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Community Adoption of Appropriate Technology Through Persuasive Communication Design

Aaron Richard Brown

University of Colorado at Boulder, abrow118@msudenver.edu

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Community Adoption of Appropriate Technology through Persuasive Communication Design

By

Aaron Brown

B.S., California State University Chico, 2001

M.S., University of Colorado Boulder, 2004

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Dr. Bernard Amadei, Committee Chair
University of Colorado, Boulder

Committee Members:

Dr. Paul Chinowski
University of Colorado, Boulder

Dr. Sarah Revi Sterling
University of Colorado, Boulder

Dr. Michael Brandemuehl
University of Colorado, Boulder

Dr Patrick Heidkamp
Southern Connecticut State University

Date _____

*The final copy of this thesis has been examined by the signatories, and we
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Brown, Aaron (Ph.D., Department of Civil, Environmental, and Architectural Engineering)

Community Adoption of Appropriate Technology through Persuasive Communication Design

Thesis directed by Professor Bernard Amadei

This dissertation examines the introduction of a new appropriate technology (AT) into a marginalized community through application of a specific behavior change communication model (BCC). For this research, the soda can solar furnace was introduced into the Hispanic community of the Westwood neighborhood in Denver using a developed BCC strategy.

The population of Westwood is predominantly Hispanic and overwhelmingly poor. The majority of its residents live at or below the poverty level. As such, they were in great need of assistance in paying their heating bills in the winter months. This study was born out of both a desire to provide this marginalized community with assistance and to ensure that the support provided would not fail once the active involvement stage had ended. Moreover, the goal of this study was to determine the best way to encourage the community in assimilating the new technology into its daily life.

Due to the need for assistance during cold winter months, the soda can solar furnace was selected as the appropriate technology (AT) to introduce to the community. This furnace is built with an array of aluminum cans – which are readily available as recycled material – that act as passages for air. As the air passes through, solar energy heats the air

and the warmer air is then circulated into the home. This air supplements the heat provided by the home's existing heating system, resulting in lower heating bills for the user.

A successful project does not end with the installation of a technology, however. In order to ensure the ongoing use and maintenance of these soda can solar furnaces beyond their initial installation, the members of the community had to be convinced of the merit and utility of these devices. That is where the BCC plan came in. Behavior change communication (BCC) is the strategic use of psychology to promote positive outcomes, based on proven theories and models of pattern change.

The relationship between behavior change communication and appropriate technology selection is a key component of this research. The BCC model used in this study is strongly influenced by the Fogg (1) methodology of persuasive psychology, which relies on three pillars: motivation, accessibility and trigger. The first two pillars align with appropriate technology principles (as described in section 4.3); therefore, in this study the selection of an appropriate technology is a critical part of the BCC model formulation. This study illustrates the effectiveness of the behavioral change communication model specifically applied to a community based on a thorough community appraisal and deliberate selection of the appropriate technology. For this research, the behavioral change communication model is assessed for effectiveness through a mixed methods qualitative collection and analysis.

This dissertation report describes the BCC model, the AT selection process, the various attributes of the community appraisal performed and the outcomes measured in the community. The results section illustrates the effectiveness of the BCC plan to implement the soda can solar furnace in the target community.

Dedication

For my Mother, Jayne Reano. April 8th 1952- May 17th 2012.

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Introduction

OVERVIEW OF THE ISSUE

Living in poverty affects people in multiple interrelated and systemic ways. This burden often denies people access to education, healthcare, adequate nutrition, and an opportunity to ascend from their current condition. There is a direct correlation between poverty level and predicted lifespan, health risks and quality of life, and the cycle is self-perpetuating for people in communities without the resources to overcome these difficulties. Development policy aimed at helping to alleviate the problem has shown mixed results (1). Even the best intentions and appropriate technologies, when not properly implemented, have often failed (1,2). Illustrating this trend, a USAID study reviewed 212 global projects, and found only 11 percent showed continuing effectiveness after the withdrawal of aid (2). This trend also pervades in local domestic projects where the success rates are similarly limited (3).

To improve the outcomes of interventions, it is imperative to consider the implementation approach. This is one of the challenges facing development strategists today. In “Development Anthropology” (4), Nolan discusses the importance of integrating culture into the context of an intervention. First, Nolan suggests, “The current paradigm (of development) is ethnocentric, largely unsuited to the realities of the developing world.” (p. 268). Some development implementation plans are too limited in their vision and not sensitive enough to the cultural differences of the communities they are meant to serve. Nolan goes on to point out that “[t]he paradigm assumes that technical advances are essentially the same thing as progress, that growth can continue indefinitely and that any problems that we may encounter along the way can essentially be solved with technology.”

Simply offering a new technology will not solve a problem if the technology cannot be used, understood, or maintained by the population it is meant to serve. This is why so many projects fail.

Nolan suggests that “our attempts to solve poverty have been hampered by an approach that is too culturally specific and does not encourage us to learn about— and use— cultural diversity.” Moreover, in “The White Man’s Burden: Why the West’s Efforts to Aid the Rest Have Done So Much Ill and So Little Good” (5), Easterly documents many failed attempts at aid efforts, points out the lessons to be learned and suggests that an incentive-based development plan has been shown to produce the best outcomes.

An “incentive” can be nebulous to define or determine and is often specific to the targeted community. Therefore, this study suggests that the formulation of a community appropriate behavior change communication model can be a critical factor in a project’s success. Also, this study proposes that the appropriateness of the BCC model often relies on the appropriateness of the technology chosen; however, there is a notable absence in the relevant literature demonstrating a correlation between forming a BCC plan and the selection of appropriate technology for marginalized communities.

The Community

Westwood is a neighborhood located in the western edges of Denver. It is a community living under marginalized conditions (as described in 4.1) which includes low per capita income, lack of access to good nutrition, language barriers, poorly built and maintained infrastructure, lack of educational attainment and poor housing stock among its issues. The Hispanic contingent of the Westwood community was chosen as the target population for implementation of this BCC model. This selection was made for several reasons including: meeting the metrics for marginalization (section 4.1), the accessibility to incorporation of the promatora model (section 4.1.1), and its established relationship with ReVision , a local NGO doing work in the Westwood community. The ReVision organization has not only worked closely with this particular community on other initiatives, but also was already partnered with the University of Colorado engineering program at the onset of this project. These attributes provided a convenient connection and relevant opportunity for this case study.

MOTIVATION

As alluded to above, there pervades a universally frustrating problem of failed attempts to implement technology interventions in communities where generational and systemic poverty persists. Despite best intentions, the failure rate for interventions in marginalized communities is very high (1,2,3,4). This study is aimed at creating a possible solution to that dilemma through an integrated approach.

More specifically, this dissertation research focuses on the development of a community specific strategy to encourage the acceptance of a technology intervention which could help the people of Westwood. Here, cold winters and poor housing stock conspire to produce high heating bills. This situation sometimes forces residents to choose between heat or food. The motivation and goal underlying this endeavor was to determine whether the selected methodology (described in Chapter 4) would prove effective in producing the hoped-for outcome: the long-term adoption and use of the soda can solar furnaces by the Westwood community.

CONTRIBUTION

A thorough review of development strategy literature (Chapter 2) identified research related to the use of behavioral change communication in health practices, and research using technology to help formulate a BCC plan. Numerous studies have also been published about the relationship between culture and habit. However, this author did not discover any prior research that utilizes community appraisal and appropriate technology selection as components of the BCC model, as proposed here. The significance of this study is that it links a community appraisal methodology with a specific AT selection process to develop a behavioral change communication model. Because this is a unique approach, it provides a distinct new addition to the literature on development strategy. Furthermore, the research reported here contributes more than just an addition to the literature collection. This case study also provided a measure for the effectiveness of the AT selection methodology, furthering the work started by Michael Bauer who was a collaborator on the Westwood community project. Perhaps most importantly, the work described here

contributed to improving the well-being of the Westwood community. The households that adopted the solar furnace have reported significant monthly savings which improves their options in a host of areas (i.e. nutrition, education options, health, and resiliency).

OVERVIEW OF APPROACH

As aforementioned, the developed behavior change communication model (BCC) presented encourages community adoption of a technology. This BCC plan relied on appropriate technology (AT) selection based on the input from people in the community. After an in-depth community appraisal and the application of an AT selection tool (developed in tandem with this study), a solar heater made of aluminum cans (described in detail in Appendix I) was introduced into the neighborhood. The selection of the soda can solar furnace as an appropriate technology was critical to the development of the unique BCC model that this dissertation puts forth. Moreover, the work described here can be explained as a case study for a new BCC approach that is built on the integration of four methods in the areas of persuasive psychology, appropriate technology and community assessment.

Behavior change communication (BCC) is a tool that can be used to promote positive adjustments to habitual patterns of action. It is based on proven theories and models of behavior change developed through research. The BCC model used is strongly influenced by the Fogg (1) methodology of persuasive psychology, which relies on three pillars: motivation, accessibility and trigger. As is described in the methodology chapter of this paper (Chapter 4), the first two pillars of Fogg's model are congruent with appropriate

technology principles; therefore, in this study, the selection of an appropriate technology acts as a critical influence on the development of the BCC model.

For this study the AT selection borrows from a methodology developed by Michael Bauer in tandem with this project. Bauer created an appropriate technology selection tool, which was also tested in Westwood in conjunction with this study (section 6.2). This tool was branded the “Appropriate Technology Assessment Tool” (ATAT) and it produces an *index of appropriateness* based on a variety of weighted contributions.

The implemented plan for BCC relies on an understanding of the targeted community. Therefore, development of the BCC plan encouraged participation of stakeholder groups and community members throughout the process. Appropriateness of the technology intervention was also determined within the context of the community’s culture and needs. The intervention plan also included post project monitoring and evaluation as well as an exit strategy intended to leave the project in the control and ownership of an invested community. The effectiveness of the BCC plan was assessed through a mixed-methods approach which included behavior surveys (conducted at pre-implementation, at two intermediate points during the process, and at post-implementation) as well as surveys to indicate community adoption (i.e., how many units are in use in the community at the exit time, how many people are present at workshops). This dissertation report describes the BCC model, the AT selection process, the various attributes of the community appraisal performed and the outcomes measured in the community. The results obtained illustrate the effectiveness of the BCC plan to implement the soda can solar furnace in the target community.

ORGANIZATION OF DISSERTATION

This dissertation represents the development of a process which integrates several methodologies from different fields of study for the purpose of improving the effectiveness of introducing new technology to the community of Westwood. Pulling together different ideas from multiple fields is an organizational challenge and, as such, the order in which the components are presented is important. This report is structured in an intentional way which begins with a description of the problem on a macro-scale, acknowledging what efforts have been made in the past to address the problem and how that leads to the current body of work being presented. The community of Westwood is very obviously a critical part of the work that was done and so they are described next. To identify and address the problems in the community, a methodology was developed which assimilates aspects from previous works done. This is described in the third section followed by discussion of the application of this methodology and the data that was collected. Specifically, this information is broken into several parts and follows a specific order as described here.

Part 1 (Sections 1 & 2) describes the problem and related literature

Part 2 (Section 4.1) describes the community of Westwood, Denver

Part 3 describes the methodology for the 3 components of this study:

- Community Appraisal (Section 4).
- AT Selection (Section 5.2)
- BCC Plan (Section 5.3)

Part 4 (Section 7) describes the data/results of acquired from the application of the previously discussed methodology

Part 5 (Sections 8 and 9) gives concluding remarks

2 - Related Literature

This dissertation presents a case study of a methodology which links a specific behavior change communication strategy with appropriate technology selection and intervention for a particular community. This methodology, or model, is built on the foundation of a functional understanding of the community obtained through a comprehensive appraisal. This study assesses the effectiveness of this BCC model in the adoption of new technology by a marginalized community. While this study is specific to the Hispanic community of Westwood in Denver, Colorado, investigation continues which will create a transferable framework to guide sound development practices.

Theoretical models in the literature of development work often draw upon studies of fieldwork (e.g. UN and NGO publications). This pursuit has resulted in a conglomeration of techniques and theory that sometimes are not aligned.

In “Methods of Development Work and Research: A Guide for Practitioners” (6), Mikkelsen offers an alternative approach, defining her work as more of “a contribution to a debate on appropriate methods for different types of development work.” The use of the word “debate” by Mikkelsen seems fitting as there is not always consensus on the best techniques for development practices; however, she is quick to point out there exists a common core of applied terminology that prevails through the literature of development research. Terms such as sustainability, good governance, feasibility, dialogue, and participation have widespread use in the literature and link many of the framework techniques. One common theme that occurs regularly in the literature is the concept of participatory research. This unifying concept can be described most simply as “people deciding over their own lives” (Mikkelsen).

Burkey (7) goes so far as to state that his framework for rural development “stems from the conviction that self-reliant participatory development is the only foundation for true development: human, economic, political and social.” Even though the literature generally agrees that good practices include a participatory element, evidence suggests this methodology is greatly strengthened with a systematic community appraisal. In assessing the effectiveness of PRA (Participatory Rural Appraisal) methods, the World Bank found indication that “[a]doption of a participatory agenda while promoting consultation and highlighting process concerns, has for the most part neglected the need for accompanying social and structural analysis.” This has contributed to less effective interventions (3). A participatory methodology with a robust community analysis thus seems to be a strong starting point for an effective intervention. Other studies have supported this observation (8, 9, 10, 11).

For this dissertation study, a thorough community appraisal was conducted to help develop an understanding of the community dynamic from a social and structural perspective. This appraisal followed the popular CARE (12) framework. This framework is helpful for laying a foundation that can support determination of an appropriate intervention and designing a behavior change communication plan that fits the community specific scenario.

In the nearly 70 years since the creation of the World Bank, and with the broad growth of planned development, one would think that a clear picture of what works and what does not work would exist; that a roadmap of development methodology might have been created. Instead, there appears to be a lack of consensus as to the best practices in the field. Furthermore, using a strategy that is successful for one community often fails in

another (13, 14, 15, 16). In the development world, despite good intent, there is a history of unsuccessful interventions. Many failed attempts at aid efforts and lessons learned have been documented (17).

In “Poor Economics” (18), Bannerjee & Duflo discuss the prevalence of failed interventions which initially seem promising in theory but are unsuccessful in implementation as communities choose not to adapt to them. Both Easterly’s and Bannerjee & Duflo’s work document a failure to ascertain in advance community participation and buy-in, which leads to unsuccessful projects. Many plans assume that community participation will flow naturally from education and awareness coupled with affordability or accessibility. However, this has not been shown to be true. In “Poor Economics” (18) there are many examples where populations do not adopt new technologies and/or ways of doing things despite a clear understanding of the benefits and despite the affordable nature of the behavior change. For example, on page 48, Banerjee & Duflo state, “There is one wrinkle (to the theory) ...that poor people are stuck in a health-based poverty trap and that money can get them out of it. Some of these technologies are so cheap that everyone, even the very poor, should be able to afford them. Breast-feeding, for example, costs nothing at all. And yet fewer than 40 percent of the world’s infants are breast-fed exclusively for six months, as the WHO recommends...” They go on to observe:

[A]nother good example is water:...a Zambian family of six can buy enough chlorine bleach to purify their entire drinking water intake for a year: ...a bottle of chlorine costs \$.018 USD PPP and lasts a month. This can reduce diarrhea in young children by up to 48%. People in Zambia know about the benefits of chlorine. Indeed, when asked to name something that cleans drinking water, 98 percent mention Chlorine...yet only 10% of the population actually use bleach to treat their water.”

One common theme that pervades the literature is that incentive based development plans tend to yield the best outcome. “Incentive based” relates to behavioral change communication (BCC) strategy, and the prevalence of incorporating incentives into development planning points to the important role BCC might play in development work. To this point, it is central to recognize which incentives work and which fail.

The literature contains many studies of failed interventions and a consistent theme of a search for a successful incentive-based intervention framework (6,8,9,10,11,12,13,14,15,16). It is in this context of repeated, paradoxical failure that this study was conceived.

2.1 - Persuasive Psychology

There is relevant research in the field of psychology and how it relates to economic decisions which may help explain why some communities elect not to implement solutions that are seemingly accessible and affordable. Dick Thaler and Cass Sunstein are professors of Behavioral Science and Economics at the University of Chicago. Some of their work on behavioral change asks why people don't make more sensible decisions for their health (19). Their research suggests that peoples' views about the present differ greatly from how they view the future. According to this theory, decision making in the present relies more on impulsivity and immediate satisfaction. Despite understanding that certain behavior is (or is not) beneficial in the long term, peoples' impulsive nature and tendency to seek immediate pleasure and rewards generally drives their behavior. Perhaps this explains in part why, so frequently, people don't do what is best for them. For example, not everyone flosses their teeth even though it's proven to be effective, it's cheap, and it's fairly easy. As another example, not everyone exercises regularly even though there are clear long term

benefits. These behaviors inarguably have positive long term results but in the immediate moment, they present some discomfort or require some effort. Similarly, it's reasonable to deduce the possibility that for the people in Zambia discussed previously there is an upfront and immediate inconvenience which drives their decision not to use chlorine to purify their drinking water despite knowing its benefits. Possible barriers might be cost, travel, time, equipment necessary to correctly use the bleach (measuring devices etc.), culture and tradition, and distrust of foreign aid, among others.

Human behavior is often perceived to be a complicated process that is hard to predict and difficult to change. Fishbein and Ajzen (20) argue that this is not the case, that, “it may appear...that human social behavior is extremely complex, with each behavior being determined by a large number of unique factors...By way of contrast we argue that human social behavior is really not that complicated, that people approach different kinds of behaviors in much the same way, and that the same limited set of constructs can be applied to predict any behavior of interest.”

Many behavior change models can be related to the Trans-theoretical Model of Behavior Change (also known as Stages of Change) developed by Prochaska (21). This theory shares the assumption that Taylor and Francis made asserting that human social behavior is universally uncomplicated and that a framework can be applied to human social behavior to encourage habit change.

In the handbook of community-lead total sanitation (CLTS) (22) Kar and Chambers set forth an approach for encouraging communities to adopt sanitation practices, specifically with the goal of ending open defecation through a systematic “triggering” method. As with other handbooks on development practices, this part of the literature lays

out a framework for participatory behavior change. Additionally, this approach relies on a community appraisal to help identify applicability of the intervention for the community and includes guidelines to identify a community as a good candidate for a proposed intervention. While the CLTS is very specific to sanitation, its methodology has similarities to this dissertation approach and, as many behavior change plans do, can relate to Prochaska's Stages of Change, including introduction of awareness in a community and triggering change through motivation. For these reasons, the CLTS approach is relevant to this dissertation. However, the methodology of this dissertation goes beyond Prochaska's model in relying on an approach which relates behavior change to outcomes and demonstrates how this could be applied to development initiatives.

While it has not been applied before in this arena, the work B.J Fogg has been doing in BCC at the Persuasive Technology Lab at Stanford is particularly relevant to this study. The Fogg model focusses on "using technology to change behaviors in positive ways." Fogg's behavioral model represents an interesting parallel to what Thaler and Sunstein proposed. As discussed, Thaler and Sunstein state that immediate results and positive feedback in behavior outweigh long term planning and payback. They propose that behavior change relies on a convergence of motivation, ability, and trigger. Designing a BCC model to accompany an intervention by this method means that one must identify the motivators and abilities of a community as well as the triggers. Fogg developed the "Behavior Wizard" method (23) to categorize "behavior change targets into one of 15 types. Later stages focus on triggers for the target behaviors and on relevant theories and techniques. This new approach to persuasive design, as well as the terminology we propose, can lead to insights into the patterns of behavior change."

Fogg's work is interesting because it attempts to produce an output template based on a series of inputs to help formulate a BCC model. As noted earlier, cookie cutter approaches to development have not worked well in the past. While on the surface Fogg's Behavior Wizard appears to adhere to the cookie cutter tradition through lack of context specific inputs, one can argue that it contains enough qualitative variables to take into account individual community identity and therefore can be a useful tool, provided one uses the output as a set of parameters to help guide a BCC plan and not as an absolute solution. Communities are not machines where a method applied universally will always generate the same results. In other words, what might work with one community may not work in another, and the reasons for why this is the case are often elusive and nebulous. This is why it is important to assess the appropriateness of the intervention for the individual community. This dissertation sets out to analyze and understand how, through a comprehensive assessment of the community and its members, these psychological methods can assist development professionals in maximizing the adoption of solutions to community problems.

2.2- Appropriate Technology

Appropriate Technology (AT) refers to the selection of solutions that fit both a community's needs and capacity. Originally coined "intermediate technology" by the economist Schumacher (24) the term "Appropriate Technology" is more commonly used today and refers to "small-scale, decentralized, labor-intensive, energy-efficient, environmentally sound, and locally controlled" (25) technology use. Appropriate Technology interventions have been used for a range of initiatives. Most commonly this

application has been for the purpose of community empowerment and poverty reduction (26,27). There is a prevalence of material in the literature intended to guide the user in the selection and application of appropriate technology (28,29,30) and a unifying theme is that, as with development strategy, appropriate technology is context specific.

For this study, the ATAT appropriate technology tool developed by Michael Bauer for his Master's Thesis (31) was applied. This tool relied on a meta-analysis of the literature related to appropriate technology. From a review of 53 papers, this meta-analysis observed the frequency of occurrence of different terms found throughout the literature and used that measure to rank the importance of those terms to AT selection. This ranking was ultimately applied (section 4.2) to the developed ATAT tool's parameters of appropriate technology selection.

As in the community development framework literature, in the arena of appropriate technology, community input is a prevalent factor. More correctly stated, "appropriateness" of a technology is defined by the community in which that technology is implemented and therefore varies by community. Consequently, any definition of AT that ignores local input is insufficient and cannot be categorized as appropriate (32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59, 60,61,62,63,64). Due to the context specific nature, appropriateness is somewhat difficult to define. Murphy et al. (2009) and Ranis (56) argue that the context specific nature is one of the obstacles in pinpointing the "appropriateness" of a technology. Perhaps because of this difficulty, there has not been a concerted effort "to evaluate the technologies at the user/field level" (45). For example, Kalbar et al. (35) note the need for a "decision-support tool" for choosing wastewater treatment technologies (p. 158). This need applies across a

range of interventions and was one of the motivators for Bauer to develop the ATAT tool. Ratnam (55) implores agencies to devise a “mechanism for technology assessment” (p. 246), and Sianipar et al. (58 or 59) suggests that an AT “selection tool must be utilized that’s applicable to all scenarios” (p. 1013), and called for further research in a “practical area with detailed issues of social, technical, and economic variables in (the’) local area” (p. 1015). Figure 1, below, illustrates the results of the literature review that this study relied upon.

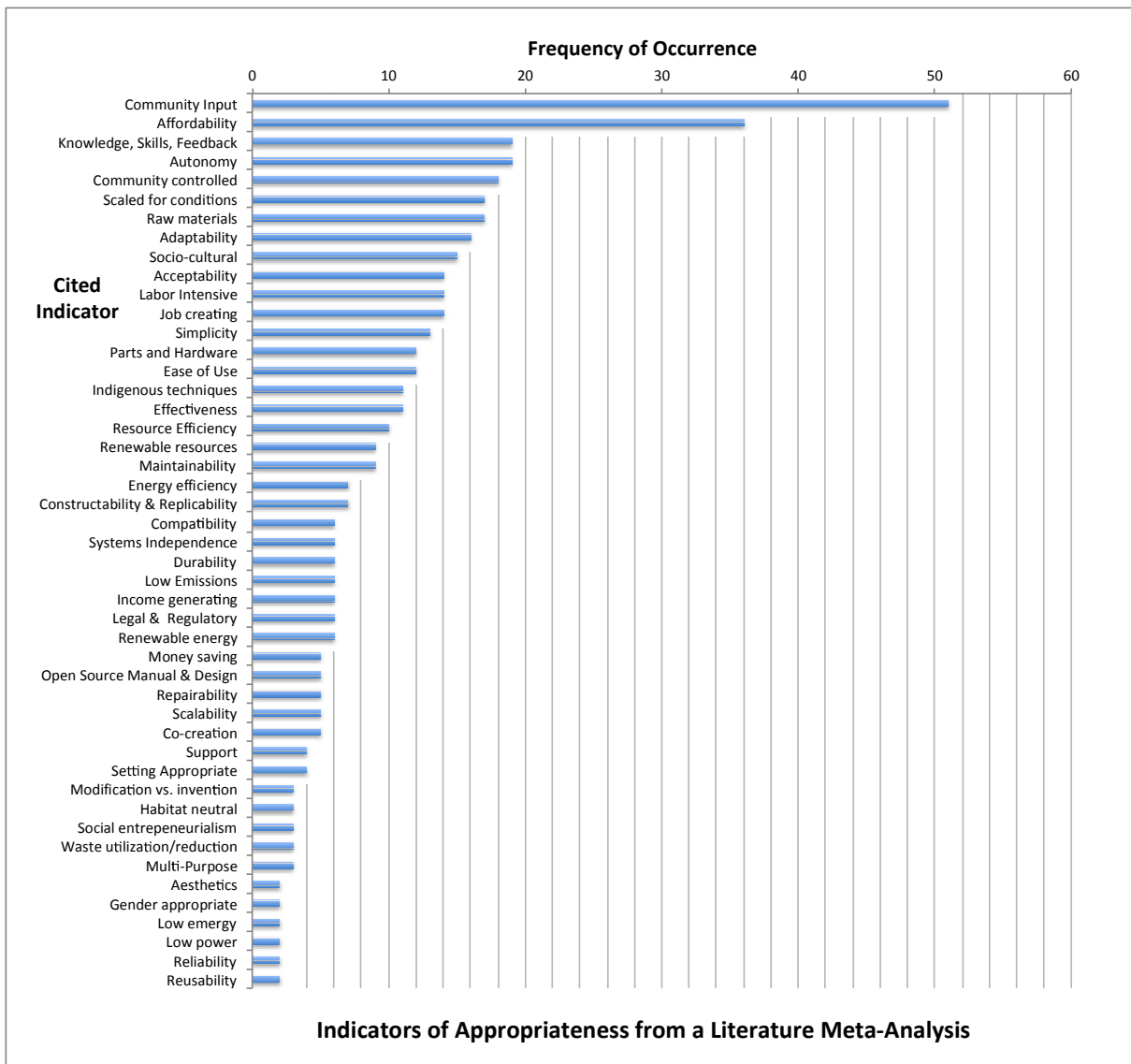


Fig. 1. Results of literature meta-analysis: appropriateness indicators vs. occurrence

(*source Bauer).

As evident throughout this literature review, previous research and discussion has been conducted around framework and AT selection. However, while there was previous research identified in the arena of BCC and health practices (65, 66), using technology to help formulate a BCC plan, and cultural differences and their relationship to habits, there was a general void of research on AT selection as a component of BCC planning. This

study's relevance, then, is to provide a case example of applying appropriate technology selection with behavioral change communication modeling based on a thorough community appraisal to provide an important addition to the literature on development strategy and possibly prove to be a catalyst for improved effectiveness of technology intervention plans in other scenarios.

3 – Primary Questions

Once a comprehensive community appraisal has been conducted, several questions arise: What is an appropriate technology to implement for this community's needs? How is that appropriateness quantified? What is the strategy for developing an appropriate BCC model specific to the culture of the community and the technology being introduced? What is the effectiveness of this methodology towards the encouragement of the community to adopt the technology?

4 - Community Appraisal

Some of the best poverty-alleviating technologies have failed due to improper implementation. For example, a high percentage of newly-installed water projects in the developing world fail within the first six months of use (14). Empirical results imply that simply providing a community with money and technology, though perhaps necessary, is not sufficient for lasting poverty reduction. However, if a project manager performs due diligence during the community appraisal, and starts with the assumption that community

members are valuable, invested stakeholders in the process, then they can reap more consistent successes with lasting results (15). Such a model necessarily includes stakeholder input and assumes that the dynamics of local culture are integral in all phases of the project: community appraisal, project design, planning, implementation, monitoring and evaluation. Within this model, planners devise an exit strategy wherein the intervention project flows naturally toward the control and ownership of an invested community. Post-study workshops are modeled after a “train the trainers” method, where participants will be encouraged to teach others these techniques, furthering the penetration of this technology into the community.

Between Sept 2012 and May 2013 a thorough community assessment was made following the CARE (12) model. This methodology is described in more detail in chapter 5. The following community appraisal focuses on highlighting the findings from the primary and secondary data collection and ends by summarizing the main problems identified in the community of Westwood.

4.1 - Operating Environment

This appraisal of Westwood relies on an understanding of the context, or operating environment, of the community. The aim of the appraisal is to paint a broad picture of the community by looking at the people, environment, infrastructure, economy, and institutions.

The Westwood neighborhood is 1.53 square miles with a population of 15,486 (City-Data. Com 2012) in southwest Denver, which is bordered by West Alameda Avenue, West Mississippi Avenue, South Federal Boulevard, and South Sheridan Boulevard (91) (see map, Figure 2, below).



Fig 2: Map of Westwood - Source: Piton Foundation

There are 4,340 homes in Westwood (91), and the average home has 3.56 persons. Most of these homes are occupied by families and 54% of the homes are occupied by families with children (City-Date.com 2012). Figure 3 below illustrates demographics with respect to age in Westwood by percentage of the total population (source Piton Foundation 2011):

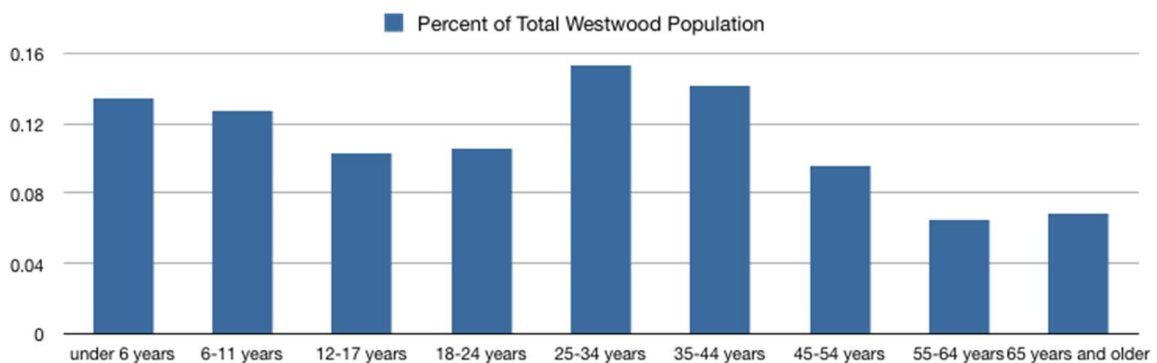


Figure 3: Population Breakdown by Age 2010

In Westwood, children make up a large part of the fabric of the community. 37% of the population is under the age of 18. Only 7% of the population is classified as elderly (65 or older). The median age for Westwood is 25.9 years old (City-Date.com). In addition, teenage pregnancy is prevalent with 18.5% reported rate for mothers under the age of 19.

The ethnic breakdown of this community illustrates its strong Latino influence. Eighty-three percent of the population is reported as Latino while 8% are Non-Latino White, 3% are African-American or African-Somali, 2% are Native American, and 2% are Asian/Pacific Islander (91). Immigration has a large influence on the makeup of Westwood. 35% of people in Westwood were not born in the United States and 57% of births are to foreign-born immigrant mothers. A large portion of Westwood's population is classified as undocumented. These social factors have an impact on the opportunities of the Westwood inhabitants. In a study of the neighborhood, it was reported that many people of Westwood feel helpless because of their legal status or language barriers (Livewell Westwood 2008). These limitations were expressed as extended to driving, utilizing public resources and reporting crimes.

Moreover, the people of Westwood are at a disadvantage because they live in poverty. For 2012 (when this appraisal was conducted), the US Department of Housing and Human Services determined that for a household of four persons the threshold of poverty was \$23,050 per year (US Department of Health and Human Services 2012). According to the US Census of 2010, 37% of Westwood households live in poverty. This is a stark deviation from the greater Denver area which is reported at a 14.8% poverty rate (US Census 2011). This represents a 67% greater rate of household poverty (Ibid.). Lack

of access to adequate child care facilities contributes to parents' staying at home instead of working, which only compounds the problem of poverty (Livewell Westwood 2012).

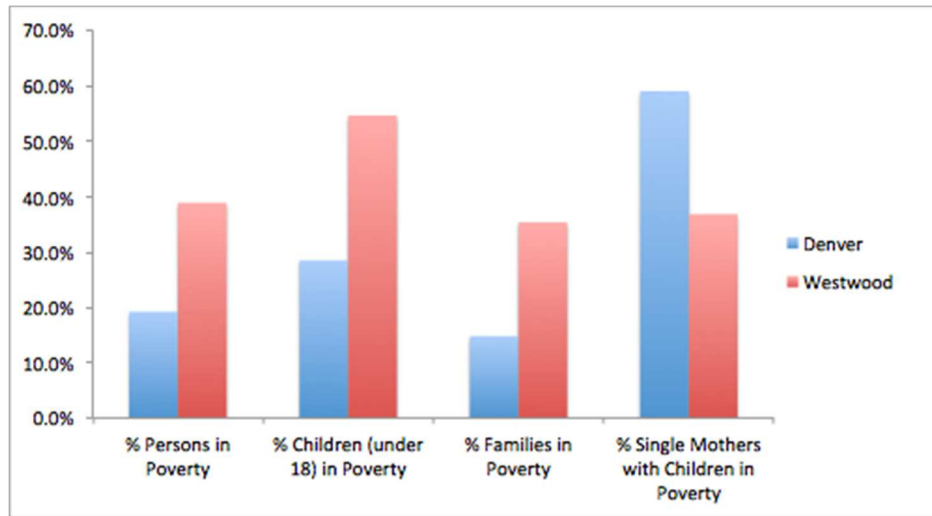


Figure 4: Impoverished Populations in Westwood vs. Denver 2006-2010 (US CENSUS)

As an urban neighborhood, the environment and infrastructure of Westwood are less than ideal. Safety has been reported as a major concern. Infrastructure complaints have included poor or nonexistent sidewalks, broken street lighting, excessive graffiti, and litter (ReVision International; Semillas De Esperanza). In terms of institutional safety, although Westwood's crime rate is slightly lower than the crime rate in nearby areas of Denver, the percentage of burglaries and violent crimes are both higher in Westwood than in Denver as a whole (Piton Foundation). Another critical infrastructure issue in this community is aging housing, because the majority of homes in the community were built in the 1950's (City-Data). Houses that have been poorly maintained also are equipped with inadequate insulation and windows, creating higher heating expenses than more efficient homes.



Photo 1: The poor conditions of the Westwood built environment

6.2 - Needs Assessment

This needs assessment summarizes the data collected throughout the appraisal process from September 2012 through December 2012. Table 1 below highlights the various sources of data gathered and their sources. This table illustrates the secondary data set focused on demographic information while the primary data gave more informative and specific context. Additionally, data was collected to investigate other areas including gender, rights, and capacity and vulnerability. This section ends with a table ranking the discovered problems in order of most importance.

4.2.1 - Summary of Data Collection

Main Data Sources	Type (Primary/Secondary)	Types of Information Gathered							
		Community Demographic Data	General Community Needs or Problems	Specific Community Food Problems	Specific Community Housing Problems	Information to help partner with Re:Vision	Community Strengths	How to Connect to Community	Additional Resources
First meeting at Re:Vision	1	X	X	X	X	X	X	X	X
Re:Vision's Files or Data	1	X	X	X		X			
Promotora Meeting	1		X	X	X	X	X	X	
Re:Vision Staff Meetings	1	X	X	X	X	X	X	X	X
Harvest Festival	1	X	X	X		X	X	X	X
Home Visits	1		X	X	X		X	X	
Other Garden Projects ⁷	2					X			X
LiveWell Westwood's Data	2	X	X	X	X		X		X
Re:Vision's Website	2	X		X		X			X
City Data's Website	2	X	X						
Piton Foundation's Website	2	X	X						
Online Census Data	2	X							

Table 1

For primary data collection, information was gathered through an initial meeting with ReVision International, a non-governmental organization (NGO) working in the Westwood community for many years. ReVision presented what they felt were the largest issues facing the Westwood community, based upon their years of experience: (1) access to local, healthy, and nutritious food; (2) safe pedestrian passage through the neighborhood for residents who cannot drive (for various reasons noted above; see also 95, 96); and (3) adequate, affordable heating in the homes. ReVision had attempted to address some of these issues through their ReFarm program to build backyard gardens and through a program called ReBuild which assists homeowners to repair walls, windows and doors. Yet, it was apparent that high heating bills in winter was a cause of stress to residents of

Westwood; that carbon monoxide leaks from old, poorly maintained furnaces were causing health issues; and that in a community lacking funds for other basic needs, investment in repairs or maintenance of the house's heating system and insulation was not going to be a priority.

4.2.2 - Summary of Household Interviews

The next step in the Westwood community appraisal was making contact with community leaders known as *promotoras*. *Promotoras* are members of the community who work for the promotion of social improvement and welfare in their neighborhoods through the dissemination of information to their neighbors. This arrangement is commonly employed in Hispanic communities where the role is often filled by women.

By partnering with ReVision's *promotoras* (Section 5.1.1), access to the community was enabled and ten different Westwood households were visited. These visits facilitated discussion on a variety of community issues. The general course of dialogue was aimed at developing a general understanding of the community.

Questions were targeted with the goal of understanding community issues. A universal concern expressed was the condition of homes in Westwood. All ten families interviewed expressed concern about the quality of their homes and the impact that had on their monthly bills. In fact, one household stated that home improvements were a top priority, even above food. Many of the households shared that windows were a main concern. They said that their windows were leaky and that they could feel cold air coming through. The windows were described as "old, single-paned, broken, and leaky." Families also communicated concern with poor insulation.

The common motivation shared by all ten households was the high cost of energy bills. Families communicated that heating expense was something they would like to learn how to reduce. While energy kits had been distributed to some families in the past through from ReVision's ReBuild program, only two of the ten families interviewed felt that the kits had been useful. One household expressed that they did not understand the energy kit and did not know how to use it.

Overall, the comments regarding home improvement during these interviews were consistent. All households had commonality in their concerns about energy use, heating and the poor condition of their homes. This shared concern helped rate the appropriateness of the chosen intervention for this research by helping direct the choice of technology intervention to align with the community's expressed concerns and needs.

Additional data collected provided an understanding about the roles of gender in the Latino community of Westwood. The community of Westwood is comprised of 52% males and 48% females where the majority of residents are between the ages of 21 and 64 (97). The average family of Westwood consists of 4 people. Both male and female populations work to support their families, leaving little time to invest in community activities. Westwood residents who reported occupational information tend to work largely in service and labor sectors. Furthermore, these two categories of work are largely stratified by gender as shown in Table 2 below (source Piton Foundation).

Occupation	Men		Women	
	Westwood (%)	Denver (%)	Westwood (%)	Denver (%)
1 Management (not farming)	2.7	9.6	2.8	9.2
2 Service	21.1	13.6	33.1	17.2
3 Sales and Office	11.8	19.8	36.6	34.3
4 Construction, Extraction, Maintenance	37.1	17.4	1.4	1
5 Production	9.6	6.4	9.4	3.8
6 Transportation and Material Moving	14.1	18.1	3	1.8
7 Business and Financial Operations	0	6.4	2.3	6.4
8 Computers and Mathematical	0	2.6	1.3	2.6
9 Community and Social Services	0	2.3	1.3	2.3
10 Legal	0	2.2	1.2	2.2
11 Education, Training, Library	0	7.3	4.3	7.3
Arts, Design, Entertainment, Sports, Media	0	3.4	1.3	3.4
13 Healthcare and Technical	0	6.3	1.4	6.3

Table 2 - Occupations Held in Westwood and Denver by Gender, 2008

4.2.3 - Capacity & Vulnerability Analysis

From the data collection, the capacities and vulnerabilities of the Westwood community were determined. The primary capacities that were considered to be important to the community project are those displayed by the partnering NGO, ReVision, such as earned community trust, a strong *promotora* partnership, and their ability to build the sense of community in Westwood. ReVision’s *promotora* model is a powerful tool they can use and has had good success in reaching community members in their other programs, even those of a distinct culture—including the Somali Bantu community.

While the residents of Westwood have low economic capacity, ReVision has seen that the community is comprised of many hard workers who are willing to learn. This capacity will be very important in any type of project as community members can learn how to complete projects and take ownership of them fairly quickly.

Research revealed that the community and ReVision also have vulnerabilities. Westwood is a low-income community in need of more well-paying jobs. Residents do

not have a lot of disposable income as evidenced by their need for local and affordable produce. Many residents have limited education, speak limited English, and are members of various minority ethnic groups, making them vulnerable to societal demands and changes. Being aware of these vulnerabilities is important as they can greatly impact the types of projects that will or will not be successful in the community. ReVision itself is also not immune to vulnerability. Their sustained community presence is key to success in a project such as the implementation of the solar furnace, but they are hampered by lack of funding, shortage of staff, and lack of sufficient resources which requires them to split their focus between both community projects and efforts to sustain the organization long term, such as grant writing.

Women are socially influential members of the Westwood community. Some of the women of Westwood have formed a strong social network through the *Promotora* Model (section 4.1.1), empowering residents and promoting positive community relations. Women in Westwood play a large role in the transformative changes occurring through ReVision's garden program and, of the 13 *promotoras* working with ReVision, 12 are women. Additionally, Westwood Unidos is a strong community group in the neighborhood that encourages positive growth for the community. This group is also comprised primarily of females. It seems evident that women are the primary advocates for positive change within the community of Westwood.

4.3 - Problem Ranking Matrix

The following table ranks Westwood’s needs based on perceptions gained after data collection. The top needs are those of highest concern to residents, *promotoras*, ReVision staff, etc. High-ranking needs such as jobs, decreased violence, and stronger educational institutions may be indirectly influenced by an infrastructure project; however, the fourth and fifth concerns, poor housing stock and poor food options, are needs that seemed more appropriate for a study of this scope and nature.

Rank	Community Needs	Comment
1	Economic needs (jobs and income)	Institutional concern/not directly addressable by this study
2	Violence or negative influencers (Gangs, drugs, alcohol, pornography, robberies)	Institutional concern better addressed by politicians and law enforcement, although could be indirectly influenced by a built environment project
3	Educational needs (better schools for children, more education for adults including about good food)	Institutional concern which cannot directly be addressed by this study topic
4	Poor housing stock (Windows, insulation, safety, expense of repairs)	Relevant to this study and one of the issues to compare in AT Matrix
5	Poor food options (No local grocery stores, expensive healthy food, limited space or time to garden)	Relevant to this study (there are technology solutions to help improve growing season for example) and one of the issues to compare in AT Matrix
6	Lack of sense of community (trash on streets, graffiti, abandoned buildings, stray dogs)	Institutional concern better addressed by politicians and law enforcement, although could be indirectly influenced by a built environment project
7	Health concerns (diabetes, high blood pressure, lack of insurance or adequate care)	Can be indirectly addressed through improved food options, increased income, or improved safety of homes

Table 3

4.4 - Casual Analysis

Based on this in-depth community appraisal, and after considering various options for the focus of the study, it was determined that the most appropriate issue to address for this study was the financial burden of high energy bills on the residents of Westwood. The

choice of intervention aligns with the strong commonality of concerns expressed by Westwood residents and ReVision, stating that the poor housing stock is a major financial burden for families in this community. This is coupled with the fact that, of all the problems mentioned, this one seems particularly appropriate for a technology intervention.

Once the decision was made to address the problem of high energy costs, six technology solutions were chosen to consider and compare. The options were evaluated subjectively for their strengths in different categories. The alternatives reviewed were: (1) keep the traditional furnace (implying no change), (2) reduce the use of heat in the homes (implying behavior change but no technology intervention), (3) improve insulation or home efficiency, or introduce one of three types of heating/energy supplements: (4) traditional space heaters, (5) solar PV panels, and (6) the solar furnace.

4.5 - Action Identification Matrix

Problem	Solutions	Assumptions	Actions
Expensive Heating Bills: Need for more energy to heat homes	Supplemental Solar Furnace (explained further in report)	Economically feasible to build and maintain	1. Ensure that this would be a useful and needed solution
		Enough solar exposure for heating needs	2. Make measurements on sun exposure and heat output
		Locals are willing to learn a new system	3. Estimate construction costs and energy savings
		Locals would like to reduce cost of heating	4. Create training session for construction and maintenance
		Systems are simple enough to operate and maintain	5. Schedule and invite people to training
		Systems are sufficient for heating needs	6. Purchase materials for training and run training
			7. Aid community in assembly and installation
	Supplemental Solar PV Panels	Economically feasible for community	1. Ensure that this would be a useful and needed solution
		Enough solar exposure	2. Make measurements on sun exposure and heat output
		Locals are willing to learn a new system	3. Estimate construction costs and energy savings
		Simple enough to operate and maintain	4. Create awareness information
		Sufficient for heating needs	5. Aid community in assembly and installation
	Keep Traditional Furnace/No Change	No changes take place with current systems	1. No work needed
		Current systems are not working well and are expensive	
	Supplemental Space Heaters	Residents have electricity to use space heaters	1. Ensure that this would be an adequate solution
		Residents are willing to pay for additional electricity	2. Behavior change communication to inform locals
		Sufficient for heating needs	
	Reduce Heat Use	Residents could reduce costs by using less heat	1. Behavior change communication needed to inform locals
		Homes are heated with excess heat	2. Promoters or advocates needed to encourage residents
		Health concerns would not arise from less heat use	
	Improve Insulation or Efficiency	Residents do not have efficient homes or insulation	1. Ensure that this would be a useful and needed solution
		Improvements would require less heat to be needed	2. Make individual home inspections for improvements
		Locals are willing to let people work on their homes	3. Estimate construction costs and energy savings
		Simple maintenance	4. Create awareness information
			5. Gather materials and either hand out or train locals
		6. Provide the help or train others to make improvements	

Table 4

These options were considered using the ranking matrix described in 4.6 below which assigned a score for each criterion in each option and then multiplied that score by the weight of a specific criterion. These products were then tabulated and a final score for each option was calculated. The scale assigned a score of 10 as a ‘good’ score while a score of zero was considered a ‘poor’ score. Therefore, an option with a higher final score is preferred over a lower score and indicates a better or more appropriate option.

4.6 - Multiple Criteria Utility Assessment Matrix

Criteria	Weight	Options											
		Supplemental Solar Furnace		Supplemental Solar PV Panels		Keep Traditional Furnace/No change		Supplemental Space Heaters		Reduce Heat Use		Improve Insulation or Efficiency	
		Score	Scorex Weight	Score	Scorex Weight	Score	Scorex Weight	Score	Scorex Weight	Score	Scorex Weight	Score	Scorex Weight
Capital cost	5	9	45	1	5	10	50	7	35	10	50	7	35
O&M cost	4	9	36	1	4	1	4	2	8	5	20	9	36
Cultural acceptability	3	5	15	8	24	10	30	8	24	1	3	5	15
Constructability	3	8	24	6	18	10	30	10	30	10	30	5	15
O & M reliability	4	8	32	8	32	2	8	9	36	2	8	9	36
Feasibility	3	6	18	1	3	10	30	9	27	10	30	6	18
Sustainability	2	8	16	9	18	1	2	0	0	10	20	9	18
Reproducibility	1	5	5	5	5	10	10	3	3	7	7	2	2
Environmental effects	2	9	18	9	18	3	6	0	0	10	20	9	18
Efficiency	3	4	12	8	24	3	9	4	12	0	0	8	24
Total score			221		151		179		175		188		217
Extra Factors													
Educational Potential	2	9	18	9	18	0	0	0	0	0	0	9	18
Local Economic Potential	2	9	18	2	4	0	0	0	0	0	0	7	14
Security	2	5	10	2	4	10	20	6	12	10	20	8	16
Health Concerns	2	9	18	10	20	4	8	8	16	2	4	9	18
New Totals			285		197		207		203		212		283

Table 5

This matrix illustrates that two total scores were given for each option. The first final scores rank the initial criteria with the result that there were two high-performing options: the supplemental solar furnace and improving the insulation and efficiency of an existing system. In order to compare and choose between these two top-ranked solutions, additional options such as educational and economic potential of the projects were included and new final scores were calculated. Even with these additional factors, the same two top options came out highest and nearly equal. As stakeholder input is critical to appropriate technology decision making, feedback from ReVision was sought to help determine which avenue to pursue. ReVision felt that the solar furnace had more potential for success in the community based on their own less than successful prior attempt to implement an insulation project.

4.7 - Marginalization Metrics

This dissertation is a discussion of a study of the effectiveness of a specific BCC methodology in the adoption of an appropriate technology by a marginalized community. Therefore, it is important to qualify the metrics of what defines a community as marginalized and relate this qualification with the data collected from the community appraisal.

Marginalizing forces are generally community specific. Furthermore, there is an extensive array of variables that might contribute. Some of the common problems that persist among people living in the oppressive conditions of poverty include, but are not limited to, issues such as lack of adequate nutrition, access to health care and medicines,

adequate shelter, and heating. People living in communities with these barriers can be classified as marginalized. According to Onyije & Francis (98): “Marginalization can be defined as not belonging to the mainstream culture, and thus lacking the ‘social capital’ to partake from the benefits of a society and to have an effect on its culture. Reasons might be found in poverty, lack of competencies in mainstream language and/or culture, or lack of motivation”.

The Westwood Community of Denver, Colorado meets this definition of marginalization. In Westwood, the criteria for marginalization are met through income level, household occupancy, educational attainment opportunity, language barriers, food security, and the built environments. Based on a 2008 survey, Westwood households had a median household income of \$31,886, which was 57% of the median household income for Denver of \$55,129. At this same time, Westwood residents paid \$689 average rent. This equated to 95% of the average rent price in Denver of \$725. Additionally, at the time of this survey the average Westwood household had 3.3 people. In comparison, this survey found that the greater Denver area had an average of 2.3 people per household. This additional household density creates greater financial burden (99).

Westwood residents also fall short in education, compared with their counterparts in the rest of Denver. Following is a chart that compares education attainment in Westwood and Denver:

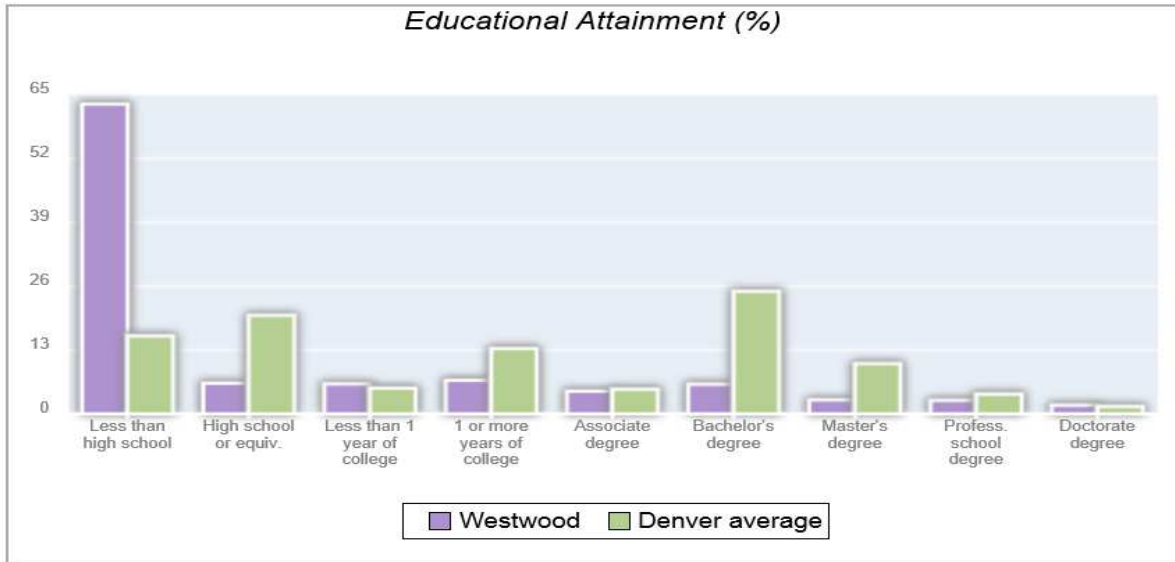


Fig. 3: Source: city-data.com

Strikingly, 21.1% of Westwood spoke “English not well or not at all” vs. 7.6% for the rest of Denver. Coupled with lower education attainment, this creates barriers for upward mobility in Westwood (98). In addition to these marginalizing forces, Westwood has a higher percentage of undocumented residents than Denver as a whole (91). This status restricts job and education opportunities.

The people of Westwood also suffer isolation from resources. There are no grocery stores in the neighborhood and the infrastructure for mobility is poor (i.e. lack of sidewalks and adequate pedestrian amenities, poor bus service, no access to Denver light rail system, etc.). This combination is extremely detrimental to the health and prospects of the residents.

Communities that lack access to healthy nutrition and grocery stores are termed “food deserts” (92,93,94). Such a situation has far-reaching implications to health and is a strong contributor to marginalization. Land development policies and capitalistic forces tend to favor grocery markets in areas where profit potential is maximized. (98) Factors weighing against the opening of grocery stores in poorer communities like Westwood

might include higher delivery/transportation costs, less affluent customers, and higher crime rates. The cost of living in a food desert is more than just the increase in expense (i.e., transportation, time) to get food. Studies have shown a link to health and wellness with distance to supermarkets (93). A US Department of Agriculture report indicates that approximately 2.4 million households in the US fall a mile or more from a grocery store and do not have access to a vehicle (100). The homes in Westwood fall into this category. This negative effect on health may be in part because the effort required to buy healthful food simply may be too much, or may not seem worth it, and so instead, the individual relies on cheap, local, unhealthy fast food instead. Additionally, the spillover effect of not having access to adequate food sources perpetuates the poverty of the neighborhood. As people are forced to travel to other areas for their shopping, they divert the capital that would otherwise be reinvested into Westwood.

In addition, the community appraisal study (a large component of this research) found Westwood suffers from a poor housing stock. In assessing the built environment, it was determined that many of the homes in Westwood are old, not well-maintained, lack adequate insulation and often have dilapidated or non-functioning heating sources. These factors affect the monthly output of money, have impacts on health and contribute to the barriers for escaping the trap of poverty and marginalization. As demonstrated by the Colorado LEAP program and other energy subsidizing initiatives (102), lowered energy expenditure frees up capital to improve the overall standing and capacity of the households.

In 2013 panelists from the ULI (Urban Land Institute) advisory services surveyed the Westwood neighborhood. They concluded that Westwood met criteria as an “endangered” community with regards to health (101). The ULI Panel concluded that

“Westwood faces numerous challenges that make it difficult to foster a healthy lifestyle”

including:

- a lack of adequate parkland and green space. The neighborhood has only one park, though a second one is in the early stages of construction;
- few places where teens and residents can gather for public events or celebrations;
- a lack of public transportation;
- many unpaved alleys, which attract illegal dumping (complicating the situation, some alleys are owned by residents, while others are owned by the city);
- narrow, broken, or nonexistent sidewalks; and
- an automobile-oriented street design that is not pedestrian friendly (Westwood’s walkability score is only 48 on a 100-point scale).

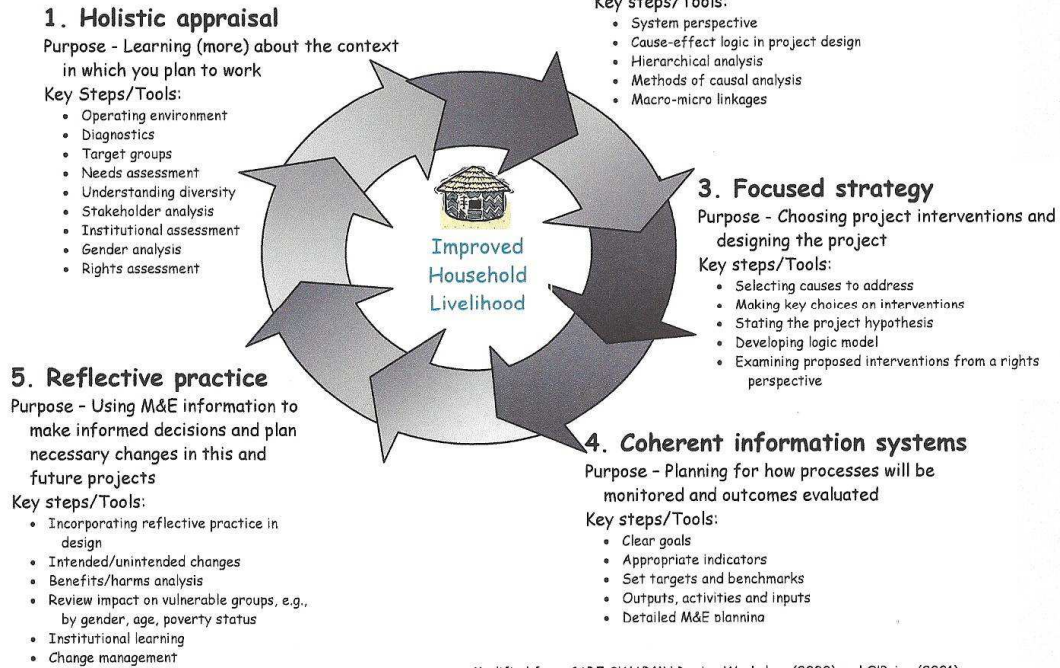
Thus, based upon all of the foregoing factors, Westwood can truly be said to be a marginalized community.

5 – Research Methods

5.1 - Participatory Research Model

To determine the appropriateness of an intervention and also to design a BCC model, this case study takes a participatory research approach, which places the greatest importance on context and community capacity (12). As threaded consistently throughout the literature as a recurring theme, successful projects nearly always rely on community investment; therefore, it is imperative that the community is well understood. To achieve this understanding, a community appraisal following Caldwell's CARE "Project Design Handbook" (12) was conducted from 2012-2013. Caldwell's structure offers guidelines to help direct best design practices. This methodology emphasizes a holistic plan that approaches the project diagnosis in a methodical and systemic manner. This approach engages the targeted community in an inclusive identification of community issues to be addressed. Diagnosis is aimed at establishing recognition of the underlying causes of these concerns and approaching them in a thoughtful and appropriate way that enhances the community. The following diagram was borrowed from Caldwell's handbook and illustrates the interrelationship of the components of this methodology.

CARE's project design framework



7

Fig 4: Project Design Frame Work * Source CARE

To help identify community issues through a systemic appraisal, this dissertation study adopted components of the Caldwell CARE methodology.

The analysis performed in Westwood using these guidelines included:

- Capacity and vulnerability analysis
- Gender analysis
- Diversity and target groups
- Stakeholder analysis
- Causal analysis

5.1.1 - The *Promotora* Model

A key contribution to this study has been the involvement and advocacy by the *promotoras* who work with ReVision in Westwood. *Promotoras* are community members who work to promote civic advancement through the propagation of information to the people of their respective neighborhoods. This arrangement is common in Hispanic communities and most often the role is assumed by women who are respected and active in the improvement of their neighborhoods. *Promotoras* usually are responsible for sharing information to their communities. Often this material is not within the territory of their expertise and usually of a specialized nature (67). Because of this, education and training for the *promotoras* is commonly a necessary step to help them better understand the content they will be distributing. This model has shown great effectiveness for a number of community initiatives. There are many documented case examples where *promotoras* have contributed to successful interventions leading to positive change in their communities. Furthermore, this model has been used to disseminate a wide range of information on a variety of subjects that range from health education to backyard gardening.

The success of the *promotora* model owes a lot to community context and relies greatly on *promotora* status as trusted community liaisons. This established trust helps the *promotoras* to connect their community with ideas from external service organizations. Moreover, this model is effective because *promotoras* are able to provide a better avenue of access for outside entities to their community through the confidence they have built. Although generally they do not have medical or health care training, *promotoras* often act in a role comparable to that of a professional health worker. This occurs more regularly in underserved Hispanic communities where this model often replaces regular medical

services. Frequently, in the role of their duties, *promotoras* act as volunteers with the main motivation aimed towards community improvement and civic duty. However, there are many circumstances where *promotoras* are paid for their contributions to their communities. In Westwood the *promotoras* working for ReVision earn an equitable and livable wage.

Traditionally in this model, *promotoras* have been women; however a growing number of men are taking on this role and the gender-neutral term “*promotores*” is increasingly being used to indicate this more inclusive model (68). At ReVision, 12 of the 13 *promotores* are women.

The *promotoras* model has contributed to improved community health for US Latinos. Latinos are the fastest expanding ethnic group in the US (70). Despite this growth, their communities are confronted with large health care inequalities (70). Due to a multitude of reasons such as language barriers, documentation/residency issues and cultural dissimilarities, these communities often do not have the same access to health care as compared to other groups of people living in the US (70). These marginalizing forces are felt especially by new immigrants. Immigrants are three times more likely to lack medical insurance as compared to the US population in general (70). Because the *promotora* model has demonstrated effectiveness in health care interventions, this model has helped empower Hispanic communities through education of health care options and behavior change (71, 72, 73, and 74).

Many of the documented *promotora* efforts have focused on behavior change communication, especially in areas such as chronic disease prevention (e.g. diabetes), cancer prevention, lifestyle behavior change (e.g. smoking, diet, exercise), and

environmental health etc. (71,72,73,74,75,76). It should be noted that this aspect of the promatora model is particularly relevant to the study of this dissertation.

5.2 Appropriate Design

Appropriate Design is the utilization of engineering solutions within the context of the application. This context takes into account community culture, resources, tradition, and capacity. The implementation of appropriate design occurs through technology that is selected with community based intent. This means that the technology is targeted and implemented so as to be community controlled and sustainable and to solve identified community issues which emerge during the community appraisal.

Based on the community appraisal conducted for this study, several issues were identified in Westwood. These included, but were not limited to, concerns with the built environment; housing stock, nutrition attainment etc. These recognized issues were ranked with metrics of a) importance/relevance to community members and b) feasibility of the intervention. This methodology helped direct the study towards a decision on which community problems should be prioritized and addressed given the resources of the project and community needs.

After choosing what to address, alternate solutions to the chosen problem were measured and ranked using a Multi-Criteria Utility Assessment Matrix. This comparative analysis method produces a quantitative ranking of multiple choices and allows the user to exchange intuition with a decision making tool that is quantifiable. Using Multi-Criteria Utility Assessment Matrix methods, several qualitative inputs for each choice are assigned. Each of these input's apportioned values are largely based on instinct and user judgment.

The values then deliver an overall ranking for the various choices. While on the surface this may seem synonymous to making an intuitive decision, the methodology acts as reinforcement for the decision made and can help clarify a direction on competing solutions.

To further support the validity of this technique from a statistical perspective, one can look to Fermi estimation (79) as an illustration of how several projected values can converge towards a contextually correct solution. Fermi estimation offers an avenue for attainment of a contextually credible answer provided you have enough variables that can be reasonably estimated. The process is predicated on the premise that if a number of unknown variables are provided and realistic assumptions are made within the context of the problem for those input variables, the output will converge towards an answer that is contextually accurate. This method is classically demonstrated by an often cited example in which Enrico Fermi predicts the number of piano tuners in Chicago (79). To solve this problem, Fermi assumed inputs for six different variables based on intuition. These assumptions, when combined mathematically, yielded a guess of 225 piano tuners in Chicago. When researched, it was found that the actual number of piano tuners in Chicago at the time of the problem was 290 which confirmed that the outcome was realistic and that reasonable guesses might converge towards an output that makes sense and can be trusted contextually.

In the same way, the chosen Multi-Criteria Utility Assessment Matrix utilizes enough input variables which are reasonably estimated and therefore, the output ranking can be justified. What's more, the Multiple-Criteria Utility Assessment Matrix used in this study determined that among the proposed intervention solutions the solar furnace was

ranked most appropriate (section 4.6). To add robustness to this approach, additional variables were assigned. This technology was further dissected with particular attention to costs, costs savings, life cycle analysis, and efficiency. In addition to the projected money savings of this project, other benefits were considered. Additional aspects such as technical appropriateness, health impacts, and business prospects affect the overall costs and benefits weight of this design. Non-monetary costs such as limited maintenance requirements (e.g. for checking on hose connections), were accounted for as an additional project cost. Moreover, context specific attributes of the technology were accounted for in the initial assessment.

Intuitively it can be assumed that with minimal maintenance, simplified and user-specific connections and basic training, this technological solution should have small non-monetary costs to the community. These gains increase the benefits of the solar furnace beyond energy savings which have an overall effective positive result on the community's capacity as outlined in the capacity analysis for the technology (Appendix 1). From an environmental perspective, by supplementing heating loads in homes, the units reduce the use of nonrenewable energy sources which is positive. Additionally, because the furnaces are constructed partially from the reuse of disposed materials this can benefit the community on several fronts: recycling and available resources. From a health perspective, the supplementation of heating from the furnaces could reduce emissions from use of ill-maintained furnaces and might improve indoor air quality and help reduce risk of health issues related to cold homes. The reduced cost of heating might also free up household capital that could potentially be invested into items that contribute to better health as well (e.g. better nutrition). From a social perspective, the units can aid community-building.

This is demonstrated in the social aspect of the community workshops (discussed in sections 7.5 and 7.7) where the furnace building activities created an avenue for a fun and uniting community event. Economically, aside from the energy savings, the units provide potential entrepreneurship opportunities and local business. The Multi-Criteria Utility Assessment Matrix accounts for these assumptions through a method of quantification and supports the notion that these benefits fit the specific community needs and are appropriate for Westwood. These benefits then include a reduced economic burden (the furnace provides savings), improved health (the furnace allows warmer homes during cold winter months or income for medical expenses and improved air quality), and increased local business opportunity (the furnace could generate business for local hardware stores or create a new locally-owned small business in the future).

5.2.1 - Index for Appropriate Technology

While the Multi-Criteria Utility Assessment Matrix was useful to quantify the appropriateness of the solar furnace in Westwood as compared to other potential solutions, this study also relied a tool developed by Michael Bauer to further support this choice of intervention. (31). The appropriate technology selection tool developed during this project relies on qualitative data established through the community appraisal. This data is leveraged to build a quantitative assessment of the available technology options. The BCC component of this study allowed an avenue to test this appropriate technology selection method in a contextual setting and therefore the Westwood community acted as a case study for testing this tool, in essence assessing the appropriateness of the furnace for Westwood (31). In the design of this assessment tool, it was important first to understand

what defines appropriateness. This was accomplished through the establishment of an index of criteria. The criteria were identified from a literature meta-analysis (section 2). This review found forty nine independent indicators of appropriateness that recurred throughout the analyzed literature.

To create a ranking structure for appropriateness, a criterion's frequency of citation was determined to be a measurement of importance. The indicators found most often in the literature were (in no particular order) community input, autonomy, scalability, affordability, local availability of raw materials, community control, transferability and adaptability. The frequency of occurrence of these terms was ranked and this ranking was used as the input for a quantitative assessment tool branded "The Appropriate Technology Assessment Tool" (ATAT). ATAT computationally integrates the selected variables through a Multi-Criteria Decision Analysis (MCDA) method to rate the various appropriate technology alternatives for a project. Coupled with the initial selection process performed earlier, this additional step strengthened the choice of technology and, consequently increased confidence in the selection process and its appropriateness. Using Rank Order Centroid method, the indicators (determined through the literature meta-analysis) were given weighted values. The technology was then rated on each indicator using a five-point ordinal scale; these two steps provided inputs which were grouped using a weighted-sum method. This last component produced the "Index of Appropriateness" for the technology. This index is a number that indicates appropriateness. The possible outputs range from 1, representing not appropriate to 5, which would indicate perfect appropriateness for the given scenario and community.

This methodology is beneficial for providing support in making real-world Appropriate Technology selection decisions. Using the Multi Criteria Decision Analysis (MCDA) is often a better decision-making approach than simple linear analysis for AT. This process relies on many variables developed through community input, and weighs competing perspectives to choose appropriateness relevant to identified community issues. Because appropriate technology is very contextually tied to community input, this method is particularly relevant for AT (31, 80, 81, 82, 83, 84). In summary, Multi Criteria Decision Analysis provides a holistic approach that uses systematic methods for combining identified appropriate technology criteria with stakeholder input and local context to quantify project alternatives.

Often Multi-Criteria Decision Analysis relies on the “weighted-sum method” (84,85). A weighted summation gives a *composite indicator*. The Appropriateness Index (AI_i) then, is a composite indicator defined by its input. Equation 1 [43] gives the formal definition as follows:

Equation (1)

$$AI_i = \sum_{j=1}^N w_j x_{ij}, \quad i = 1, 2, \dots, N$$

where: x_{ij} is the j th attribute of the i th alternative,
 w_j is a weight attached to x_{ij} , and
 $0 \leq w_j \leq 1$

AI_i , then, is a weighted linear aggregation of variables, the overall multi-criteria value of technology alternative i .

5.2.2 - Rank Order Centroid for Indicator Weighting

Equation 1, the Appropriateness Index (AI_i) illustrates the reliance on a method for weighting (w_j) the criteria (x_{ij}) before the summation function. According to Barron and Barrett (85), weights derived from Rank Order Centroid (ROC) are “efficacious weights...

superior to that of previously proposed rank-based surrogate weights” (p. 1520). Stakeholder ranks are provided through community workshops which are converted to weights for each criterion for the final evaluation [44] using the following equation (86)

$$w_j = \left(\frac{1}{M}\right) \sum_{n=j}^M \frac{1}{n}, \quad j = 1, 2, \dots, M$$

Equation (2)

where: w_j is the weight applied to the j th criterion,
 M is the number of criteria being considered, and
 $\sum_{j=1}^M w_j = 1$.

This data provides a simplex whose centroid corresponds to the prescribed weights (86). As touched upon earlier, community participation is a key component of selecting AT. For this tool then to provide relevant outputs, a participatory approach is used which obtains input from community members to choose and rank which criteria is valued by the people who the technology is aiming to help. The ATAT methodology uses these inputs from the community to compare the technology against pre-chosen criteria. To collect stakeholder input for this study, the Mini-Delphi method was utilized through a community workshop held at ReVision. The Mini-Delphi method asks participants to give individual feedback, but then share and discuss their survey responses openly with the group. These values are then used as values for input of the assessment tool (section 7).

5.2.3 - Survey Design

The ATAT tool relies on the community input gained through a survey. Survey design is a critical factor in contributing relevant data (86). For this study, the survey was used to identify indicators of appropriateness and rank those based on community perceptions of the solar furnace. The survey is short (three questions), simple (one task per question) and adjectival. Survey questions are as follows:

1. **Choosing Relevant Indicators:** “Thinking only of the solar furnace, circle any of the following qualities that you consider important for bringing these devices to your home or your community.”
2. **Ranking Chosen Indicators:** “Using only the qualities that you circled in Question 1, please rank them here from most important (top) to least important (bottom).”
3. **Rating AT on Chosen Indicators:** “Please rate the solar furnace for each one of your listed qualities as Very Low, Low, Medium, High, Very High.”

From this survey, questions 1 and 2 determine the inputs in the ROC weighting calculations (w_j), while Question 3 determines the performance rating of the given AT in each indicator (x_{ij}). The linear aggregation of these two comprise the Appropriateness Index (AI_i)

5.2.4 - Survey Response Scale

The participants were asked to rate the given technology for each indicator along a scale. Stakeholder input was then used as values for input of the assessment tool (section 7). Sociological data collection (85) often relies on this methodology which offers validity through its response scale. Commonly this method of survey uses five to seven response categories, and can be an effective tool for articulating distinction between categories (86,87). In this study, the survey relied on five response categories (Table 6 below).

Research has shown that “adjectival” response categories are more effective than “numerical” categories for people to understand (88). The survey used in this study followed this guideline and concentrated on descriptive word oriented questions. The

consensus adjectival responses are converted to nominal-discrete measures to quantify the qualitative data x_{ij} , as shown in Table 6.

Table 6 - Conversion factors for survey responses

Survey Response Score	Converted Score
Very Low	1
Low	2
Medium	3
High	4
Very High	5

5.2.5 - Stakeholder Workshop

The CARE participatory research framework that this study followed (12) relies heavily on context and community participation. These are core components to the selection of an appropriate technology. For the ATAT tool, community involvement was encouraged through a community workshop where the *promotoras* provided input by answering questions on a pre-designed survey (section 7).

5.2.6 - Conducting the Workshop

During community workshop, practitioners take on the role of facilitators allowing the community to provide input from an impartial vantage. For this methodology, the workshop begins with introductions and a brief project overview. Along with a review of the selected technology, the participants were also presented with alternatives under consideration and were informed of what they do, why they were chosen and why everyone was called together for the meeting.

Participants were then sectoried into groups of three or four people. Each group was given one survey. The facilitator explained the survey by going through each question individually, as follows:

Question 1: Spend 7-10 minutes identifying all of the important criteria from the list of indicators provided.

Question 2: Spend 7-10 minutes ranking the importance of each criterion from most important to least important

Question 3: Spend 7-10 minutes rating each criterion (very low to very high).

After addressing any preliminary questions, the surveying begins.

Once everyone is finished with their surveys, the facilitator calls for a return to the larger group where results are reported to the facilitator and the larger group. These results are recorded for everyone's review and indicator rank occurrence is tallied.

The first group process is then repeated. As the small groups report their opinions from the second round, criteria are re-tallied. Consensus can be agreed upon verbally, or through simple counting of rank positions. Once consensus has been reached on how to rank indicators, the process is wholly repeated for the AT rating inputs.

5.2.7 - Using ATAT to Compute the Appropriateness Index

As described earlier, AT is scored via the Appropriateness Index (AI_i). Once social data has been collected and analyzed by the established methods (ROC, linear aggregation), the AI_i score will reflect the appropriateness of the given technology in terms of its underlying context. The AI_i score provided by ATAT will range from 1 (low appropriateness) to 5 (perfect appropriateness). An example is given in Table 7, below.

Table 7 - Example MCDA weighted sum impact matrix

Criteria <i>Alternative</i>	1	2	3	<i>AI_{a,b,c}</i>
<i>A</i>	2	3	2	2.8
<i>B</i>	3	4	4	3.4
<i>C</i>	5	2	2	3.8
<i>w_{1,2,3}</i>	0.611	0.278	0.111	

5.3 - Behavior Change Communication Strategy

The Behavior Change Communication plan in this study integrates theories from two distinct models of behavior change: the “Stages of Change” (also known as the “Trans-theoretical Model of Change”) model (11) and the Fogg Model (12). The Stages of Change model connects emotions, cognitions and behavior with a particular focus on change from a process perspective (as opposed to one specific event). The Fogg model proposes that an individual’s behavior will change at the convergence of motivation, ability and trigger (13). Each of these models contributed to the development of the BCC in this study, and will be examined in turn.

The Stages of Change model has been a leading guide for developing interventions to promote health behavior change since its development (11). While it has been used in a wide array of applications, this model has primarily been applied to individual behavior change. This study translates the theory of this model from an individual approach to a community application.

The Stages of Change are as follows:

- Pre-contemplation: This stage is characterized as one where the participant is lacking motivation. That is, at this stage, the intended person (or persons) who will be undertaking behavior change at some future time is not yet anticipating that

- action in the foreseeable future. Often this stage exists because the participant is uninformed or under-informed about the consequences of the behavior in question.
- Contemplation (Getting Ready): This stage represents a developed consciousness or an awareness of the issues that need change. It is the stage where a cognizance is developed of the benefits of the intended change.
 - Preparation (Readiness): When the participant takes action to initiate the change that has been introduced through the previous stages, he or she has reached the stage of preparation. This can manifest itself through various forms; for example, people may begin to share with others their intention to make the change.
 - Action: The stage in which specific and explicit adjustment in behavior begins and the participant makes the behavior change.
 - Maintenance: In this stage, the newly formed behavior patterns become regular routine and develop into habits.



Fig 5: Stages of Change

These stages are closely associated with another component of the Trans Theoretical Model of behavior change: a subset of behaviors at each stage called the “Processes of Change.” (89) The Processes of Change consist of “covert and overt activities that people use to progress through the stages.” (90) Cognitive, affective, and evaluative processes are predominantly applied through the early stages (pre-contemplation, contemplation and preparation). Commitments, conditioning, contingencies, environmental controls, and support are the foundational processes for the action and maintenance stage.



Fig. 6: Processes of Change

In the context of the Stages of Change theory, for a community to fully embrace a new technology, its members must recognize the benefits of the change that the technology brings. For this study, this understanding (pre-contemplation and contemplation stages) was developed through communication to the community during workshops and through the *promotora* community outreach model.

The residents of Westwood developed cognizance (the contemplation stage) through a two-tier process. First, during the appraisal or information-gathering process, the act of answering interview questions encouraged awareness and required articulation of the problems faced by the community which promoted thought and pre-conception. This kind of analytical thinking relies on developing cognition and an evaluative process. Second, the benefit of the technology to the community was disseminated through distributed literature, presentations, *promotora* outreach and loaner demonstration units given to volunteer households. Thus, through interviews, workshops, demonstrations, and the efforts of the *promotoras*, the members of the community of Westwood reached a level of cognizance where they were ready to make a behavior change (preparation).

The stage of action will occur when community members begin to construct and install their own devices; that conduct is outside of the scope of this study, but the fact that at least one community member has represented his availability to build these units for others in the community is a positive sign that the behavior will be on-going. The stage of maintenance is likewise outside the scope of this study, but it will be represented by the community's continued use of the heaters for a second winter season.

The Stages of Change model provides useful guideposts for presenting the ideas of the technology to the community in a methodical way. However, for this study, a more

directed plan related to the community appraisal was also integrated. In addition to the Stages of Change guidelines, this study adopts the Fogg BCC model (12); its component drivers are integrated from the data gathered during the community appraisal and the method offers an avenue to link this data with human behavior of change (as presented in the Stages of Change) to a plan to persuade behavior change

The basis of the Fogg model is that an individual's behavior will change at the convergence of motivation, ability, and trigger (13). According to the model, human behavior has three core motivators: sensation, anticipation, and social cohesion. Each of these motivators has two opposing parts: pleasure/pain, hope/fear, and acceptance/rejection. Of these, pleasure and pain are the most primitive motivators exhibited through immediate response to incitement. The pleasure/pain motivator is adaptive and relates to human behavior in areas such as hunger, sex, and response to extreme temperature (i.e. seeking warmth when cold). The abrupt responses associated with pleasure/pain distinguish this motivator from the others. In addition, unlike the pleasure/pain motivator, hope/fear and acceptance/rejection are long term focused motivators.

These motivators may be effective tools when used in the design of a behavior change plan (although the pleasure/pain motivator certainly has been abused throughout history and needs to be ethically prescribed). The elements of the hope/fear motivator align with anticipation or expectation that something positive will occur or, on the flip side, a negative outcome is on its way and thus can also be a powerful force in controlling human behavior.

Of greatest interest to this study, however, is Fogg's third core motivator, which is made up of social acceptance and social rejection. People generally are inclined towards behavior that will provide social acceptance. In much the same way, the avoidance of social rejection is a big motivator for most people.

While the pain/pleasure motivator tends to be focused on immediate response, the other two motivators carry a long-term orientation. It might be assumed then that hope/fear and social acceptance/social reject are less powerful than pain/pleasure as a behavior change motivator. In fact, some research has shown that natural human tendency is to choose immediate gratification over long term reward.

Dick Thaler and Cass Sunstein professors of Behavioral Science and Economics at the University of Chicago are performing research on behavioral change which includes the question of why people don't make better decisions for their health (19). Their research suggests that present-time decision-making might differ greatly from how people make decisions for the future. According to their research, decision-making in the present is driven more by impulsivity and immediate satisfaction. Despite the knowledge that certain behavior is or is not beneficial in the long term, the impulsive nature of humans and their tendency to seek immediate gratification generally motivates their behavior. This may help to explain why people don't always do what is best for them. For example, many people do not brush and floss their teeth as recommended by dentists, even though the long term health benefits are clear. .

Motivation, then, is the foundational driver that relates to pre-contemplation and contemplation in the stages of change. Motivation is a powerful tool for behavior change; however, in the design of a BCC plan, one may have to acknowledge that motivation may

be absent, or not easily modifiable. In these cases, it may be necessary to move on to the second prong of the Fogg model, and the BCC design may require increasing an individual's ability.

Ability relates to how simple a behavior is to do. Fogg suggests that ability can be acquired through two methods: providing more skills (increasing ability to do the target behavior through training) or making the targeted behavior easier to do. Fogg states: "In real world design, increasing ability is not about teaching people to do new things or training them for improvement. People are generally resistant to teaching and training because it requires effort. This clashes with the natural wiring of human adults: We are fundamentally lazy. As a result, products that require people to learn new things routinely fail." (1) Instead, if we make the behavior easy to do, it will increase the chances that the desired change in behavior will occur, thus increasing a person's ability. Deciding what is "easy" is not an easy task in itself; easiness can take on many forms. Fogg gives four elements of simplicity to consider when planning a BCC. They are:

- Physical Effort - Fogg believes that humans in general tend to avoid adopting behavior that requires physical effort;
- "Brain Cycles" - If people have to think hard, that is considered not to be simple;
- Social Deviance - If the chosen behavior demands going against social norms it is not considered simple;
- Non-routine - People tend to stick to routines so behaviors that force people to change routines are considered not simple.

The final piece of the puzzle to consider when designing a behavior change plan is what Fogg refers to as "trigger." The trigger is the cue that encourages people to

undertake the targeted behavior or action now. Thus, it is not enough to simply fuel the motivation for a behavior change and provide simple actions that enable people to take action towards a desired goal. There must also be a push, an “a-ha moment,” that forces immediate action. The strength of the trigger will vary depending on the interaction of the other two prongs of the Fogg model, motivation and ability. For example, lack of motivation or low motivation might encourage the BCC design to incorporate a strong trigger – what the Fogg model calls “spark”. A spark plays off of the motivational elements to encourage the behavior change by focusing on the emotional aspects (such as hope/fear) of the change. If motivation is high but ability is low, the use of “facilitator” can be effective as a trigger. A facilitator is usually a communication that helps the intended user understand or perceive the behavior as easy to do. When the users have both high motivation and ability often “signal” is chosen as the trigger. Signal acts simply as a reminder to the user to do a behavior. An example of this is the kind of apps available on smartphones which are aimed at weight loss and health and remind the users to get up and move periodically. Figure 7, below, provides a graphical illustration of the Fogg model for BCC.

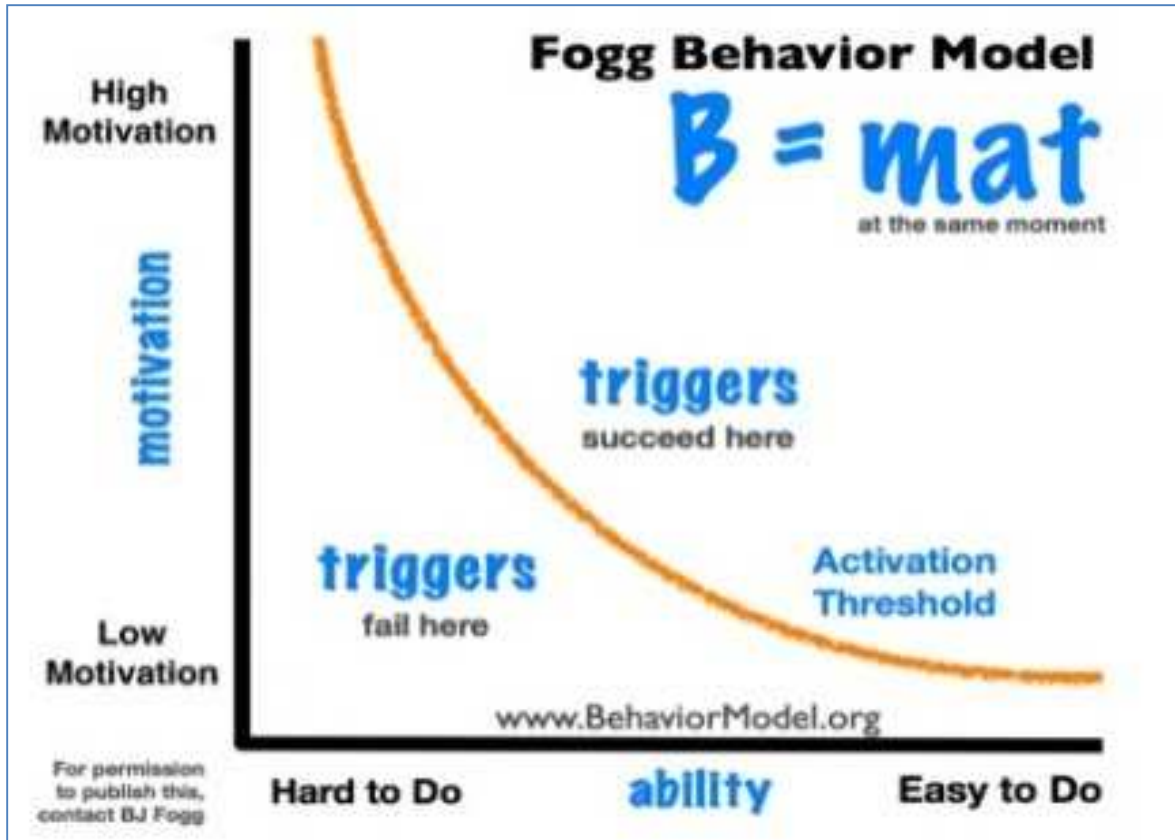


Fig 7: Fogg Behavior Model

5.4 - Applying the Fogg BCC model and Stages of Change to Westwood

In Westwood, the “motivation” and “ability” inputs for the Fogg model were determined from the extensive community appraisal. From this assessment, it is understood that the household stock is poor, heating costs are high and the community is economically stressed. These three components can be classified as our motivators. This appraisal also illustrated the “ability” of Westwood to adopt this technology. The solar furnace was identified as affordable, and certain members of the community were recognized as having the skills necessary to construct the devices. The materials needed to construct the devices

were determined to be readily accessible. Connecting the two initial components of the Fogg model (motivation and ability) essentially correlates with the appropriateness of the project (as quantified by the Appropriateness Index of the ATAT tool, section 5.2.7). This also correlates to the Pre-Contemplation and Contemplation components of the Stages of Change.

The final component of the Fogg model is the trigger. The choice of installing the initial demonstration models after the first cold weather event was intentional: cold weather may serve as an excellent trigger for the community to engage in the furnace-building workshops described previously. Cold weather aligns with the category of trigger associated with pain/pleasure and so it falls into the more powerful area of behavior triggers. From an understanding of the community social structure developed in the community appraisal, it was anticipated that members of Westwood would be aware of the four demonstration models in the community at the time of the community workshop. This was confirmed when the *promotoras* were interviewed (results section 7.1). These interviews also intentionally acted as a connector between the pre-contemplation to contemplation areas as described in the Stages of Change. By posing deliberate questions about the potential solutions for the identified problem of household heating, the community was lead towards developing a consciousness about the Solar Heater Technology.

5.5 Methodology for evaluating the BBC plan in Westwood

To evaluate the effectiveness of the BCC plan, a mixed methods approach was implemented. The components of this approach loosely follow the “Community Tool Box-

Evaluating Comprehensive Community Initiatives” (7) Model with the following components:

- Rating Community Goals
- Constituent Survey of Outcomes: Ratings of Importance
- Behavioral Surveys
- Rating Member Satisfaction
- Conducting Interviews with Key Participants to Analyze Critical Events
- Gathering and Using Community-Level Indicators

Community goals were rated through several methods. The understanding of these goals was attained through the community appraisal (section 4) which helped identify needs and potential solutions. These possible solutions were evaluated for appropriateness through a multi-use criteria index and through the ATAT appropriateness index (section 5.2.7). Pre-project surveys were also conducted to obtain constituent input on the perceived importance of the project by the community. These surveys included data points about the community’s motivation to try the proposed technology.

Behavioral surveys were taken at three months, six months and one year from the original surveys. These timelines roughly correspond to the installation of the loaner models, several months of use of these loaner models, the start of the community workshop, and the end of the winter after a season of use and exposure of the technology in the community. Interviews also took place with key participants in this study: the volunteers who received the loaner models.

The community indicators measured for this project include a satisfaction index, a community survey at the second workshop on the community’s perception and

understanding of the technology and a physical count of known installations in the community after one winter season. Additionally, there was a head count of the attendance at the workshops to help evaluate interest and investment by the community in the technology. Based upon all of these surveys, interviews, and ratings, it was determined that the BCC model used in this study was successful. This was indicated by the community awareness and interest (as expressed in the surveys) and by the adoption of the technology by a portion of the community with indication that more households intended to use the solar furnaces. Additionally, the establishment of a local business producing solar heaters for the community shows buy-in for the technology. These indicators are discussed in more detail in the concluding remarks.

5.6 – Timeline

The following table represents a timeline of the major events/components of this study.

Item	Date
Community appraisal	October 2012 to May 2013
AT assessment	March 2013 to July 2013
Loan demonstration model to ReVision	April 2013
Community workshop 1 (introduction of technology)	April 2013
Loaner model design, construction, testing	June 2103 to July 2013
Community workshop 2 (stakeholder ranking)	Oct 2013
Installation of first two loaner models	Nov 2013
Installation of second two loaner models	Dec 2013
Survey households using first two loaner models	Dec 2013
Community workshop 3 (<i>promotora</i> training)	Feb 2014
Survey households with four loaner models	Feb 2014
Distribute instructional literature	Feb 2014
Community workshop 4 (community build day)	April 2014
Survey of community use 1 (in service)	April 2014
Survey of community use 2 (intended use)	Oct 2014
Project exit	Oct 2014

Table 8: Timeline

6 – Results: Introducing the EZ Heat Solar Furnace as Appropriate Technology in Westwood

Though preliminary community appraisal (section 4) of Westwood was extensive, more specific appraisals of participating homes were conducted through interviews and secondary data analysis. This assessment included:

- The operating environment
- Capacity and vulnerability analysis
- Gender analysis
- Diversity and target groups
- Stakeholder analysis
- Causal analysis

After determining that the technology was conceptually appropriate (see results section 7, a meeting was held with the *promotoras* at Westwood to get community input. The technology was overwhelmingly well-received and, in fact, the *promotoras* branded the device "EZ Heat."

To implement the BCC plan, four household were chosen to receive the initial loaner models.

Discussions with ReVision staff and the *promotoras* yielded the appropriate selection of these four households to receive the loaner furnaces. Site visits to the participating households were conducted during the summer of 2013, where each house was individually assessed on site characteristics, including location, solar aspect, potential insulation and aesthetics.

From this appraisal data, investigators designed educational materials that describe the furnace in detail, including its function, benefits, construction techniques, maintenance

and operation. In cooperation with ReVision, a strategy was devised to educate and disperse the technology throughout Westwood. This strategy included:

- fliers and brochures with concise descriptions of the furnace, and announcements about the workshops, and
- workshops to teach interested households how to build their own furnaces

Four EZ Heat solar air heaters (furnaces) were built for use in Westwood over the summer of 2013. Two of these furnaces were installed in November 2013 at the volunteer households, and installation of the other demonstration furnaces occurred in December, 2013.

Following these installations, community workshops were hosted by ReVision in February and April 2014. The first involved only the *promotoras* and was aimed at training them to build the devices. The second was an open community project promoted by ReVision and the *promotoras*. The monitoring and evaluation plan included survey of users of the solar furnace at 30-day intervals.

Monitoring consisted of site visits to assess user sustainability, metrics of satisfaction, user duration (continuation of use) and system reliability. The final evaluation held in October, 2014, assessed how many houses adopted the technology, and how many of those intend to use it again in future cold seasons.

7 - Results Data

7.1 - Community Workshop 1 (Introduction of Technology) - April 2013

The first Community Workshop took place in April 2013. This workshop was held with just the *promotoras* and was coordinated with an interpreter. In this meeting the solar furnace technology was introduced for the first time to this group and they were asked for their feedback. To do this, a prototype furnace was brought to the community meeting and a demonstration was offered for the *promotoras* at ReVision's office. At this meeting 10 *promotoras* were in attendance.

The following questions were asked:

- Do you think this technology would work in Westwood?
- Do you think the aesthetics would affect acceptance of the furnaces by the community?
- Do you have any input?

Their responses were recorded. This is a sample of the qualitative feedback that the *promotoras* gave to these questions:

- "I really like the free heat. This would definitely be useful for some houses"
- "This is very smart"
- "The only problem I see is that it is not very pretty"
- "I didn't believe it would work when I first saw it but feeling the heat come out was a surprise. Amazing."

In this meeting one *promotora* suggested we brand the heaters "EZ HEAT."

By conducting this workshop the community was given their first exposure to the solar furnace technology. This workshop coincides with the “Contemplation” stage of the trans-theoretical behavior change model as the community is being exposed to the technology and being made aware of the benefits of the technology through demonstration and explanation. This workshop serves not only as a part of the participatory/community input but also as primer for the behavior change which is the adoption of the technology.



Photo 2: Promotora Workshop

7.2 - Community Workshop 2 - Oct 2013

For the second workshop held in Oct 2013 in Westwood, the *promotoras* were invited back to provide input on EZ Heat using the Mini-Delphi method so that their opinions could be quantified to help determine the appropriateness of the furnace. The feedback given was utilized by the methodology of the ATAT method. Through this method, EZ Heat was quantified as having an index value of appropriateness of $I=4.2$ out

of 5. In effect, this score is the quantification of qualitative input and the relatively high score of 4.2 illustrates the empirical support to the deterministic selection of EZ Heat by ReVision, Westwood and the community appraisal, and validates its use as an appropriate technology for reducing household energy costs.

7.2.1 - The Mini-Delphi Workshop

The Mini-Delphi session took place at the ReVision International offices in Westwood (31). Because this study is focused on the Hispanic community of Westwood, the surveys were written in Spanish as well as English (Appendix C). To help with communication, Re-Vision provided an interpreter. Ten *promotoras* attended the meeting; it was expressed that more *promotoras* wanted to attend, but could not due to schedule conflicts.

Following the methodology previously described in this paper, an introduction was made and background details on the furnace models and the status of the four heaters being loaned to identified community members and the scope of the project were provided. Next, the survey process and the questionnaire were explained, and then the surveys were distributed to the three groups. The participants were guided through the three survey questions and when groups felt satisfied with their responses, they were tallied and organized by prevalence in the final consensus. Due to time constraints, the second round of input was shortened to tallying of rankings and verbal consensus. (31)

7.2.2 - Results from the Mini-Delphi Workshop

Tables 9 and 10 illustrate the results of AT evaluation for EZ Heat in the Mini-Delphi session (31).

Table 9: EZ Heat indicator ranking consensus

Group 1	Group 2	Group 3	Consensus
Simplicity	Efficient Resource Use	Renewable Resources	Availability of Raw Materials
Ease of Use	Availability of Raw Materials	Efficient Resource Use	Efficient Resource Use
Availability of Raw Materials	Job Creating	Adaptability	Job Creating
Socio-culturally Accessible	Autonomy	Availability of Parts & Hardware	Simplicity
Job Creating	Simplicity	Job Creating	Ease of Use
Autonomy	Ease of Use	Availability of Raw Materials	Renewable Resources
Renewable Resources	Adaptability	Ease of Use	Adaptability
Adaptability	Renewable Resources	Simplicity	Autonomy

Table 10: Results from EZ Heat Mini-Delphi workshop

Consensus Ranking	Survey Rating (N)	Consensus Rating
Availability of Raw Materials	Very High; High (2);	High
Efficient Resource Use	Very High (2); High	Very High
Job Creating	High (2); Medium	High
Simplicity	Very High; High (2)	High
Ease of Use	Very High; High (2)	High
Renewable Resources	High (3)	High
Adaptability	Medium (3)	Medium
Autonomy	High (2); Medium (1)	High

7.2.3 - Final AT Assessment of EZ Heat Solar Air Heater

The Mini-Delphi survey data was plugged into ATAT to determine AI_i for the EZ Heat solar furnace. The tabulated consensus results, along with final AI_i , are shown in Table 11, below.

Table 11: Results from EZ Heat Mini-Delphi Workshop

Consensus Indicator Rank	Consensus AT Rating	Converted Ratings	ROC Weights	Tabulated Results
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Availability of Raw Materials	High	4	0.3397	1.3589
Efficient Resource Use	Very High	5	0.2147	1.0735
Job Creating	High	4	0.1522	0.6088
Simplicity	High	4	0.1106	0.4424
Ease of Use	High	4	0.0793	0.3172
Renewable Resources	High	4	0.0543	0.2172
Adaptability	Medium	3	0.0335	0.1005
Autonomy	High	4	0.0156	0.0624
Solar Furnace $AI_t = 4.2$				

7.3 - Installation of First Two Loaner Models - Nov 2013, Dec 2013

The first two workshops with *promotoras* helped build trust and establish buy-in which was useful in moving forward with implementation of the technology intervention. *Promotoras* identified four households in Westwood willing to have furnaces installed for the purpose of this study. These furnaces were installed over the course of two visits, the first in November of 2013 followed by a second visit in December, 2013. The scheduling of these installations was intentional as it coincided with two cold weather periods. The weather conditions helped to act as the “trigger” component of the BCC Design.

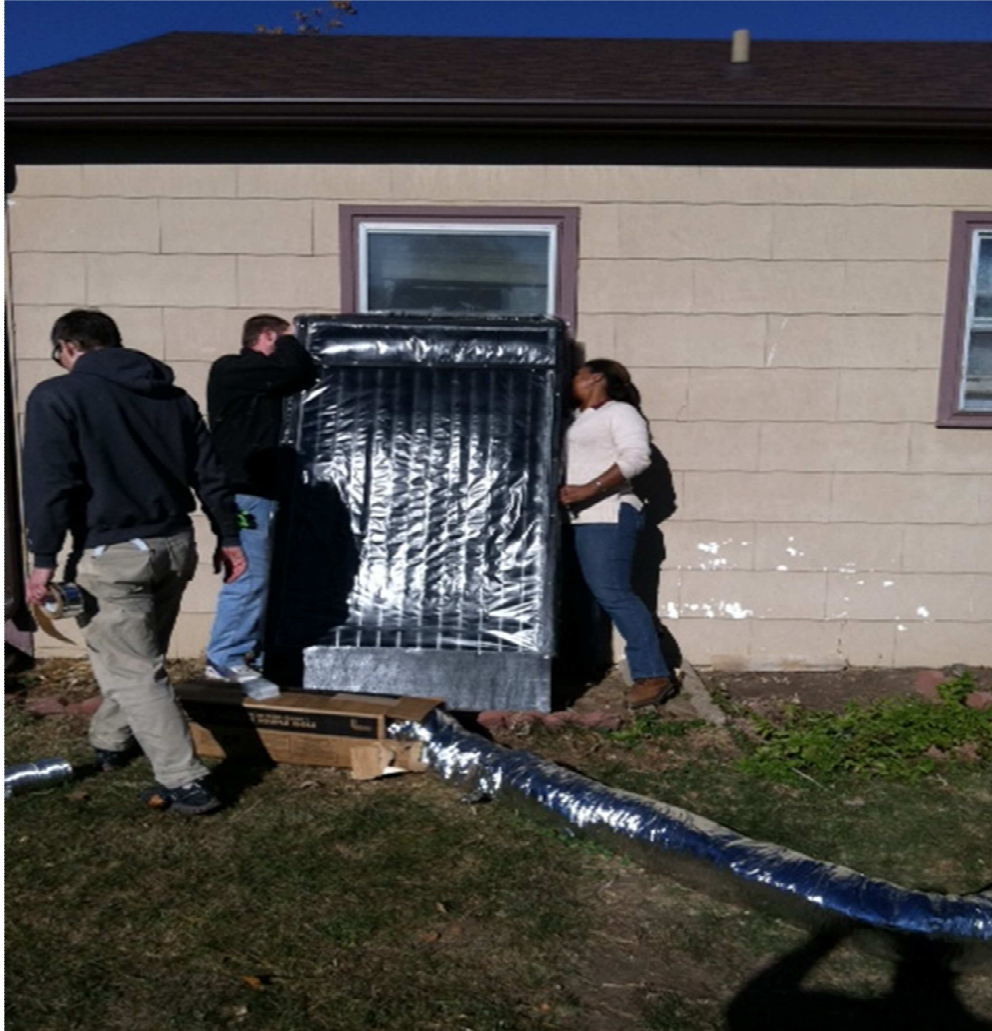


Photo 3: Installing EZ Heat Loaner Models on Westwood home

7.4 - Survey Households Using First Two Loaner Models - Dec 2013

During the second installation in December of 2013, the visit included time to survey the households who had received heaters a month earlier. The surveys were brief and structured to gather qualitative data about user satisfaction, neighbor interest/curiosity, and general comments.

The survey asked the following questions:

- Is the heater working well for you?
- Would you recommend this technology to others in your neighborhood?
- Do you have any comments about the technology?

The following responses were recorded:

- “The basement (where the heater is hooked up to) “is so much more comfortable now”
- “Our bills are less than before”
- “We are very happy with it. Thank you”

The responses were positive and indicate that, for the initial installations, user satisfaction was high. Through the understanding of the community developed in the thorough appraisal, and in particular the gathered knowledge from the ReVision garden project, it was anticipated that there would be curiosity from the neighbors. Neighborhood interest fit into the BCC plan. To support this anticipated interest, others in the community were given an informal introduction to the technology which corresponds to “preconception” in the “Stages of Change” model. The surveys indicated that the neighbors were interested.

The following comments recorded in the survey are indicative of this interest:

- “The heater is working very well. We like it a lot. All the neighbors have been curious about it”
- “Some people have come by to ask what is on our home”

7.5 - Community Workshop 3 (*Promotora* Training) - Feb 2014

In February, 2014, a workshop was held with the *promotoras* to show them the basic methods of constructing the devices. Ten *promotoras* attended and communication was facilitated through an interpreter provided by ReVision. The workshop taught the *promotoras* how to build a solar furnace through a hands-on workshop. A small heating unit was built to demonstrate the construction methods and better explain the technology. In addition, a pamphlet was distributed which had instructions to build a solar furnace (Appendix C) in both English and Spanish, and also explained the benefits of the solar furnaces. At this workshop plans were made for the *promotoras* to host a community workshop in which members of Westwood be invited to build their own solar furnaces. It was planned that participants could pay for provided materials and they would be taught by this author and the *promotoras* to build their own furnaces.



Photo 4: Demonstration unit from *Promotora* Workshop

7.6 - Survey Households with Four Loaner Models - Feb 2014

During the visit to ReVision in February, 2014, in which the *promotoras* were trained in solar furnace building, the households who had now been using the models (since November and December respectively) were surveyed for their satisfaction.

The following questions were asked:

- Is the heater working well for you?
- Would you recommend this technology to others in your neighborhood?
- Do you have any comments about the technology?

The following statements are representative samples of the responses given:

- “We like the heater. Our home stays warmer than before”
- “I am planning to build heaters for people in my hometown in Mexico where it gets cold”
- “The plastic cover ripped but otherwise the heater has worked well for us”
- “The neighbors want one too”
- “Our heating bill is noticeably less”

With the exception of one response (above) expressing some damage to an installed heater unit, the feedback continued to reflect the positive response from the earlier surveys. Additionally there were further indications from the responses that others in the community also were interested in having their own solar furnaces. This was reinforced by the *promotora* workshop in which the lead *promotora* expressed that many in the community would be interested in learning how to build their own heaters. This shared information was part of the decision to move forward with the Community Workshop 4 in which community members would be shown how to build their own heaters.

7.7 - Community Workshop 4 (Community Build Day) - April 2014

In April of 2014, a workshop coordinated by the *promotoras* was held in the parking lot of ReVision. To participate in this workshop, community members had to pay \$35 for

the materials to build their own heaters. Twenty-two families signed up in advance and paid the \$35. It was optimistically anticipated that there might be 10 participating households at this event so the large turnout was a pleasant surprise. This might be attributed to the trust of the promotoras, their buy-in on the project and their recruiting efforts. To facilitate an effective workshop, materials to build 22 heaters were ordered from a local lumber and supply yard in the Westwood neighborhood. At the workshop there were 43 people in attendance all working together under instruction by the *promotoras* and this author to construct their heaters. Due to time constraints, only 7 heaters were completed. However, one of the participants offered to complete the additional heaters for a small fee, in essence creating a small business and taking community control of the project. As outlined by the CARE guidelines, the ultimate direction community projects strive for is community investment and control of the project. By facilitating, through the education of the workshop, the skills and knowledge to make the heaters, this project effectively handed the ownership to the community on this day. This corresponds to the “ability” component of the BCC model.



Photo 6: Community Workshop



Photo 5: Community Workshop 4

7.8 - Survey of Community Use 2 (Intended Use) - Oct 2014

Final surveys were collected with questions intended to collect mixed data which could be useful in determining the community's intention to continue using the technology (Appendix C). These surveys were distributed to the recipients of the four original furnaces and also to several participants from the community workshop. In all, twelve households responded to the survey questions. Three of the questions were rated on a five point scale with higher scores indicating a stronger intention of use. The maximum combined score possible (among the twelve households) for those three questions was 180 points. The minimum (which would have leaned towards indicating the community had not adopted the technology) was 36. On this range, the recorded score

was 154 strongly suggesting community adoption. Several of the respondents chose five on all three questions. The lowest score recorded was three for the question “After using the solar furnace, how would you rate your satisfaction with the technology?”. This same respondent did indicate for question five that they would recommend the technology to others and also indicated that they planned to use the technology again this winter. Furthermore, every respondent indicated that they planned to use the technology again this winter and nine of the twelve indicated that others had asked about their solar furnaces. For question four, “Have people expressed interest in having their own solar furnace?”, eleven of the twelve respondents answered yes. The most varied response range of the survey was the final question related to estimated savings. Responses ranged from \$5 to \$50 and there did not seem to be a consistent pattern to the answer.

In addition to this questionnaire, 32 solar furnaces were identified as being in use in the community at the time of this survey.

8 - Concluding Remarks

This project was intended to study the effectiveness of a community-tailored behavior change communication model, coupled with appropriate technology selection, both built on the foundations of a thorough community assessment. It was hypothesized that a community specific persuasive communication model for the adoption of the selected technology might improve the effectiveness of the intervention. The “effectiveness” is a difficult thing to quantify. The metrics chosen were qualitative in nature (with the exception of counting actual units in the community). Even the interpretation of those measures is subjective. One could say that the project was very successful as there are now over thirty solar heaters in the community that at the start of the study had none (known of). Just as easily one could argue that thirty-some odd heaters in a community of around 3,000 homes represents a small percentage and statistically indicates that the technology was not adopted.

To help clarify the measure of success or failure of this project it might be useful to compare the results to another project in Westwood that has generally been seen as a successful intervention in the community: in 2009 Revision International launched an initiative called “Farm Denver”. As the ReVision website describes this program “The model is designed to empower low-income families and vulnerable communities to overcome the barriers to growing food, namely resources and education, and to use food as a spark to ignite wider economic and community development.” (95). ReVision chose Westwood as the location to institute Farm Denver. On their website, ReVision describes this location decision based on Westwood’s built and social environment: “As one of the city’s poorest and most at-risk neighborhoods, this area is also a food desert, making the

conversion of household yards into organic vegetable gardens that much more important.” (95). The “RE-Farm” program aimed to educate and facilitate backyard gardens in Westwood. ReVision started small with 7 initial “demonstration” backyard gardens (which parallels this study’s model). Word-of mouth helped neighbors become interested and soon more people enrolled in ReVision’s backyard garden program.

In 2010 the vision of the garden project was given a big boost when ReVision received an \$80,000 grant to grow the program. By 2011 (which corresponds to a similar time frame as this study) there were 87 families participating in the backyard garden program (95). The backyard garden program has been hailed as a successful project (95) and recently received significant funding to grow it both within Westwood and beyond the boundaries of the community as well. Thus, it seems appropriate, not only because it occurs in Westwood but also because of the program’s ongoing success, that it might act as a benchmark for this study. With 32 counted solar furnaces in use now in Westwood, it can be said that the adoption is similar as with the backyard garden project after a similar period of time noting that there are more barriers to this adoption (e.g. the seeds and seedlings for gardens are provided by ReVision’s grant while families are paying for their own furnaces). By this measure it could be argued that the BCC plan was effective (at this point) for community adoption of the heaters.

However, counting units used is not adequate for assessing effectiveness of the plan. To evaluate the overall effectiveness this study loosely follows the “Community Tool Box-Evaluating Comprehensive Community Initiatives” (12). This method places value on survey data and so it is useful to compare the qualitative surveys from inputs to outcome. For example, early in the study community goals were rated. The understanding of these

goals was attained through the community appraisal which helped identify needs and potential solutions. These solutions were evaluated for appropriateness through a Multi-Use Criteria Index and through the ATAT appropriateness index so it can be inferred that through this methodology the technology selected is appropriate for Westwood.

Constituent survey of outcomes and ratings of importance occurred through pre-project surveys conducted to obtain input on the importance of the project as perceived by the community. These surveys also included data points to assess the community's motivation to try the proposed technology. These surveys indicated that the community had initial buy-in and acted as a beacon that the BCC plan following "Stages of Change" and the Fogg model was on-course. Once the units were installed it became important to rate the user satisfaction which was done through follow-up surveys conducted at approximately three months, six months and one year from the initial installations. The results from these surveys overwhelmingly suggested that the users were not only satisfied with the heaters but also were disseminating knowledge of the technology to their neighbors and even beyond their community (see Appendix D for unintended consequences).

Additionally, key participants in this study were the *promotoras*. As expressed in this dissertation (section 5.1.1), there is a strong community trust in what the *promotoras* believe in. The ReVision backyard garden project owes much of its success to the employment of the *promotora* model and the same can be said for this study. Moreover, it was important when assessing the effectiveness of this BCC plan to have an understanding of *promotora* attitude and perspective on the technology. Through survey, it was determined that the *promotoras* strongly supported the technology and, in fact several of

the participants in the workshop were the proud owners of their own solar heaters at the time this dissertation is being written. Finally, to understand how effective this model was it was important to survey the community on the intended future use and identify who among the community was invested in dissemination of the technology to others. This knowledge was gained through the final two surveys. These surveys asked “do you plan to continue to use your furnace?” and “would you recommend this technology to others in your community?” The data collected for these two questions strongly supported the notion that this technology will continue to be used in Westwood and also that it likely will be used by more households in the future. Supporting this likelihood is the fact that a community member who was present at the community workshop is continuing to offer his services as a small business building heaters for members in the community who want to buy them. This data suggests that the project is now community owned and has some level of sustainability.

From the indications listed above, it appears that there has been community buy-in. Residents of Westwood who have the heaters are overwhelmingly happy with them and others are interested in also acquiring their own heaters. A business has been started in the community which might contribute to the growth of use by Westwood residents.

As mentioned earlier in this section, at year two of the backyard garden project there were 87 gardens in Westwood. In 2014 (which is year 6 of that program) there are now over 300 backyard gardens in the community. Similarly, to evaluate the effectiveness of this study over a longer period of time, monitoring and evaluation should be planned which could help understand long term adoption by Westwood for the furnaces. After two years and two months from the initial contact with the community the furnaces appear to

be integrated into Westwood and the BCC plan is working for the community adoption of solar furnaces.

9 - Limitations of this Study

While the purpose of this research was to demonstrate a methodology for developing an effective BCC plan to improve the success of a technology intervention, it is recognized that this research is specific only to the Hispanic community of Westwood and any found results can only be representative of the effectiveness of the methodology for that sample group. Additionally, the appropriateness of technology is very much reliant on context. The solar furnace was evaluated to be an appropriate technology for Westwood based upon a number of variables. This technology, however, might not be appropriate for other scenarios or in other communities and it is important to recognize that the BCC plan is dependent on the robustness of the selection process for AT. The measurements of this study are post two years and a couple months from initial contact. The results then can only be relied upon for this period in time. Further monitoring and evaluation is necessary to understand long term trajectory of the BCC plan in Westwood.

10 - Work Moving Forward

With the conclusion of this work, naturally the questions arise, “How can what was learned be applied to new initiatives? Where will this go next?” In Westwood at the time of the close of this study, the collected data suggest that the BCC plan had some success and the solar furnace technology was accepted. In surveys, community members have indicated they plan to continue using the devices and that others will be adopting the

technology too. Moreover, the community has shown many signs of ownership, an important metric of success under the CARE framework. While this data is promising, a deeper understanding of the effectiveness of this methodology might be gained through a long term monitoring and evaluation plan. The continued use and potential growth of household investment would be good to understand. For this task, the relationship with the community partner Re:Vision could prove an important asset and this author plans to meet with Re:Vision to discuss the project. Among items to be discussed are the implementation of a long term monitoring and evaluation plan which incorporates annual surveys.

Meanwhile, at the time this dissertation is being concluded, there are two grant proposals submitted to find funding for expanding this work to other communities. Both proposals suggest to operate the projects through the paradigm of service learning courses which engage undergraduate students in the implementation.

Additionally, a community in Pueblo, Colorado with very similar demographics is forming an energy co-op which is investigating ways to save the residents money on their utilities. There has been some initial talk of implementing this methodology in Pueblo to determine an AT solution for their problems and an implementation plan to help encourage a successful outcome. This initiative would likely leverage the already completed appraisal that was conducted in that community.

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Appendix A

Furnace Description and Analysis

Although the focus of this dissertation is not on the technical aspects of the chosen technology but rather on the application of a behavior change communication model for the adoption of that technology, the dissertation would not be complete without analyzing the technology so that its characteristics were understood. With this in mind, this section will discuss the development of a predictive model which can be useful to forecast solar furnace performance over a wide range of conditions and also can be used for the optimization of the design. This model explores the heat transfer characteristics of one design of soda can solar furnace within set constraints, explores the fluid flow characteristics, and yields predictions for BTU output and savings. The model is flexible for a host of variables (i.e. furnace size, flow rate, time of year (based on a review of average conditions), angle of furnace etc). To verify the accuracy of this model, a furnace was constructed and testing was conducted. It should be noted that the model that was used and verified through physical testing is applicable only for one design of the furnace, specifically for a 110 can unit with given dimensions and a well-sealed acrylic cover. While the model has flexible capability built into it, the results that were predicted and tested for were particular for the aforementioned design. For a project where community members build their own furnaces, such as what occurred in Westwood, there are many variables which will affect the performance of individual furnaces (i.e. the cover material, the size of the units, the length of ducting, the speed of the fan used, how well sealed the units are, the thickness of the plywood etc). For this experiment the goal

was to develop a model that could reasonably predict the performance of one model of solar furnace. It is very possible to dive deeper in analysis for the heat transfer characteristics than this model does. The fidelity that would be gained by doing so is not significant enough to justify that direction. Moreover, this test is about better understanding the performance of a relatively simple device and how it can be sensibly used. For practical purposes, the model uses simplified assumptions when appropriate (which are discussed below). The model was verified through experimental testing. While there were many variables that have an effect on forecasting the overall performance, testing showed that the models functionality in predicting the furnace worked reasonably well in establishing a baseline understanding. This section reports on these experiments and discusses the results.

Nomenclature

α	Absorptivity
A_s	Surface Area m^2
A_x	Cross Sectional Area m^2
C_p	Specific Heat J/kg-K
$T_{in,home}$	Temperature from home C
$T_{out,ducting}$	Temperature out of Ducting C
$T_{surface}$	Surface Temperature of Can C
$T_{sky/ambient}$	Outside Temperature C
$T_{out\ furnace}$	Temperature of Air leaving Furnace C
r_1	Radius of inside of ducting m
r_2	Radius of outside of ducting m
k	Thermal Conductivity W/m-K
v	Velocity of air m/s
L	Length of ducting m
L_{th}	Thickness of Insulation [m]
V_{wind}	Average Velocity of wind outside m/s
μ_b	Fluid Viscosity. at T_b [N-s/m ²]
μ_w	Fluid Viscosity. at T_w [N-s/m ²]
U_L	Overall Heat Loss coefficient [W/m ² *C]
T_b	Average Temperature of air C

T_w	Average Temperature of wall of can C
Q	Heat Transfer Rate
Q_u	Useful energy gain of the collector
h_o	Coefficient of convection kJ/hr-m ² -K
h_1	Coefficient of convection with Temperature correction kJ/hr-m ² -K
h_w	Coefficient of convection from wind on flat surface kJ/hr-m ² -K
h_{rad}	Coefficient of Heat Transfer for Radiation kJ/hr-m ² -K
\dot{m}	Mass flow rate kg/s
ρ	Average density of air kg/m ³
ε	Emissivity
σ	Stefan-Boltzmann constant = 5.670 x 10 ⁻⁸ W/m ² *K ⁴
R_{air}	Gas constant for dry air = 287.05 J/kg*K
R	Thermal Resistance [C/W]
I_{GH}	Total Hemispheric shortwave irradiance measured at 45° from Horizon with a sun tracker.

Equations:

$$Q = \frac{T_2 - T_1}{R_{total}}$$

$$R_{total,cylinder} = \frac{1}{(2\pi r_1 L_1) h_1} + \frac{\ln(r_2/r_1)}{2\pi L_1 k_1} + \frac{1}{(2\pi r_2 L_1) h_w}$$

$$h_w = 5.7 + 3.8V_w$$

$$T_2 = T_1 + \frac{Q}{\dot{m}C_p}$$

$$\dot{m} = \rho v A_x$$

$$Q_{convection,cans} = hA_s(T_p - T_{air,in})$$

$$h_r = \varepsilon_{plexiglass} \sigma (T_{cover} + T_{sky})(T_{cover}^2 + T_{sky}^2)$$

$$h_{combined} = h_{radiation} + h_{convection}$$

$$h_{convection} = h_o \left(\frac{\mu_b}{\mu_w} \right)^{0.14}$$

$$h_o = 3600 \times \frac{Nu}{D}$$

$$Q_{radiation} = \varepsilon \sigma A_s (T_s^4 - T_{sky}^4)$$

$$T_{surface} = T_{\infty} + \alpha \left(\frac{I}{h_{combined}} \right)$$

$$\text{Median Plate Temp } T_p = Q_u \left(\frac{1}{h_{plate}} \right) + T_f$$

$$R_{total,box} = \frac{L_{th,plywood}}{k_1 A_s} + \frac{L_{th,air}}{k A_s} + \frac{1}{h_w A_s}$$

$$I_{GH,Corrected} = I_{GH} \sin \theta \cos \Phi$$

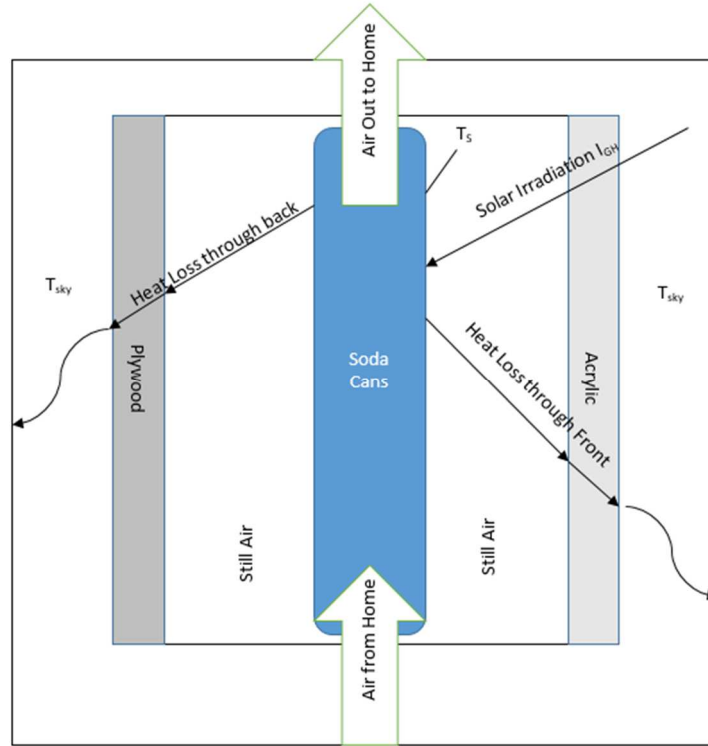
$\theta = \text{Zenith Angle (Angle above horizon)}$

$\Phi = \text{Azimuth angle (Horizontal Angle)}$

In predicting the performance of the solar furnace, heat loss must be determined for the system. The following section describes the methodology used for this evaluation.

Calculating Heat loss from Ducting

The solar air heater design pulls air from inside a home using a low power axial fan. For the installations in Westwood, the air travels a short distance through flexible, insulated ducting. There is heat loss in the ducting which is dependent on the outside air temperature, outside wind speed, the temperature of air passing through the ducting, the insulation factor of the ducting and the mass flow rate of the air.



Appendix A- Figure 1: Heat Transfer Model of Solar Furnace

Exit temperature at the termination of the ducting is calculated using eq. (1):

$$T_2 = T_1 + \frac{Q}{\dot{m}c_p} \quad (1)$$

Where: T_2 is the exit temperature of the air °C, T_1 is the average temperature entering the ducting °C. Q is the heat transfer found using eq. (3), \dot{m} is the mass flow rate calculated using an (ρ) average air density, kg/m^3 , and (v) is the average velocity of the air through the cans m/s.

$$\dot{m} = \rho v A_x \quad (2)$$

Heat transfer is calculated using the heat transfer eq. (3):

$$Q = \frac{\Delta T}{R_{total}} \quad (3)$$

Q is found through the difference of the air inside the ducting and the outside air temperature (ΔT) divided by the insulation factor (R). The total insulation of the ducting R_{total} found using the following equation for R in series for a cylinder.

$$R_{total,cylinder} = \frac{1}{(2\pi r_1 L_1) h_1} + \frac{\ln(r_2/r_1)}{2\pi L_1 k_1} + \frac{1}{(2\pi r_2 L_1) h_w} \quad (4)$$

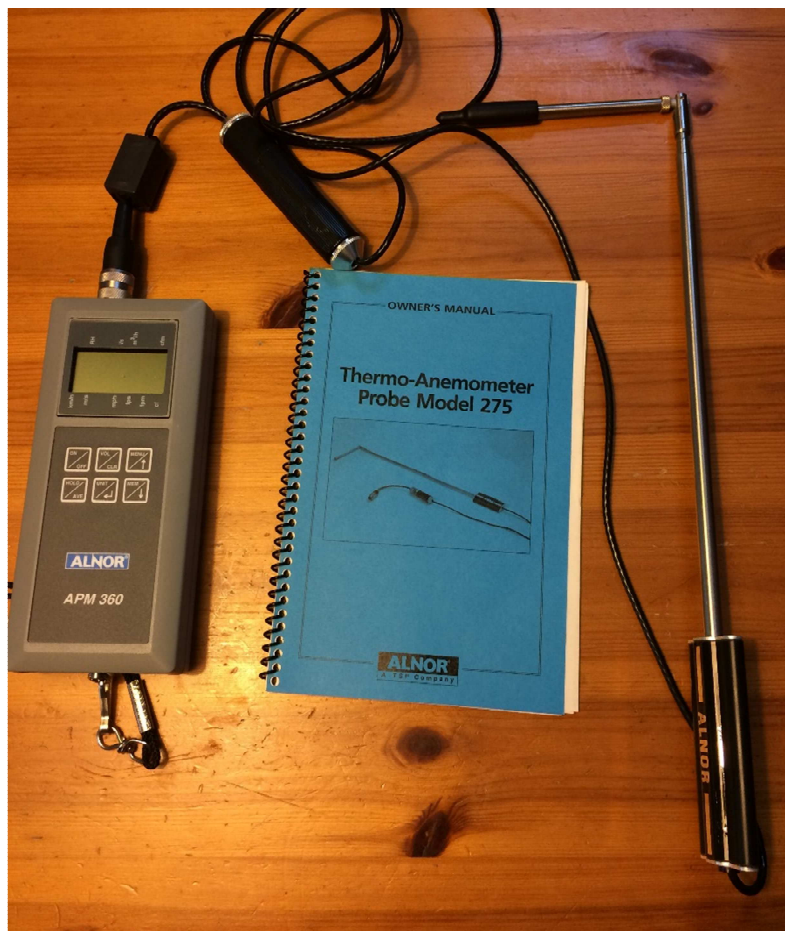
Where: L_1 is the length of the ducting, r_1 is the inside radius of the ducting, h_1 is the coefficient of convection for forced air convection; and k_1 is the thermal conductivity of the insulation.

The coefficient of convection for the wind h_w was found by using the McAdams equation (1):

$$h_{wind} = 5.7 + 3.8V_{wind} \quad (5)$$

Where V_{wind} is the average velocity of outside wind. This equation is for the convection on a flat plate, however for our simple model, the estimation for a flat plate is sufficient for our calculations.

While the commercially available ducting was advertised as having a given insulation factor, the thermal data during testing seemed to contradict the expected values given by the manufacturer's specification. To improve fidelity of the results, experimentation was conducted to extrapolate the correct. The k_1 value for the insulated ducting. For this test, the temperature at the inlet and outlet of the duct was found by inserting the ALNOR Thermo-Anemometer Probe Model 275 (see Appendix figure 2) in each end of the ducting. The probe was also used to confirm the airspeed going through the solar furnace.



Appendix A - Figure 5: Thermo-Anemometer Probe

Using the temperature difference of the air entering and exiting the ducting and the known value of the outside air temperature and the outside wind speed, the k_1 value was calculated by arranging equation (1), (3) and (4):

$$k_1 = \frac{\ln r_2/r_1}{2\pi L_1 \left(\frac{\Delta T}{(T_2 - T_1)(Cp)(\dot{m})} - \frac{1}{(2\pi r_1 L_1)h_1} - \frac{1}{(2\pi r_2 L_1)h_w} \right)} \quad (6)$$

The coefficient of convection h_1 was found by using the eq. (7) and (8):

$$h_{convection} = h_o \left(\frac{\mu_b}{\mu_w} \right)^{0.14} \quad (7)$$

$$h_o = 3600 \times \frac{Nu}{D} \quad (8)$$

$$Nu = \frac{hD}{k} \quad (8a) \text{ where } D \text{ is the diameter of ducting}$$

$$\text{or } Nu_u = 0.664(\text{Pr})^{\frac{1}{3}} * \sqrt{Re}$$

From earlier calculations...

$$\text{Pr} = 0.7323$$

$$\text{Re} = 5439$$

k = thermal conductivity of air W/m^*K

Calculating Heat Losses on Solar Furnace

The solar furnace box used for this experiment was constructed from plywood and fir 2x4 lumber. The box contains the columns of cans and is sealed with a cover made from 3/16” acrylic. There is significant heat loss from the front and back of the solar furnace. The overall Heat Loss coefficient for the solar furnace U_L was calculated using eq. (3) and (9):

$$R_{total,box} = \frac{L_{th}}{k_{air}A_s} + \frac{L_{th}}{kA_s} + \frac{1}{h_w A_s} \quad (9)$$

K is calculated for the front of the box assuming a 3/16” acrylic sheet. The back of the box k calculation assume standard plywood of 1/2” thickness. There is a layer of air in between the cans and the top and bottom of the box which is also considered. Because the box is sealed, the airflow in the spaces between the columns of cans and the box is small. While it is recognized that natural convection will exist in the box between the hot cans and cooler cover, literature research indicated that when modeling was run on similar devices to include this component the effect on the results were extremely small (106). Because this model is essentially designed to examine the practical application of the solar furnace, this small effect was deemed negligible for the meaningful data and because of this assumption, natural convection is ignored as a heat transfer mechanism in these areas. The coefficient of convection h_w is as used in equation

(6). As the box gets bigger the heat loss increases and the effectiveness of the solar furnace is decreased.

Heat loss is the greatest at the ends of the box near the inlet and outlet connections to the ducting. At the entrance to the solar furnace the air loses a large amount of energy before it enters the tubes. This also happens as the air exits the solar furnace on its way into the home. This loss reduces the output of the box. From a systems perspective, the losses external to the box need to be considered for their effect on the practical application of the furnace. For this reason, the model takes into account these losses. To find the R_{total} for this section eq. (9) is adjusted to account for no insulation other than the plywood. Using Eq (9):

$$R_{total,box} = \frac{1}{h_{air}A_s} + \frac{L}{kA_s} + \frac{1}{h_wA_s} \quad (9)$$

The coefficient of convection for the air inside the ends of the box were found experimentally by finding using the temperature. (The bottom end of the box the air is taken in from the interior of the house and then sent through the cans.) (The top end the heated air is pushed out back into the house.)

The Heat Loss is found by using eq. (3a) and eq. (3b)

$$Q_{inlet,box\ end} = \frac{T_{inside} - T_{exterior\ surface}}{R_{plywood}} \quad (3a)$$

$$Q_{outlet,box\ end} = \frac{T_{inside} - T_{exterior\ surface}}{R_{plywood}} \quad (3b)$$

For the inlet section of the solar furnace the ΔT is the difference of the outside temperature and the temperature of the air coming out of the duct

For the outlet side of the solar furnace the ΔT is the difference outside temperature and the temperature of the heated air coming out of the cans.

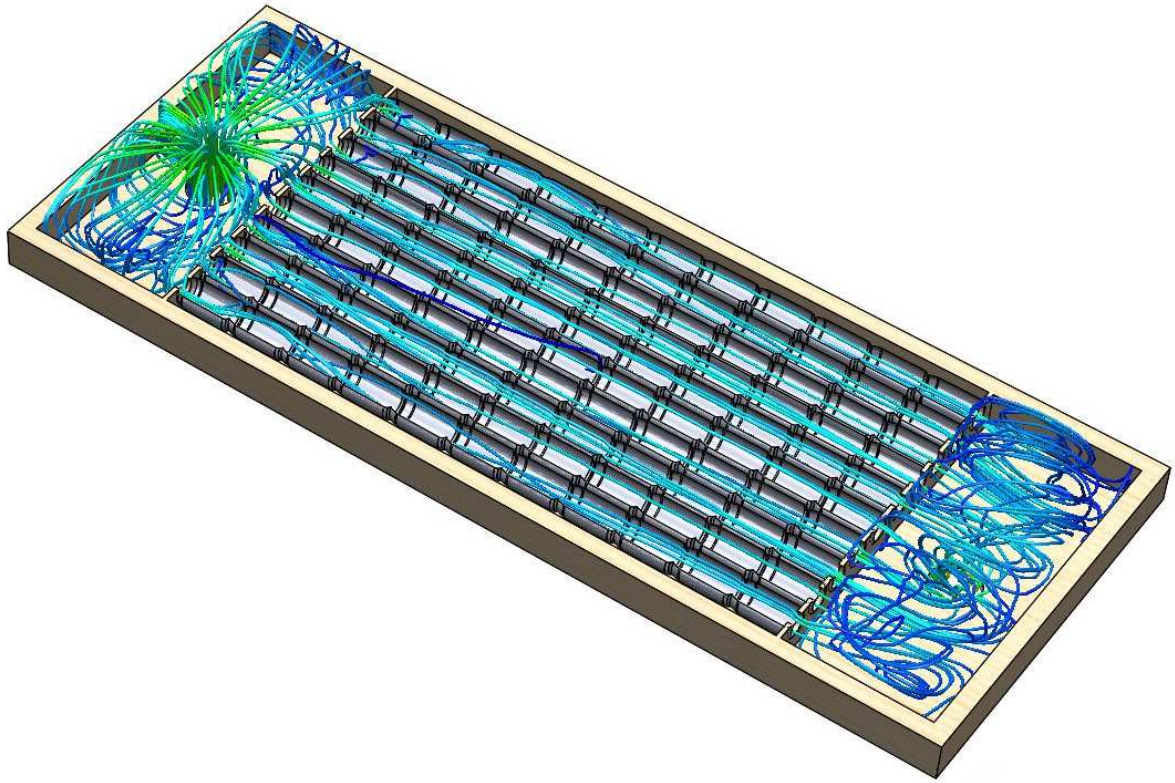
The total Heat Losses U_L includes the losses on the front of the box and the back of the box and the ends of the boxes. $U_L = Q_{out,top} + Q_{out,bottom} + Q_{inlet,box\ end} +$

$Q_{outlet,box\ end}$

Surface Temperature of Cans

A computational flow dynamics model was created using the SolidWorks 2014 x64 FloXpress Analysis application that was used to predict the average velocity through the cans..

A computer generated model (Appendix I Figure 3 below) illustrates the predicted flow for a fan rated 80 cfm flow rate.



Appendix I - Figure 6: SolidWorks FloXpress Analysis for 80cfm axial fan

This analysis predicts that the flow across each row of cans is relatively even with an air speed of approximately 1.5 m/s. The parameters for the flow analysis used inlet air temperature of 300K and air flow rate of 0.03m³/s. The exit air pressure was assumed to be atmospheric pressure.

The soda cans in the the solar furnace are heated by absorbing the suns radiation.

Using equation 1

$$T_2 = T_1 + \frac{Q_u}{\dot{m}C_p}$$

and the equation for Q_u it is possible to estimate the exit temperature of the air.

$$Q_u = A_s F_r [I_{GH,Corrected} - U_L (T_{out,ducting} - T_{ambient})]$$

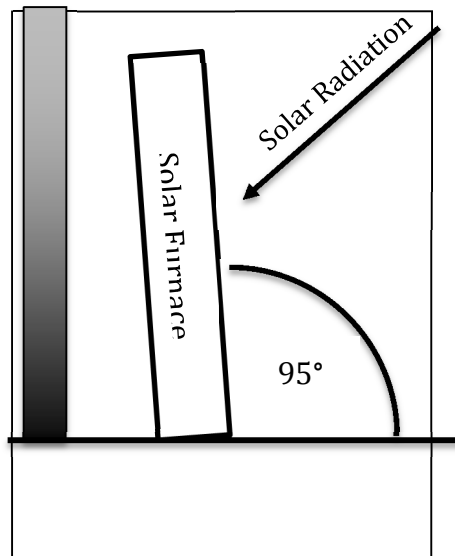
The Heat loss removal factor was found by iteration of the equation for F_R since $T_{out,cans}$ is unknown.

$$F_R = \frac{\dot{m}C_p}{U_L} \left[\frac{T_{out,cans} - T_{out,ducting}}{\frac{I_{GH,Corrected}}{U_L} - (T_{out,ducting} - T_{ambient})} \right]$$

Equations for Q_u , are from “Solar Energy Thermal Processes”, (2)Duffie & Beckman.

$$I_{GH,Corrected} = I_{GH} \sin \theta \cos \Phi \quad (13)$$

The Solar Intensity value, I_{GH} is collected from the website SolarTac.org. The values were downloaded from the SolarTac.org website when they were posted (typically 24 past observation date). SolarTac data is measured using the Total

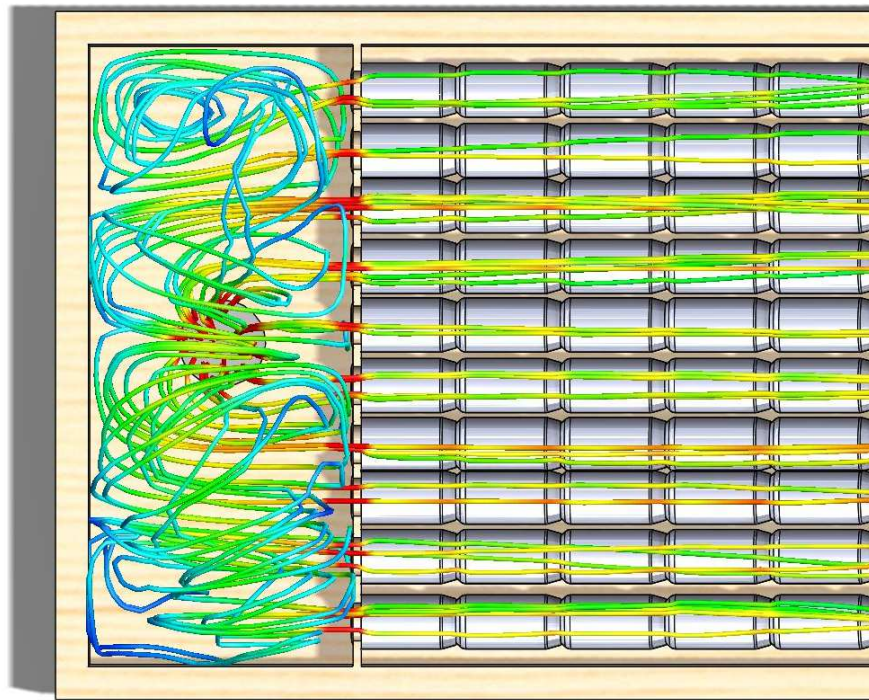


Hemispheric shortwave irradiance as measured by an

Appendix A Figure 4: Solar Angle

Kipp & Zonen Model CMP22 with calibration factor traceable to the World Radiometric Reference (WRR). In addition to the responsivity at 45 degrees, a responsivity function (based on zenith angle) is also applied to the data. (SolarTac.org) I_{GH} is the total solar intensity of the sun, plus the diffused solar radiation. An additional 20% of solar intensity is lost because of the acrylic covering. This value is assumed from the material sheet of the acrylic type. For the Experimental procedure, the solar furnace model was mounted at a 95° from the horizon⁵, facing south. While an optimum angle for the latitude of Denver (where the tests were performed) in November would be approximately a 36° angle from the horizontal, the angle of this experiment is a better approximation of how the furnaces were used in Westwood. The measured solar intensity and the usable solar intensity on the solar furnace is different from the sensor because the device follows the sun and the solar furnace is always pointing due south. This angle is the azimuth angle. The measured intensity does not have this error because the device follows the sun throughout the day, but the furnace is stationary. The SolarTac sensor is tilted to 45° but output data value is correct for the zenith angle, the data output is now calculated for an angle normal to the sun. To account for the difference in angle, the solar intensity was corrected u eq. (13) . Where $\theta = (\text{Zenith Angle of the sun} - \text{Angle of the Collector plate})$, and $\Phi = \text{Azimuth Angle}$. The Altitude (zenith Angle) and Azimuth Angle for each test day were collected from the “Astronomical Applications Department” website - <http://aa.usno.navy.mil/data/docs/AltAz.php>.

The cans are painted with a black matte high temperature paint. Using the information in the McGraw Hill Heat and Mass Transfer (appendix 1, Table A-19) the emissivity of black paint is 0.98. It is assumed the heat transfer is steady state and the surface temperature of the can reaches equilibrium front and back after short exposure time. To test this, a separate experiment was conducted in which the acrylic cover was removed and the temperature of the cans were measured on the front and back after 10 minutes exposure to the sun. The test confirmed that the temperature is evenly distributed at this time interval.



Appendix A - Figure 7: SolidWorks FloXpress at outlet of Solar Furnace

Heat Transfer From Convection Through Cans

Radiative heat gain is transferred through the thin-walled aluminum cans by conduction. Because aluminum is a very good conductor and the walls are very thin, this component of the heat transfer is not part of the analysis as the additive or subtractive components are negligible. At this juncture, the air flow through the cans will be heated via convection. The heat transfer of the surface of the cans to the air is calculated using Q_{total} which is determined with the sum of all the heat transfer mechanisms $Q_{total,system} = Q_{convection} + Q_{radiation} + Q_{out\ bottom} + Q_{out\ top} + Q_{out\ ends}$. Again using equations (1) and (3), the temperature leaving the box can be calculated. The air is now passed back through the ducting into the home, again there is heat loss from the ducting. For practical applications, shorter ducting is desirable.

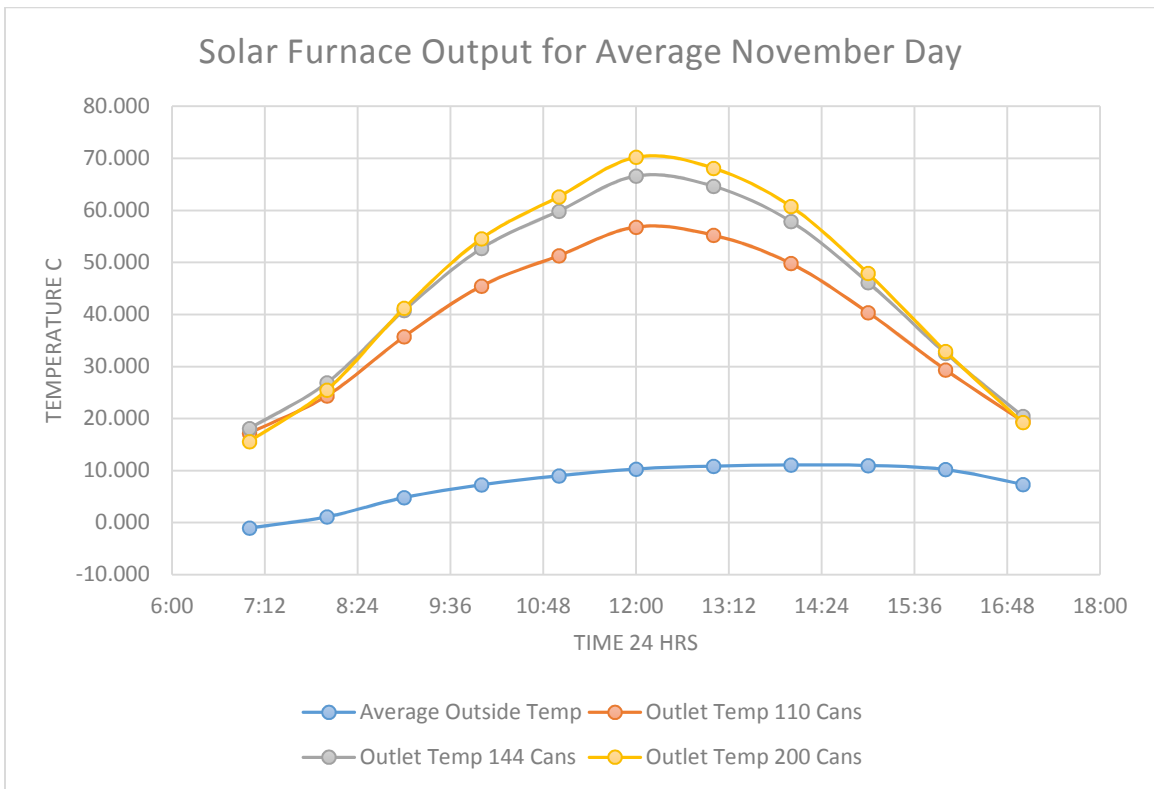
The Heat Transfer for three sizes of the Solar Furnace was compared to find most effective size of solar furnace. The larger the solar furnace the more irradiation it can use, but it will also lose more heat. Using eq. (14) an efficiency was found each hour the sun was up, then the average for November's data was calculated. (Note: the first hour 07:00-07:59 was not included because the solar irradiation was so low (an average of 2.5 W/m²) that the efficiency number would give false indication of the overall steady state efficiency of the solar furnace.)

$$\eta = \frac{\sum Q_{Total,System}}{I_{GHA_s}} \quad (14)$$

Appendix A: Table 1: Thermal Efficiency

Size of Solar Furnace	Average Efficiency from 08:00-17:00 hours.
110 Can	33%
144 Can	34%
200 Can	24%

Appendix A -Figure 8: Comparison of outputs for different sizes of Solar Furnaces



The Test Box

To verify the accuracy of the predictive model described above, a solar furnace was constructed and tested in a variety of conditions.

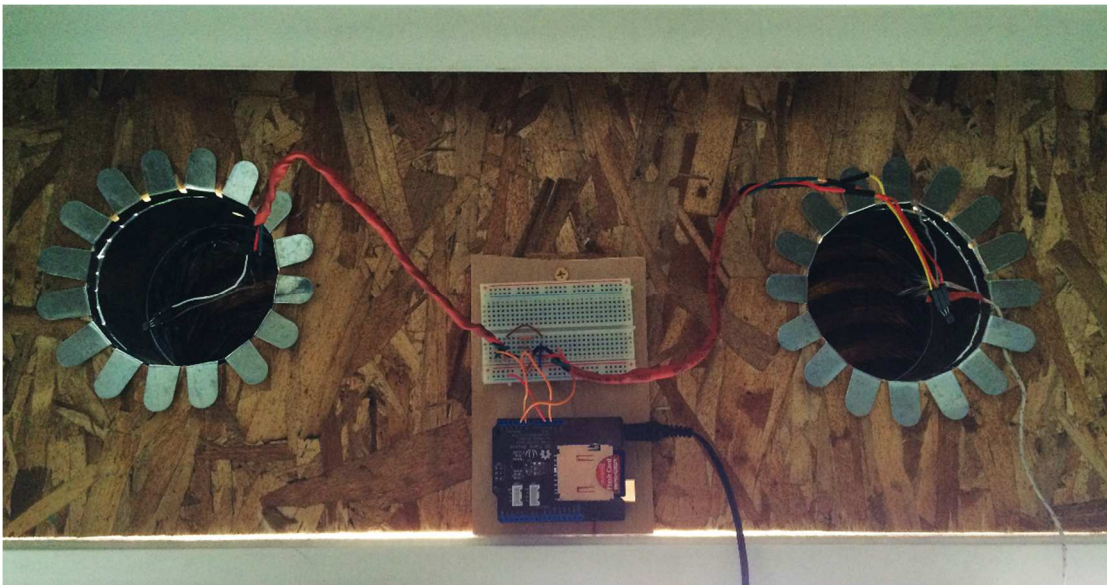
Build Conditions of Test Box.

- 110 soda cans
- 10 rows of 11 cans in each row.
- The front face of the cans are painted with “High Heat” black paint
- The cans have the tops and bottoms removed and are sealed end to end with general silicon.
- The sides of the box are made from construction grade 2x4s
- Bottom of box is made from 3/8in OSB plywood
- The box ends are made from 3/8in OSB plywood
- There is a sheet of clear 9mm thick PLASKOLITE, INC acrylic over the cans.
- The Box is connected using 6 feet of insulated ducting with an inside radius of 2in and an outside radius of 4in.
- To move the air through the unit a TRICOOL 120mm, 79cfm case fan from ANTEC is attached to bottom inlet. The fan spins at 2000 rpm with 12 VDC.
- Data Logging was accomplished with an Arduino UNO R3 microcontroller and Seeed SD card shield.

- Temperature sensors are two TMP36 digital Low Voltage Sensors

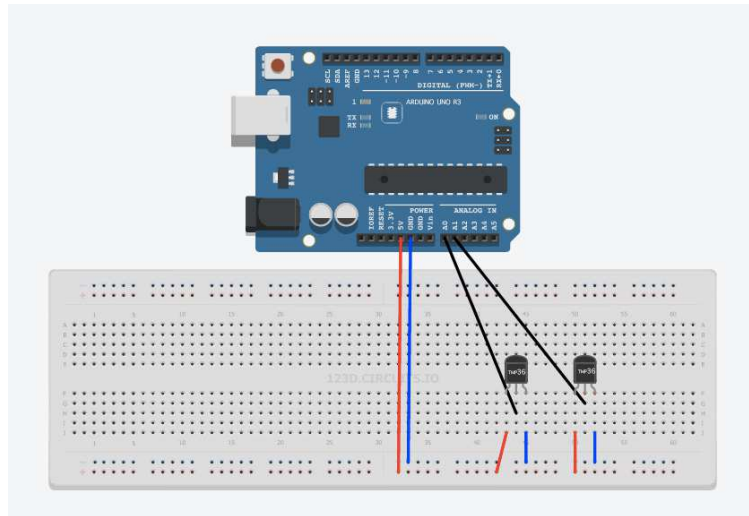
Recording the Temperatures:

The inlet and outlet temperatures are measured at the ends of the ducting using a custom Arduino Data logging system (Appendix A: fig 7) configured for this experiment. This Data Logging system was configured so that the temperature sensors measure, record and log the temperature at 30 second intervals. The sensors are setup in the center of the ducting opening. Each sensor has an analog sensor pin assigned to it. Sensor 1 has a 100ms delay which is intended to prevent the sensors from interfering with each other. The wires from the TMP36 sensors to the Arduino board are approximately 15 cm long and they are twisted to reduce feedback.



Appendix A-Figure 9: Arduino Setup Schematic with two TMP36 Temperature Sensors

Appendix:A - Figure 10: Temperature Data Collection using Arduino R3 UNO and Seed SD Shield



Appendix A-Figure 8: Arduino Circuit

The TMP36 has an accuracy of $\pm 2^{\circ}\text{C}$ with a temperature range of -40°C to $+125^{\circ}\text{C}$ and a max operating temperature of 150°C . For the purposes of this experiment the sensor have an acceptable level of accuracy and range of usable temperatures. The total possible error is 4°C . The Thermal analysis of the solar furnaces from 144 to 200 cans does not have a difference of more than 3°C at certain points of the model, however these are theoretical numbers based on the model. The only size furnace tested was a 110 can furnace. If the 144 can furnace and 200 can furnace were tested a more accurate means of measurement would be needed in order to get accurate temperature differences of the two sizes.

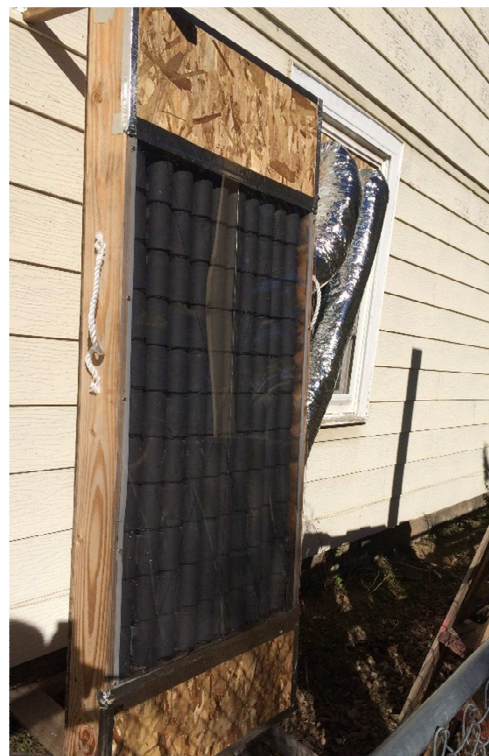
The Arduino was tested prior to using in this experiment by watching the spread of each temperature sensor when placed close to each other. The temperature in a 5 min test run had less than 0.5 °C difference. The temperature reading was validated by using a handheld thermocouple reader. The Arduino board takes a reading every 30 seconds from each sensor.

For testing; the solar furnace has been placed approximately 20 cm from the side of the house, facing south at 95° from the horizon.

Appendix A-Figure 9: Inlet and Outlet ducting at window



Appendix A-Figure 10: Solar Furnace Setup facing South



Error Analysis

The solar furnace was tested as installed on a home. While this set up does have some restrictions, it was more realistic of what might be encountered in a community like Westwood where not every home has ideal sun exposure. For this installation, the furnace was shaded by nearby trees in the early morning and late evening. During the test the sun has risen but the solar furnace is partially shaded until 11:00 am and then it received full sunlight. In the evening the sun again goes behind trees and the solar furnace is in partial shade starting at 3:30 pm and full shade by 4:00 pm. The shade causes a sharp decrease of solar irradiance to heat the cans and decreases the air temperature produced. During the time when the solar furnace is in the shade the inlet temperature is higher than the outlet temperature.

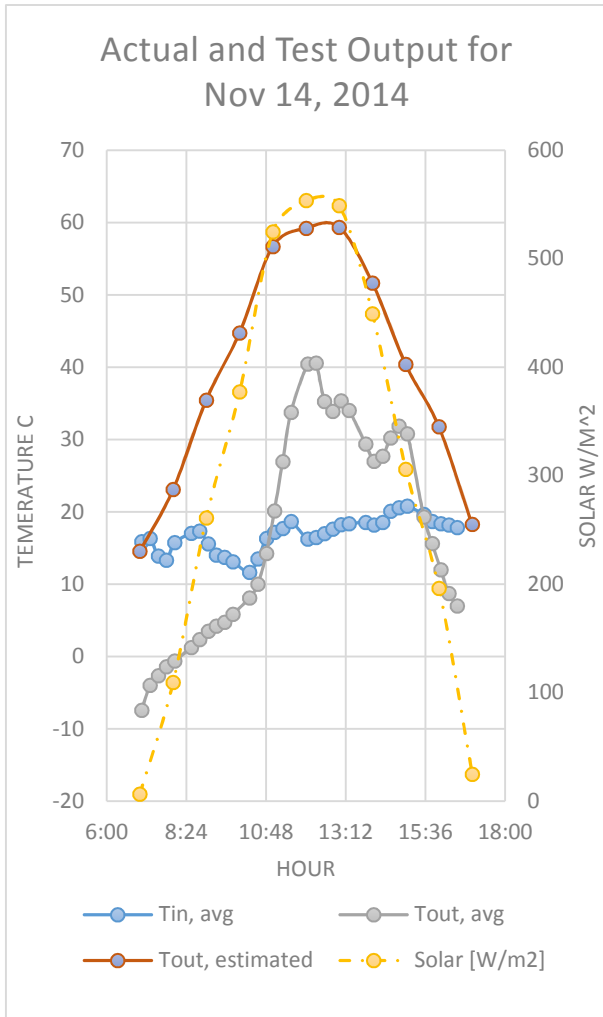
There are heat losses in the solar furnace from several areas. Having the box airtight has a profound effect on heat loss of the solar can furnace. The heat losses of the solar furnace make it necessary to only operate this box when the sun is shining or the net heat gain of the room will be negative. Additionally, the data used as an input for solar gain was from a sensor that was approximately 20 miles from the test site. This can have a large effect on results as cloud cover, snow on the ground etc. might vary greatly in the two locations. With the resources of this tes though, this was the best option for solar data available.

Test Results

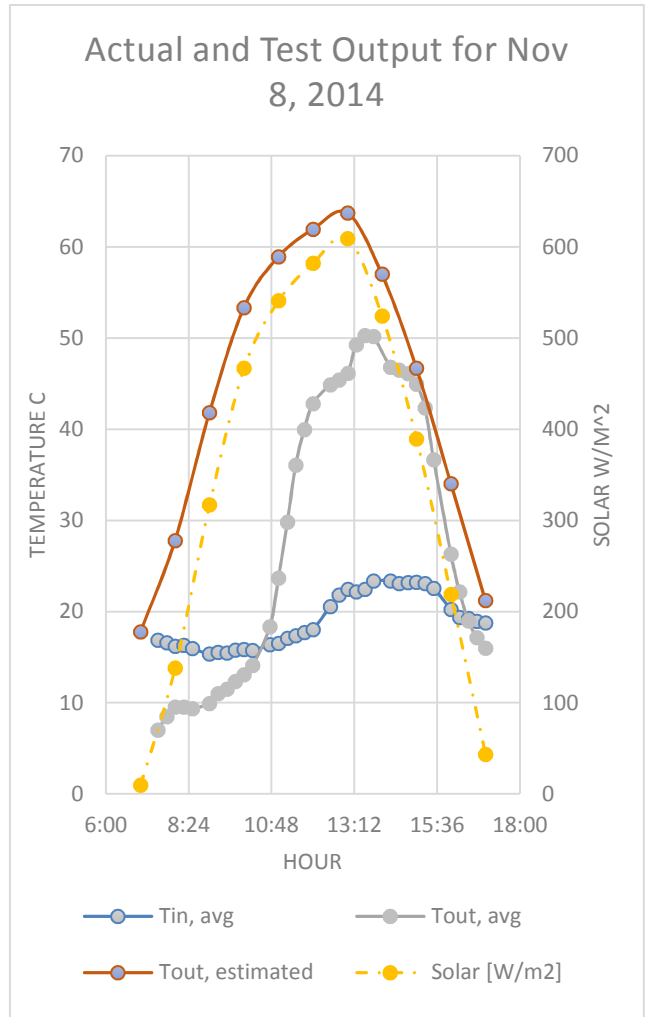
The Solar Furnace was tested on several days from Nov 8th, 2014 – Nov 28th, 2014. The boxes were turned on from 7:00am to 8:00 am and left unattended the majority of the day. During this time the custom Arduino measurement device logged performance data of the furnace. The logged data was compared to the predictive model and an allowable tolerance of plus or minus 5 degrees C was deemed acceptable.

The recorded results fell within this acceptable tolerance of the predictive model. Variation that was observed can be accounted for because of several reasons. The predictive model assumed calm conditions and constant sun as well as a well-sealed box.. Heat loss of the solar furnace greater than the model can be accounted for by external variables that were not easily predicted or accounted for in the modeling. Variation in wind velocity, outside temperature for example , a box not perfectly sealed etc. caused variation in the recorded values from the model.

Average wind speed was used for the calculations but wind speed has a big effect on the heat loss.



Appendix A-Figure11 : Test Data



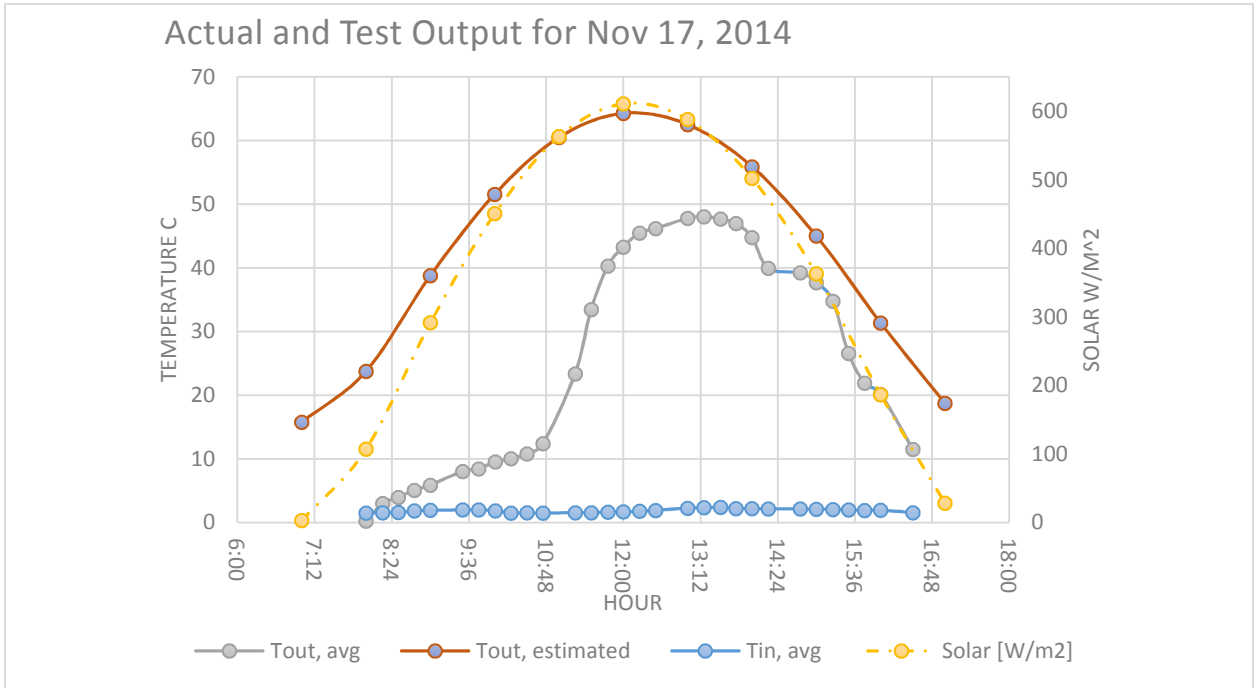
Appendix A-Fig 12: Test Data

The solar furnace did not get the full solar intensity all day. The furnace was in full or partial shade until approximately 11:00 am, this had a big effect on how it performed. When the solar furnace was in the sun it had to establish a steady state and warm up the cold soak during the night time to work efficiently

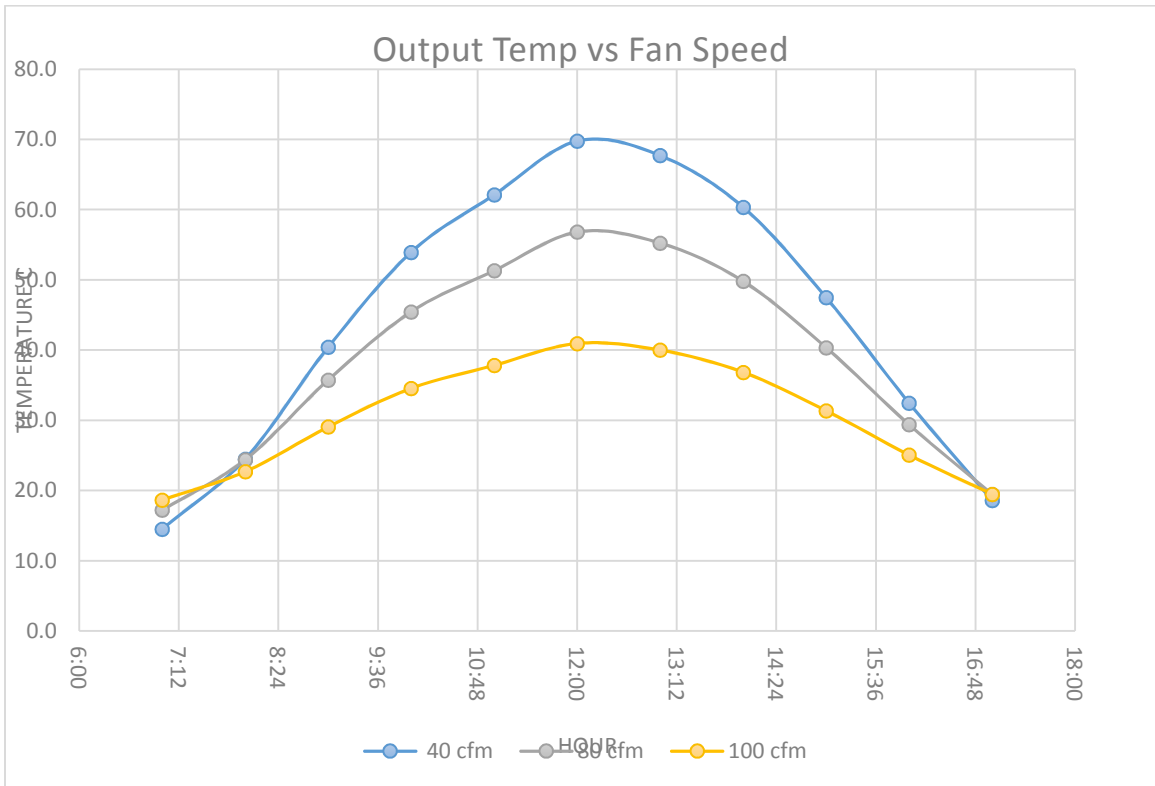
Figure 11, and 12 show that at about 10:45am the output of the furnace starts to climb. The calculated output of the solar furnace does not take into account the effects of shade on the performance. Figure 11 and 13 show smooth curves for the output temperature, figure 12 the output bounces up and down, this variation of temperature is most likely the effect of wind on the box, however this data is not available and is merely speculation based on experience.

The Solar furnace was tested using only one speed of fan, the mass flow rate can be extrapolated by entering higher flow values into the SolidWorks FloXpress application. The flow through the cans with a 40 cfm fan is approximately 0.9 m/s, the flow through the cans with a 100 cfm fan is approximately 3.0 m/s. Figure 14 illustrates the effect of fan speed on the output of the solar furnace.

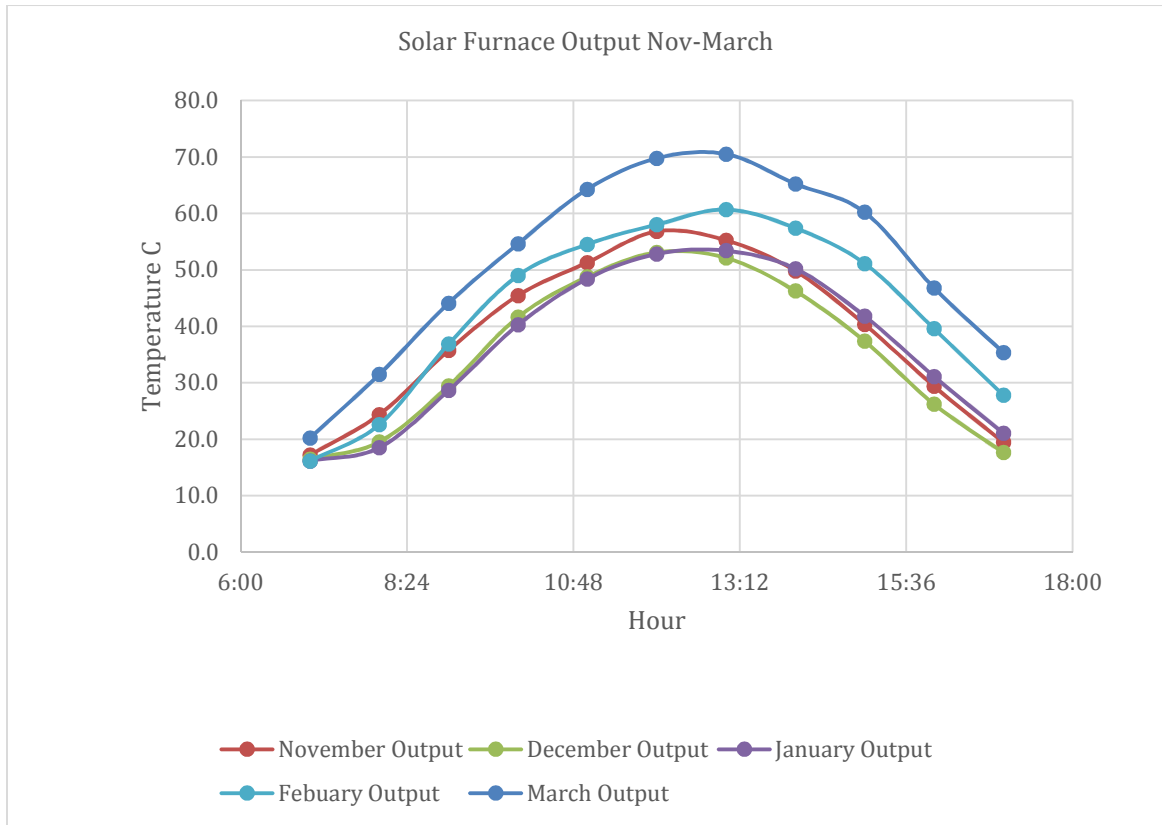
Appendix A-Figure 13: Test data for Nov 17, 2014



Appendix A-Figure 14: Predicted fan speed vs output temperature



Appendix A-Figure 15: regional data based on month



Cost Examination

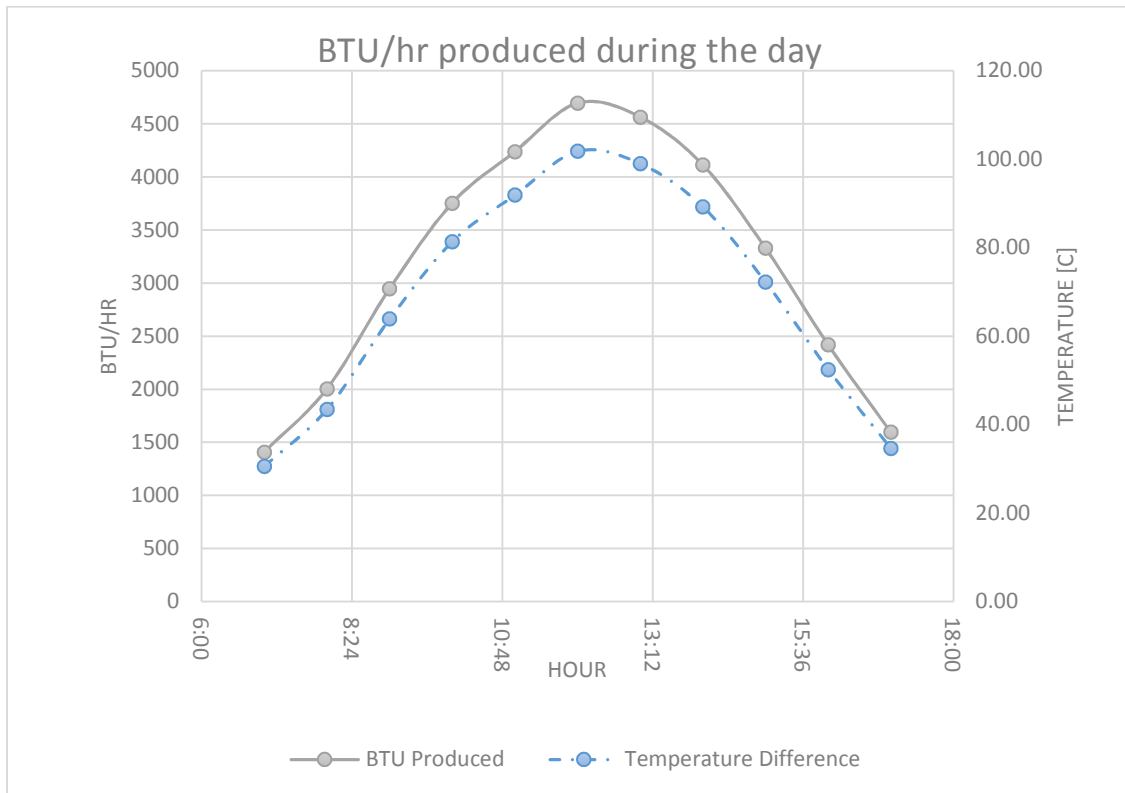
The estimated saving of the solar furnace can be estimated by using eq. (15)

$$BTUH = \rho_{air} \times CFM \times \Delta T \quad (15)$$

The average airspeed out of the box measure with the thermo-anemometer probe is approximately 590 ft/min, the outlet is a 4 inch diameter. Using eq. (16) to find CFM.

$$CFM = FPM \times Area \quad (16)$$

Appendix A-Figure 16: BTU produced



The BTUs produced are based on the temperature output at the ends of the solar furnace, in the test model the air had to pass through 6 feet of ducting which caused it to drop in both mass flow and temperature. The most effective way to install the solar furnace would be to use a little ducting at possible, or eliminate ducting all together by piping directing through an external wall.

The following is the sketchbook code for the data-logging and temperature sensing program loaded on the Arduino UNO R3.

```
/*
  SD card datalogger

  The circuit:
  * analog sensors on analog ins 0, 1, and 2
  * SD card attached to SPI bus as follows:
  ** MOSI - pin 11
  ** MISO - pin 12
  ** CLK - pin 13
  ** CS - pin 4

  */
#include <SD.h>

// On the Ethernet Shield, CS is pin 4. Note that even if it's not
// used as the CS pin, the hardware CS pin (10 on most Arduino
boards)
// must be left as an output or the SD library
// functions will not work.
const int chipSelect = 4;
unsigned long time;

int sensorPin1 = 0;
int sensorPin2 = 1;
void setup()
{
  // Open serial communications and wait for port to open:
  Serial.begin(9600);
  while (!Serial) {
    ; // wait for serial port to connect.
  }

  Serial.print("Initializing SD card...");
  // make sure that the default chip select pin is set to
  // output, even if you don't use it:
  pinMode(10, OUTPUT);

  // see if the card is present and can be initialized:
  if (!SD.begin(chipSelect)) {
    Serial.println("Card failed, or not present");
    // don't do anything more:
  }
}
```

```

    return;
}
Serial.println("card initialized.");
}

void loop()
{

//sensors:
int reading1 = analogRead(sensorPin1);
  delay (100);
int reading2 = analogRead(sensorPin2);
  delay (0);

// converting that reading to voltage
// Sensor 1
float voltage1 = reading1 * 5.0;
voltage1 /= 1024.0;
// Sensor 2
float voltage2 = reading2 * 5.0;
voltage2 /= 1024.0;
// now print out the temperature
float Temp1 = (voltage1 - 0.5) * 100 ;
float Temp2 = (voltage2 - 0.5) * 100 ;

File dataFile = SD.open("dtest111.txt", FILE_WRITE);
//FILE NAME MUST BE MANUALLY CHANGED:

//start writing data:
  time = millis()/1000;
//prints time since program started
Serial.print(time);
Serial.print(",");
Serial.print(Temp1);
Serial.print(",");
Serial.println(Temp2);

// wait 30 seconds so as not to send massive amounts of data
dataFile.print(time);
dataFile.print(",");
dataFile.print(Temp1);
dataFile.print(",");
dataFile.println(Temp2);
dataFile.close();
delay(30000);
}

```

Sources

Experimental study on heat transfer of solar air heater (1. Aufl. ed.). Saarbrücken: LAP LAMBERT Academic Publishing.

SolidWorks FloXpress Report

SolidWorks FloXpress is a first pass qualitative flow analysis tool which gives insight into water or air flow inside your SolidWorks model. To get more quantitative results like pressure drop, flow rate etc you will have to use Flow Simulation. Please visit www.solidworks.com to learn more about the capabilities of Flow Simulation.

Model

Model Name: complete box.SLDASM

Fluid

Air

Inlet Volume Flow 1

Type	Volume Flow Rate
Faces	Face<1>@Part3^complete box-1
Value	Volume Flow Rate: 0.0300 m ³ /s (80cfm) Temperature: 300.00 K

Environment Pressure 1

Type	Environment Pressure
Faces	Face<2>@Part1^complete box-1
Value	Environment Pressure: 101325.00 Pa Temperature: 293.20 K

Results

Name	Unit	Value
Maximum Velocity	m/s	5.421

Description of Furnace

The aluminum can solar furnace is a cheap and effective method for using the sun to provide warm air using greenhouse principles. In this simple design, sunlight passively heats air within columns of aluminum cans, and the air then flows into the living space. The design is very flexible and can be tailored to use locally available materials, and scaled to perform at the needed level.

To assess its technological viability, a solar furnace was assembled. Test data from the completed furnace showed a temperature rise of 70° F on a cloudy March day in Colorado. As a proof of concept, this furnace was then installed as a functional display at Revision in Westwood for heating their offices. Appendix A: part 2 below provides a detailed approach to the construction of the solar furnaces for Westwood, including materials, tools and assembly.

Appendix A: Part 2

Materials and Tools

The tools and materials required to build the solar furnace, along with their cost (locally), are outlined below in Tables 1 and 2.

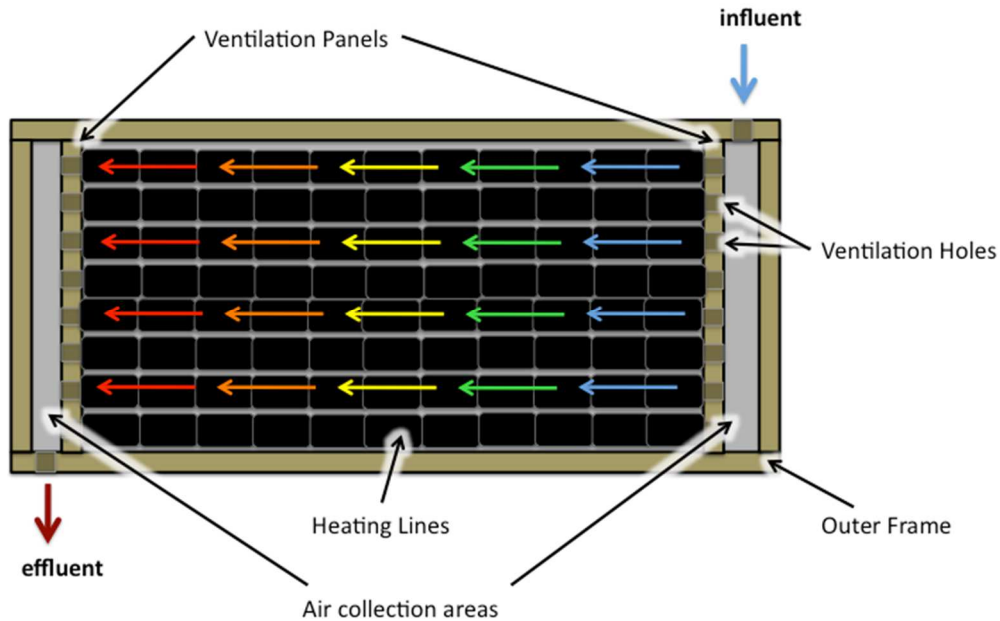
Appendix A: Table 2 . Materials for Prototype Furnace

Qty.	Materials	Cost
144	Aluminum cans	Donated
3	Tubes of fast-drying silicon caulking	\$5.68
1	One sheet of plywood (1/2" x 48" x 96")	\$9.00
3	2x6 wood - 8 ft. lengths	\$11.64
1	Non-yellowing acrylic shield (36" x 48")	\$35.00
1	Nails and screws	\$6.00
1	Matte black spray paint	\$4.00

Appendix A:Table 3. Tools for Prototype Furnace

Qty.	Tool	Cost
1	Electric Drill/Screw gun	Donated
1	Drill bit - 1/4 to 5/8 inch diameter	Donated
1	Caulking gun	Donated
1	Table saw	Donated

Appendix A: Figure 16, below, illustrates the furnace's main component: the solar collector. The collector is installed at a window to the preferred space. A simple, removable box is built to fit in the window opening, and air ducting is connected between the collector and the window box. As the collector heats up, air rises through the heating lines by convection, drawing air from inside the house, through the window opening and into the collector; there, by the same convection process, the heated air is blown back into the house via a small, inexpensive fan through the same window opening.



Appendix A: Figure 16. Solar collector concept design

Furnace Life Cycle Cost

The following life cycle costing is a present worth analysis of initial costs, maintenance costs and annual benefits of the 4 new designs. Present worth analysis used factors. A negative value indicates money saved. This analysis is based upon the following (conservative) assumptions and boundary conditions:

- Five-year analysis period
- 3% real inflation rate
- Acrylic sheet replaced every 5 years
- Shower curtain replaced every 2 years
- Furnaces offset 37 therms per heating season, on average
- Natural gas costs \$0.64 per therm

<i>Design</i>		<i>Donated Cans</i>			<i>Bought Cans</i>		<i>Dryer Venting</i>	
		<i>Proto- type</i>	<i>Shower Curtain</i>	<i>Acrylic</i>	<i>Shower Curtain</i>	<i>Acrylic</i>	<i>Shower Curtain</i>	<i>Acrylic</i>
Initial Costs	Cans	--	--	--	\$32.16	\$32.16	--	--
	Dryer Venting	--	--	--	--	--	\$43.00	\$43.00
	Wood	\$11.64	\$11.64	\$11.64	\$11.64	\$11.64	\$11.64	\$11.64
	Caulk	\$5.68	\$5.68	\$5.68	\$5.68	\$5.68	\$5.68	\$5.68
	Foam Board	\$9.00	\$9.00	\$9.00	\$9.00	\$9.00	\$9.00	\$9.00
	Acrylic	\$35.00	--	\$35.00	--	\$35.00	--	\$35.00
	Shower Curtain	--	\$2.14	--	\$2.14	--	\$2.14	--
	Nails & Screws	\$6.00	\$6.00	\$6.00	\$6.00	\$6.00	\$6.00	\$6.00
	Black Matte Paint	\$4.00	\$4.00	\$4.00	\$4.00	\$4.00	\$4.00	\$4.00
	4-inch Axial Fan	--	\$1.25	\$1.25	\$1.25	\$1.25	\$1.25	\$1.25
	Polystyrene Insulation	--	\$11.58	\$11.58	\$11.58	\$11.58	\$11.58	\$11.58
	Aluminum Tape	--	\$8.48	\$8.48	\$8.48	\$8.48	\$8.48	\$8.48
Maintenanc e Costs	Shower Curtain (every 2 years)	--	\$4.28	--	\$4.28	--	\$4.28	--
	Polycarbonate (every 5 years)	\$35.00	--	\$35.00	--	\$35.00	--	\$35.00
Annual Benefits	Annual Energy Savings	\$23.72	\$23.72	\$23.72	\$23.72	\$23.72	\$23.72	\$23.72
Present Worth Analysis (t=5 years, i=3%)	Initial Costs	\$72.57	\$59.77	\$92.63	\$91.93	\$124.79	\$102.77	\$135.63
	NPW: Maintenance Costs	\$30.19	\$3.81	\$30.19	\$3.82	\$30.19	\$3.81	\$18.92
	NPW: Annual Energy Savings	\$97.76	\$97.76	\$97.76	\$97.76	\$97.76	\$97.76	\$97.76
	<i>Net Present Worth</i>	\$5.01	-\$34.18	\$25.07	-\$2.02	\$57.23	\$8.82	\$68.07
	Discounted Payback Period (months)	13	8	15.6	12.1	19.8	13.5	21.2

Appendix A: Table 4. Life Cycle Costs for Six (6) Solar Furnace Designs
(negative value = money saved)

This Life cycle analysis was applied to the 4 separate designs including. The most economical design utilized donated (or already bought) aluminum cans and a

clear vinyl shower curtain for the solar collector module: conservatively provides a \$34.18 benefit to the user over 5 years at 3%, with a capital cost payback of eight months. But even the least economic design had a payback of 21 months, at which point the beneficiary can collect free heat into the future.

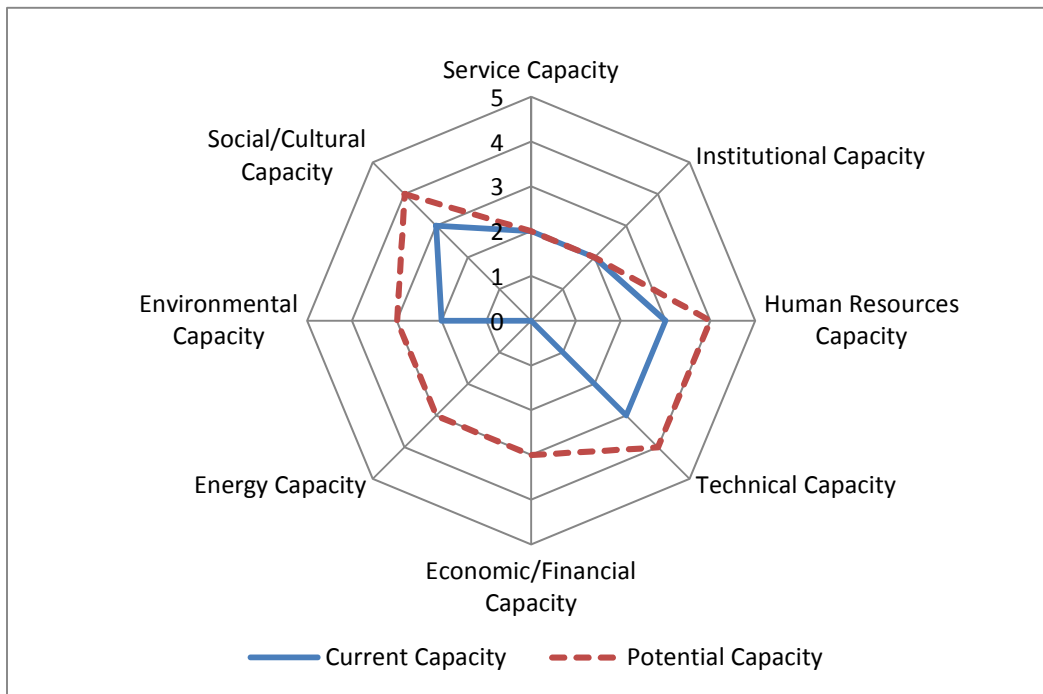
Capacity for Solar Furnace

In order to consider Westwood's capacity to accept and implement the designed solar furnace, the community was evaluated for total capacity for supplemental home energy by assessing eight types of capacity: service, institutional, human resources, technical, economic, energy, environmental, and social. Appendix A: Figure 17 illustrates the results of this evaluation. The solid line indicates the community's current capacity for alternative home energy while the dashed line predicts the improved capacity after successful implementation, which is discussed in a later section of the report.

As indicated, Westwood has some existing capacity for supplemental home energy. The factors were evaluated based on the community appraisal with type given a score between zero and five representing non-existent, low, medium-low, medium, medium-high, and high levels of capacity. Based on qualitative analysis Westwood's greatest capacity for supplemental home energy currently lies in their medium levels of social, human resource, and technical capacities. While the community has some social vulnerability, the sub-community of most direct access—those involved with ReVision International—possess a growing social

capacity through social networks and participation. Westwood also has some very skilled technical workers with noticeable human resource and technical capacities that create a strong baseline for implementing the proposed solar furnace.

Westwood's weakest capacity factors are its seemingly nonexistent economic and energy capacities for supplemental home energy. Many residents do not seem to have backup forms of energy in their homes (for example, fire places or generators), and the low-income nature of the community assumes that few residents have funds set aside for supplemental energy in the case of sporadic outages or large cost increases. These weak links in the capacity analysis show challenges facing the furnace implementation; however, the combination of medium level capacity for social, human resource, and technical factors, and the low level of capacity for energy and economic factors highlight the importance of the proposed solar furnace in Westwood. While the community has the needs for the design solution, the community also has the networks to support both the initial idea and the future ownership of the solar furnace. These networks will be used to address, and likely improve, the weaker links in the community's capacity.



Appendix A: Figure 17: Capacity Analysis Diagram

Community Risks for Solar Furnace

Initial indicators suggest that Westwood has sufficient capacity to take up the proposed design (following the implementation plan outlined below), there will be some risks to the community. Most poignant is in implementing the solar furnaces as a supplemental home energy unit, there will be some risks to residents centered on the installation of the unit. The solar furnace requires some type of connection between the outdoor unit and the indoor air, which will often through a window (although an additional hole through walls or roofs are possible). These connections pose risks to damage homes (which for renters could damage owner-renter relations) through creating drafts, letting in moisture, or damaging existing window treatment. While the implementation section stresses the importance of fitting units to specific windows on a case-level basis, the potential risk should be known. Homeowners will be notified of such risks and, if the community should

chose to implement the units, the design team will provide an overseer for the implementation of the first units, as well as for the training of community members, in order to address this risk.

Environmental Impact

The environmental impact of the solar furnace is largely positive. The unit is constructed of a few purchased materials (such as acrylic sheet, high temperature paint, and cooking) and then primarily recycled materials (144 recycled aluminum cans). Reusing aluminum cans is an intentional part of the design to reduce waste. Other materials are possible to use (as demonstrated by the models built in summer of 2013) which increases the flexibility of the design. Additionally, because the units produce heat that can supplement heat from a home furnace through the sun's renewable energy, this solar furnace creates energy without using any. While one environmental concern, as indicated by the promotoras, is that the unit is "ugly", an aesthetic concern is the primary negative environmental impact. There may also be some value in this negative side as the lack of outward appeal may help prevent theft. As a final note of environmental impact, although long-term testing has not been done, with proper care a five year lifespan for these solar furnaces can be used as a conservative prediction. This length of lifespan could minimize the need for constant need for rebuilding.

Appendix B

Survey

Consent to participate in study

You are being asked to participate in a research study. The study will attempt to evaluate the acceptance of the solar heaters in your community. You will be asked to take a short survey which will be used to measure your satisfaction with your heater and your likelihood to keep using the heater. Participation in this research project is completely voluntary. You have the right to say no. You may change your mind at any time and withdraw. You may choose not to answer specific questions or to stop participating at any time.

There is no cost and no compensation for this survey. Your name and /or any identifying information will not be shared. The results of the study will be published and you can have access to the results if you desire.

If you have questions about your rights as a research study participant, you can call the Institutional Review Board (IRB) at the University of Colorado. The IRB is independent from the research team. You can contact the IRB if you have concerns or complaints that you do not want to talk to the study team about. The IRB phone number is (303) 735-3702."

If you would like to participate please sign the statement below:

Your signature below means that you voluntarily agree to participate in this research study.

Signature

Date

El consentimiento para participar en el estudio

Se le pide a participar en un estudio de investigación. El estudio tratará de evaluar la aceptación de los calentadores solares de su comunidad. Se le pedirá a tomar una breve encuesta que servirá para medir su satisfacción con su calentador y su probabilidad de mantener el uso del calentador. La participación en este proyecto de investigación es completamente voluntaria. Usted tiene el derecho a decir no. Usted puede cambiar de opinión en cualquier momento y retirar. Usted puede optar por no responder a preguntas específicas o dejar de participar en cualquier momento.

No hay costa y ninguna compensación por esta encuesta. Su nombre y / o cualquier información de identificación no será compartida. Los resultados del estudio serán publicados y se puede tener acceso a los resultados si lo desea.

Si tiene alguna pregunta sobre sus derechos como participante de un estudio de investigación, usted puede llamar a la Junta de Revisión Institucional (IRB) de la Universidad de Colorado. El IRB es independiente del equipo de investigación. Puede contactar con el IRB si tiene inquietudes o quejas que usted no quiere hablar con el equipo de estudio sobre. El número de teléfono IRB es (303) 735-3702 ".

Si desea participar, por favor firmar la siguiente declaración:

Su firma significa que usted voluntariamente acepta participar en este estudio de investigación.

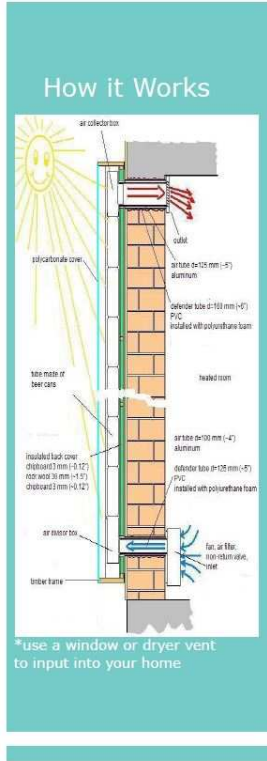
Firma
Fecha

“EZ HEAT” Solar Furnace Survey

- 1) After using your solar furnace how would you rate your satisfaction with the technology on a scale of 1-5 with 1 being dislike and 5 being like very much
- 2) Do you plan to use your solar furnace again this winter?
- 3) Have you had any questions from others about your solar furnace?
- 4) If yes to 3, have people expressed interest in having their own solar furnace?
- 5) On a scale of 1 to 5 (with 1 = to would not recommend and 5 equal to would highly recommend), would you recommend this heater to others?
- 6) On a scale of 1 to 5 (with 1 = it is not a good way and 5 = to it is excellent) Do you think the solar furnace is good way for your community members to lower their heating bills?
- 7) Approximately how much do you guess you saved in heating bills per month because of your solar furnace?

Appendix C

Solar Heater Brochure

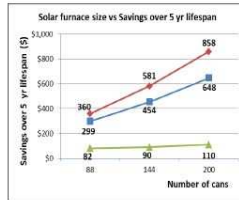
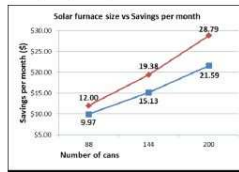


Key Savings

Incredible temperature increase!



Monthly & 5yr Projections



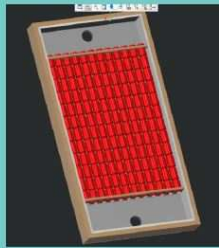
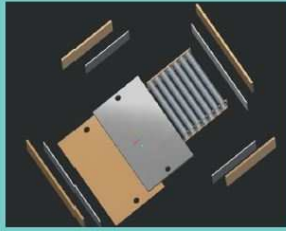
These units pay for themselves in less than two months depending on your material cost

PASSIVE SOLAR HEATERS

FREE HEAT from up-cycled aluminum cans and other reclaimed materials



SAVE \$30 EVERY MONTH



The Basics

- Array of soda can towers (other materials include: aluminum gutters, dryer ventilation)
- Enclosed in insulated box (built to size)
- Polycarbonate screen (other materials include: glass, shower curtains, acrylic)
- Mixing manifolds at top and bottom (Solar or AC powered fan)

Putting it Together

- Use a 1 3/4" hole saw and drill, remove both can ends (Note: using a jig helps hold the can)
- Use silicone glue to assemble cans (Note: a jig made from 2x4's can hold the columns in place)
- Cover cans with high temp black spray paint (BBQ spray paint matte or flat finish works best)
- Build a wooden box to size with horizontal columns at the top and bottom, insulate the box

- Cut ventilation holes in the back of the box at the top and bottom and install dryer ducts
- Install fans and solar cell wiring (ideal range for fans is 80 CFM+ with an appropriate voltage cell)
- Build wooden slats to hold the can columns in the box with a 2" hole saw (seal the cans in columns)
- Place the can columns in the box so the air columns through the cans intersect the top and bottom rows
- Seal all the insulation layers and can columns with silicone and a final clear barrier (acrylic, glass, etc.)

* Tutorials and Videos are available online

Passive Green Heat

These heaters provide a clean and free alternative to fossil fuel based expensive energy. Build yours for winter and start enjoying the incredible energy savings.

List of Materials

Qty	Materials
144	Aluminum cans
2	Tubes of fast-drying silicon caulking
1	4 x 8 plywood
3	2x6 wood - 8ft long
1	Non-yellowing acrylic shield (48" x 60") Or shower curtain (for less expensive option)
1	Box of Nails or screws
1	Matte Black high temperature spray paint
1	AC fan (from ebay - 80+ cfm range)
1	Dryer vent tubing
1	Sheet of foam insulation (optional)

Appendix D

Unintended consequences

This dissertation is concerned with the specific effectiveness of a structured behavior change communication plan for implementing solar furnace use in the Hispanic community of Westwood, Denver. An interesting event took place during the project, which created several unintended side consequences. Tim Carroll, a reporter from Metropolitan State University of Denver's Media Division, took an interest in the project and coordinated a short story which chronicled how the project was involving Metro State Students for the construction and implementation of the furnaces into Westwood. Almost overnight, others in the media who read the article took an interest in this story and the exposure was suddenly and unexpectedly being shared nationally. In addition, this project was presented at several conferences where others found an interest and a connection to how the technology and behavior model might work for projects they were involved with. The exposure, both from media coverage and conference presentations, led to more widespread adoption of this technology beyond Westwood. The following section briefly describes several unintended consequences that sprouted tangentially from the research project.

Media Exposure

The Westwood study gained recognition through media exposure. The first article written ran in the Metropolitan State University News and spoke of the

community impact of the technology in Westwood. From that story, the Denver Post took notice and ran a piece on the project. This led to news coverage on the television by Fox 31 news and NBC (who named me “Community Game Changer” for the month of January 2014). Colorado Public Radio followed suit as well as National Public Radio. The story also ran in the Journal of Higher Education, the Washington Post and other papers.

Below is a partial sharing of some of the articles that covered this project:

DENVER AND THE WEST

Soda-can furnaces powered by solar energy heat Denver neighborhood

[By Anthony Cotton](#)

[The Denver Post](#)

POSTED: 01/09/2014 12:01:00 AM MST

[7 COMMENTS](#)

| UPDATED: ABOUT A YEAR AGO



Metro students Richard Anderson and Zyola Mix install a solar furnace they designed. (*Kathryn Scott Osler, The Denver Post*)

Aaron Brown has built water heaters for schools in Costa Rica and done charity work all around the world. But the Metropolitan State University of Denver professor says some of the most rewarding work he's ever done is happening right now in Denver's Westwood neighborhood.

"You don't have to go to far off places to help people — there are plenty of things to do right here," Brown said. "With this project you feel a lot more rewarded and you see a direct, very local benefit."

Brown, who teaches mechanical engineering at Metro State, is working with students, as well as a local nonprofit organization, Revision International, to build

solar powered furnaces for homes in the neighborhood. With empty soda cans as one of the main parts of the design, the furnaces cost around \$30 to make and are expected to save about the same amount in monthly energy costs.

In November, the group installed two of the heaters in homes, with more installations scheduled for later this month. And while it's possible to "upgrade" the units — spending another \$20 for an acrylic cover, \$2 for a thermostat or \$2.50 for a shower curtain to drape around it — that almost defeats the purpose of providing reliable and inexpensive energy, Brown said.

An initial effort, undertaken with graduate students at the University of Colorado Boulder, yielded a furnace that cost about \$60. But Brown thought the price could be lowered. That was the challenge he posed to his students at Metro State, tasking them with making the units faster, cheaper and more efficient and reliable. "You have to be really creative," said Richard Anderson, a Metro State senior who's part of the project team. "Right now, the unit will last for about a winter without any maintenance. If you bumped up the cost to about \$100, it would last three or four times longer. But you're talking about soda cans and computer fans that you can buy six for \$10 on eBay and you're supplying heat to an entire house."

Anderson said the electricity used by the fans costs about two cents a day. Cool air is drawn into the unit's base and then heated as it travels up through drilled holes in the 144 aluminum cans, which have been heated by the sun. The air then exits through ventilation holes at the top of the unit. While there has to be a supplemental source for heat at night, the units can reach about 170 degrees

during the day. In one of the units installed in November, Anderson said, a room that was about 60 degrees increased to 90 degrees within 20 minutes.

"There was a little boy who was going to be sleeping there. He was going, 'I'm going to be so warm tonight,'" Anderson said. "That was just so cool — it's really exceeded my expectations."

The success has helped temper some of the initial skepticism from some members of the neighborhood. Even though the idea of inexpensive heat came from area residents, there were doubts that the unattractive, simple contraptions would actually work.

Brown and Joseph Teipel, the director of operations and co-founder of Revision, held a series of meetings in the community. And while Revision had previous successes there in areas like backyard gardens and urban farms, some people were still leery.

"You talking about soda cans being glued together, so it's not something that just comes to people's minds," Teipel said. "But the initial installations were key. Now that they've seen it and see how well it works, they're really excited."

When Revision started its backyard gardening initiative in 2009 there were seven families involved. By the end of 2013 there were 200 families, and Teipel said another 100 are expected to join this year.

The plan for the heaters is for Brown and Revision to show residents how to build them themselves and install them in their homes.

"We'd love to see this grow just like the farming did, where the people take over and it just grows," Teipel said.

Brown said there's no reason why the project can't spread beyond Colorado. He's already talked with people in Chicago and recently corresponded with a woman who's connected to refugee camps in Syria.

"It would certainly help them," he said. "It's just a simple, inexpensive technology."

Anthony Cotton: 303-954-1292, acotton@denverpost.com or twitter.com/anthonycottondp

anthonycottondp

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Public radio's live

midday news program

Soda Can Solar Furnace Helps Cut Heating Bills

Here & Now

[Soda Can Solar Furnace Helps Cut Heating Bills](#)

0:00 / 05:01

[Download this story](#)

418 plays

Embed Copy/paste the following code

```
<iframe width="100%" height="124" scrolling="no" frameborder="no"
src="//embed.wbur.org/player/hereandnow/2014/03/06/soda-solar-
furnace"></iframe>
```

[View slideshow](#)



When residents of Westwood, a low-income neighborhood in Denver, were asked what would help them the most, the answer was simple: Help us lower our utility bills.

Engineering students at Metro State University took up that challenge. They designed a furnace that uses recycled materials, is solar powered and costs less than \$50 to build — and pennies a day to run.

From the [Here & Now](#) Contributors Network, **Jenny Brundin** of Colorado Public Radio found out how the design is working.

[Read more on this story via Colorado Public Radio](#)

Reporter

[Jenny Brundin](#), education reporter for Colorado Public Radio. She tweets [@CPRBrundin](#).

Transcript

ROBIN YOUNG, HOST:

It's *HERE AND NOW*.

When residents of Westwood, a low-income neighborhood in Denver, were asked what would help them the most, the answer was simple: Help us lower our utility bills. So engineering students at Metro State University took up that challenge. They designed a furnace that uses recycled materials, is solar-powered, cost less than \$50 to build and pennies a day to run.

From the *HERE AND NOW* contributor's network Colorado Public Radio's Jenny Brundin found out how the design is working.

JENNY BRUNDIN, BYLINE: At the end of every month after his daughter pays the bills, 73-year-old Jose Pitones says...

JOSE PITONES: (Spanish spoken)

BRUNDIN: ...there's nothing left over. He and other families in this southwest Denver neighborhood are barely scraping by. In fact, many here report an income of less than \$17,000 a year.

ERIC KORNACKI: One of the first things you notice when driving through this neighborhood is the poor housing stock.

BRUNDIN: This is Eric Kornacki, executive director of the neighborhood-based group Revision International, which helps families here be more self-sufficient.

KORNACKI: Many of the homes here are terrible in terms of heating, so a lot of families spend a big portion of their budget on trying to heat their homes.

BRUNDIN: Revision enlisted students at Denver's Metro State University to meet that challenge. They designed a low-cost solar furnace, simple enough that families themselves could build it, install it and replace it. The students started with a surprising but familiar material. You know that aluminum soda pop can you toss into the recycle bin? Turns out it's an excellent heat conductor.

RICHARD ANDERSON: The hard part is getting the tops and the bottoms off.

BRUNDIN: Metro State mechanical engineering student Richard Anderson helped build a mechanism that pops out the tops and bottoms of 144 cans in 40 minutes. That's the number needed for one solar heating unit. They're set in a wooden frame, like a big bookcase. The unit pulls air from the house and funnels it through the cans. The sun warms up the air, and a computer fan pushes the air back into the house.

At first, families were skeptical, so was Revision International's Eric Kornacki.

KORNACKI: How is this thing actually going to work? It has soda cans and a computer fan and some spray paint, you know? But after feeling the heat coming out of it, we were sold.

BRUNDIN: Revision still had to sell the idea to the community. What helped was Revision's promotora model. The nonprofit employs women from the community who know how to network and can help convince residents to get on board.

KORNACKI: If a promotora is sold on the idea, they sell the community.

UNIDENTIFIED MAN #1: This is yours? Where's the cord?

BRUNDIN: On a sunny winter morning, the student engineers and the promotoras arrive at Jose Pitones' house. But something's different from when they scoped out the house in the summer.

ZYOLA MIX: This is one that has caused us the most grief.

BRUNDIN: Student Zyola Mix says the sun isn't in the same place in the sky as when they made their first visit. They thought there would be more sun hitting the backyard than there is.

MIX: Yeah. I should have used the app on my phone to determine the sun angle for the winter, but I did not.

(LAUGHTER)

BRUNDIN: They find another vent on the roof to attach the furnace to, but there's a large juniper tree next door that partially blocks the sun.

MIX: Shadow, it's going to...

UNIDENTIFIED MAN #2: Yep.

MIX: ...go over for two to three hours on this thing.

UNIDENTIFIED MAN #2: Yeah.

MIX: So we want morning...

BRUNDIN: The students discuss adjustments and cut an insert into a piece of wood that will bring air into the unit. Many of these engineering students will eventually get jobs on big projects with big firms, but the chance to help out a struggling community has made this project especially worthwhile for the students. Here's Zyola Mix.

MIX: I grew up also needing a lot of help. And so it's just nice to be able to help other people. It makes me feel like I'm still involved in the world and I can see how it is improving.

AARON BROWN: OK.

UNIDENTIFIED MAN #3: Is it running?

BRUNDIN: After a couple hours of work, the solar heater is finally plugged in.

BROWN: There you go. Preheat.

BRUNDIN: Metro State University assistant professor Aaron Brown tells a neighbor the solar heaters save on average about \$25 a month on heating bills.

BROWN: One cent a day.

UNIDENTIFIED MAN #3: One cent. That's good.

BRUNDIN: (Unintelligible) one cent.

Jose Pitones' daughter, Rafaela(ph), says she's excited about the money they'll save.

RAFAELA PITONES: (Spanish spoken)

BRUNDIN: She'll use the extra money for a trip to the grocery, on milk run, or even to pay other bills.

UNIDENTIFIED MAN #4: Thank you.

PITONES: Thank you.

PITONES: Thank you.

BRUNDIN: As the sun continues its arc across the sky, the Pitones family and the students shake hands and offer thanks. Metro student Richard Anderson knows the impact of this furnace will go beyond saving a few dollars. He remembers a child's reaction after installing a solar heater in another home.

ANDERSON: And I walked into the bedroom and the little boy that had that bedroom turned to me, and he had the biggest grin on his face, and he's like, I'm going to sleep so nice tonight because it's so warm in here. And I was like, well, that's it. That's all I needed to hear.

BRUNDIN: For HERE AND NOW, I'm Jenny Brundin, in Denver. Transcript provided by NPR, Copyright NPR.

May 13, 2013

Canned heat: Engineering prof and students build low-tech device to heat homes

[By Cliff Foster](#)



Aluminum cans are the main component of a solar furnace built by Aaron Brown, assistant professor of mechanical engineering technology, and a group of engineering students for last year's Undergraduate Research Conference.

Most people probably think "recycle bin" when they finish a canned soda or a beer. Aaron Brown, assistant professor of mechanical engineering technology, thinks of heat.

Aluminum cans are the main component of a solar furnace built by [Brown](#) and a group of engineering students for last year's Undergraduate Research Conference. Recently he donated the device to a nonprofit in Denver's low-income Westwood neighborhood and he and his students plan on building five more this summer to demonstrate to the community how the units can cut energy bills.

On one level, the idea is to show how an inexpensive and simple technology can help heat a home for nothing. But beyond that, it is meant to strengthen the sense of community in Westwood and promote “humanitarian engineering,” a concept that encourages engineers to use their skills to serve people in need.

“These engineering students are going to have good careers and make good money,” Brown says. “I tell them, ‘You’re going to have a skill set that if you just spent one or two weeks...somewhere in the world doing something for somebody it can really change the lives of a whole generation.”

The existing Westwood solar furnace is made up of 144 cans stacked in 12 rows of 12 cans. The only other materials are plywood, acrylic plastic, paint and a small fan. As air enters the unit, it passes through columns of the hollowed-out cans and is heated by the sun. The fan pushes the warm air into the home through a vent attached to a window-mounted box. One test measured the temperature of the air going into the unit at 70 degrees and leaving it at 150 degrees, Brown says.

Using cans for a solar furnace is not a new idea, but Brown has tweaked the design to make it more efficient and affordable. The materials cost about \$100 but that’s still a sizable amount for many of the households in Westwood.

Brown is working with the nonprofit [Revision International](#) that organized community gardens in Westwood, among other projects. In April, he and his students presented the solar furnace to community leaders, who dubbed the device “Easy Heat.” They will be working with MSU Denver and University of Colorado Boulder students and Revision International to educate residents about the

technology. The project is also the inspiration for Brown's doctoral dissertation through CU Boulder.

Megan Bixler, a junior mechanical engineering technology student, was among the small team that built the furnace. "It's important as an engineer to really understand what you can do for your community," she says. "To know that I built and designed something that will ease financial stress on a low-income family...there is no feeling compared to it."

In January, Brown took 12 MSU Denver students to Costa Rica where they built a solar hot water heater, made of wood and aluminum panels, for a school. This summer he will travel to the Galapagos Islands to work on a clean water project for a group of monks.

Such projects speak to Brown's humanitarian engineering philosophy.

"Ninety percent of the engineering is for 10 percent of the world," says Brown, who once worked on Curiosity, the \$2.5 billion Mars rover. "And there are people who live and die in terrible conditions that are easily remedied through simple engineering solutions."

"We're not talking about Mars technology. We're talking about soda cans."



January Community Game Changer

Pioneering professor at MSU Denver fabricates low-cost furnace □ *By Amy Phare*

With his [students](#) help, support from a local nonprofit and 144 aluminum cans, [Metropolitan State University of Denver](#) Professor Aaron Brown fabricated a solar device that will help reduce heating bills in Denver's Westwood neighborhood by an average of \$30 per month.

And while the [technology](#) isn't revolutionary, the low cost certainly is. Built with simple materials such as soda cans, plywood, paint, plastic and a fan, the device costs just \$35 to create.

"There are people who live and die in terrible conditions that are easily remedied through simple engineering [solutions](#)," says Brown, a professor of [mechanical engineering technology](#). "We're not talking about Mars technology. We're talking about soda cans."

Brown knows all about Mars technology. While working for a Colorado space technology company, Brown helped build the tethering system used to lower the Mars rover Curiosity to the Red Planet's surface.

At MSU Denver, his efforts are geared toward giving back. He launched a humanitarian engineering club and course, through which he and a team of students built a solar hot water heater at a school in Costa Rica.

"One thing I've noticed is that 90 percent of engineering affects only 10 percent of the world," says Brown. "When we identified the high-energy [costs](#) of the low-income Westwood neighborhood, it was really rewarding to be able to

directly benefit the community. Helping people – and having the means to help less-fortunate people – is rewarding in its own right.”

The beauty of the solar furnace project is that it is a gift that keeps giving. The team worked with the nonprofit [Revision International](#), which saw the project as a way to sustain a neighborhood and create jobs. Brown is training the Revision team to build the furnaces, which will eventually create employment for local residents.

As for Brown, his efforts don't stop here. In February, he is organizing a panel discussion on sustainability at MSU Denver's [campus](#). Also next month, he and Ali Thobhani, the University's executive director of the Office of International Studies, will conduct a community assessment in the Dominican Republic.

“We don't want to have preconceived notions of what the community will need, so we're heading there with an open mind to see how engineering can fit,” Brown says.

In the coming months, Brown's work will take him – and his students – worldwide. With a project in the Galapagos, another visit to Costa Rica and a goal of seeing the solar furnace technology expand to Syria, Brown is leaving a lasting impact around the globe, in the Denver community and in MSU Denver's [classrooms](#).

“The service learning aspect for students is such a good experience,” says Brown. “They take away something with them – that this project will make difference in world.”

Colorado Weatherization Program

From the Denver Post article, the CEO of the Colorado Weatherization Program (a program run through the governor's office which is dedicated to reducing energy use and bills for people who qualify under certain financial criteria) discovered the project. Her interest in the effectiveness of the technology led her to contact me to discuss how solar furnaces might be useful to the State's mission of reducing heating expenses for people as part of the Colorado Weatherization program. Our conversations have led to a partnership with their office to develop an implementation plan that could provide solar furnaces to a wider audience in Colorado.

City of Pueblo Energy Project

The city of Pueblo, Colorado is also investigating ways to reduce energy use and, specifically for impoverished members of that community. Moreover, they are concerned with becoming less reliant on carbon producing energy sources. In reading about this technology, the person spearheading this effort approached me to discuss how to collaborate to implement solar furnaces in Pueblo through the program they are creating. At the time I am writing this I am in discussions about how this technology can be implemented in Pueblo

Power for the People Syrian Refugee Camp Project

The Westwood solar furnace project was presented at the IEEE Humanitarian Technology Conference in 2013. At that time I was approached by the CEO of Power for the People, a non-profit group who works on humanitarian causes for refugees. Their work is focused on improving refugee camp conditions. We talked a little bit about her work and contact information was exchanged. Several weeks after, this conversation I National Public Radio ran a report describing how refugees in Jordan and Lebanon from the Syrian crisis were burning their shoes to keep warm in the harsh winter conditions. I immediately contacted Power for the People and we have been discussing how to find financial contributors who can help support implanting solar furnaces to refugee camps in these areas.

Implementation of Solar Furnaces on American Indian Reservation near Durango

I was contacted by an NPR listener who heard the story of the Westwood Project. This person lives in Durango and requested instructions for building their own device, which I supplied. 6 months after this initial conversation, he re-contacted me to express gratitude and describe how he had built solar furnaces for the local reservation and was teaching them how to build their own.