BUILDING ENERGY RESEARCH GRANT (BERG) PROGRAM

BERG FINAL REPORT

Improving Cost Effectiveness of Radiant Floor Cooling

University of California, Davis
Western Cooling Efficiency Center
1450 Drew Ave., Suite 100
Davis CA 95616
Phone: (530) 754-7670
Email: dbourne@ucdavis.edu

AUTHORS
Richard Bourne, Principal Investigator
Theresa Pistochini
Jonathan Woolley

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Table of Contents

List of Figures

Abstract

Radiant floors can reduce annual cooling energy costs up to 70% in comparison with conventional forced air cooling systems. Savings result from reducing blower energy use, improving cooling efficiency, and facilitating non-compressor cooling sources. The technology was developed in partnership with Walmart. It is suitable for use by most major retailers, and in other "large area" slabs in new retail malls, offices, and schools. Prior to this project, a related system was developed with Walmart by the UC Davis Western Cooling Efficiency Center and Viega LLC. That system is now marketed by Viega as "Climate Mat."Climate Mat is the first "large area" pre-fabricated tubing array designed for low-cost installation of radiant cooling arrays in large buildings. Climate-Mat systems can be installed for approximately $2/sq.ft.; the goal of this project was to value-engineer the design toward lowering the installed cost by 50%, to $1/sq.ft. The project team developed and field-tested a revised system that reduces both materials and labor costs. Key improvements include more compact manifolds, elimination of spacer strips, and significantly reduced roll diameter and shipping volume. UC Davis expects to license this new technology to a production firm capable of high volume production and installation in competition with Viega's Climate Mat product. Combining the materials and labor savings with the benefits of higher volume (resulting from competition and reduced costs) should drive installed costs down to the $1/sq.ft. range within several years.

Key Words: cooling, radiant floors, radiant floor cooling, cost-reduction, large retail, slab-on-grade, tube spacing, HDPE, pipe fusion

Executive Summary

Introduction

Chain retailers that build large single-story buildings with concrete slab floors have shown interest in radiant floor cooling as an energy efficiency measure. Circulating cool water through slab tubing can save energy by facilitating cooling from efficient non-compressor sources, and reducing energy use for blowers and unnecessary dehumidification. In most California locations, these benefits can combine to generate up to 70% annual HVAC electrical savings. But slab tubing is expensive if installed using materials and processes common to the radiant floor heating industry. In 2005, Walmart installed large radiant floor systems in two experimental stores, but the $6-7/sq. ft. installed cost precluded further use in prototype or production stores.

Since mid-2006, the UC Davis Western Cooling Efficiency Center (WCEC), Davis Energy Group (DEG), and tubing manufacturer Viega have worked with Walmart to develop a low-cost radiant floor cooling system. The concept uses large pre-fabricated "roll-up" tubing arrays that can be deployed quickly and do not interfere with concrete placement. In February, 2007, the team installed a 12,500 sq. ft. test array in the new Walmart store in West Sacramento, CA. The test focused on installability with Walmart's well-developed "green slab" technology. Since the prototype, Walmart has installed the Climate-Mat system in two complete stores (Las Vegas and Sacramento) with others scheduled. From this work Walmart has concluded that the below-floor components (circuit tubing and manifolds) can be installed for approximately $2/sq. ft.; but an installed cost of $1/sq. ft. is needed for broad applicability.

The WCEC proposed this project to further reduce costs for "large mat" radiant cooling systems appropriate for large slabs. The overall goal was an improved system that, in volume production, can achieve the $1/sq. ft. installed cost target. The proposed work included five tasks:

1. preliminary design
2. final design
3. prototyping
4. field testing
5. program management

Project Objectives:

Tasks 1-3 have objectives are to complete preliminary designs, final designs, and prototypes in preparation for a field test in Task 4. The main objectives for the field test are to demonstrate a large mat radiant cooling system that will:

1. Manifold Stabilization-
    a. Hold manifolds in fixed linear pattern during fabrication, shipping and deployment
    b. Keep manifolds located without compromising slab strength
    c. Be economical enough for the stabilizer to be left in place

2. Tubing Stabilization-
    a. Maintain tubing spacing at 6 inches on center plus or minus 1 inch and hold tubing against the base until held by concrete
    b. Provide a rugged and cleanable rake operable and movable by one person without excessive force
3. Return Bend Stabilization-
    a. Accept and hold the return bends of the ½ inch HDPE pipe
    b. Be rigid, low cost and easily formed
    c. Be fabricated with guides that spool up the tubing as it is rolled for shipment
    d. Become part of the packaging and shipping of the radiant mats
4. Concrete Placement-
    a. Place concrete without significantly moving radiant tubing
    b. Not slow down concrete placement
    c. Allow concrete distribution to be controlled by one person
    d. Be low cost, rugged and cleanable.

Project Outcomes

The project achieved virtually all desired outcomes, as summarized here by the four outcome categories listed for Task 4. For manifold stabilization, the project team developed a proprietary extrusion shape that can be assembled in two different configurations. The new manifold pairs reduce HDPE weight by more than two-thirds compared to the current Climate-Mat design. They also reduce cost by only requiring two fusion joints per circuit compared to eight for the current product. One configuration is useful for placement next to existing slabs, where it eliminates the need to excavate for the manifolds. The second manifold configuration is useful with minimal excavation expense when burial is necessary. The extruded HDPE shapes are partially enclosed in a sheet metal sleeve that keeps them straight and stable.

For tubing stabilization, the project team developed an easy-to-use 5′ wide "rake" that pulls all the circuit tubes straight during unrolling. The rake is pulled just ahead of the concrete, holding the tubes in place until the heavy concrete holds them permanently. The rake has features that allow it to be rapidly placed from above just as rollout begins. Moving a lever frees the rake from the circuits near the end of each rollout. In the field test, the aluminum rake required two puller-personnel, but a later adjustment reduced drag force enough to eliminate one puller. The rake maintained acceptably uniform spacing of the tubes until they were held permanently by the concrete. The rake proved to be rugged and required minimal cleaning after the pour.

For return bend stabilization, the project team developed a 5′ wide sheet steel plate with integral clips that hold the five return bends in a single plane. As proven in the field test, the plate has enough surface area for the concrete to hold the return bends without the need for fasteners into the prepared base material. The design includes two bars that couple with the end plate to facilitate spooling at the factory. Spooling also includes a reusable axle sleeve and end wheels that facilitate deployment in the field, and can then be sent back to the factory for reuse. The tightly-wound spool has only 23" diameter for the 130' long roll, compared to 32" diameter for the current Climate-Mat. This feature will result in more than 40% savings in shipping costs.

For concrete placement, field test experience showed that rollout of the new product design is no more difficult than for the current Climate-Mat, despite elimination of spacer bars every 3-4' along the roll length. Concrete is placed without significantly moving the tubing, whose presence does not slow down the concrete placement process. There was no need to develop a distribution accessory for the concrete chute as originally expected. Based on project work, the project team reviewed the product cost model and confirmed that cost reductions strategies proven in the project, and increased competition that will result from a second "large rollout radiant" product reaching the marketplace, will likely drive prices down to the $1/sq. ft. installed cost target.

Conclusions

Key conclusions at project completion are:

1. The new manifold design is practical and will provide the following advantages over the current Climate-Mat product:
    a. reduces product cost by eliminating fusion tees and 75% of fusion joints
    b. reduces installation cost by minimizing excavation and backfill labor
2. The spacer-less rollout strategy is workable and will provide the following advantages over the current Climate-Mat product:
    a. reduces materials cost and assembly labor by eliminating spacer bars and clips
    b. reduces shipping cost by facilitating greater shipping density
3. The new end plate reduces field labor by eliminating the need to drive fasteners into the ground to hold circuit return-bends at the bottom of the slab.
4. No "chute accessory" is needed to prevent the falling concrete from pushing tubes out of alignment.
5. If a manufacturer adopts these new designs in competition with the existing Climate-Mat product, the installed price for large-scale installations will likely fall to the $1.00/sq. ft. target within several years as industry volume grows.

Recommendations

Recommended next steps to advance these designs toward the marketplace are:

1. Secure patent protection for the innovative features
2. Present improved designs to potential manufacturers
3. Secure license agreement with selected manufacturer(s)
4. Assist manufacturer(s) by linking with major retailers and other potential purchasers
5. Organize and assist with full-building installation and case study

Public Benefits to California

Calculated public benefits from successful product implementation in California, assuming 30% of the potential market, equal to 30,000,000 sq. ft. per year for 15 years) include:

1. 765,000 kW peak demand reduction
2. 10,080,000 kWh energy savings
3. $1,512,000,000 energy cost savings to building owners
4. 4,538,000 tons reduction in CO_2 emissions

Introduction

Radiant heating technologies are well-developed but little used in U.S. commercial buildings. Radiant floor heating is widely used in custom homes, due to its reputation as the most comfortable heating delivery alternative. Despite the relatively low cost of popular plastic tubing types, radiant floors are typically expensive ($6-$12/sq. ft.) due to low volume and extravagant hardware components. Technologies that deliver radiant cooling from the ceiling are well developed in Europe where they are used in premium buildings, and are even more expensive than radiant heating systems.

Integrating radiant cooling into slab-on-grade construction in California's hot, dry climates offers substantial energy benefits, but requires major cost reduction if it is to capture market share from packaged rooftop units (RTUs) that are now the preferred HVAC technology for most low-rise commercial buildings. Potential energy benefits of radiant cooling derive from:

1. Applying non-compressor sources- circulating water from a cooling tower or fluid cooler directly through floor tubing can significantly reduce compressor energy consumption
2. Reducing blower energy use- most RTUs operate constant speed blowers continuously during occupancy; by comparison, floor cooling uses only modest pumping energy
3. Reducing unnecessary dehumidification- little of the typical RTU's 15-20% energy use for dehumidification is needed in California; floor cooling minimizes dehumidification
4. Reducing demand charges- floor mass can facilitate building pre-cooling and reduce peak loads, by reducing on-peak compressor and blower energy use.

In concert, these benefits can combine to reduce annual HVAC electrical consumption by 70% in typical large chain retail applications in California.

Chain retailers that build large single-story buildings with concrete slab floors have shown interest in radiant floor cooling as an energy efficiency measure. For example, in 2005 Walmart built two experimental stores that used radiant floor cooling; one in Colorado and one in Texas. The systems performed as desired, but at $6-7 per square foot installed cost (for tubing on 6" centers and manifolds) the economics of radiant floor cooling were not attractive.

Since mid-2006, the UC Davis Western Cooling Efficiency Center (WCEC), Davis Energy Group (DEG), and tubing manufacturer Viega have worked with Walmart to develop a low-cost radiant floor cooling system. The concept uses large pre-fabricated "roll-up" tubing arrays that can be deployed quickly and do not interfere with concrete placement. In February, 2007, the team installed a 12,500 sq. ft. test array in the new Walmart store in West Sacramento, CA. The basic system uses an inlet/outlet manifold pair along one end of the array that connects to long orthogonal "out and back" circuits that start at the inlet manifold, extend approximately 130' to a 180 degree turn from which they return 130' to the outlet manifold. This configuration delivers relatively uniform cooling to all locations in the array and facilitates placement of supply and return piping in or on walls.

The West Sacramento test focused on installability with Walmart's well-developed "green slab" technology. While many of Walmart's competitors place 5-6" thick steel-reinforced slabs for their new stores, Walmart has developed a very successful process that places 4" un-reinforced slabs for their new stores. Walmart invested to develop the process, and cannot consider radiant cooling strategies that require significant changes to it. The West Sacramento prototype was successful in demonstrating that Walmart's slab process could accommodate "rollout" tubing at the base of the slab. Since the prototype, Walmart has installed the Climate-Mat system in two complete stores (Las Vegas and Sacramento) with others scheduled. From this work Walmart has concluded that the below-floor components (circuit tubing and manifolds) can be installed for approximately $2/sq.ft.; but an installed cost of $1/sq.ft. would broaden the technology's applicability for them and probably for other retailers as well.

The WCEC proposed this project to further advance and reduce costs for "rollout" radiant cooling systems appropriate for large slabs. The overall goal was an improved system that, in volume production, can achieve the $1/sq. ft. installed cost target. The proposed work included the following five tasks:

Task 1: Develop Preliminary Design of Process and Devices: complete preliminary designs for both the process and devices to be used in installing the low-cost radiant cooling system, including development of design concepts, review of suitability of alternative designs, identification of design criteria, and selection of design approaches.

Task 2: Develop Final Design of Process and Devices: complete final designs for both the process and devices to be used in installing the low-cost radiant cooling system.

Task 3: Build Prototype Devices: fabricate prototype devices, to be tested during the field test. Anticipated devices included a manifold pair and rail, an end panel, a spooler, a "rake", and a chute deflector.

Task 4: Field Test Process and Devices: complete a field test of the revised system; develop test procedures and acceptance criteria; select candidate location, coordinate with fabricator and construction team, assess test results, document.

Task 5: Program Management: plan resources; track staffing, budget, schedule and deliverables; communicate with team; prepare quarterly progress reports, and final report.

This project was in the PIER Buildings area and its overall goal was to reduce the cost of an energy-efficient cooling technology to enhance its marketability.

Project Objectives

The overall project goal was to reduce the installed cost of large “rollout” tubing systems imbedded in concrete slabs. The project sought to achieve this goal by reducing materials, labor, and shipping costs. Specific objectives by task were to:

<u>Task 1 – Preliminary Design:</u>The task 1 objectives are:

1. Create a preliminary design likely to meet the objectives stated in Task 4 that will:
    a. Stabilize and precisely place manifolds
    b. Space and place tubing
    c. Hold-down return bends
    d. Improve concrete placement
2. Produce drawings and mockups to illustrate solutions

<u>Task 2 – Final Design:</u>The task 2 objectives are:

1. Review of preliminary design by project team
2. Make modifications in design in response to reviewer discussions
3. Produce drawings and mockups to further development
4. Prepare final design for prototype development
5. Final design meets the objectives state in task 4

<u>Task 3 – Build Prototypes:</u> The task 3 objectives are:

1. Prototype team reviews drawings and mock-ups, recommends improvements and builds prototypes
2. Prototypes are hand built with mass production in mind
3. Prototypes tested in small scale situation
4. Prototypes are improved
5. Prototypes achieve performance goals in small scale testing
6. Prototypes finalized for full scale field test

<u>Task 4:</u>The task 4 objectives are to field test the device that will provide:

5. Manifold Stabilization:
    a. Hold manifolds in fixed linear pattern during fabrication, shipping and deployment
    b. Keep manifolds located without compromising slab strength
    c. Stabilizer economical enough to be left in place.
6. Tubing Stabilization:
    a. Maintain tubing spacing at 6 inches on center plus or minus 1 inch and hold tubing against the base until held by concrete
    b. Rake operable and movable by one person without excessive force
    c. Rake rugged and cleanable.
7. Return Bend Stabilization:
    a. Accept and hold the return bends of the ½ inch HDPE pipe
    b. Rigid, low cost and easily formed

    c. Fabricated with guides that spool up the tubing as it is rolled for shipment
    d. Becomes part of the packaging and shipping of the radiant mats
8. Concrete Placement:
    a. Concrete is placed without significantly moving radiant tubing
    b. Tubing system does not slow down concrete placement process
    c. Concrete distribution can be controlled by one person
    d. Distribution accessory is low cost, rugged and cleanable.

<u>Task 5:</u>The task 5 objectives are to:

1. Meet schedule and budget constraints
2. Complete final report that meets sponsors requirements

Project Approach

This project progressed through four tasks including a preliminary design phase, a final design phase, prototyping, and a field test of the resulting system.

Task 1 – Develop Preliminary Design of Process and Devices

The preliminary design addressed four major design objectives for an economical commercial radiant flooring project including:

1) Manifold Stabilization – Stabilizing and precisely placing the manifolds.
2) Tubing Stabilization – Maintain 6″ spacing for tubing until held by concrete.
3) Return Bend Stabilization – Holds down return bends and is fabricated as part of the spool that is packaged and shipped with the product.
4) Concrete placement – Concrete is placed without significantly moving radiant tubing and tubing system does not slow down concrete placement process.

Manifold Stabilization

The manifold is intended to distribute the chilled water to the tubing circuits and return the warm water to the cooling equipment. The manifold needs to be installed in the slab without compromising the slab strength. The preliminary manifold design includes two extruded high density polyethylene (HDPE) triangle shaped tubes that have straight walls and 1/8″ corner radii. There is a 0.005″ insulation spacer between the two tubes to reduce heat transfer (Figure 1, left). The height of the assembly is 1 7/8″ and is designed to fit below the splice plate in the concrete slab. A sheet metal sleeve holds the manifold and provides added strength to the manifold walls. The radiant floor tubing with an outer diameter of 5/8″ is attached to the manifold at 6″ spacing through holes in the manifold sleeve (Figure 2). The 1″ supply and return tubes attach to the manifold once for every ten foot section. In order for the supply tube to attach to the inlet, the base needs to be excavated (Figure 1, right).

Return Bend Stabilization

The return bend stabilization device is intended to hold the return bends and keep them held flatly on the ground. The device should be manufactured as part of the roll and left in the concrete after the pour. The preliminary design included a 16 gauge steel sheet metal end plate with clips to hold the return bends at a 10″ diameter (Figure 3). The end plate will be the start of the roll of tubing and define two points on the circumference of the roll (Figure 13). The design also envisioned inclusion of three 1″spacer bars that would provide the desired 6″ spacing at the end of the rollout (the last 6′). The spacer bars also serve to define additional points on the circumference of the roll. Because there are no spacer bars after the first interior roll, the rest of the tubing rolls up side by side in three layers. The entire 130′ roll fits inside a 23″ diameter. The prototype clearly shows the 130′ roll can fit compactly into a 23″ diameter compared to 32″ for the original design currently manufactured by Viega (Figure 4). This feature will allow an increased shipping density that should result in more than 40% savings in shipping costs.

Tubing Stabilization/Concrete Placement

The tubing stabilization device is intended to keep the tubes flat on the ground spaced at 6″ centers with a tolerance of +/- 1″ until concrete is poured. It should be operable and moveable by one person without excessive force. The preliminary design included a reusable sled that would have two wheels and hold the tubing inside (Figure 6). An axle would slide through the holes in the sled and a chain attached to the move the sled. As the sled was pulled across the floor, the tubing would be pulled through slots in the sled to guide the tubing on 6″ centers. The concrete would be poured onto the surface of the sled, which would slide down and bury the tubes.The concept was designed to appropriately hold and space the tubes while also placing the concrete without disturbing the tubes. If the concrete slides down the sled parallel to the tubes, it does not come in from the side and knock the tube out of place. A prototype of the sled was made out of plywood to evaluate the preliminary design.

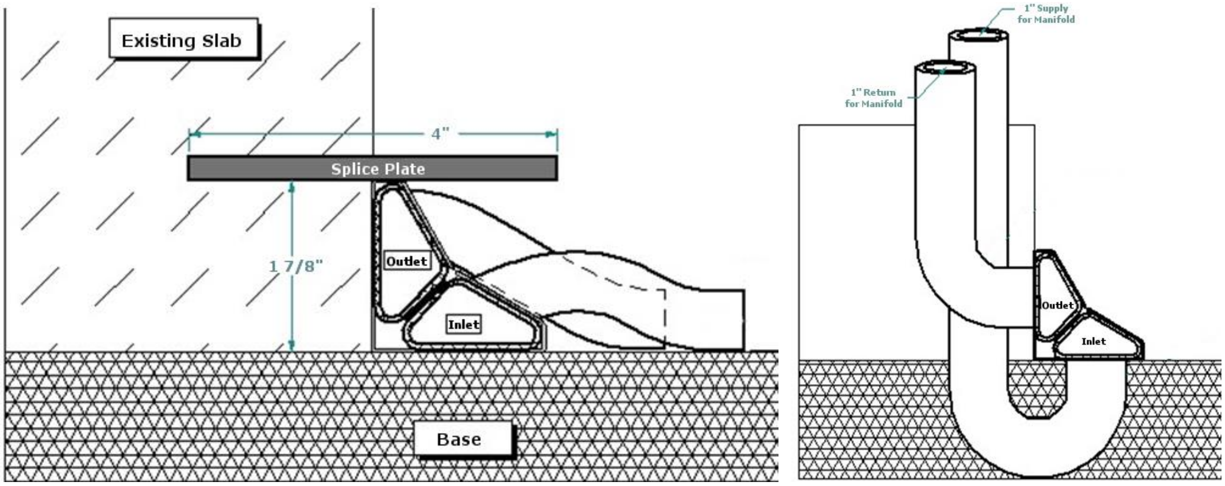

Figure 1 - Manifold design with two triangle shaped HDPE extruded tubes

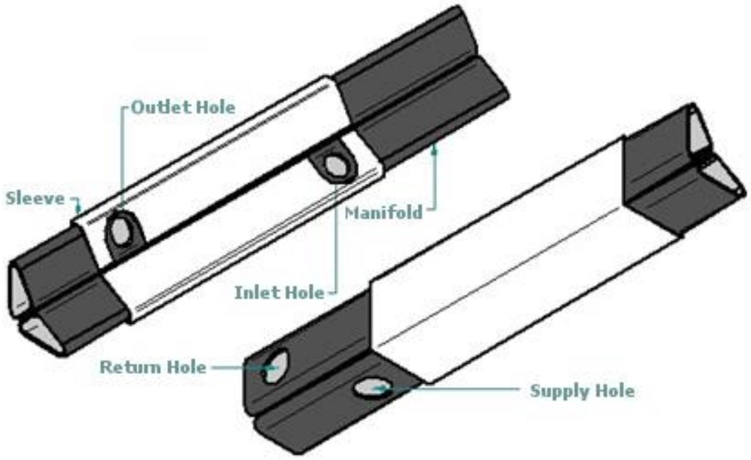

Figure 2 – Sheet metal sleeve adds additional strength to the manifold walls

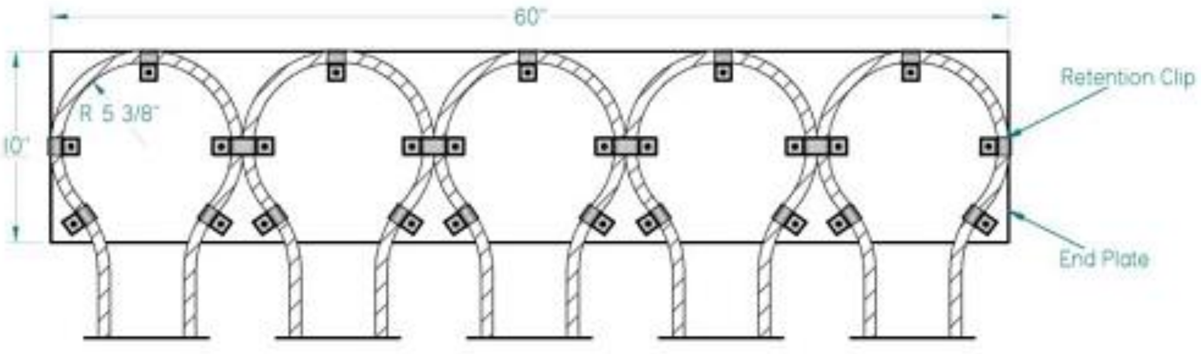

Figure 3 – End plate of 16 gauge steel sheet with clips to hold down return bends

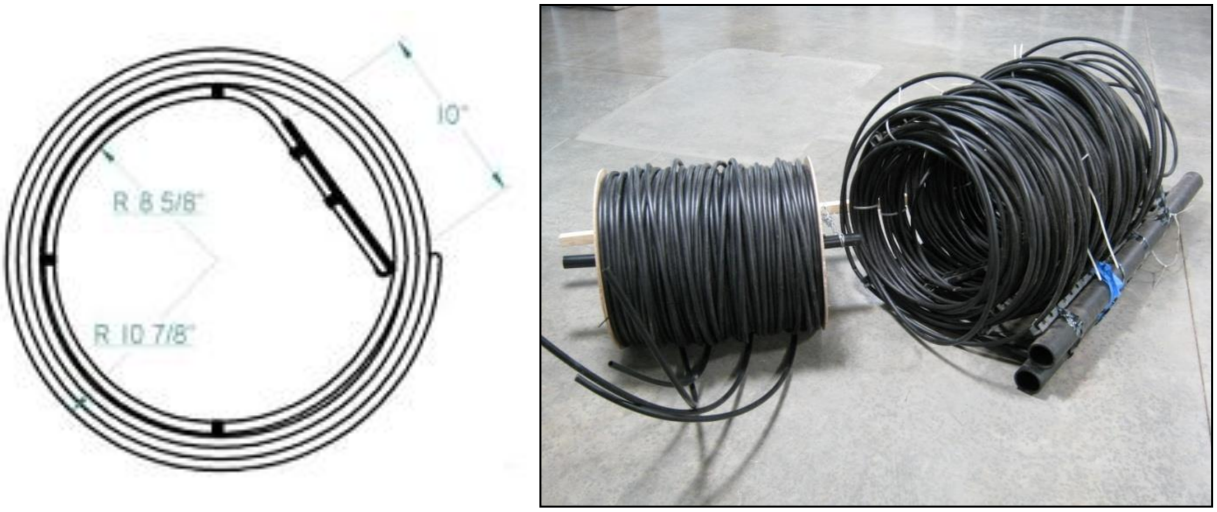

Figure 4 – Compact 23″ roll diameter achieved by removing spacer bars from the tubing circuit (left) and the improved 23″ roll next to the larger 32″ roll (right).

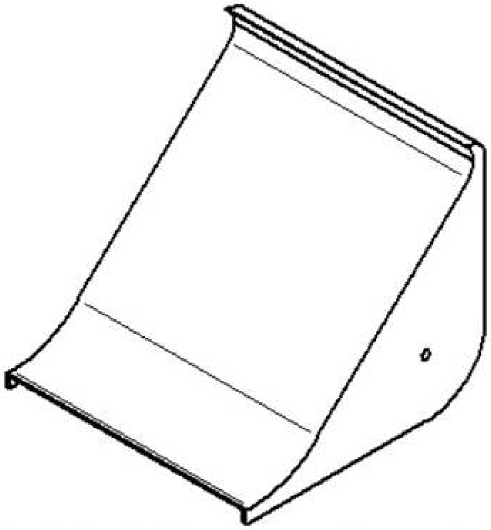

Figure 5 – Reusable sled to place and space tubing on 6″ centers

Task 2 – Develop Final Design of Process and Devices

The preliminary designs were reviewed by the project team and stake holders and design modifications were made for all of the components system.

Manifold Stabilization

The following shortcomings and improvements were identified for the preliminary manifold design:

- The straight wall with the hose connections is a weak surface and should be replaced with a rounded surface. Using a rounded surface will reduce the need for the sheet metal sleeve to surround the entire manifold.
- The sleeve is overly complicated requiring holes for the connections.
- Fusing of the tubes to the manifold is difficult at the sloped angle.
- It would be more efficient to install the supply tube to the inlet manifold through a break in the outlet manifold so that the base does not have to be excavated.

The final manifold design has rounded surfaces to increase the strength of the manifold and a simplified sheet metal sleeve (Figure 6). The connections to the 10′ manifold section are made in the center of the section (Figure 7). The supply tube is attached to the lower inlet manifold through a break in the upper outlet manifold. At the beginning of the installation, the sheet metal sleeve is secured to the base, adjoining concrete slab, or concrete forms though the holes at the end of the sleeve. A Walmart concrete consultant expects the design to work without weakening the concrete slab. This is because the manifold fits below the slab movement "key" plates and because the concrete displaced by the manifold forms a 45 degree angle, in cross-section, that will not result in a problematic weakness in the slab.

After a discussion with a plastics manufacturer it was also determined that large scale production of the manifolds could be manufactured by injection molding instead of extrusion. An injection molding process could result in a part with straight tube stubs already integrated into the manifold. This would allow a simple butt fusion process for attaching the tube stubs to the longer tubing circuit.

Return Bend Stabilization

The end plate for the return bend stabilization was modified slightly to reduce costs and simplify manufacturing by using laser cut and punched clips (Figure 8, top). The number of clips was also reduced and the locations were moved to facilitate the cut and punch strategy. A similar strategy is used for punching the clips from the two spacer bars (Figure 8, bottom).

Tubing Stabilization/Concrete Placement

Evaluation of the sled concept revealed several concerns; the main one being that the sled is too heavy and too awkward to be easily pulled by one person. It would also be very awkward to move from one roll to the next. In addition, the slots may not apply adequate tension to keep the tubing straight as the spool is unrolled. Therefore, the sled concept was discarded and replaced with a spacer rake attached to the spool axle by two arms (Figure 9). The pull chain attaches to the arms. As the operator pulls on the chain, the spool unwinds and the tubing is kept straight and taught by the rake. The concrete is poured directly on the tubing with a standard concrete chute. The original concern with pouring the concrete out of the chute is that the concrete would knock the tubing out of alignment when it comes from the side at a high velocity. By attending a Walmart concrete pour with the existing radiant product, WCEC observed that the installers avoided this by pouring the concrete from the chute on top of wet concrete instead of directly onto the tubes. The poured concrete slowly spreads onto the tubes and does not knock the tubes out of position. It was decided that this simpler method was a workable solution. The concrete operator needs to be informed at the beginning of the pour to avoid pouring fresh concrete directly on to the tubes. Therefore, a concrete pour accessory was not needed and was not further developed.

Spacer Rake

The spacer rake has two nesting channels with opposed wheel-shaped guide stationary bushings that exert pressure on the tubing as the rake is pulled (Figure 10). This pressure creates drag that pulls the tubes straight. A linkage-type latch allows the relative position of the channels to be adjusted. This adjustment varies the pressure on the tubes and the drag force. When wide open, the latch allows the rake to be removed and placed atop the newly-exposed circuits of the next roll, near the manifold spacer bar, just as unrolling begins. As the latch is closed, each opposed bushing set grips a circuit tube due to the grooved bushing design.

Spool

Two wheels and an axle sleeve, designed to be manufactured from rigid plastic, form the basis of the HDPE spool (Figure 11). The wheels, which are reusable, attach with a press fit to the axle sleeve. The flange of the wheel and the joint attaching it to the axle sleeve are sloped at a 22.5° angle so that the wheels will nest when shipped back to the manufacturer for reuse in another spool. The flange is 1.25″ wide to support the spool and is 23″ wide to hold the tubing on the roll. There are three slots cut in the wheels; one large slot for the end plate and two small slots for the spacer bars. The plate and bars are secured to the wheels with removable pins. The rigid axle sleeve runs the length of the spool, adding stability to the spool and guiding the removable axle through the two wheels.

Arms

Rigid arms attach each side of the axle to each side of the rake (Figure 12). The arm is secured to the axle with a hex head bolt. The end of the arm is attached to the rake with a bolt on each side. A hole is drilled in each arm to allow for the attachment of the pull chain. The location for the pull chain attachment is carefully chosen to create the desired pull force on the rake without rotating the wheel/rake assembly.

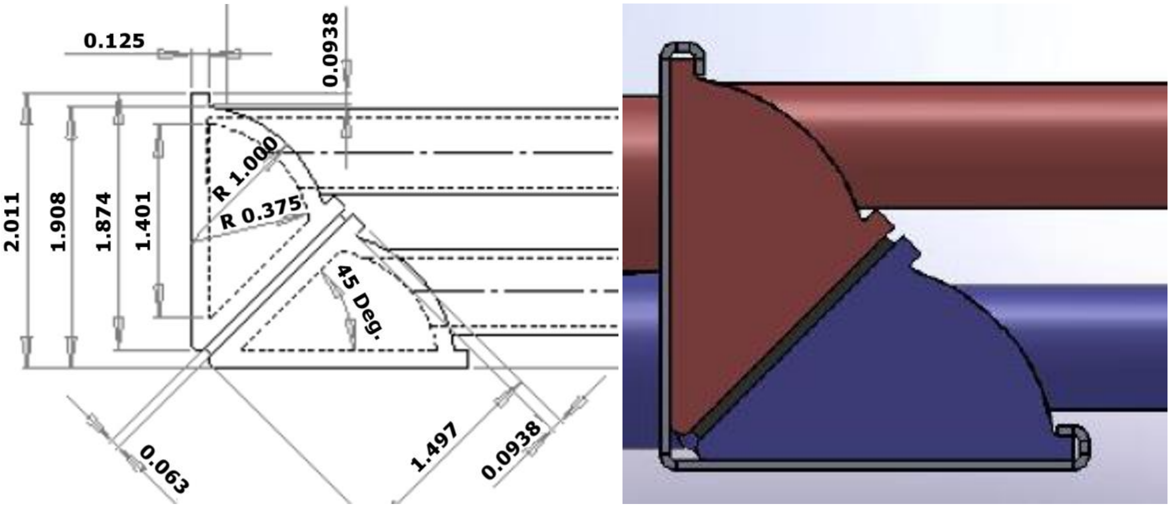

Figure 6–Final manifold design with rounded walls and simplified sheet metal sleeve.

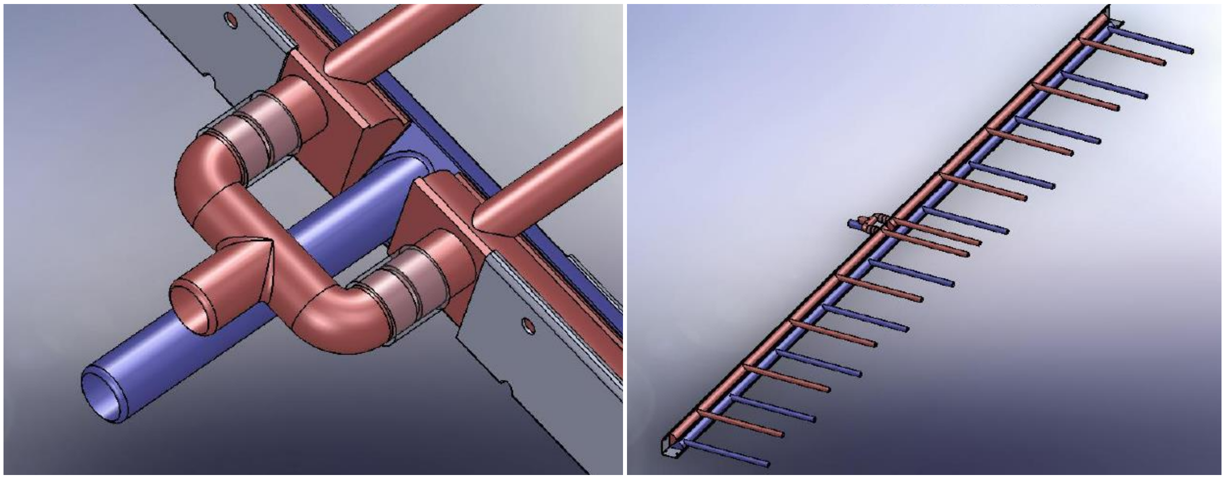

Figure 7 – 10′manifold section with supply and return connections.

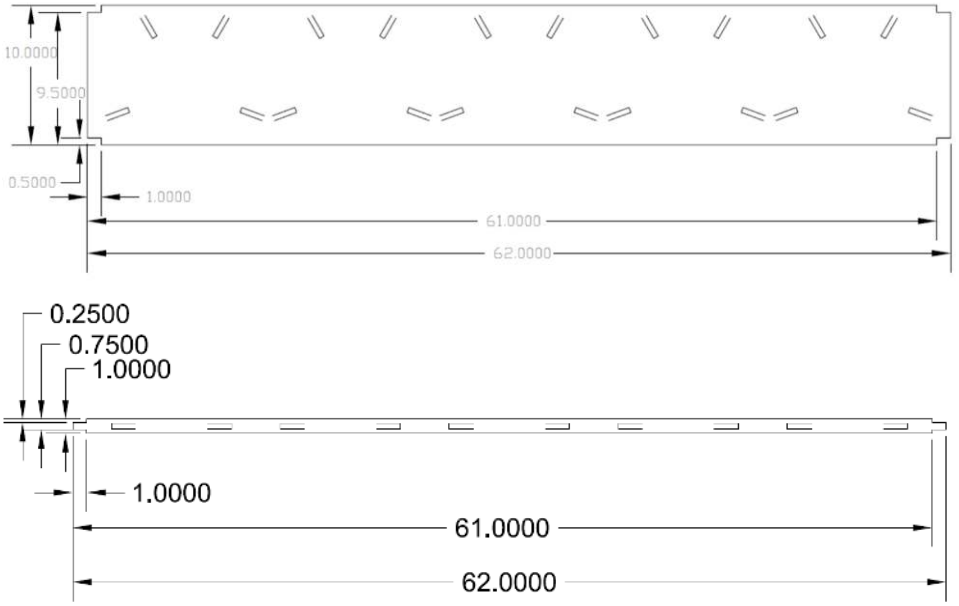

Figure 8 – End plate (top) and two spacer bars (bottom) are manufactured from sheet metal with clips laser cut (shown) and punched with a clip shaped die (not shown).

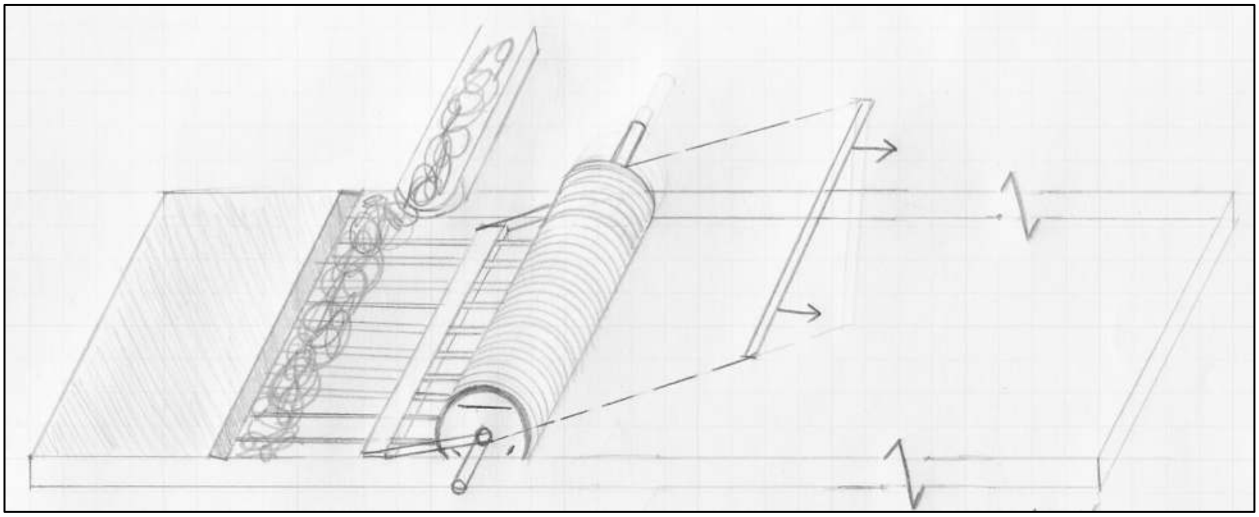

Figure 9 – Improved concept for rollout and tube stabilization with spacer rake and arms attached to the spool assembly.

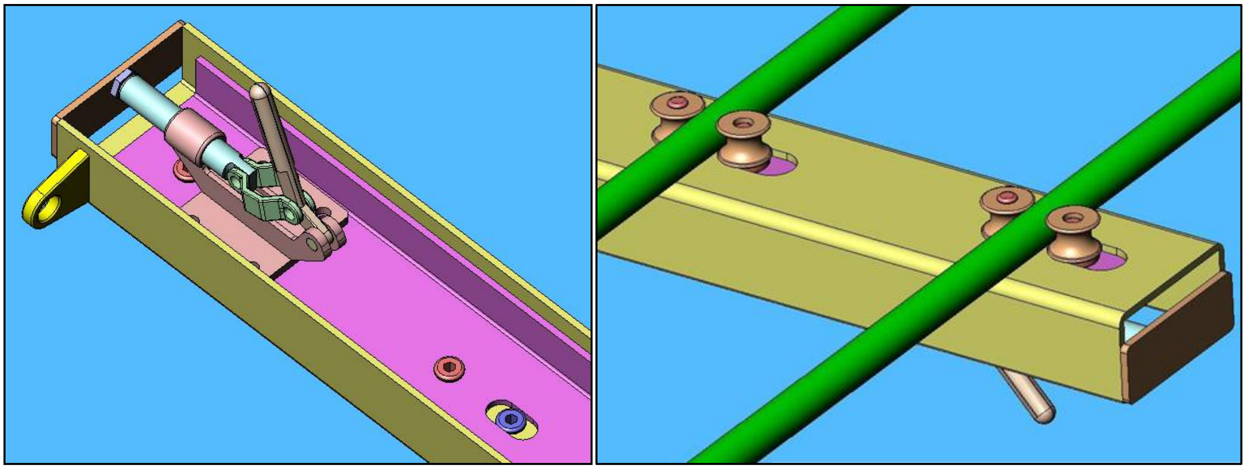

Figure 10 – Spacer rake that applies adjustable tension to the tubing as the spool is unrolled.

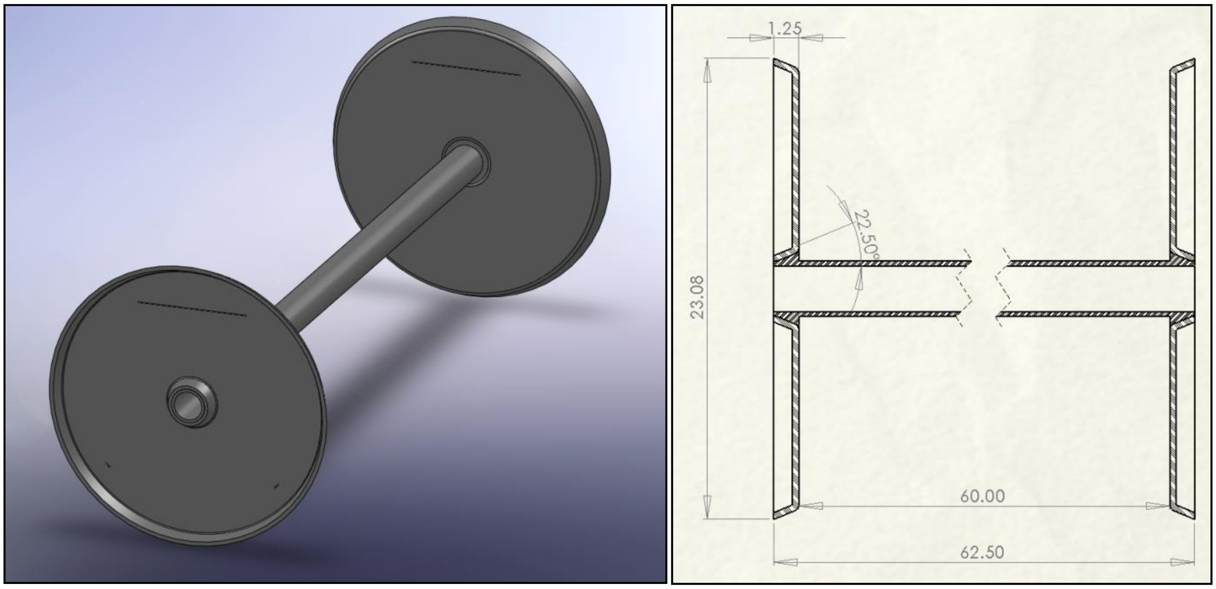

Figure 11 – Wheel and axle sleeve assembly that forms the spool of HDPE tubing.

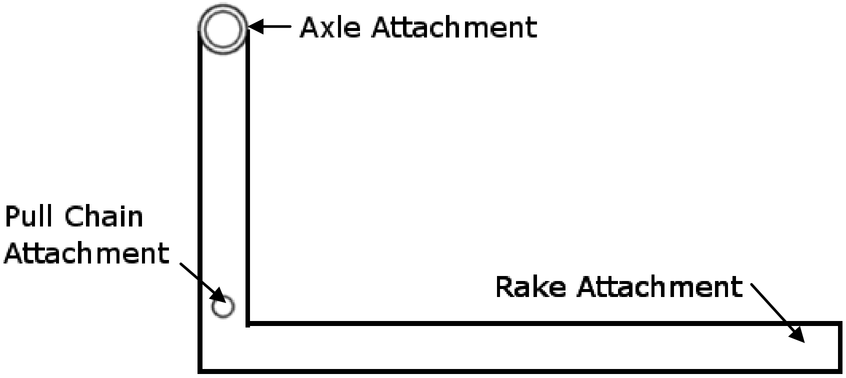

Figure 12 – Rigid arms that attach the spool axle to the rake.

Task 3 – Build Prototype Devices

With the final design complete prototypes were constructed for the entire system including the manifold, rake, and wheel/end plate assembly. The prototype parts were designed to be tested for installation but not for operation with water. The prototype was built as a 5′ wide by 130′ long 10 tube rollout, although commercial products will likely be built with 10′ manifolds and may be of different lengths depending on store configuration.

Manifold Stabilization

The manifold prototype was fabricated by PolyFab in Wilmington, MA. Although the commercial product will be extruded or injection molded, the prototype was constructed from HDPE with machining and fusion methods (Figure 13). The prototype functioned as desired.

Return Bend Stabilization

The return bend stabilization parts including the end plate and two spacer bars were laser cut by Van Dyke Fabrication in Rocklin, CA and punched into the clip shape at the Engineering Shop at UC Davis. The end plate effectively stabilized the return bends and held them securely to ground with the weight of the end plate (Figure 14, left). The two spacer bars assisted in completing the turn and defining the start of the 6″ spacing, which is maintained by the rake during the rollout process. Although the plates worked as desired, it was discovered that the laser cut clips have sharp edges that occasionally nick the tubing as it is being inserted into the clips(Figure 14, right). The production clips should be made with a punch that flares the edges up slightly away from the tubing to avoid this problem.

Tubing Stabilization/Concrete Placement

Prototypes of the spacer rake and arms were manufactured from aluminum by the Engineering Shop at UC Davis.Prototypes of the wheels and axle sleeve were manufactured from ABS plastic and PVC plastic, respectively, by PolyFabin Wilmington, MA. The spacer rake was tested in the laboratory to practice pulling the tubing and adjusting the tension (Figure 15). The spacer rake performed as desired, although adjusting the force was a little cumbersome. This feature could be made more user-friendly in the production product. The wheels and axle sleeve were tested and assembled in the laboratory (Figure 16). They were rigid and performed as desired, and nested inside of each other for reduced shipping volume. The aluminum arms attached the axle to the rake as required and provided the correct location for attaching the pull chain (Figure 17).

Assembly and Rollup

The assembly and rollup of the spool with arms and rake was completed in the WCEC laboratory in Davis, CA. It took approximately four people to manage the roll up process. In production the entire rollup would be completed on machinery with little manual labor. The end plate, spacer bars, and axle sleeve were attached to the two wheels and secured with cotter pins through the end plate and spacer bars (Figure 18). The 1″ aluminum tube axle slid through the spool and the arms were clamped on. The rake was installed onto the tubing and used as a guide to help roll the tubing correctly onto the spool.

As the team starting rolling the spool the tubing exerted force on the spacer bars and end plate, causing them to deform (Figure 19, left). This caused the center of the spool to become a smaller diameter than the rest of the spool, which would lead to shorter circuit lengths in the center than on the edges. The spool was unwound and 2″x4″ pieces of lumber were secured to resist the force deforming the spacer bars and end plate (Figure 19, right). Wood was used because this was an unexpected problem that needed a quick solution, but square rigid plastic tubes would likely be a better solution in the production product. Once this problem was solved the rolling went smoothly. Nine tubes of 5/8″ diameter fit into the available 6″ spacing, for a total of 90 tubes rolled side by side for each layer (Figure 20). Because ninety tubes of 5/8″ diameter only use 56.25″ inches of length on the 60″ roll, there were small gaps left in each layer which made it difficult to roll the tubing up evenly. Eventually it was decided to gather the extra space at one end of the roll (Figure 20, right). In the commercial product the roll should be designed to be only 56.25″ in length (from the inside of one wheel to the other). The completed roll resulted in approximately 2.5 layers of tubing with an outer diameter of 23″. The tubes were cut straight and butt fused to the manifold (Figure 21). Once this was completed the entire roll was ready for the field test to begin.

Figure 13 – Prototype of 5′ manifold section with connections to tubing circuit.

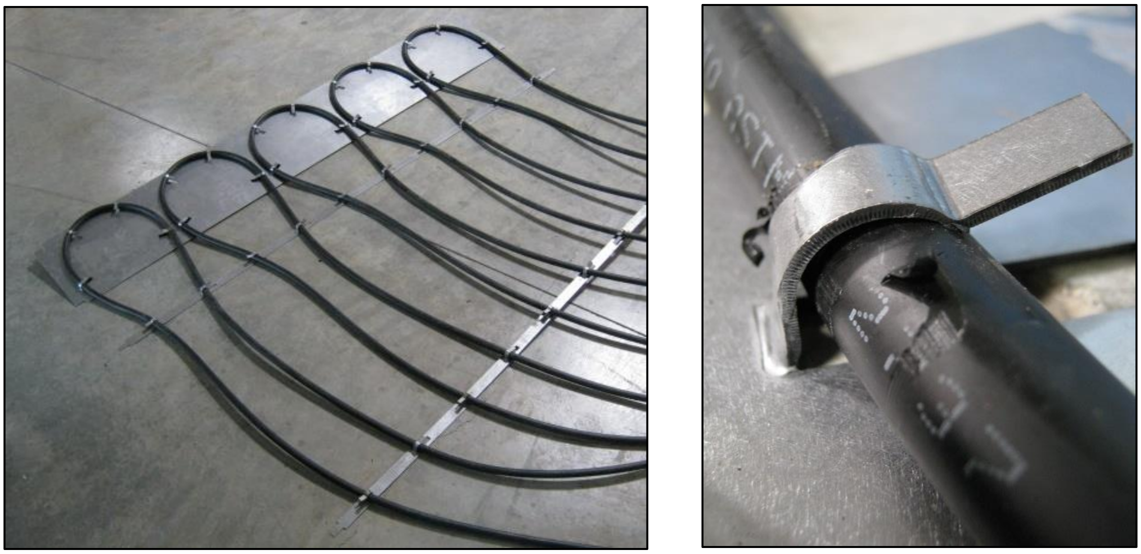

Figure 14 – Return bend stabilization consisting of end plate and two spacer bars with clips punched from sheet metal.

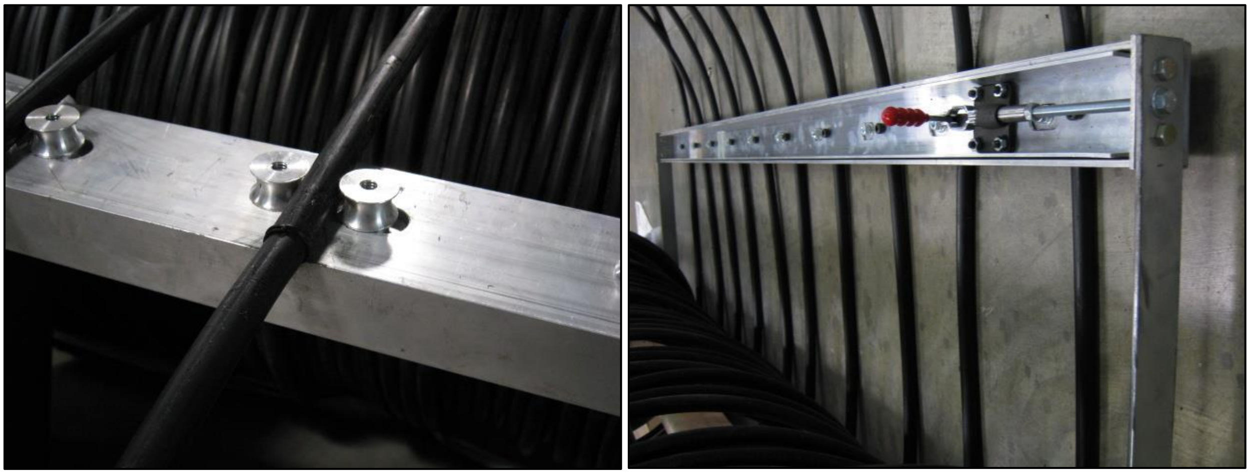

Figure 15 – Aluminum spacer rake guiding HDPE tubes at 6″ spacing.

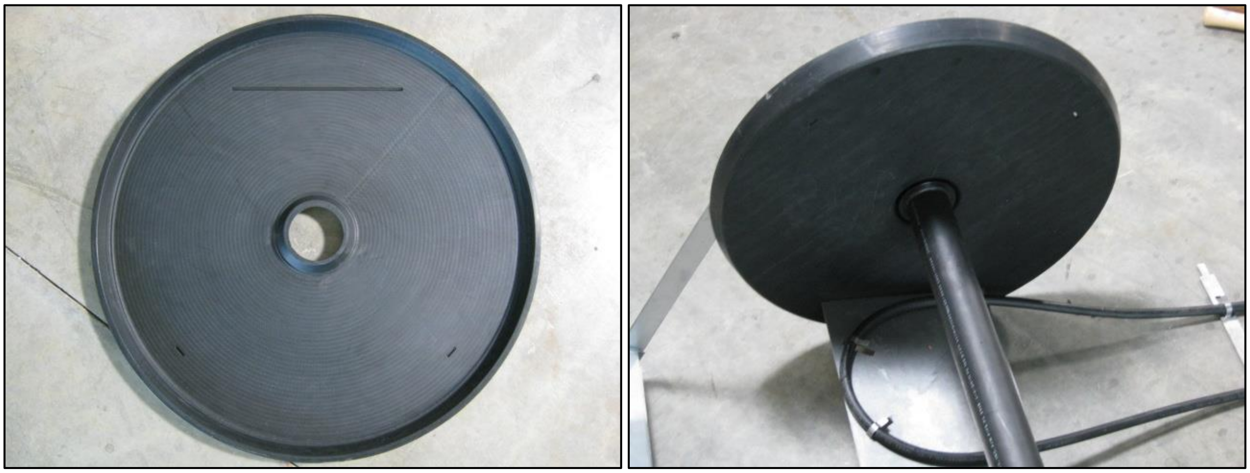

Figure 16 – Reusable rigid plastic wheel and axle sleeve assembly.

Figure 17 – Aluminum arms attach the rake to the axle with a location to attach the pull chain.

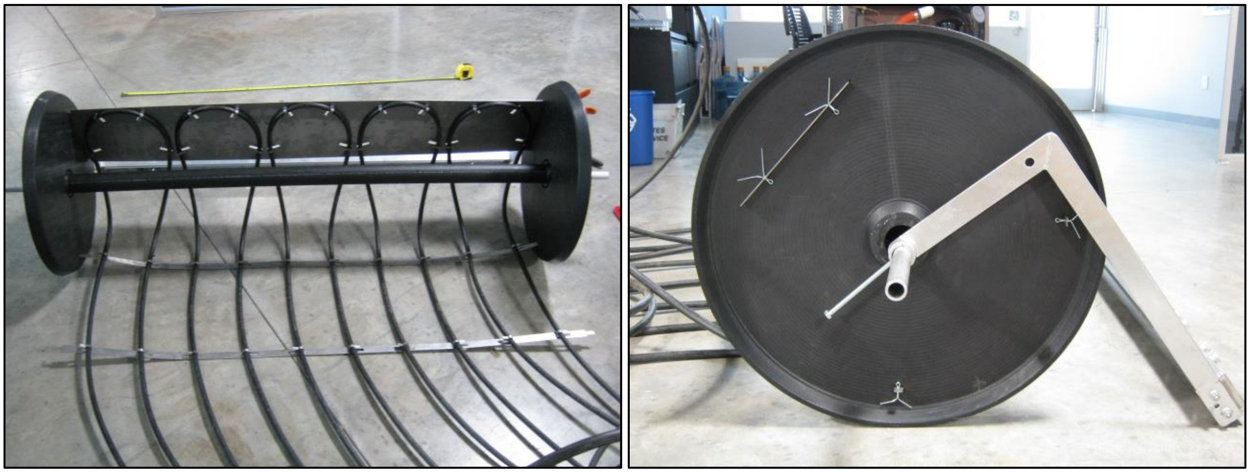

Figure 18 – Spool is assembled with end plate and two spacer bars inserted into the two wheels and pinned with cotter pins.

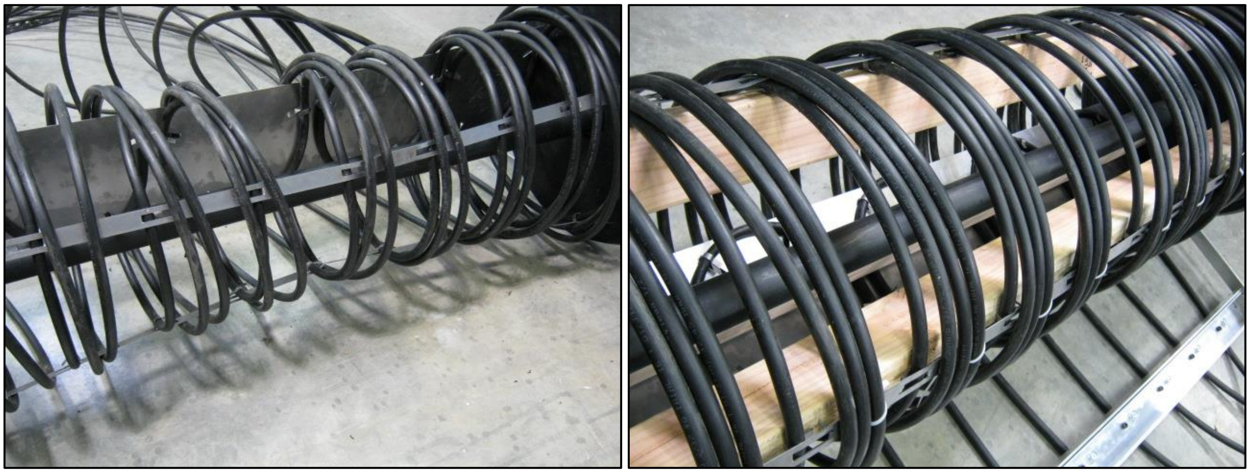

Figure 19 – Spacer bars and end plate deformed as the spool was rolled (left), so 2"x4"s were placed under the plates for additional support.

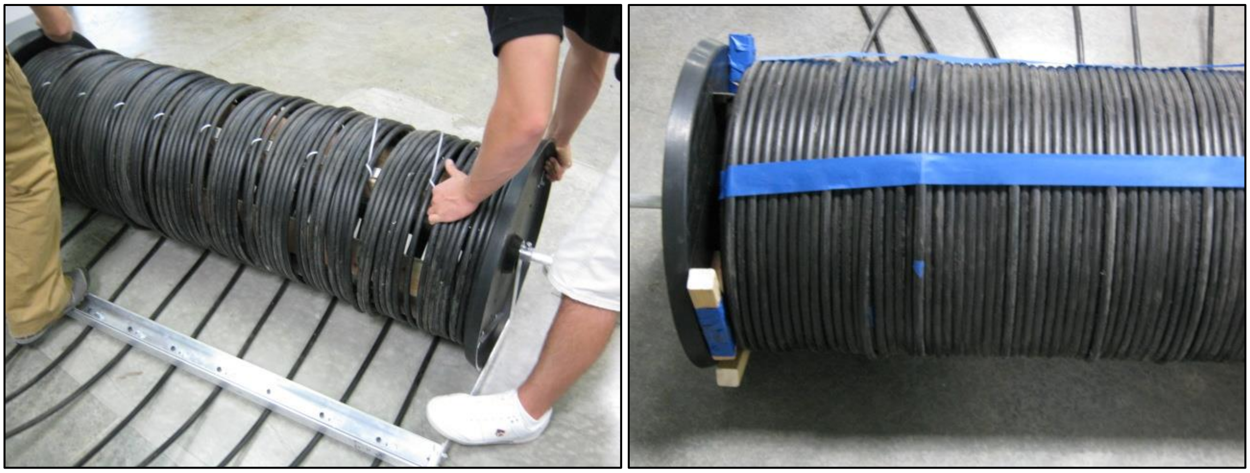

Figure 20 – Rolling the last tube for the 1st layer (left) and completion of the 2nd layer (right).

Figure 21 – Completed roll with 2.5 layers (left) and butt fusion of the manifold tubes to the spool (right).

Task 4 – Field Test Process and Devices

The original plan was to complete the field test installing the 5′ x 130′ roll of tubing in the slab of a Walmart store. The test would be to document the installation process and the tubing would not be functional. However, the pour schedule for local Walmart stores did not match with the required schedule for the project. Since the tubing was not operational, the test could be completed during the pour of any 4″ slab of the appropriate shape. WCEC decided to build a 4″ x 5.5′ x 135′ form and execute the concrete pour and associated experiment on the project schedule. Empty land was found at a private home of a local demolition contractor in Davis, CA. As an added bonus, the demolition contractor plans to cut up the concrete into 10′ sections for reuse. While that will occur after this report is published, WCEC plans to go inspect the final location of the tubing after the concrete has cured. The pour site was leveled and compacted and a 4″ x 5.5′ x 135′ form was built. Crushed red, compacted rock filled the bottom of the form.

Manifold Stabilization

The manifold sleeve was easily secured to one end of the form with screws driven through prepared holes in the sheet metal angle "wrap" into the edge of the form board. As can be seen clearly in Fig. 22 left, the relatively smooth angled wall of the manifold surface will not contribute to weakness or cracking at the slab edge.

Tubing Stabilization/Concrete Placement

The spool and rake assembly was setup to prepare for the concrete pour (Figure 22, right). The rake was placed on the tubing near the manifolds and was then pulled with the spool to keep the tubing circuits in straight alignment. The concrete was poured onto the tubes, with fresh concrete poured onto previously poured concrete so as not to knock the tubes out of position (Figure 23). The tubes were covered with concrete as the spool was continually unrolled (Figure 24). The tension the rake exerted on the tubing was high and two people were required to pull the roll. It was difficult to adjust the tension in the field because the rake adjustment mechanism was cumbersome. Therefore, it was left somewhat high and two people were required to move the spool. The production rake should have a quick adjustment mechanism, which would allow the tension to be optimized so that one person can pull the roll. Although additional labor was needed to move the roll, the process was very fast and should not slow down the pour with experienced operators in commercial applications. Although the spacing cannot be measured until the concrete it cut, the rake appeared to maintain the required 6" spacing within the desired 1" tolerance.

Return Bend Stabilization

At the end of the roll the spool was disassembled to remove the end plate and spacer bars (Figure 25, left). Unfortunately the imperfect "by hand"rolling resulted in circuits of differing lengths (Figure 25, right). The tube on the far right was too short and prevented the rest of the tubing from being extended. This tube was rolled next to the gap, so it is suspected that this tube was rolled around a small diameter. With a shorter roll length between wheels and a machine rolled process this is not expected to be an issue in production. The remaining tubing was covered with concrete, including the spacer bars and end plate. The end plate held down the return bends securely as desired (Figure 26). The entire pour took approximately 45 minutes.

Figure 22 – Securing the manifold at the beginning of the installation (left) and setting up the spool and rake assembly for the rollout (right).

Figure 23 – Pouring concrete onto the manifold and tubes.

Figure 24 – Pouring concrete onto the tubes while moving the rake/spool assembly (left) and finished concrete (right).

Figure 25 – Disassembling the spool to remove the spacer bars and end plate (left) and slack at the end of the roll in some circuits from imperfect rolling in the laboratory (right).

Figure 26 – Pouring concrete over the spacer bars and end plate

Task 5 – Program Management

Throughout the project the principal investigator and other WCEC staff tracked staffing, budgets, schedule and deliverables; communicated with team participants; prepared quarterly progress reports, and prepared this final report. After the field test, the team reviewed the original cost model and modified it based on project experience. The revised cost model is included as Appendix A. The revised model shows expected an expected installed cost of $0.93 per square foot compared to $2.03 per square foot for the Climate Mat system. The projected savings of $1.10 per square foot accrue as follows:

Manifolds	$0.46
Rollout	$0.58
Shipping	$0.06

Before preparing the final report, the team also computed projected benefits to California and completed the required questionnaire. Appendix B shows calculations used to estimate benefits.

Project Outcomes

The overall project goal was to reduce the installed cost of large "rollout" tubing systems imbedded in concrete slabs. The project sought to achieve this goal by reducing materials, labor, and shipping costs. The outcomes listed by task are:

Task 1 – Preliminary Design:The task 1 objectives and outcomes were:
Objective: Create a preliminary design likely to meet the objectives stated in Task 4 that will:

a. Stabilize and precisely place manifolds
b. Space and place tubing
c. Hold-down return bends
d. Improve concrete placement

Outcome: Preliminary designs were created for the manifold, return bend end plate and spacer bars, and for a sled that would both stabilize and place tubing and assist in concrete placement.

Objective: Produce drawings and mockups to illustrate solutions
Outcome: Drawings were produced for the manifold, return bend end plate, the spacer bars and sled. A mockup of the sled was made to help evaluate that solution.

Task 2 – Final Design:The task 2 objectives and outcomes were:
Objective: Review of preliminary design by project team
Outcome: The preliminary design was reviewed by the project team at WCEC and Walmart.

Objective: Make modifications in design in response to reviewer discussions
Outcome: Small modifications were made to the design of the manifold for increased strength, simpler assembly, and ease of installation. Small modifications were made to the end plate and spacer bar design to allow laser cut and punched clips to hold the tubing. Major modifications were made to the tubing stabilization and concrete placement method. The cumbersome and heavy sled was redesigned into a lighter and easier to operate spool, rake, and arm assembly.

Objective: Produce drawings and mockups to further development
Outcome: Drawings were produced for all parts including the manifold, end plate, spacer bars, rake, spool, and arms.

Objective: Prepare final design for prototype development
Outcome: Manufacturing drawings were produced and several shops and prototypes were contacted to evaluate capabilities, schedule, and cost.

Objective: Final design meets the objectives state in task 4
Outcome: The final design was anticipated to meet all the objectives stated in task 4, although this could not be completely evaluated until testing.

Task 3 – Build Prototypes: The task 3 objectives and outcomes were:
Objective: Prototype team reviews drawings and mock-ups, recommends improvements and builds prototypes
Outcome: The prototype teams including PolyFab and the Engineering Shop at UC Davis recommended small changes for ease of manufacture that were incorporated into the design. For example, the wheel originally had an 18° angle on the rim which was changed to 22.5° to match a standard machining bit.

Objective: Prototypes are hand built with mass production in mind
Outcome: The prototypes were hand built by PolyFab and the Engineering Shop with machining and fusing methods. However, the design was developed with continual discussion of the ease of manufacturer for mass production.

Objective: Prototypes tested in small scale situation
Outcome: As the prototypes arrived they were tested in the laboratory before the field test. For example, a weld in the rake was found to be too weak and fixed before the field test.

Objective: Prototypes are improved
Outcome: A few improvements were needed to the prototypes, however there was not budget or schedule remaining for additional manufacturing. The only significant change was the addition of the 2"x4"s between the spool wheels. A prototype revision would use hollow plastic tubing instead of lumber.

Objective: Prototypes achieve performance goals in small scale testing
Outcome: The prototypes worked well in the laboratory and the spool was rolled and prepped for the field test.

Objective: Prototypes finalized for full scale field test
Outcome: The prototype was finalized and stored in the laboratory until the field test later in the week.

Task 4:The task 4 objectives and outcomes were:

Objective: Manifold Stabilization:

a. Hold manifolds in fixed linear pattern during fabrication, shipping and deployment
b. Keep manifolds located without compromising slab strength
c. Stabilizer economical enough to be left in place.

Outcome: The tested sheet metal manifold stabilizer is low cost and holds the manifold securely during fabrication, shipping, and deployment. The manifold assembly was placed in the concrete without excavation and without comprising slab strength. The manifold was attached to the tubing circuits with a quick butt fusion joint for each tube.

Objective: Tubing Stabilization:

a. Maintain tubing spacing at 6 inches on center plus or minus 1 inch and hold tubing against the base until held by concrete
b. Rake operable and movable by one person without excessive force
c. Rake rugged and cleanable.

Outcome: The rake maintained the tubing at the required 6″ +/- 1″ spacing. In the field test, the rake and associated assembly required two people to move. With design changes to simply the adjustment for the pulling tension, this could likely be reduced to one person. The rake is rugged and cleanable.

Objective: Return Bend Stabilization:

a. Accept and hold the return bends of the ½ inch HDPE pipe
b. Rigid, low cost and easily formed
c. Fabricated with guides that spool up the tubing as it is rolled for shipment
d. Becomes part of the packaging and shipping of the radiant mats

Outcome: The end plate and spacer bars are low cost sheet metal and easily formed by laser cutting and punching. The clips for the tubing generally functioned well but occasionally nicked the tubing. The clip punch can be modified in production to avoid this problem. The wheels define the edge of the roll and act as guides for the tubing as it is rolled for shipment. The end plate and spacer bars are part of the entire 23″ diameter assembly that is packaged for shipment.

Objective: Concrete Placement:

a. Concrete is placed without significantly moving radiant tubing
b. Tubing system does not slow down concrete placement process
c. Concrete distribution can be controlled by one person
d. Distribution accessory is low cost, rugged and cleanable

Outcome: After observing a Walmart pour it was determined that a concrete placement accessory was not needed because the concrete can be easily poured with existing equipment without disturbing the tubing. The tubing system did not slow down the concrete placement process in the field test. There was a small delay in removing the wheels from the roll, but this is easily resolved by improving the pin design. The concrete distribution was easily controlled by one person.

<u>Task 5:</u>The task 5 objectives are to:
Objective: Meet schedule and budget constraints
Outcome: The project was completed on schedule and within budget constraints.

Objective: Complete final report that meets sponsors requirements
Outcome: This document is the completed final report.

Conclusions

Key conclusions at project completion, deriving from the project objectives are:

1. *The new manifold design is practical and will provide the following key advantages over the current Climate-Mat product.*
    a. *reduces product cost by eliminating fusion tees and 75% of fusion joints*
    b. *reduces installation cost by eliminating excavation and backfill labor*

The prototypes were built by a plastics fabricator and thus were considerably more expensive in comparison with an extruded product. However, their cross-sectional shape is designed for extrusion and clearly can be produced economically when extrusion dies are made. An injected-molded version is also possible so that simple butt-fusion, instead of "arc-fusion" joints are made to circuit tubes. The fusion joints between the circuit tubes and the manifolds were made by hand, so additional work is required to develop high production cutting and fusion tools to mechanize this process, but again, there are no apparent technical reasons why such tools cannot be successfully developed.

2. *The spacer-less rollout strategy is workable and will provide the following advantages over the current Climate-Mat product:*
    a. *reduces materials cost and assembly labor by eliminating spacer bars and clips*
    b. *reduces shipping cost by facilitating greater shipping density*

Project work clearly demonstrated that tubing can be kept at the bottom of the slab and reasonably spaced (within an inch of desired location) by using a "rake" to pull tubes tight as concrete is placed on them. The slight imperfections noted in the field test pour (excess effort to pull, unequal circuit lengths near the end plate, and delays removing the wheels) can be resolved with modest improvements in manufacturing and design. The most expensive of these resolutions involves factory coiling equipment to evenly feed tubing as it is rolled on the spool, but this expense is likely less than would be required to develop and implement a high-speed process to install spacer-bars for the current Climate-Mat product.

3. *The new end plate reduces field labor by eliminating the need to drive fasteners into the ground to hold circuit return-bends at the bottom of the slab.*

This feature was quite successful and the only additional work anticipated for production setup is a modified "integral clip" design that cannot cut the tubing with sharp steel edges. A slightly more-sophisticated but easily-designed punching die is needed for this purpose.

4. *No "chute accessory" is needed to prevent the falling concrete from pushing tubes out of alignment.*

Observations of how concrete is poured for Walmart slabs confirmed that the concrete tends to fall onto wet concrete that is already in place rather than directly onto the tubes.

5. *If a manufacturer adopts these new designs in competition with the existing Climate-Mat product, the installed price for large-scale installations will likely fall to the $1.00/sq. ft. target within several years as industry volume grows.*

A detailed cost model indicates that materials costs, labor costs, and shipping costs will be reduced using these new designs such that the target installed cost of $1.00 per square foot can be achieved. The assumed scenario includes conservative markups including a 200% multiplier on factory direct costs and a 125% multiplier for the installation contractor.

Recommendations

Recommended next steps to advance these designs toward the marketplace are:

1. *Secure patent protection for the innovative features.*

The Western Cooling Efficiency Center has filed two "record of invention" (ROI) documents with the UC Davis Technology Transfer Services (in the Office of Research) for the technologies developed in this project. The first ROI covers the innovative manifold set, and the second ROI covers the spacer-less spooling concept and end plate. UC Davis should immediately file provisional patent applications based on these two ROI's, and should submit a full application as soon as a license agreement is reached with a manufacturer.

2. *Present improved designs to potential manufacturers*

Recommended design improvements based on project experience include a narrower spool to improve rollup and rollout, elimination of one spacer and stiffener bar set at the spool end, pegged end plate and stiffener bar connections to the wheels to speed their removal at the end of the rollout, revised end plate and spacer bar "punch out" clips to protect the tubing, and addition of a turnbuckle to improve rake adjustment. With these five improvements, the project team can present a very attractive opportunity to potential manufacturers. The focus will be on firms located in or near California that either extrude high density polyethylene tubing or manufacture and distribute radiant heating products.

3. *Secure license agreement with selected manufacturer(s)*

Based on their interest, resources, and relative commitment, select one or more preferred manufacturers for manufacturing development and marketing of the technologies developed in this project. If selected manufacturer(s) is/are inexperienced with radiant heating and cooling products, structure agreement to involve WCEC personnel in design of technical literature for marketing.

4. *Assist manufacturer(s) by linking with major retailers and other potential purchasers*

Maximize the market opportunity by assisting the selected manufacturer(s) with key market contacts including Walmart, Target, the Commercial Buildings Energy Alliance (CBEA) and with electric utility incentive programs.

5. *Organize and assist with full-building installation and case study*

Help secure utility incentive funding for a first full-building installation of the improved system, and help select an appropriate owner and project site in California. Monitor installation and performance, and from results, write a case study for posting on the WCEC website. Based on full project results, suggest further system improvements.

Public Benefits to California

Benefits California has already received from this contract: Not applicable.

Benefits California will receive if the results of this project are widely used:

Future project benefits should accrue to California in four specific categories. These four are listed below and then quantified in subsequent sections.

1. Reduced peak electricity demand for cooling, resulting in lower electricity rates because the cost of new generators has significant impact on rates.
2. Reduced electricity use for cooling that will result in lower electricity bills and potentially lower fuel rates due to overall lower demand for generation fuels
3. Reduced electric bills freeing more customer funds for other purchases that can contribute to economic growth
4. Reduced GHG emissions, a benefit that will have increasing value as the world focus on combating climate change gathers momentum.

Historical data suggest that about 100,000,000 square feet of new low-rise, non-residential slab area are added to California's building stock in an average year. The project team estimates that within several years slab tubing systems will be so economical that the technology can capture a significant share of the potential market. The quantitative benefits estimates in this section assume that this technology averages 30% market penetration over a 15-year period. The spreadsheet include as Appendix B shows the calculations summarized below.

Reduced Peak Demand: Unpublished data developed by Walmart consultants and referenced in the proposal for this project indicate that radiant floor cooling will reduce peak summer demand in typical California applications by 1.7 watts per square foot. By the end of the 15th year period with 30% average market penetration per year, the total peak demand reduction will be approximately 765,000 kW- thus eliminating the need for a 765 mW generating plant.

Reduced Electricity Use: Unpublished data developed by Walmart consultants and referenced in the proposal for this project indicate that radiant floor cooling will reduce annual electricity use in typical California applications by 2.8 kWh/year per square foot. By the end of the 15th year with 30% average market penetration per year, the total energy savings for the 15 year period will exceed 10,000,000,000 kWh- the amount of electricity consumed annually by approximately 1.4 million typical California residences.

Reduced Electric Bills: The 10,000,000,000 kWh, 15 year savings noted above convert to $1.5 billion total savings at a $0.15/kWh average electric rate. This projection does not assume rate reduction or stabilization effects that may accrue from reduced electricity demand and use.

Reduced GHG Emissions: A 2007 study by Dennis Silverman at UC Irvine[1] shows CO_2 emissions for California utilities ranging from a low of 553 lb/MWh for PG&E to a high of 1349 lb/MWh for LADWP. A straight average for SCE, SDG&E, PG&E, SMUD, and LADWP is 900.4 lb/MWh. Using this value times the 10,000,000,000 estimated total kWh 15-year savings results in more than 4.5 million tons CO_2 reduction.

An additional difficult-to-quantify benefit to California involves substitution of local materials and labor for rooftop cooling unit capacity that under the status quo is manufactured entirely outside of California. This benefit will be greatest if a California firm steps forward to manufacture the new products demonstrated in this project.

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[1] http://www.physics.uci.edu/~silverma/actions/greenhousereduction.html

Appendix A

Table 1: Comparative Costs per Sqft		
Component installed including factory & site margins	Baseline	Proposed
manifolds & test	$0.59	0.13
spacers & rollout	$0.70	0.12
circuit tubing	$0.64	0.64
shipping	$0.10	0.04
Totals	$2.03	0.94

Large Radiant Floor Cost Model: Baseline (Climate Mat)

Pricing per 1300' sq. ft. 6 inch spacing
10' by 130' modules, 1 per 1300 sq. ft. 1300 sq.ft.

1. Factory Materials	unit	#/units	$/unit	M
mains avg. 3" HDPE	ft	20	$ 2.10	$ 42.00
fusion saddles	each	20	$ 6.00	$ 120.00
tubes 1/2" HDPE	ft	2600	$ 0.13	$ 332.80
spacer bars	ft	450	$ 0.50	$ 225.00
wire ties	each	900	$ 0.03	$ 27.00
shipping lumber	LS	1	$ 20.00	$ 20.00
Total				$ 766.80
2. Factory Labor	# to do	min/ea.	$/hour	L
cut and align circuit sets	10	4	$ 20.00	$ 13.33
drill mains	20	3	$ 20.00	$ 20.00
fuse branches	20	10	$ 20.00	$ 66.67
tie to spacers	900	0.1	$ 20.00	$ 30.00
roll, wrap, stack	1	30	$ 20.00	$ 10.00
Total				$ 140.00
3. Direct Costs				$ 906.80
4. Factory Margin			100%	$ 906.80
5. Price to Contractor				$ 1,813.60
6. Shipping to Site	36 per truck, $1500/truck			$ 41.67
7. Site Materials				
tie-downs	each	10	$ 2.00	$ 20.00
miscell	LS	1	$ 20.00	$ 20.00
Total				$ 81.67
8. Site Labor	# to do	min/ea.	$/hour	L
excavate, backfill for headers	1	30	$ 55.00	$ 27.50
unpack, carry, unroll	1	20	$ 55.00	$ 18.33
fuse headers	2.1	20	$ 55.00	$ 38.50
fill and test	1	10	$ 55.00	$ 9.17
pour	1	90	$ 55.00	$ 82.50
Total				$ 176.00
9. Module Site Costs				$ 257.67
10. Contractor Cost				$ 2,113
11. Contractor Margin			25%	$ 528
12. Total Price to Owner				$ 2,641
13. Installed Cost per Sq. Ft.				**$ 2.03**

Headers & test	
$ 162.00	matl
$ 100.00	labor
$ 524.00	w/margin
$ 75.17	site labor
$ 599.17	subtotal
$ 748.96	w/site mar
$ 0.60	per sq ft
Spacers, roll-out, pour	
$ 252.00	matl
$ 30.00	labor
$ 564.00	w/margin
$ 140.83	site labor
$ 704.83	subtotal
$ 881.04	w/site mar
$ 0.70	per sq ft
Shipping	
$ 20.00	matl
$ 10.00	labor
$ 60.00	w/margin
$ 41.67	site labor
$ 101.67	subtotal
$ 127.08	w/site mar
$ 0.10	per sq ft
Tubing matls	
$ 332.80	matl
	labor
$ 665.60	w/margin
	site labor
$ 665.60	subtotal
$ 832.00	w/site mar
$ 0.64	per sq ft
$ 2.03	Total

Large Radiant Floor Cost Model: Proposed

Large Radiant Floor Cost Model: Improved System 6 inch spacing
Pricing per 1300' sq. ft. 1300 sq.ft.
10' by 130' modules, 1 per 1300 sq. ft.

1. Factory Materials	unit	#/units	$/unit	M
mains new extrusion	ft	20	$ 0.60	$ 12.00
tubes 1/2" HDPE	ft	2600	$ 0.13	$ 332.80
manifold rail and end panel	set	1	$ 20.00	$ 20.00
shipping bag (reusable, 5 uses)	LS	1	$ 5.00	$ 5.00
Total				$ 369.80
2. Factory Labor	# to do	min/ea.	$/hour	L
cut and align circuit sets	10	4	$ 20.00	$ 13.33
cut and drill manifolds	20	2	$ 20.00	$ 13.33
fuse circuits	20	3	$ 20.00	$ 20.00
roll, wrap, stack	1	10	$ 20.00	$ 3.33
Total				$ 50.00
3. Direct Costs				$ 419.80
4. Factory Margin			100%	$ 419.80
5. Price to Contractor				$ 839.60
6. Shipping to Site	64	/truck@	$ 1,500	$ 23.44
8. Site Labor	# to do	min/ea.	$/hour	L
unpack, carry, unroll	1	40	$ 55.00	$ 36.67
place headers	1	10	$ 55.00	$ 9.17
roll and pour	1	60	$ 55.00	$ 55.00
Total				$ 100.83
10. Contractor Cost				$ 964
11. Contractor Margin			25%	$ 241
12. Total Price to Owner				$ 1,205
13. Installed Cost per Sq. Ft.				**$ 0.93**

Headers & test

$ 32.00	matl
$ 33.33	labor
$ 130.67	w/margin
$ 9.17	site labor
$ 139.83	subtotal
$ 174.79	w/site margin
$ 0.13	per sq ft

Spacers, roll-out, pour

$ -	matl
$ 13.33	labor
$ 26.67	w/margin
$ 91.67	site labor &matls
$ 118.33	subtotal
$ 147.92	w/site margin
$ 0.12	per sq ft

Shipping

$ 5.00	matl
$ 3.33	labor
$ 16.67	w/margin
$ 23.44	site labor
$ 40.10	subtotal
$ 50.13	w/site margin
$ 0.04	per sq ft

Tubing matls

$ 332.80	matl
$ 665.60	w/margin
$ 665.60	subtotal
$ 832.00	w/site margin
$ 0.64	per sq ft
$ 0.94	Total

Appendix B

Savings Calculations for Benefits to California

Demand:	yrs		15
	W/sqft		1.7
	sqf/yr		30,000,000
	Watts saved		765,000,000
	kW saved		**765,000**
Energy	yrs		15
	kWh/sqft-yr		2.8
	sqft/yr		30,000,000
	total sqft		450,000,000
		Year	kWh saved
		1	84,000,000
		2	168,000,000
		3	252,000,000
		4	336,000,000
		5	420,000,000
		6	504,000,000
		7	588,000,000
		8	672,000,000
		9	756,000,000
		10	840,000,000
		11	924,000,000
		12	1,008,000,000
		13	1,092,000,000
		14	1,176,000,000
		15	1,260,000,000
	kWh saved		**10,080,000,000**
Avg residential kWh/yr			7,000
/houses/year			1,440,000
	$/kWh		0.15
	Cost saving		**$ 1,512,000,000**
GHG Emissions: #/1000 kWh			
Edison			798
SDGE			949
PGE			553
SMUD			853
LADWP			1349
Total			4502
Average			900.4
Total # saved			9,076,032,000
Tons saved			**4,538,016**