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Radiant Wall Cooling for Sheltered Structures in Underdeveloped Countries in Extreme Climates

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Abstract

Hot and harsh climates of many underdeveloped countries are extremely problematic. People find themselves battling heat exhaustion and premature death caused by unforgiving heat events. The aim of this research is to improve the thermal comfort of Haitian residential shelters through testing radiant wall cooling and sustainable design principles. The research is limited to concentrate on small sheltered structures typically found in locations of low-income families, specifically in Haiti. The researchers focused on through literature review by investigating (1) previous case studies, (2) industry standards means and methods of sustainable construction, and (3) current trends in the host nation residential construction, striving for the most plausible acceptance of residential hybrid technology. The study includes the assemblies of a composite design--i.e., corrugated metal, bamboo and water delivery--to function and achieve a betterment for an interior shelter climate, by constructing a small replica test model. The limited scale model was constructed and tested in an effort to prove or disprove the theory of thermal comfort utilizing radiant wall cooling in hot climates. The model used both host nation common materials, and limited outside technology; thus enabling ease of accessibility to the native people. The testing of the models occurred in three phases; two of which are presented in this paper. The use of Fluke thermal imaging and Fluke temperature and moisture instrumentation were utilized collect data from the models. The findings of this study conclude the integration of such material assemblies are appropriate to change the performance of the interior shelter space during hot climates. It is with these efforts and findings the researchers are encouraged and look to open dialogue among architectural, engineering and building professionals to create new levels of thinking into more exploratory means per each individual host nation's challenges. These hybrid methods of construction may quickly be implemented and continued long after humanitarian efforts have departed.

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1. Introduction

Hot, harsh climates of many underdeveloped countries are extremely problematic. Although the definition of a shelter can be most anything; there lies one component of the shelter which is frequently challenging in providing comfort for those residing and far from electricity: a controlled interior climate. People find themselves battling heat exhaustion and premature death caused by unforgiving heat events. Attention to interior comfort and health is as important as the basic shelter itself, but where most fall short is the marriage between the two; structure and thermal comfort, pending geographic location of sheltered needs.

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In an effort to reduce heat related deaths and possibly some diseases, the interior climate and way the shelter can be constructed using materials composed primarily of the host nation may be able to reduce this chain. If there is an ability to create an assembly of components both natural, and with limited manufactured material; there may be a central core to the basis of impoverished nation residential design [1]. Organizations from years past have accomplished many feats in helping those in need, but there lies one common shortfall, the people. Despite all the success stories over time, some of these efforts are short lived, or until the funding and outside resources are depleted. Thus, the native people are left to fend for themselves, not knowing how to build the western influenced shelters. It is said the only successful improved shelter will be one made from the host countries natural resources, while staying within the methods of construction familiar to those who live there with limited outside resources, which may be readily available after support aid has subsided [2].

The ability to run small water filled lines within the foundation, walls, and/or roofs has been experimented to various degrees in efforts to find an alternative way to cool or heat interior spaces without the high cost of energy. Radiant cooling is a different approach than the conventional “Western” method of forced air, split system cooling you typically find in most homes in the U.S.; it performs by way of convection. As the hot air rises, the cooler air falls to lower levels of the interior space near most areas inhabited by occupants [3]. As the interior water circulates within the inter floors, walls and sometimes roofs, it is always within a set limit of temperature settings; thus the more the water is moving, the cooler the water can be maintained from the regulated source. The aim of this research is to improve the thermal comfort of Haitian residential shelters through testing radiant wall cooling and sustainable design principles. The research is limited to concentrate on small sheltered structures typically found in locations of low-income families, specifically in Haiti.

2. Literature Review

Previous investigations into building envelope radiant cooling are the launching pad to create a composite assembly, which may work within the restrictions of host nation’s architectural developments [4]. Harnessing the power of the sun is always looked upon favourably to reduce the dependency of manufactured energy [5], and enlightens many components into one large resource to assist in the design of a sustainable systems. Other resources in the host countries basic resources and methods of construction may be investigated to assure, methods of new assemblies may likely be utilized or experimented for general acceptance.

Haiti over many years has faced natural disaster challenges such as earthquakes and hurricanes; often leaving many residents without basic shelter [6]. Many previous attempts to rebuild in Haiti have seen both success stories and tragedies [2]. Teaching the local construction trades of an undeveloped country new Western standards, does not always lead to an improved structure. As with most humanitarian efforts many structures have been built by the local trades using Western like standards, but tragically have failed in some cases under dynamic loading [7]. These studies may touch on some construction detailing areas, but will not digress into lateral and dynamic impacts of small sheltered structures. By integrating more professional developmental with proven technology, cultural building techniques, and resources typically found in host nations; other related issues may see resolutions [8]. The ability to work along host nation's primary needs, in addition to giving them tools that they can embellish their life styles will pay dividends for years to come.

The International Federation of Red Cross and Red Crescent Societies are organizations which have given years of support towards areas in need around the world; and in doing so have established a base line criteria towards design, which are typical needs to be address. Six standards are described in the International Federation of Red Cross and Red Crescent Societies. Standard number 4, under the Shelter and Settlement section, calls for “sufficient thermal comfort and fresh air among other general building criteria.” Other publications, by the International Federation of Red Cross and Red Crescent Societies, Traditional Shelters-Eight Designs; attempt to design and construct to area specific climates and traditions, but do not elaborate on how, only indicating ventilation [9]. The criteria by the Red Cross and Red Crescent Societies gives the presumption of open thinking in terms of humanitarian problem solving while working alongside local nationals [8]. Influences towards betterment in most Western humanitarian efforts

includes sustainable design, Western standards of design, humanitarian design standards, regional climates, and host country's natural resources as illustrated in Figure 1.

Figure 1: Influences toward betterment

(1)

Water for example is always a concern pending geographical locations; however, areas such as Haiti have the ability to use rain, humidity condensing collectors or saltwater for the purpose of radiant cooling, thus in this case may not be a major dilemma. The single most important possible issue is condensation due to the humid climate of Haiti [10] and the ability to control the effectiveness of the wall assembly. Although there are other fabricated components, which may eliminate or reduce this occurrence, the cost implications may not be advantageous. Further, any desiccant humidity controls product will only be a hazard to children if solution efforts stray this direction in the future.

Further research and development into radiant heat and cooling has occurred for many years [4]. The radiant cooling approach issues identified stem from lack of industry use or willingness to adapt a new methodology in the West specifically; despite this technology having been used in European countries for many years past [4]. In an effort to arrive at a plausible solution, the focus of this study will evolve around a methodological approach using a base scale model approximately thirty inches in width, height and depth. The culmination of design standards and other applicable elements shall be in some cases assumed in the construction of the model (i.e. structural and wind loads) due to condense time of analysis [11]. It shall be noted this study will not attempt to solve all aspects of the interior thermal comfort theory; only to raise awareness of the plausible solution and applications still awaiting to be discovered, if certain marriages of technology and materials are further explored. The study focuses on assemblies of common materials in conjunction with limited solar resources, in order to achieve a betterment of the interior living environment [12]. Further analysis will sustain some common traditional practices, but introducing uncommon methods of interior environmental cooling.

3. Research Methodology

A plan was formulated from the knowledge gained in the literature review to test specific materials. The study includes the assemblies of a composite design to function and achieve a betterment for an interior shelter climate, by constructing a small replica test model. The proposed composite testing material for the model is based on two basic materials most prevalent in the country of Haiti: corrugated metal and bamboo. Corrugated metal is found in most countries; however, even if this material is not an option, the use of any metal panel may produce similar result. Since corrugated metal comes in a variety of depth, 7/8" will be used for testing and model purpose. The other material found in Haiti is bamboo. Since this country has seen heavy deforestation over many years, the new and promising material can provide ease of use for just about anything buildable. Sizes of bamboo are in the range of approximately 1-1/2" in diameter, but may vary plus or minus 1/2" in diameter.

The limited scale model was a box shape, approximately 30 inches width x 30 inches deep x 30 inches height as shown in Figure 2. This sample box utilized 7/8" corrugated metal on three sides of the box, with bamboo facing all exterior sides of all three walls. Over the bamboo was 1/2" polystyrene insulation material with an R-4 insulation value to represent other plausible material used for insulating walls, such as palm leaves or green vegetation potentially found in most tropical areas. Integration of a small solar powered submersible fountain pump was installed for limited water movement; this assembly will replicate those limited fabricate components easily found in most parts of the world.

The form of information gathering was broken down into three simple phases with the use of a sample model. The testing of the models occurred in three phases. The use of Fluke thermal imaging and Fluke temperature and moisture instrumentation were utilized collect data from the models.

Figure 2: Testing Model - 30"x30"x30"

(2)

The limited scale model was constructed and tested in an effort to prove or disprove the theory of thermal comfort utilizing radiant wall cooling in hot climates. Analysis from fundamental of material usage in addition to performance

of the interior space occurred in this study. A benchmark, limited-scale model was established to create a better understanding of other field data being gathered for interpretation. Further, differing configurations were attempted to attain the best performance of wall assemblies. As with differing configurations, came additional manufactured components, which may or may not be the best fit to ensure the least amount of outside material is used [13]. The comparison of each configurations using a lesser manufactured reliance on assembly evaluated compatibility with host countries social acceptance [2].

Given the data from the base scale model, these data marks will be charted for comparison to determine best plausible solution for thermal comfort. Other benchmarks will be evaluated for conformance to ensure if the best solution will be the most acceptable to host counties cultural building trades. Other graphical information will be presented to witness phase changes occurring within the wall components under no improvement, followed by two tested assemblies, which resemble each other, but differ slightly [14, 15].

Experimental research with a field constructed scale model provided realistic data given the complexity of the components being installed in an unlikely ensemble. Although this method of experimentation can be somewhat subjective, the application use of the snowball-cluster sampling effect is well justified in the given proposed study [16].

The method of information gathering will be broken down into three simple phase (Table 1) with the use of a sample model. The three phases are: Phase-1 (Baseline), Phase-2 (Horizontal Bamboo/Corrugated Metal panels) and Phase-3 (Vertical Bamboo/Corrugated Metal panels). Note Phase-3 is not included in this study and will be included in the data set in future works. Small water fountain pumps powered by solar panels were used to facilitate the movement of water within the bamboo pipes. Temperatures readings are recorded during most afternoon times of higher average temperatures.

Table 1. Phase temperature readings approach

Phase	Reading type	Testing method	Unit
Phase-1 Baseline	Exterior temperature readings	FLUKE Temperature	Fahrenheit (F)
	Interior temperature readings	FLUKE Temperature	Fahrenheit (F)
	Interior humidity readings	FLUKE Humidity	Percentage (%)
	Exterior Infrared Imaging	FLUKE Camera	
	Panel Condensation	Visual examination	Yes or No
	Solar Water Pump	Visual examination	Yes or No
Phase-2 Horizontal Bamboo	Exterior temperature readings	FLUKE Temperature	Fahrenheit (F)
	Interior temperature readings	FLUKE Temperature	Fahrenheit (F)
	Interior humidity readings	FLUKE Humidity	Percentage (%)
	Exterior Infrared Imaging	FLUKE Camera	
	Panel Condensation	Visual examination	Yes or No
	Solar Water Pump	Visual examination	Yes or No
Phase-3 Vertical Bamboo	<i>Not included in this particular study analysis</i>		

Information derived from the aforementioned phase testing was incorporated into a series of simple graphs, each depicting their own results. Phase-1 established a base line comparison, both exterior temperatures with interior temperatures and interior humidity. The tracking information gave indications to any performance increase is the temperature delta between the exterior and interior temperatures. Functionality of wall components was evaluated on ease of construction and delivery of water through bamboo pipe systems; both horizontally (Phase-2) and vertically (Phase-3) to measure overall performance. Solar and water pump components will be evaluated for basic functionality given the placement and simple delivery of water with the bamboo pipes.

4. Results and Findings

The testing for all phases were compiled into an excel spreadsheet for simplicity and visual comparative analysis. Basic calculations showing Phase-1 (Baseline) vs. Phase -2 (Vertical bamboo) attest on how each performed within their design limitations.

4.1 Phase-1 (Baseline)

The establishment of the Phase-1 Baseline was accomplished before any water was introduced into all bamboo piping, thus the elimination of bamboo fibers becoming water logged after water drainage. Under the Phase-1 Baseline, the exterior and interior temperature delta was seen at approximately 6.7 degrees cooler inside the scale model box (Table 2). Since the test was being performed in October, temperature fluctuations were more common than ideal testing performed in the summer months with more constant high temperature readings.

Table 2. Baseline Readings for Phase-1

Exterior Temp (F)	Exterior Humidity (%)	Interior Temp (F)	Interior Humidity (%)	Exterior/Interior Temp Delta	Panel Condensation (Y/N)	Water Temp	Solar Water Pump (Y/N)	Water Flow Problems (Y/N)
99.3	28.60	92.6	29.60	6.7	N		N	N/A

4.2 Phase -2 (Horizontal Bamboo) – Average Temperatures

Once the Phase-1 Baseline was established, testing began with introducing water into the bamboo pipes during varying times during the day. The strategy behind this method was to capture performance with both higher temperatures and lower temperatures during the course of mid-day till late afternoon. Thus, temperature deltas could be evaluated on how much an impact was being made during the differing demands on the wall panels. Under the Phase-2 test, readings were an improvement from the Phase-1 baseline on average of 10.10 degrees less than the exterior temperature; an increase of 3.40 degrees interior temperature reduction from the Phase-1 Baseline model (Table 3).

Table 3. Phase-2 Readings (Horizontal Bamboo) – Average Temperatures

	Exterior Temp (F)	Exterior Humidity (%)	Interior Temp (F)	Interior Humidity (%)	Exterior/Interior Temp Delta	Panel Condensation (Y/N)	Water Temp (F)	Solar Water Pump (Y/N)	Water Flow Problems (Y/N)	Notes
Test-1 2 Oct, 14:00	105	24	96.2	27.20	8.8	N	86.3	Y	Y	Upper tube water flow issue
Test-2 2 Oct, 15:00	105	26.60	94.1	31.30	10.9	N	85.6	Y	Y	Upper tube water flow issue
Test-3 3 Oct., 17:00	93.2	37.10	85.1	44.70	8.1	N	83.7	Y	Y	Upper tube water flow issue
Test-4 4 Oct., 11:00	103	41.10	90.4	47.40	12.6	N	89.7	Y	Y	Upper tube water flow issue

4.3 Phase -2 (Horizontal Bamboo) – Average High Temperatures

The Phase-2 model was also evaluated by utilizing the two average higher temperature readings given during those peak temperature time periods. As a result, the Phase-2 high temperature readings produced and improvement from the Phase-1 baseline on average of 9.85 degrees less than the exterior temperature; a decrease of 3.15 degrees interior temperature reduction from the Phase-1 Baseline model.

Although Phase-1 provided minimum R-3 polystyrene insulation, its performance only resulted in minimally reduction of the interior temperatures during peak time of afternoon heat. Phase-2 on the other hand proved to show improvements, reducing the interior temperature further by a few degrees, however the function of the system can be problematic due to different sizes of bamboo and providing enough water pressure to ensure all bamboo pipes have water.

Water coverage within the bamboo pipes proved to be the underlying factor by physical attributes of both the bamboo pipe and the curvature of the corrugated metal panels. Under Phase-2 horizontal test, the bamboo panels are running horizontally with the corrugated metal panels; this only enables half-filled bamboo pipes to transfer radiant cool bamboo surface to only 1/4 of the metal panel wall.

5. Conclusions and Future Research

The findings of this study conclude the integration of such material assemblies are appropriate to change the performance of the interior shelter space during hot climates. During phase testing of model, those materials such as corrugated metal panels and bamboo may be found in Haiti. Betterment of interior temperatures as it compares to exterior higher afternoon temperatures was achieved in the Phase-2 model testing.

A limitation of this study includes the use of polystyrene insulating wall which is not prevalent as a material to most residence in Haiti. There is however, the ability to use about any insulating material or dried vegetation to provide similar results of the polystyrene insulation board used during testing. Other native materials would have to be used to replicate insulating values. Small solar panel pumps are common, and may be found in most countries, but system may still operate under natural water head pressure, thus the solar water pump may be an option.

Attention to the amount of thickness must be adhered, the more material the better the performance of the bamboo and metal panels. Further, despite all phase models showing exposed polystyrene insulation, insulating materials should always be covered with a rain screen material for added protection. Additional material critical from a water infiltration into the interior space is base wall flashing towards the exterior; absence of this simple metal component will be introduce potential overfilled or cracked bamboo water within the cavity and into the shelter, thus opening cause for illness.

Due to the limited amount of time during the academic semester, further testing scenarios could not be examined. The researchers continued this study with Phase-3 testing. As well as recommending to reiterate the phase testing. The testing in this study were conducted in the changing seasons from summer into fall; during multiple tests, typical high temperatures most common in Texas are stable for only a few hours during the day, which were recorded but may vary from one day to another. The best times to test these phase assemblies are during late spring and summer months; preferably in a southern climate to measure in-depth wall performance since conditions as this will be similar to Haiti.

It is with these efforts and findings the researchers are encouraged and look to open dialogue among architectural, engineering and building professionals to create new levels of thinking into more exploratory means per each individual host nation's challenges. These hybrid methods of construction may quickly be implemented and continued long after humanitarian efforts have departed.

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