PREFAB FOR HUMANITY

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INTRODUCTION

Radiant systems have passively heated and cooled buildings for several centuries. The Romans channelled hot air through walls to maintain thermal comfort while the Turks diverted streams through them for cooling. Today, it is common practice for builders to use the lowest cost assemblies available to provide indoor comfort. Unfortunately these solutions can sacrifice long term building performance by limiting the choices to less advanced systems. Opportunities exist today that challenge methods of providing thermal comfort. One method is to operate outside the traditional design-bid-build model by utilizing delivery methods that promote flexibility and controlled experimentation. In Alabama, Habitat for Humanity is employing one such strategy, by collaborating with Auburn University's Integrated Design and Construction (ID&C) Master's Program. Researchers are exploring ways to incorporate full scale prefabricated radiant wall systems in future test houses.

Habitat for Humanity

Founded in 1976, Habitat for Humanity is a non-profit organization that constructs affordable housing for low-income families. Habitat has helped provide housing for over one million people worldwide constructing over five thousand homes a year in the United States; making it the sixth largest home builder in the country. In Alabama alone, 34 Habitat for Humanity affiliates build over 150 homes annually.

The main priority in constructing affordable housing is typically first cost. However, ownership and operational expenses often surpass this initial capital expenditure. According to the Alabama Association of Habitat Affiliates (AAHA) families eligible for Habitat homes spend up to 30% of their income on utility bills ; the majority of which are directed towards heating and cooling. These significant numbers coupled with Habitat's mission of providing affordable housing make Habitat an ideal place to implement sustainable building practices that aim to reduce the operating cost of the homes that they build. AAHA has been proactive in addressing this energy consumption issue, supporting local affiliates' efforts to build Energy Star Homes and testing energy efficiency strategies through a continuing partnership with the Auburn University's DESIGNhabitat program.

Radiant Systems

Human thermal comfort is based on three factors: 50% radiation, 30-40% convection, and 10-20% evaporation (humidity/perspiration). Radiant energy is the energy transferred directly from one object to another, convective energy is the energy transferred through fluid movement, and humidity is the amount of water vapor in the air. A typical forced air HVAC system addresses only two of the three factors, convection by changing the temperature of the air and evaporation by controlling the humidity in the air, completely ignoring the other half of the comfort equation, radiation of the objects in a space. A typical forced air system also utilizes large amounts of energy, two-thirds of which goes to powering the system's fan. Alternatively, using water (which can hold 3,000 times more thermal energy than air) as the transfer medium through a radiant system yields a system which can operate at lower temperatures for both heating and cooling. Radiant systems can better manage thermal comfort because humans perceive the rate that heat transfers from the body and not air temperature change. Therefore, the air temperature in a room that is radiantly controlled can be lower for heating or higher for cooling, than a room that is heated or cooled by convection despite the fact that the perceived temperature is the same.

Current material technologies have also made the failure of hydronic systems less of a concern, renewing interest in their application for both heating and cooling. In Europe the radiant component of human comfort has been addressed for almost two decades after the appearance of heat producing computers in the office. Due to building constraints that make duct work installation nearly impossible, radiant systems have been installed for heating and cooling purposes. The most common system utilizes capillary mats that can be embedded into plastered walls and ceilings or integrated into suspended ceiling panels. Although these systems have been a success in some areas, they have not yet become prevalent in the built environment due to lack of testing and proof of functionality, difficulty of installation, and high cost of application. This study seeks to develop an affordable strategy for practical implementation into current building practices.

Prefabrication

Alabama Habitat affiliates are increasingly turning to prefabrication in order to provide ever more efficient and affordable homes for their clients. Affiliates work with a number of local contractors in order to prefabricate anything from building components to panelized wall systems. Prefabricated trusses, wall assemblies, and even SIPs panels are being incorporated into these homes; increasing quality and decreasing construction times. Communication with manufacturers is imperative to integrating this studies proposed system into new habitat homes as mass production will facilitate easier installation by Habitat's volunteer workforce and help offset the high cost of custom-built panels.

Habitat Testbed

Habitat for Humanity constantly seeks innovative ideas and technologies to incorporate into its home designs. One of the goals of this study is to provide the design and engineering parameters for a radiant system that is efficient, affordable, and durable so that it can be utilized by Habitat for Humanity. The proposed investigation will advance the understanding of the implementation of radiant assemblies for heating and cooling residential scale buildings in a hot humid climate. The novelty of this proposal lies in the aspiration to utilize solar thermal powered radiant heating coupled with a shallow geo-exchange (foundation depth heat sink) radiant cooling *(see Figure 1.)* This study evaluates two different pipe materials with the intention of discovering their relative efficiencies in order to determine and specify a cost effective solution for Habitat and its affiliates. By utilizing the combined efforts of an integrated design and construction endeavour, an innovative and cost effective solution has been created that can be easily installed in existing and future Habitat homes. AAHA and the Lee County Habitat for Humanity Affiliate are committed to this study with the aim of building a house to test these systems full scale.

A COLLABORATIVE APPROACH

The ID&C graduate program at Auburn University applies a cross-disciplinary approach to achieving successful buildings, by combining students from backgrounds in architecture and building science into one joint environment. It strives to traverse common disciplinary boundaries and practices by employing collaboration and combining expertise.

The Master of ID&C consists of two tracks: the Design Track utilizes a studio environment technique and is designed for graduates seeking to work in the design field and the Construction Track utilizes a construction management technique and is designed for graduates seeking to work in the construction field. "The Mas-

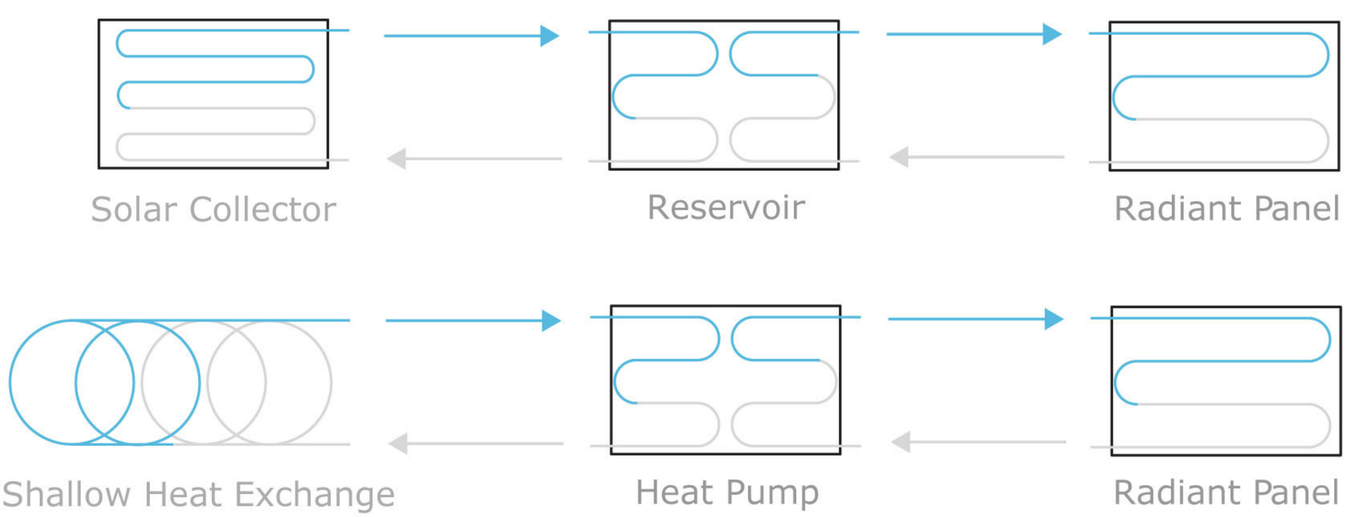

Figure 1. Water flow in a solar collector heating system, (top) and a shallow geo-exchange system for heating and cooling (bottom).

ter of ID&C program will foster an integrated delivery of projects in the built environment, leveraging the most current strategies in project development, risk analysis, and digital tools."
During the 2012 spring semester, fifteen graduate students, eight Design Track students and seven Construction Track students were enrolled in the Sustainability for Integrated Project Delivery class. The course's focus was on the principles, terminology, and methods of sustainable design and construction, with an emphasis on the role of interdisciplinary design and construction collaboration. To conduct the experiment, the students were divided up into four teams to undertake the various aspects of the study. These four teams consisted of: Room build-out, Fluid build-out, Testing, and Documentation. The Room build-out team was responsible for designing and constructing the "testing room" which was constructed, transported, and later assembled within the thermal lab. The Fluid build-out team constructed the design for all of the system components used for heating and conveying the water. The Testing team created a procedural process for conducting the experiment and the Documentation team created all of the presentations and necessary documents for the study. Although all students participated in every aspect of the experiment, the organization of these teams created a hierarchy and structure for responsibility that facilitated the success of the experiment within the sixteen week semester. The research for the study was conducted by a team of several interdisciplinary collaborators including affordable housing advocates, bio-systems engineers, and architects investigating the viability of low-energy consumption heating and cooling systems for affordable housing. The experiment was conducted in the thermal laboratory of the Auburn University Kinesiology department, whose faculty and staff assisted in facilitating the testing. The diverse team structure provided varied perspectives and insights to the experiment benefitting the participants and the study.

THE EXPERIMENTAL DESIGN

The experiment was intended to be conducted in three phases; beginning with rigorous research into materiality performance during heating and cooling process, progressing through adaptive design and testing, and culminating into a complete system design with simulated application into a Habitat home. In the First Phase the cost and performance efficiencies of two popular materials currently used in radiant systems were evaluated in order to support the application of an affordable radiant system. For the second phase the design of the panel was analyzed in order to perfect the prefabricated assemblies for application in both new construction and retrofit. In the final phase the performance of the panel will be quantified to determine relative efficiency and the output. This phase of the study will explore the various types of system applications for a DESIGNhabitat home. By using the Home Efficiency Rating System (HERS) the performance of the proposed system will be compared to a typical HVAC system.

THE EXPERIMENT: PHASE I

In order to determine the most efficient and affordable materials for a radiant panel that would be implemented into a Habitat home, testing was conducted on the two most popular materials for radiant tubing: copper and pex-al-pex.

Copper's long lasting and maintenance free characteristics make it a popular choice for plumbing, heating, cooling and other mechanical systems. It is light, strong, corrosion-resistant, and because of its high thermal conductivity (eight times that of other metals), it is used in air conditioning, refrigeration, and radiant systems. Pex, a plastic material made of cross linked polyethylene, was introduced to the U.S. in 1980s as an alternative piping system. Its flexibility, fast installation, resistance to scale, chlorine, corrosion, pinholes, and reduced need for connections and fittings make it a popular alternative to more expensive choices. These advantages over metal pipe and rigid plastic pipe systems have resulted in pex replacing these options in many applications; most significantly replacing copper in radiant heating systems. For this reason the first experiment consisted of testing the efficiency of these two materials in order to validate this popular material substitution. Understanding the properties of the two materials and their associated cost would influence the future application of the proposed system within an Alabama Habitat home.

Material Selection

For the experiment two radiant wall panels were constructed, each with half inch (O.D.) tubing in one of the chosen materials. Copper pipe costs approximately $1.50 per linear foot and has a thermal conductivity rate of 200 BTU per square inch. However, due to its rising cost and demand copper is becoming increasingly less feasible as a building material for use in large quantities. Pex-al-pex is a pex piping with an additional metallic layer that increases the radiant properties of the material. At $0.40 per linear foot pex-al-pex is considerably less expensive than copper; though its thermal conductivity is considerably lower than copper at 3.1 BTU per square inch.

Buildout Design

The Kinesiology department's thermal laboratory where the tests were conducted dictated the design of the testing parameters. To accurately measure the performance of the radiant panels a simulation room was built to mimic the construction of a typical Habitat home. A four foot by eight foot room was designed to fit inside the thermal laboratory. The simulation room was constructed as six separate wall panels and two ceiling panels so it could be assembled within the thermal laboratory together (see Figure 2). Special attention was given to the connections to ease assembly and disassembly while minimizing air leaks that would skew the results. The building materials and assemblies of the typical Habitat home were duplicated in the simulation room walls. The framing consisted of 2"x4" studs at sixteen inch spacing with batt insulation

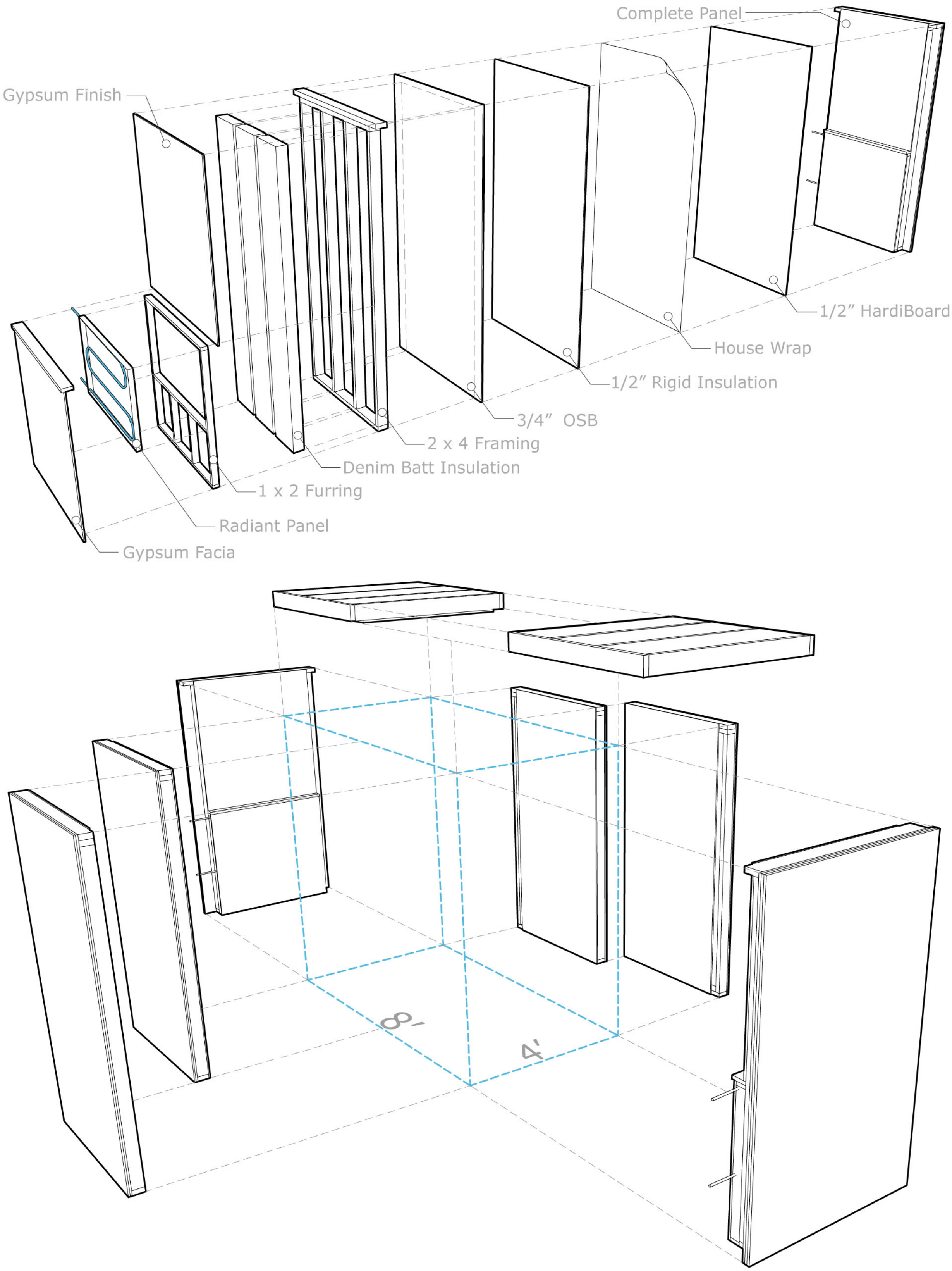

Figure 2. Wall panel assembly (top) and Simulation room assembly (bottom) conditioning unit.

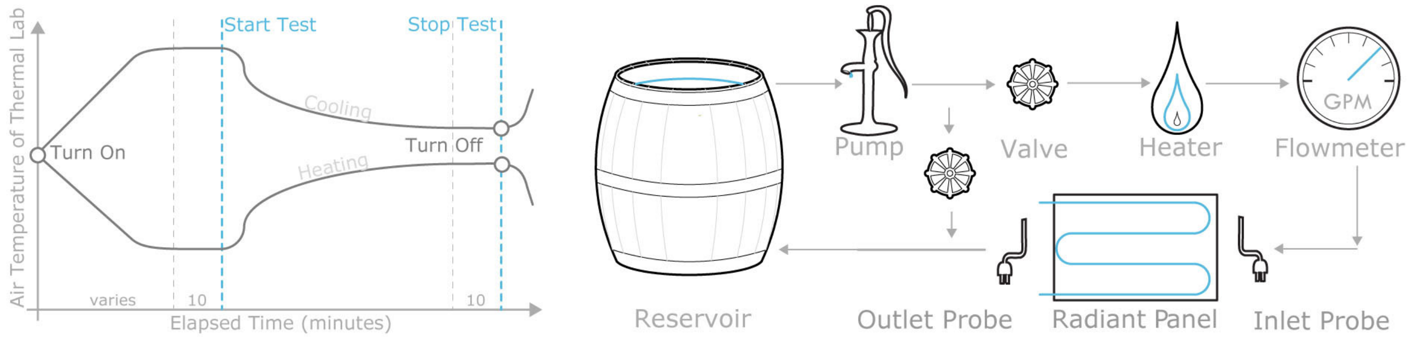

Figure 3. Testing temperature process (left) and Fluid system process (right).

replicating a traditional wood frame site built home. Although different methods of insulation (fiberglass, spayed in cellulose, and spray foam) are used by different affiliates, R-13 denim insulation was chosen for its ease of installation and the health benefits for the students installing it. The exterior sheathing consisted of: rigid insulation, oriented strand board, and cementitious siding (see Figure 2). Additional furring was added to support the radiant panel and gypsum finish outside the structure of the wall.

Testing Procedure

Testing was conducted over a two week period with the heating tests first and the cooling test second. The thermal lab was heated by two resistance space heaters and cooled by a laboratory grade freezer air.

In order to heat and cool the temperature inside the testing room, one of the panels was removed until the thermal lab reached and maintained a constant temperature for at least ten minutes. On average, it took approximately 60-90 minutes to cool the lab to its stable temperature of 5°C and 45-75 minutes to heat the lab to its stable temperature of 35°C. The testing room wall panel was then replaced and the testing began. The lab temperature was gauged by a wet/dry bulb/black globe thermometer located within the thermal lab and the thermal couplings located within the testing room. Testing was stopped when the temperature of the testing room had stabilized for at least ten minutes, after approximately one hour of testing, indicating the capacity of the radiant panel (see Figure 3).

To measure the change in water temperature (ΔT) inside the radiant panels, probes were place in the entrance and exit connections of each panel providing accurate readings of the fluid temperature at the exact moment it entered and left the panel; reducing the risk of inaccuracies due to heat loss or gain through the piping outside of the testing room. The testing room contained nine thermal couplings suspended in the center of the room at two foot intervals from the panel and the ceiling. This grid orientation provided measurement that reflected the temperature differences within the room as a result of the distance from the panel as well as the stratification of air within the space. The couplings were labeled with a letter and number that corresponds to the coupling's row and column location respectively.

The data from these devices was collected and stored on two data acquisition boards (DAQ boards). These boards received data, in one minute intervals, from the probes and couplings and convert the resulting samples into a digital format.

For the tests, the water running through the radiant panels was heated by a Rheem tankless water heater to a temperature of approximately 32°C. The water was cooled by a continuous ice bath in the water reservoir maintaining a constant temperature of 10°C. In order to maintain a constant flow, a flow meter was attached to the discharge connection of the water heater to monitor the flow rate measured in gallons per minute (gpm). Water was pumped into the heater by an electric laboratory pump that had a maximum flow of six gpm (see Figure 3). Pex tubing used for the supply and return piping was protected from heat loss or gain with pipe insulation. Compression fittings were utilized to make the repeated assembly and disassembly of the panel connections simple and quick.

Test Results

The raw data acquired from the DAQ boards was combined and analyzed to evaluate the performance of pex and copper piping in heating and cooling the simulation room. Outliers were removed in order to eliminate skewing of the results.

Heating

The thermal lab was first cooled to lower the air temperature and then the radiant heating abilities of the panels were tested. In order to increase the temperature of the room, hot water was pumped through the panel radiating heat into the room.

Pex-al-pex piping increased the temperature of the room an average of 3.2°C (5.76°F). The temperature of the water leaving the panel was lower than the temperature entering the panel indicating that heat from the water was radiating into the room. Copper piping increased the temperature of the room an average of 1.4°C (2.52°F). The smaller difference in the temperature of the water entering and leaving the panel indicates that the capacity of copper to radiate heat is lower than that of pex-al-pex piping.

A
B
C
D

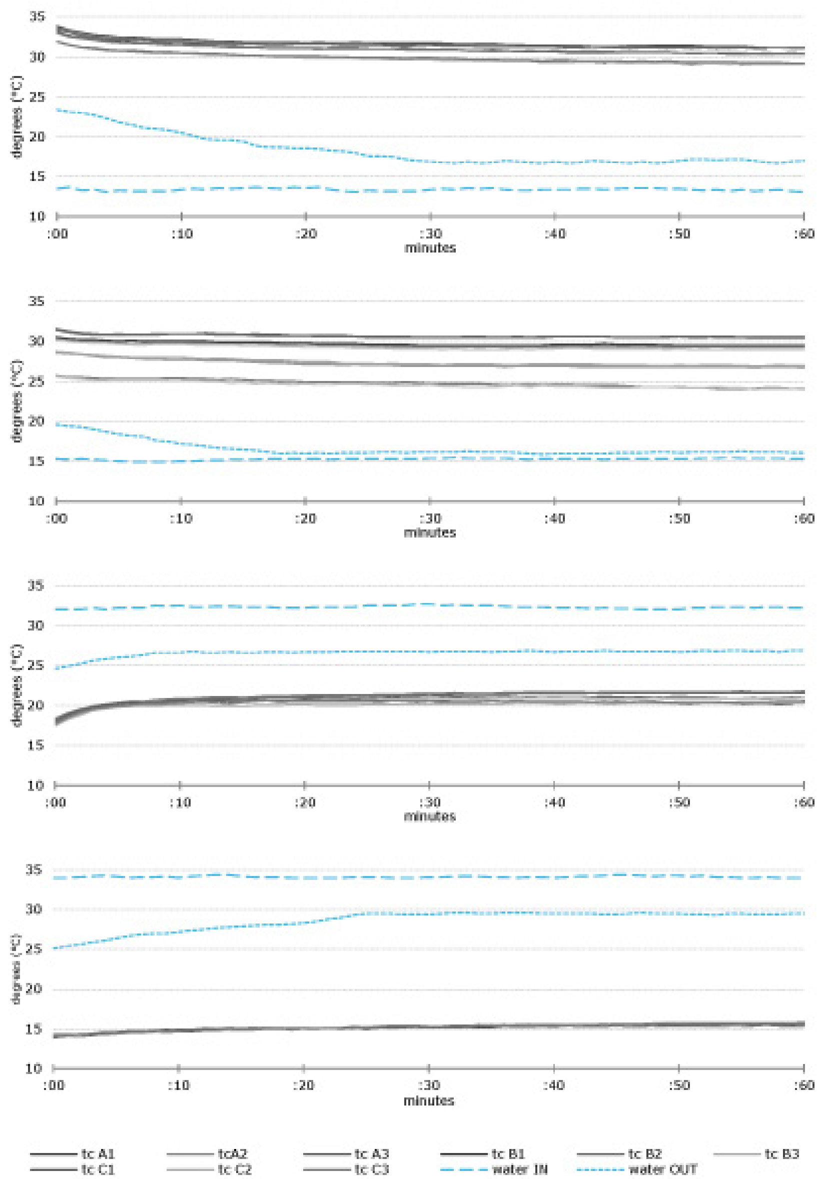

Figure 4. Test results; (a) cooling: pex-al-pex, (b) cooling: copper, (c) heating: pex-al-pex, (d) heating: copper

Cooling

The testing room was first heated to higher the air temperature and then the radiant cooling abilities of the panels were tested. In order to decrease the temperature of the room, cold water was pumped through the panel removing heat from the room.

Pex-al-pex piping decreased the temperature of the room an average of -2.4°C (4.32°F). The temperature of the water leaving the panel was higher than the temperature entering the panel indicating that heat from the room was removed from the air. Pex-al-pex had no condensation on the piping. Copper piping decreased the temperature of the room an average of -1.4°C (2.16°F). The smaller difference in the temperature of the water entering and leaving the panel indicates that the capacity of copper to remove heat is lower than that of pex-al-pex piping. Copper had significant amounts condensation on the piping.

Analysis

The results indicated that pex-al-pex piping performed better than copper piping. In addition, it's much lower cost and ease of installation make pex-al-pex the superior material for radiant panels. These factors also facilitate the prefabrication of the panels making them more affordable, durable, and installable by Habitat for Humanity volunteers.

PANEL DESIGN: PHASE II

In general people prefer the area around their head to be cool and their feet to be warm.[1] For this reason most radiant heating systems are installed in the floors of homes utilizing a concrete slab as a thermal mass to radiant heat from a larger surface area. Unfortunately, while a slab on grad foundation is a cheaper form of construction, it is not ideal in hot and humid climates where an elevated floor is essential for a home to be removed from the moist ground allowing cool air to insulate it during the summer months.

Conversely radiant cooling systems are embedded within the ceiling. In order to provide a building with the combined effectiveness of radiant heating and cooling, the panel was placed on the wall between the ceiling and the floor. This surface appears to be the ideal location, but instead this space is littered with random apertures and penetrations thereby reducing the area for application. The panel was designed so that it could be easily mass produced with minimal amounts of materials and easily handled and assembled by a volunteer work force.

The radiant panel was designed to fit below a typical window sill and above a standard electrical outlet (see Figure 5). Designing within this two foot limit eliminated interference with two main components of the wall; ensuring ease of installation and eliminating the need for custom sizes. A width of four feet was chosen to conform to the industry standard material size creating a system that is composed of several manageable panels.

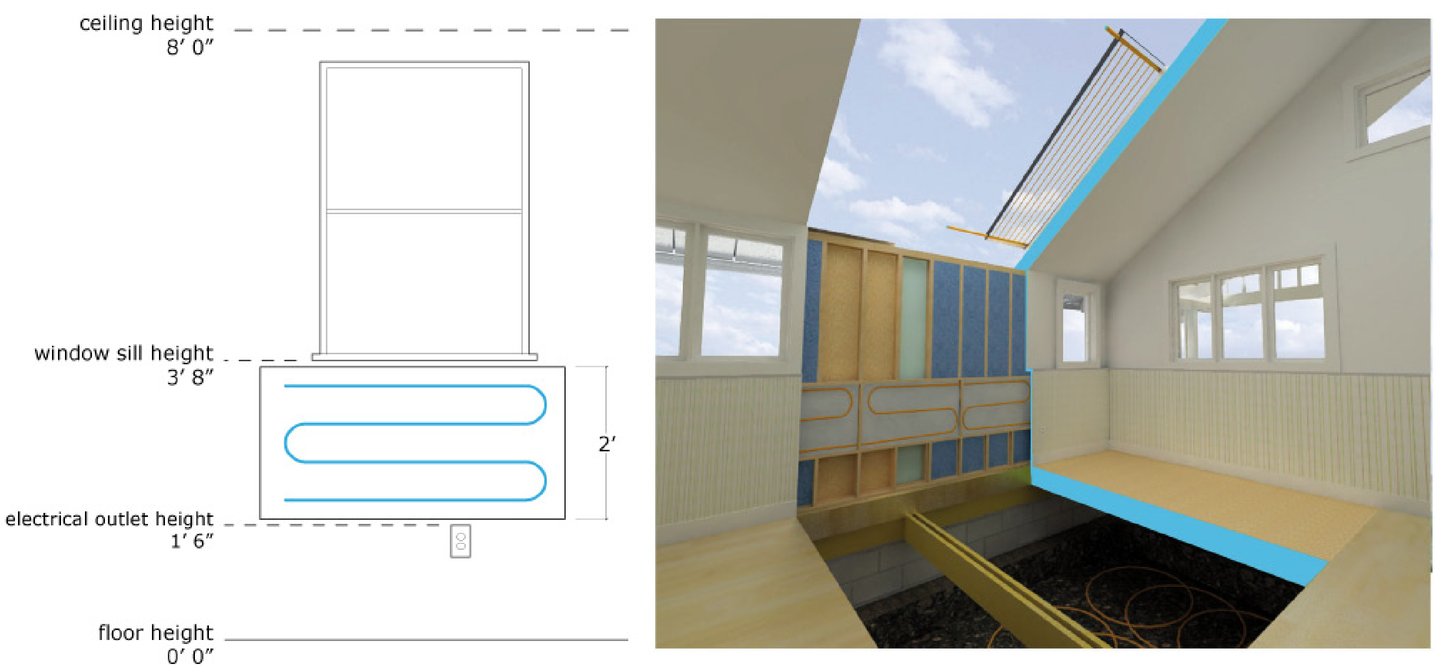

Figure 5. Panel location elevation (left) and application in DESIGNhabitat 3.1 home (right).

The pex-al-pex tubing was attached to piece of twenty-four gauge sheet metal that served as the radiant barrier and provided a rigid backing. This modular assembly can be integrated into the framing as well as applied to the outside face allowing for the option to retrofit the system into existing homes. Tubing was attached in a horizontal flow pattern that minimizes the amount of vertical rises thus reducing the size of the pump and other various system components.

In order for this radiant system to deliver the heat quickly and efficiently, a thermal mass, which would store heat, was avoided to prevent system lag and facilitate quick conductivity.[2] Furthermore, embedding the pipes into a thermal mass, such as a slab or a plaster wall would prevent the system from being prefabricated. Since the system is also not heating a thermal mass, a lower water temperature could be used therefore making ground coupled and active solar sources more probable.

FUTURE RESEARCH: PHASE III

This ongoing study was designed to be constructed in a series of phases. General research and design has been conducted by the integrated teams of students on each of the three phases. Further research is required to understand all of the complexities of applying this proposed system into a Habitat home. The final phase has been examined to create a base from which succeeding cohorts could build upon. In the following semesters students can apply the extensive research and acquired knowledge of the experiment in Phases I and II in order to proceed with developing the subsequent phase with comparable fervor. Ideally, this research will aid in the eventual application of an affordable and efficient radiant system within a Habitat home in Alabama; continued research is the way to attain that goal. For each of its designs AAHA runs a series of test, collectively known as the HERS rating system in order to project the energy cost for its clients. In order to compare results of the proposed system with a traditional forced air system data was collected on the DESIGNhabitat 3.1 home that was constructed in Escambia County, Alabama by AAHA affiliates. Energy bills were collected and used to evaluate the home's actual performance with its projected performance based on the HERS model. Comparing these results provided a foundation on which the projected performance of the radiant panels could be gauged in order to more accurately estimate their performance in a real world application.

APPLICATION TO EDUCATORS

This course serves as a great example for successful technology transfer implementation within the class setting. The extensive collaboration between the departments of Kinesiology and Architecture are instrumental in the success of the experiment and the class as a whole. Education is a prime area in which to use technology transfer. Universities are commonly at the cutting edge of research in many fields and have nothing to lose by sharing technologies among departments. As the bridge between academics and industry continues to shrink, hopefully architecture schools around the country will begin to see the inherent opportunity in partnering with the private sector in the development of new building technologies. It is through this model that highly commoditized building industries can again afford to re-integrate research and development into the business model. As constantly circulating Habitat for Humanity volunteers and Auburn University students become aware of radiant systems, knowledge of the panels will increase and disseminate into the community and industry. The authors hope that first and foremost, spreading knowledge of the success of this particular course will encourage other similar institutions and their respective programs to adopt similar courses in an effort to proliferate the practice of technology transfer that was once common practice.

ENDNOTES

1. Lechner, Norbert. 2009. *Heating, Cooling, and Lighting*. Hoboken: John Wiley & Sons.
2. Warm Board. 2011. "Radiant Heat: Conductivity Is King Not Mass."