 1. List of Construction Material Thermal Mass

MATERIAL THERMAL MASS	Volumetric heat capacity, (KJ/m ³ .k)
Concrete	2060
Sandstone	1800
Compressed earth blocks	1740
Rammed earth	1673
Brick	1360
Earth wall (adobe)	1300

Wall thermal insulation: Insulation is commonly used for cost-effective energy conservation measures for residential buildings. However, insulation may trap heat inside at night when outdoor temperatures drop and heat loss would be beneficial. A ventilation system at night is necessary in tropical climate to achieve comfort level due to the diurnal range^[21].

Wall summary: To optimize the wall thermal performance the following criteria have to be

considered in selecting and detailing of the wall system.

- Low thermal conduction and high thermal mass wall material (like brick, stone, and concrete)
- Wall shading
- High albedo wall material (exterior surface)
- High reflective insulation
- Thick wall system

Openings: For naturally ventilated building design openings are crucial elements to achieve indoor comfort level. Openings can reduce indoor heat and humidity, but on the other hand the location and orientation of the openings can increase the indoor temperature with solar penetration.

For example, to cool down the indoor temperature by capturing the prevailing wind in Haiti, an opening in the east and west faces of the building is important. At the same time, due to the proximity of Haiti to the equator, the solar heat gain in the east and west sides are intense and unwanted morning and afternoon solar penetration will have an adverse effect. To reduce the heat gain but catch the prevailing wind two factors must be considered in the building design: solar shade and ventilation.

Solar Shade: The primary goal of climate conscious design in the tropics primary goal is to prevent solar heat gain into the building especially through openings. This goal can be achieved by means of natural shading and sun control devices. Natural shading is discussed in detail under landscape

Sun control devices can be divided into two major parts; internal and external devices. Internal sun shading devices like blinds, screens and drapers are not effective for naturally ventilated building design. This is because they allow solar radiation to strike on the vertical surface of the building and permit the heat to enter the building. In contrast the external sun shading devices intercept the solar radiation before it reaches the vertical surface of the building enclosure and let the obstructed heat to dissipate to outside air.

External sun shadings are divided into two basic forms, horizontal and vertical. The shadings can be done as fixed form like recessed walls and cantilevered floor or adjustable with light weight material shading devices. Adjustable shading devices require frequent maintenance but it is useful and more flexible to control glare in summer and solar heat in winter. The fixed shading devices do not require maintenance or occupancy handling; however, they have limitations imposed by architectural and structural reasons^[22].

Ventilation: Natural ventilation relies on breeze in the summer to remove heat from the building and provide air movement to cool the occupants. Natural

ventilation can be divided into two categories: cross ventilation and stacked ventilation.

Cross ventilation is when windows on windward side (east) and leeward side (west) are opened and allow air flow across the space.

The opening of the windward side has to be less than the leeward side to get fresh, comfortable indoor air based on natural ventilation principles^[23] (Figure 24). Stack ventilation is mostly located at the attic and roof to reduce the ceiling temperature. These types of high opening vents collect the hot air near the ceiling and are most useful for night-flush cooling^[24] (Figure 23).

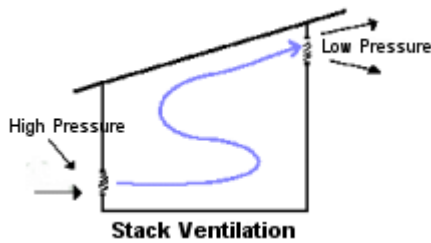


Figure 23. Stack Ventilation System

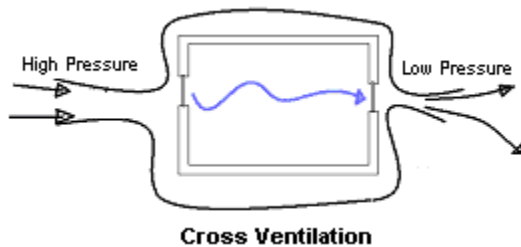


Figure 24. Cross Ventilation System

To cool the indoor temperature the following criteria have to be considered in the design of openings.

- Use of exterior shading devices
- Provide vertical shading devices for openings in the east and west side
- Provide horizontal shading devices for openings in the south side
- Provide ventilation for attic

Landscape: In tropical climate the landscape surrounding the building can affect the air temperature, humidity, solar radiation and air movement. Landscape design helps to control microclimate and thereby reduces the amount of heat gain in the building. The two major systems to control microclimate are natural shading and ground surface treatment.

Natural Solar Shade: Trees and vegetation are the most effective method to shield a building from solar radiation. Leaves absorb the solar radiation and use its energy by photosynthesis while shading the area and cooling the ambient hot air. High canopy

deciduous trees in the east and west side of the building help block solar radiation and allow summer air flow underneath.

Ground Surface Treatment: When an object absorbs light, it converts that light to thermal energy, and emits that energy as heat. Black objects absorb more light and also emit more heat than light color materials. In a tropical region like Haiti solar radiation is intense throughout the year and surface temperatures of landscape materials can heat up.

For example material like asphalt can heat up in a daytime and reaches temperatures as high as 120°F^[25]. As a result, the more the object absorbs light, the more the microclimate heats up. This is called the heat island effect. To minimize the heat island effect any ground surface design has to use high albedo materials. It is also good to use rough surface finishes to reduce glare.

Vegetation also plays a large part in keeping microclimate cool through a process called evaporative cooling. Plants absorb water through their roots and lose water through their leaves to the dry air ambient air by evaporation which turns it into gaseous water vapor. The air loses heat during this process and becomes cooler, hence the name evaporative cooling.

To control and cool the microclimate in landscape design the following criteria have to be considered in the design and selection of materials.

- Use High canopy deciduous trees to block east and west sun but allow summer air flow underneath
- Use native trees and vegetation as solar shade
- Use high albedo material for landscape
- Use rough surface material to reduce glare

WATER MANAGEMENT

Haiti has a fundamental deficiency of water supply and sanitation services. Except isolated small water treatment units throughout the country, there is no public sewerage system in the cities. Only 30% of the daily volume of solid wastes produced in Port-au-Prince is collected by the Municipality. As a result, the widely practiced bad excreta disposal methods are polluting almost all 18 water sources that supply Port-au-Prince. The investment by the Haitian government to alleviate sanitary and water supply services were interrupted with frequent political crisis and trade embargos and left the fragile system without maintenance. Today, only 39% of Haitian residents have adequate access to water and only 24 % to sanitation. The lack of potable water for basic human needs is one of the most critical problems in the country. Currently there is no public system for the collection and treatment of wastewater^[26].

To ensure adequate potable water for residents, communities in Haiti should reduce the load on the main water supply and sewer system. Reduction of potable water use and sanitary water discharge to the main system can be achieved by two methods: grey water system and rainwater harvesting.

Rainwater Harvesting: Rainwater harvesting is the process of intercepting storm-water runoff and putting it to a beneficial use. By collecting Haiti's 54 inches average year annual precipitation, rainwater harvesting can be more effective. Rainwater is usually collected or harvested from rooftops, concrete patios, driveways and other impervious surfaces. Intercepted water can be collected, detained, retained, filtered and routed for drinking, lawn, and garden irrigation use^[27]. As a result it conserves the potable water supply. Typically these systems consist of gutters, downspouts, and storage containers.

Greywater Systems: Greywater refers to the reuse of water drained from baths, showers, and sink or any household wastewater excluding toilet wastes for other water conservation applications. I do not propose graywater as a safe product to use for any purpose except for toilet flushing due to lack a regulatory institution to oversight the treatment process in Haiti. Graywater use reduces overburdened municipal sewage very effectively by reducing waste water entering to the septic tank. It also reduces the amount of potable fresh water used by the household. Typically the systems consist of settling tanks, sand filters, and pumps^[28].

To conserve water with rain water harvesting and graywater recycling the following criteria have to be considered in the design process.

- Consider methods in landscape and building designs to maximize the amount of catchments area, thereby increasing rainwater harvesting possibilities.
- Use a separate plumbing system to collect gray water from black water in sewer line design to ease gray water filtration.

CONCLUSION

Building construction and operation have extensive direct and indirect impacts on the environment. Buildings use energy and water for operation and raw materials for construction. They also generate waste and emit potentially harmful atmospheric emissions. To minimize their impact on environment, as well as the economy, building design, material, and water management play important roles.

The main issues that were considered in Haiti to design a sustainable housing complex were hot climate due to solar radiation and storm water due to high precipitation. From the building material and environment studies it is concluded that the following

factors affect the building, energy, water, and indoor thermal comfort in tropical environment.

- Orientation of the building has to be east-west direction
- High material reflectivity is appropriate to minimize the building heat gain
- Provide material solar shade to intercept direct solar radiation
- High thermal mass materials are appropriate to slowdown heat transmission
- Openings and ventilation is appropriate to create air movement
- Harvesting rain water and grey water recycling are effective water management practices to reduce the impact on water resources
- Building material selection has to factor domestic resources and local craftsmen skill

“The earth provides enough to satisfy every man's need, but not enough to satisfy every man's greed.” Mahatma Gandhi

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