California Energy Commission

CONSULTANT REPORT

Phase 1 Research, Instrumentation, and Monitoring Plan

Lead Locally, EPIC Grant EPC-17-041

Prepared for: **California Energy Commission**
Prepared by: **Sonoma Clean Power Authority**

California Energy Commission
Edmund G. Brown Jr., Governor

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PREFACE

Project Overview

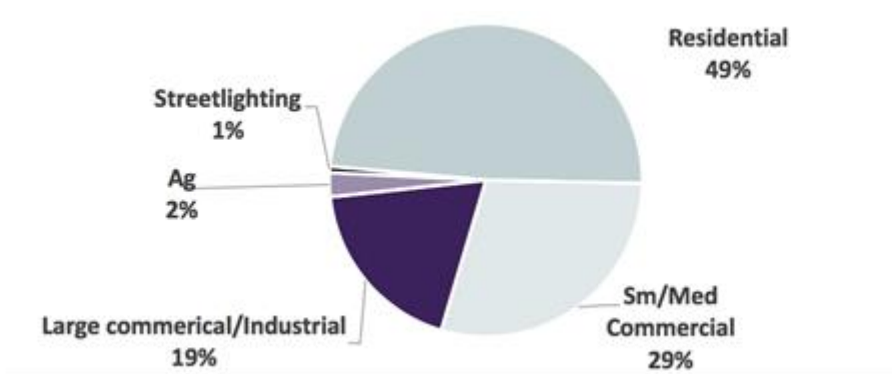
Sonoma Clean Power's (SCP) "Lead Locally" project (Project), funded through the California Energy Commission's (CEC) GFO-17-304 aims to identify strategies and technologies that can assist with the State's goals of doubling the efficiency of existing buildings by 2030. The Project will include applied research and technology deployment activities, each of which will propose innovations that could stimulate the energy efficiency market. With the applied research work, the team will investigate a series of innovative technologies that have the potential to be integrated into existing program models. Lessons learned from the applied research projects will be funneled directly to consumers, contractors, real estate professionals, and building officials through SCP and its local partner organizations. The technology deployment work will be driven in part through the SCP "Energy Marketplace", a physical storefront where consumers can directly procure energy efficient products and services. The Energy Marketplace has the potential to speed deployment of energy efficiency, make energy efficiency programs more accessible to all customers, and increase customer knowledge of energy efficiency and energy code requirements.

About Sonoma Clean Power and its Customers

SCP is a public power provider operating as a community choice aggregator (CCA) and the default electricity provider for Sonoma and Mendocino Counties. SCP exists to provide broad public benefits relating to affordability, reliability, climate change and sustainability, coordination with local agencies, customer programs, and to support the local economy. The default service for SCP customers is CleanStart, which provides customer with 45% renewable power and 87% carbon free power (2017 Climate Registry certified values). SCP customers also have the option to select EverGreen service, which is 100% renewable power produced entirely within the SCP service area.

SCP serves just over 220,000 accounts, of which 86% are residential accounts. On an annual basis, SCP's load is comprised of about 50% residential energy use as shown in Figure P-1.

Fig P-1. SCP Customer Load for 2017



Sonoma Clean Power Authority (SCP), its employees, agents, contractors, and affiliates shall maintain the confidentiality of individual customers' names, service addresses, billing addresses, telephone numbers, email addresses, account numbers, and electricity consumption, except where reasonably necessary to conduct SCP's business or to provide services to customers as required by the California Public Utilities Commission (CPUC). SCP shall not, under any circumstance, disclose customer information for third-party telemarketing, e-mail, or direct mail solicitation. Aggregated data that cannot be traced to specific customers may be released at SCP's discretion.

Any questions or concerns regarding the collection, storage, use, or distribution of customer information, or those who wish to view, inquire about, or dispute any customer information held by SCP or limit the collection, use, or disclosure of such information, may contact Erica Torgerson, Director of Customer Service, via email at etorgerson@sonomacleanpower.org.

Project Team, Roles and Responsibilities

The applied research team is comprised of the following parties (referenced in this document as the Team), with roles and responsibilities outlined below.

Sonoma Clean Power serves as the prime coordinator with the CEC, and will be responsible for identifying project sites, initial outreach to customers, and reporting Project progress to the CEC.

Frontier Energy's lead roles are management of the applied research activities and associated subcontractors, execution of laboratory testing, installation of instrumentation at test sites, analysis of monitored data, energy modeling, and technical reporting.

DNV-GL will provide independent Evaluation, Measurement, and Verification (EM&V) for the Project, specify required measurement points and accuracy levels for the instrumentation package, and evaluate performance relative to the metrics for success.

California Lighting Technology Center will manage the commercial daylighting project, select and evaluate daylighting technologies in both laboratory and field test settings, and assist in extrapolating field performance to estimate energy savings and peak electricity demand reduction for other space types and locations across California.

Energy Docs and **Rick Chitwood** will design and install the radiant panels, air-to-water heat pumps (AWHPs), and load reduction retrofits.

Chiltrix will serve as the vendor for the AWHPs and provide informal design guidance and field test support throughout the project.

PLT Multipoint and **Huvco** will serve as vendors for daylight harvesting sensors and daylight enhancement technologies, respectively, and provide informal design guidance and field test support throughout the project. Additional product vendors may join the Team and provide support as the Project proceeds.

ABSTRACT

The purpose of this Phase 1 Research, Instrumentation, and Monitoring Plan (Plan) is to document the methodology that will be used by the project team to select, refine, characterize, and evaluate specific retrofit measures involving innovative building technologies or applications that present some level of performance or economic risk to building owners and occupants. Phase 1 technologies are on the critical path for Lead Locally and require an accelerated planning schedule to meet later program targets for deployment and technology transfer within the 3½ year timeframe of the grant. This Plan addresses both Phase 1 technologies: Radiant heating and cooling combined with air-to-water heat pumps for residential applications and enhanced daylighting for commercial building applications.

The Plan also addresses proposed steps in the applied research process tailored to the specific technology and retrofit application, culminating in decision criteria for whether the technology is a suitable candidate for large-scale deployment in Sonoma and Mendocino Counties, or elsewhere in Northern California.

The applied research stage of the project will quantify actual technology energy savings through monitoring equipment for the specific installation context, supported by building simulations to normalize and extrapolate the results to additional applications and climates. The EM&V efforts will ensure that these activities are conducted in a technically sound and objective manner, leading to reliable conclusions that can be trusted and acted upon by SCP and other program implementers.

Keywords: California Energy Commission, energy, radiant panels, buildings, research, measurement, verification, EM&V, air-to-water heat pumps, energy efficiency, lighting, daylighting

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EXECUTIVE SUMMARY

This Phase 1 Research, Instrumentation, and Monitoring Plan documents the applied research process to evaluate the energy savings potential for radiant ceiling panels/air-to-water heat pumps and commercial daylighting technologies. While the applied research experiments will be limited to specific buildings and locations, this plan also describes the process for scaling the results statewide through technology demonstrations and large-scale deployment.

The process for applied research includes the following components:

1. Literature review to understand past research and identify unresolved questions.
2. Laboratory testing under controlled conditions.
3. Field testing of electricity savings and cost-effectiveness in occupied buildings.
4. Building energy simulation to evaluate technologies in other climates and building types.
5. Evaluation against success factors for inclusion in future technology demonstration projects, the Energy Marketplace, and/or state-wide energy efficiency programs.

Technology specific approaches are described in Chapters 3 and 4 of this document.

CHAPTER 1: Introduction

The Lead Locally Grant is an innovative programmatic approach to existing buildings research, development and demonstration that includes a range of innovative technologies, program features, and market strategies to engage new customers in energy efficiency upgrades and deliver benefits to California's electric ratepayers. The Grant is led by Sonoma Clean Power (SCP) under funding by the California Energy Commission (CEC) through the Electric Program Investment Charge (EPIC) program. SCP is a community choice energy program providing electricity to 189,000 residential and 31,000 commercial customers in Sonoma and Mendocino Counties. This robust existing building initiative will also serve to complement current fire recovery efforts in Sonoma and Mendocino Counties, enabling SCP programs to have impact far and beyond the scope of this project.

The applied research portion of Lead Locally focuses on several innovative technologies that will be evaluated through laboratory and field testing with the objective of expanding SCP's and other energy efficiency program administrators' portfolios of cost-effective retrofit options. These applied research projects are designed to remove uncertainty around the installed performance and cost of the technology, especially in combination with other retrofit measures, prior to broad deployment of the technology through the Lead Locally Energy Marketplace. Lead Locally will focus on adapting proven technologies and concepts to new applications by optimizing their performance in creative ways, providing building owners and contractors with the knowledge and tools they need to select the right applications, and installing the technologies in a manner that yields the expected energy savings. If at any point specific technologies prove nonviable for near-term application in Northern California, the remaining funding will be applied to more promising technology demonstration projects or technologies identified through the Energy Marketplace. The four applied research projects have been split into Phase 1 and Phase 2 technologies, allowing accelerated planning and preparation for the projects with the tightest timelines. Phase 1 technologies include (1) radiant panels with air-to-water heat pumps and (2) enhanced commercial daylighting.

Purpose

The purpose of this Phase 1 Research, Instrumentation, and Monitoring Plan (Plan) is to document the methodology that will be used by the project team to select, refine, characterize, and evaluate specific retrofit measures involving innovative building technologies or applications that present some level of performance or economic risk to building owners and occupants. Phase 1 technologies are on the critical path for Lead Locally and require an accelerated planning schedule to meet later program targets for deployment and technology transfer within the 3½ year timeframe of the grant.

Scope

This Plan addresses both Phase 1 technologies:

1. Radiant heating and cooling combined with air-to-water heat pumps for residential applications.
2. Enhanced daylighting for commercial building applications.

In the sections that follow, general strategies will be presented for conducting the applied research activities for Lead Locally. These strategies will be relevant for both Phase 1 technologies as well as the Phase 2 technologies (phase change materials and optimized grid-integrated heat pump water heaters) which are not on the critical path and will be addressed in a later plan. The Plan will also address proposed steps in the applied research process tailored to the specific technology and retrofit application, culminating in decision criteria for whether the technology is a suitable candidate for large-scale deployment in Sonoma and Mendocino Counties, or elsewhere in Northern California.

In most cases, a successful applied research projects will include the following components:

1. Literature review to understand past research and identify unresolved questions.
2. Laboratory testing under controlled conditions.
3. Field testing of electricity savings and cost-effectiveness in occupied buildings.
4. Building energy simulation to evaluate technologies in other climates and building types.
5. Evaluation against success factors for inclusion in future technology demonstration projects, the Energy Marketplace, and/or state-wide energy efficiency programs.

EM&V Coordination

SCP is working with its partners Frontier Energy and DNV-GL (collectively referred to as the Team in this document) to deliver a collaborative process for Evaluation, Measurement and Verification (EM&V) methods, baseline methodology, certainty of reported results, data management protocols and application of updates. These methodologies are documented in the Phase 1 EM&V Framework (Framework), which is a corollary to this Plan. The Framework, written by DNV-GL, addresses the following:

- a detailed summary on independent project monitoring and verification, using Investor Owned Utility accepted protocols and the CPUC's California Energy Efficiency Evaluation Protocols.
- a detailed timeline of the evaluation period pre- and post-installation.
- a description of data assumptions and inputs to be used for building simulation models.
- a description of data extrapolation strategies.
- and description of on-going monitoring and verification to evaluate persistence and sustainability of savings, post-EPIC funding.

Frontier Energy has provided feedback to the draft Phase 1 Framework document and has ensured that this Plan is consistent with the requirements set-out in the Framework. Frontier's and DNV-GL's collective experiences of implementing and evaluating CEC research programs and CPUC ratepayer Energy Efficiency programs across the state of California will be used to ensure Lead Locally technologies are deployed and evaluated with an eye for how successful measures and strategies could be integrated into statewide energy efficiency portfolios.

The applied research stage of the project will quantify actual technology energy savings through monitoring equipment for the specific installation context, supported by building simulations to normalize and extrapolate the results to additional applications and climates. The EM&V efforts will ensure that these activities are conducted in technically sound and objective manner, leading to reliable conclusions that can be trusted and acted upon by SCP and other program implementers.

Table 1 details the general roles of Frontier and DNV-GL in relation to EM&V during the Applied Research Stage:

Table 1: Applied Research Stage EM&V Roles.

Frontier Energy	DNV-GL
Write Research, Instrumentation, and Monitoring Plan consistent with the EM&V framework, including minimum data sets and collection methods specified by DNV-GL.	Write EM&V Framework for applied research projects consistent with the project vision articulated in the proposal and the Research, Instrumentation, and Monitoring Plan.
Determine characteristics of target test houses for each technology.	Advise Frontier if additional test houses, operating scenarios, or control samples will be needed to obtain reliable energy savings estimates.
Identify and purchase appropriate monitoring equipment and instrumentation.	Verify that all sources of uncertainty are monitored or addressed.
Install pre-retrofit instrumentation in test houses, install additional sensors if needed following retrofit, and remove instrumentation after one year of post-retrofit monitoring.	Perform quality assurance on monitored data, and inform Frontier when problems are observed.
Provide DNV-GL with access to monitored data.	Obtain and store utility billing data for test houses.
Characterize the performance of each technology in terms of energy savings and comfort relative to expectations.	Extrapolate energy savings to the rest of California using market diffusion modeling and Frontier's energy savings, cost, and target market data.
Develop energy models and analyze the expected cost-effectiveness of technologies in alternative building types, applications and California	Verify inputs to the energy models.

climate zones based on test results and cost data.	Ensure that energy models adequately reflect energy end-use and premise data.
Provide technical data for use in evaluating whether success factors were met.	Recommend whether to abandon a technology, proceed with a Technology Demonstration, or begin deployment.

The project team will maintain accurate, up-to-date, and secure records for individual project sites and overall grant/project data over the course of the grant (minimum: 3½ years). Reporting on customer sites will continue for up to 3 years of activity, potentially across multiple technologies and multiple phases of the project.

Baseline monitoring will be used to determine the conditions prior to the energy efficiency technology being installed. In all cases, it will be attempted to capture representative operating modes of the building (system) or the equipment during a normal seasonal operating cycle; the baseline period will representatively account for both heating and cooling seasons.

The reporting activities for each technology in the Project will include the following:

- The measurement period start and end points in time.
- Observed data of the reporting period.
- The values of independent variables.
- Description/justification for any corrections made to the recorded data.
- Any estimated values used in the calculations.
- Utility rates used.
- Details of any non-routine adjustments performed on the baseline.
- Explanation of the change in conditions since the baseline period.
- All observed facts and assumptions.
- Engineering calculations leading to any adjustments of the baseline.
- Computed reductions in energy use, electricity demand and energy costs.
- First cost (current and projected at maturity) and impacts on operating and maintenance costs.

The project will roll-out to additional sites to get to 300,000 square feet of building space achieving an average minimum site electric savings of 10% for residential sites and 20% for commercial sites. This will likely be somewhere in the neighborhood of 100-150 sites across all technologies, which may or may not include “Sites with Monitoring”.

CHAPTER 2: Lead Locally Research Approach

This section describes general concepts, strategies, and resources relevant to all Lead Locally applied research projects, including both Phase 1 and Phase 2, as well as many of the technology demonstration projects that are designed to address more limited performance uncertainties. Detailed methodologies tailored to specific Phase 1 technologies are discussed in Sections 3 and 4 of this Plan.

Literature Review

The first step in any well-conceived research project is to understand the state of the technology and the results of previous work conducted by other researchers. This is accomplished primarily through a literature search, supplemented with direct conversations with manufacturers and researchers. It is essential to properly leverage project funds by building upon the work of others, especially when past work has been performed by independent third parties, as opposed to manufacturers or advocates.

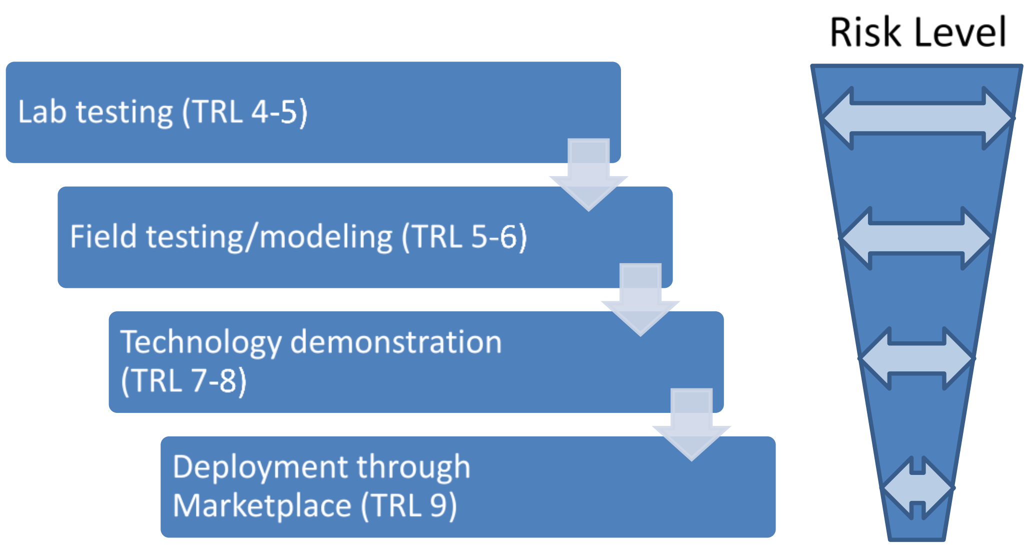
Through the literature review, the Team will estimate projected energy savings when the technology is applied to target building sectors and climate zones. If the literature indicates that the technology has the potential to help the Lead Locally achieve 10% electricity savings in residential buildings or 20% in commercial buildings, the Team will investigate installation costs, interactions with other building system, durability, reliability, noise, aesthetics, savings persistence, and documented risks related to occupant comfort, health, and safety. For some technologies, installed performance may be well understood through past laboratory and field studies, and only the technology's effectiveness in retrofit applications or specific climates remains untested. In other cases, the technology may be very new and largely unproven, in which case a more comprehensive research approach is required to manage risk to SCP ratepayers.

Risk Management

There are several categories of risk that must be considered for a research project involving real homeowners and building occupants. Performance risk involves the possibility that energy savings may be less than expected, and there is even a chance that energy bills will increase. This risk can be mitigated by carefully selecting appropriate technology applications, educating occupants about proper operation and maintenance, spotting problems early by monitoring operating characteristics continuously over a range of conditions, and fielding and responding to customer questions and concerns during the test period. There are application risks when a technology is moved from the controlled conditions of a laboratory to a real building. Unexpected systems interactions, occupant complaints, permitting issues, and other practical issues may arise. Cost risk should not be a major issue for applied research projects, because the CEC and/or SCP will pay for the equipment purchase and installation. However, it will be important to track installation costs at the test sites to determine if the technology was cost-effective, and perhaps find ways to reduce future costs through contractor training and certification efforts. With a sufficient quantity and diversity of field test sites, the Team hopes to identify many of these issues early and provide solutions to building owners and contractors during the deployment phase though education and training.

Technology Readiness Level (TRL) is a good indicator of the level of risk associated with a technology or product. The applied research projects for Lead Locally are considered either TRL 4 (Component and/or system validation in laboratory environment) or TRL 5 (Laboratory scale, similar system validation in relevant environment). Our objective is to move the technologies to TRL 8 (Actual system completed and qualified through test and demonstration) over the course of the program and take steps toward TRL 9. Lead Locally has adopted a gradual risk reduction process that includes lab testing, field testing, modeling, and technology demonstration, before proceeding with large scale deployment (see Figure 1).

Figure 1: Risk reduction strategy for Lead Locally.



Another important output of the literature review is a listing of important, unresolved research questions that will be answered during the execution of the project. Research questions are similar to hypotheses, except they don't state an expected conclusion that might give the appearance of bias. Research questions should be specific, objective, and relevant to the goals of the research project. The following are examples of poorly developed research questions:

- Is the technology cost-effective? (too broad)
- Why is the technology underused in commercial buildings? (biased)
- What product design modifications would improve performance? (not within scope)

Appropriate research questions include the following:

- Is the technology cost-effective as a retrofit for classrooms in K-12 schools in Climate Zone 2?

- What are the technology, cost, and market barriers for application of the technology in commercial buildings?
- Does installed performance align with expectations based on the manufacturer's published data?

These questions may be addressed in any or all of the research stages shown in Figure 1. If there are no relevant questions to be addressed in a particular research stage, that stage will be skipped. For example, if the only unanswered questions about the performance of a product relate to occupant interaction or acceptance, the lab testing stage is unnecessary. Similarly, if the Team is unable to answer key research questions during a particular stage, it may be necessary to either perform additional work before moving on to the next stage, or abandon the applied research project in favor of other technologies or opportunities. Research questions will also guide the amount of instrumentation, data intervals, test duration, and other aspects of the test plans. Collecting data that isn't useful for answering research questions can be costly and inefficient. Similarly, key data points from the instrumentation plan may be accidentally omitted if the desired outputs and prerequisite calculations aren't carefully considered.

Laboratory Testing

Most of the energy consuming equipment used in buildings undergoes standardized testing at a certified laboratory to establish rated performance characteristics that consumers can understand and can be used as the basis for comparing products. However, the performance of rated equipment in new applications or as part of a complete system may not be known with a high degree of confidence, and additional laboratory testing may be necessary to reduce performance uncertainty prior to implementation in occupied buildings. The lab testing activities in support of Lead Locally will focus on technology evaluation under a range of operating and environmental conditions that encompass the conditions expected in actual building installations.

Three separate laboratory facilities will be leveraged for the testing of appropriate Lead Locally technologies under controlled conditions:

1. Frontier's Building Science Research Laboratory (BSRL) is a 2200 ft^2 facility in Davis, California, that has been used since 2003 for testing equipment, fabricating prototypes, and maintaining field monitoring systems. The BSRL has been used for the evaluation of heat recovery systems, evaporative cooling technologies, tankless water heaters, furnaces and fan coils, and ventilation cooling systems. Improvements made in 2017 included construction of two large environmental chambers (see Figure 2) that can be used for the testing of residential and commercial HVAC technologies, water heating equipment, and building envelope components such as phase change materials (PCMs). A 10-ton variable speed packaged unit is currently used for conditioning the air in the larger test chamber and introducing the desired thermal loads on outdoor equipment. An additional radiant heating and cooling capability will be added to the smaller chamber as part of Lead Locally to simulate both indoor and semi-conditioned spaces and allow testing of subtler thermal phenomena such as heat transfer rates for PCMs. An air-to-water heat pump and tankless gas water heater are available for providing heated and chilled water for testing hydronic coils, radiant panels, and drain water heat

recovery devices. A LabView setup will be used to monitor and control equipment during experiments.

2. Frontier's Food Service Technology Center (FSTC) in San Ramon, California, is an ISO-certified testing lab designed to run ASTM/EnergySTAR/ASHRAE tests pertaining to commercial foodservice equipment. The facility includes six National Instruments/Labview portable data loggers which can take 20 thermocouple channels, as well as 3 pulse channels and an electric meter with a multiple-point input. There are two lab spaces at FSTC:

    - Space 1 is the main set of test cells. There are enough spaces for 6 appliances to be tested simultaneously. It has 208V, 120V, natural gas and water service. Metering equipment includes a calorimeter, numerous diaphragm gas meters, multiple grades of water meters and pressure regulators. The ventilation equipment is equipped with variable frequency drives and manual controllers, and each side of the hood can operate independently.
    - Space 2 is the Commercial Kitchen Ventilation (CKV) lab, shown in Figure 3. This space is conditioned with highly controllable ventilation, supply and return air equipment, and floor-to-shoulder diffusers. The lab is set up to easily exchange hoods, and includes a humidifier, multiple RH sensors, a few thermocouple trees, and some more-sophisticated logging software.

3. The California Lighting Technology Center (CLTC) in Davis, California, includes full-scale laboratories for research and development of next-generation, energy-efficient lighting and daylighting technologies (See Figure 4). CLTC also conducts independent product testing and market research, providing accurate data on the state of the lighting market to regulators and end-users. For Lead Locally, the CLTC test facilities will be used to evaluate the effectiveness of daylight harvesting sensors and control algorithms, and to characterize the performance of daylight enhancement technologies such as fiber optics under controlled conditions.

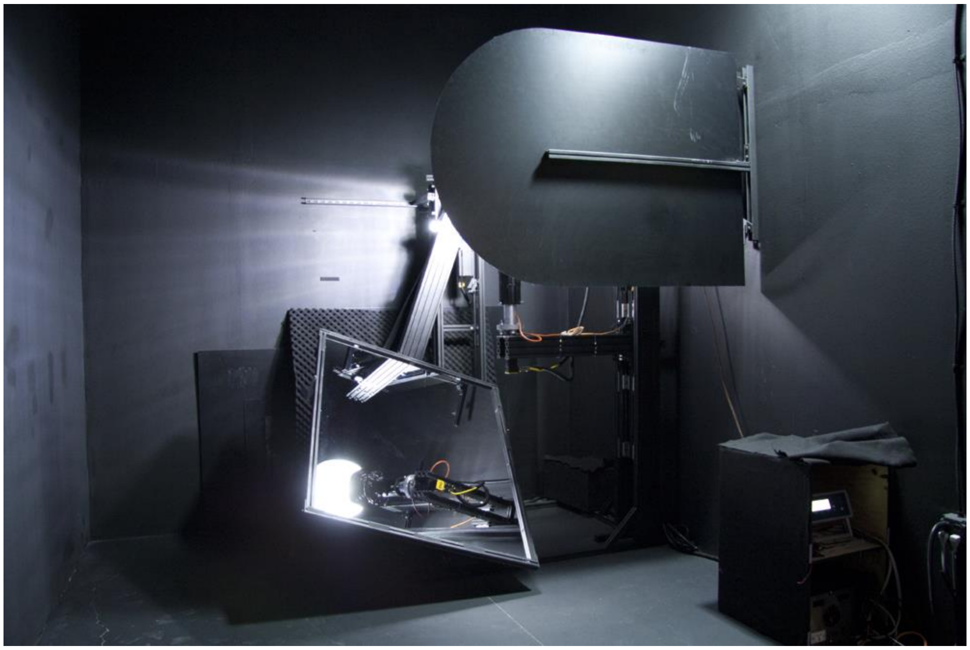
Figure 2: Environmental test chambers at the Frontier Energy – Davis lab facility

Credit: Joshua McNeil

Figure 3: Commercial Kitchen Ventilation Laboratory at the FSTC in San Ramon.

Credit: Michael Slater

Figure 4: One of several test chambers used for lighting technology evaluation at CLTC.



Credit: CLTC

The lab testing activities for Lead Locally will address multiple technologies over a compressed timeframe during the first year of the program. As a result, significant coordination is required to prioritize and schedule lab testing at each of the three facilities so disruption from competing test activities is minimized. Outlook schedules have been set up to reserve time in each chamber at the Frontier-Davis facility. A laboratory manager has been assigned by Frontier to ensure the smooth execution of all lab test activities, identify and implement any necessary lab modifications in preparation for upcoming tests, track CEC-funded equipment and test apparatus, and resolve competing requests for access to test facilities or staff. In addition, Frontier has performed job safety analyses for the laboratories in Davis and San Ramon, and has established safety protocols compliant with PG&E's safety policy, including an extensive training program for all laboratory and field test staff. CLTC has instituted similar safety programs and protocols.

Field Testing

Once laboratory testing has verified that expected performance is achieved within a reasonable margin under well-controlled operating conditions, each technology will be installed and monitored in a small number of occupied buildings. These field tests will help identify unexpected performance issues that only become apparent when the technology is subjected to realistic weather conditions and occupant behavior.

Site Selection

In general, the Team will target field test sites that offer the best opportunities for success, in terms of both electricity savings and cost-effectiveness. If the technologies do not perform well in these applications, SCP will recommend investing remaining funds into promising alternative technologies identified through the Energy Marketplace vendor solicitation. If the technologies prove successful, building energy simulations will be used to extrapolate the results to other CEC climate zones and less ideal applications. The applied research project will also transition to the technology demonstration stage, where a larger and more diverse set of buildings can be evaluated.

The first step in the site selection process is to develop a screening matrix that lists the essential, important, and desired characteristics of the field test sites. The criteria may be driven by technology performance considerations (e.g. heat recovery ventilators save more energy when outside temperatures are more extreme), cost limitations (e.g. the budget for residential phase change materials may limit the size of the attic footprint),), or practical issues (e.g. there must be enough space to install a heat pump water heater). Additional considerations will include criteria that may influence the realization of energy savings (e.g., is the building occupied year-round) and health and safety issues specific to any retrofits (e.g., is the building likely to contain asbestos based on vintage). These criteria will help ensure effective field tests with minimal complications.

The SCP, Frontier, and DNV-GL teams will use the screening matrix to identify features that will be critical, important, or desirable for each of the applied research technologies. Based on the cost of direct mail, the initial customer outreach and solicitation will be through digital channels (e-mail, social media, etc.). Interested customers will be directed to an SCP-hosted web page with additional details on Lead Locally, expectations and benefits for customer participation, and select qualifying questions based on identified screening criteria. Responses to these questions will be merged with data sets SCP has access to, including: internal customer billing data and account information; other customer data on file including participation in SCP programs; parcel data from the Sonoma County and Mendocino County Assessor's and

Recorder's Offices; and building department data from Sonoma and Mendocino County building departments. SCP customer care specialists will use the screening matrix to filter incoming interest from building owners to qualify sites. If the screening criteria prove overly restrictive and result in very few candidate test sites, the criteria will be loosened up in non-essential categories.

SCP customer care specialists are experienced in a range of outreach and marketing strategies and customer service best-practices. This is important because the recruitment effort may need to include a range of customer engagement activities to reach the target number of selected sites. Customers may be excited about the opportunity to participate in the project and have new high performing equipment installed in their home or business at no cost to them. However, some customers may be skeptical or risk-averse, especially if they are asked to accept certain responsibilities through a participant agreement. An effective strategy to recruit interested and qualified sites will increase the likelihood that those sites can be selected for the project following an initial site visit and reduce the risk of significant time and effort being spent visiting sites that turn out to be poorly suited for the project.

Once a manageable number of candidate sites have been identified and recruited, a short walk-through audit will be conducted to determine if there are any unexpected features of the building or its occupants that could affect its viability as a test site. Possible issues might include incorrect screening results, unsafe conditions, or inadequate space for the equipment. A homeowner orientation will also be held with building owners and occupants to make sure their expectations are realistic and consistent with the goals of the project. Following this final filtering step, the remaining candidates will be ranked and narrowed down to the desired number of test sites, as defined in Table 2.

Table 2: Number of Phase 1 Sites During Each Stage of Screening Process

Phase I Technology	Pre-Screened Sites from SCP Data Sources	Recruited Sites from further SCP qualification	Sites Selected for Monitoring
Radiant Panels	200	10	5
Daylighting	120	6	3

Measure Installation

Specific measure design and installation plans will be developed once the test sites have been selected. All necessary permits will be obtained prior to the start of measure installation at each test site. Installation of each measure will be performed by subcontractors that are well-trained and knowledgeable about best practices for installing and commissioning the technology in various applications. All activities will be well-coordinated with building owners to minimize inconvenience to occupants.

Customer Care

As field testing is conducted the Team will ensure that homeowners and building occupants understand the benefits of participating in the program and are given excellent customer care.

All participating building owners will be presented with a Building Owner Agreement, which will clarify what participating in the program will entail such as: expected performance and benefits of installed technologies, the installation process, monitoring required during the testing period, responsibility of proper operation and maintenance, protection of personal information, and how to address performance issues that may arise with the technology installation. This agreement, in addition to initial recruitment and site visits, will help to communicate what the building owner should expect from participation in the program. All participants' personal information will be protected and stored in a safe encrypted environment. The agreement will also protect and set expectations for SCP and subcontractor staff accessing properties. All staff accessing properties will be trained on how to safely access customer properties and work sites to help prevent incidents.

Part of delivering excellent customer care and program satisfaction is communicating effectively and responding to requests in a timely matter. A monitored call line will be available for participants to communicate performance issues, feedback or general questions. Customer care specialist staff monitoring the call line will be trained on how to address performance issues and ensure that next steps are taken to resolve issues promptly. This will include notification of points of contact at SCP and resolving the issue through work of a subcontractor or other project team member.

To help determine overall satisfaction of installed equipment each participant will fill out a questionnaire sharing their experience. This questionnaire will provide the program with valuable feedback on the usability of the technology on a day-to-day basis, and address any detailed issues not captured when the instrument package is installed.

Not only is this level of care important from a customer service perspective for SCP, but it will also help ensure that the program elicits good responsiveness and data from customers. When a customer has a positive experience participating in a program, this helps earn the program and the Energy Marketplace some of the best marketing possible – word of mouth.

Baseline Determination

Each field test must include a well-established baseline that can be compared to the retrofit case for the purpose of calculating energy savings:

- **Pre-retrofit**. The most common baseline is the site itself prior to the energy retrofit, because the space geometry, operating conditions, internal gains, air leakage, climatic conditions, and other building attributes are usually identical. However, year-to-year weather differences must be accounted for, and there must be verification that occupancy levels and usage patterns did not change significantly. In some cases, the retrofit may be part of a remodeling effort that corresponds to a change in occupancy. In those cases, the pre-retrofit case is not a viable control for the field test, except as a hypothetical scenario analyzed using building energy simulation.
- **Similar buildings**. Buildings with similar physical characteristics and occupancy types are sometimes used as the control case when pre-retrofit data is unavailable or inappropriate due to a change in occupancy or major remodeling that coincides with the energy retrofits. This approach is more common with new construction in residential

neighborhoods with standard home models, and usually requires large sample sizes to achieve reasonable accuracy and overcome variations in occupant behavior. It is unlikely that similar buildings will be used as a control case for this project.

- **Similar spaces in the same building**. In larger commercial buildings, there may be very similar spaces on different floors or different section of the buildings. This option can avoid challenges related to year-to-year weather differences, reduce the overall timeline for the field test, and be more efficient from a cost standpoint. However, spaces are never identical, and uncertainty can be introduced by small differences in geometry, layout, and occupant behavior.
- **Modeled baseline case**. When no physical control case is available, such as when a building is repurposed, an energy model can be used to analyze the theoretical energy use of the test site prior to retrofit. Often the most convenient theoretical baseline is code minimum. Because validation of the baseline model is impossible in this scenario, validation should be performed for the retrofit case, and the results (e.g. air leakage, internal gains, operating conditions) should be applied to both models. This approach is sometimes referred to as "Model Enhanced Monitoring".

The selection of an appropriate baseline depends on the nature of the technology and the characteristics of the test site. Further details on this topic are provided in the specific technology sections of this plan.

Monitoring Approach

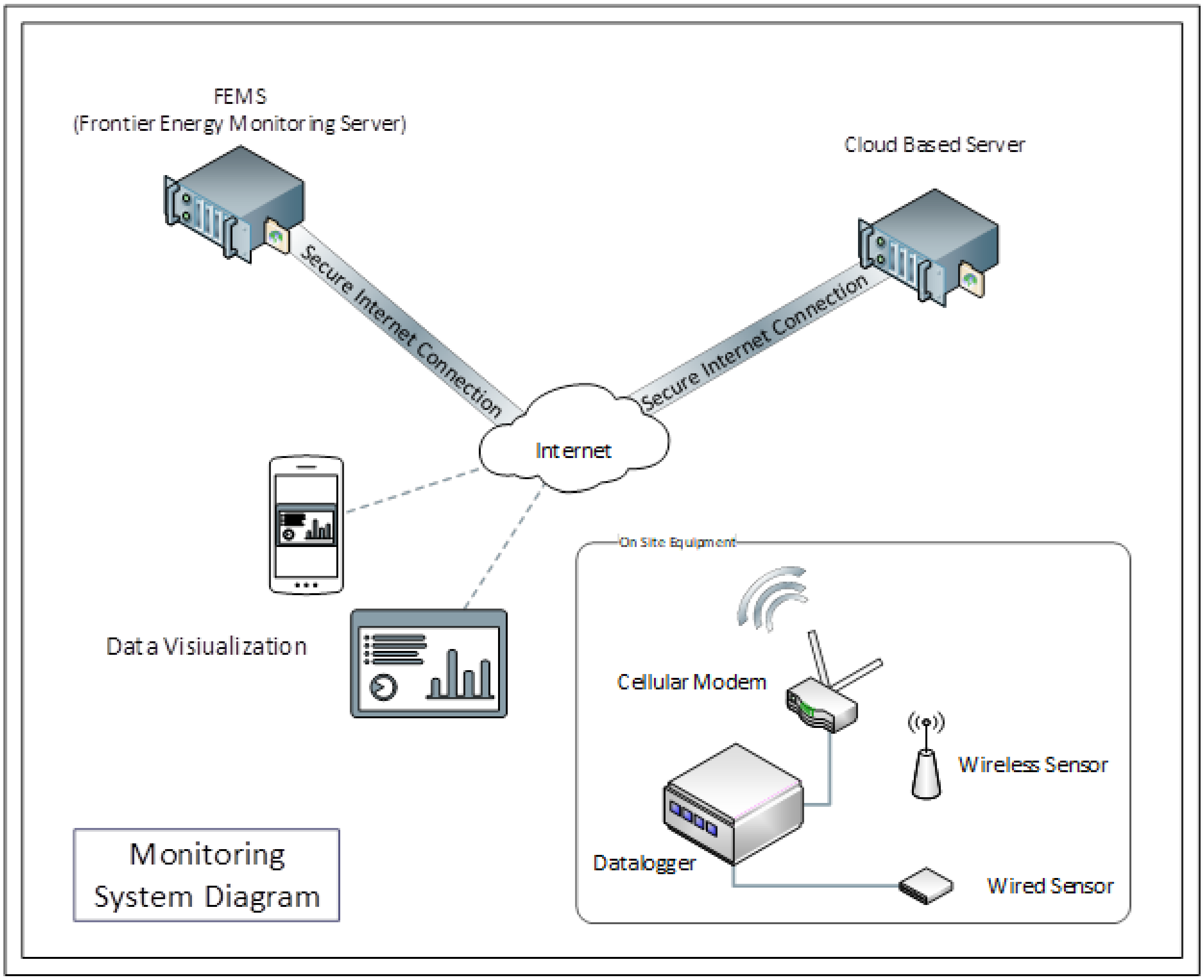
Field test data will be monitored for all test sites (baseline and post-retrofit) for the length of time necessary to ensure performance is observed under the full range of weather conditions, typically between six months and one year. Additional factors may affect test duration depending on the technology and building type, such as seasonal variations in operating conditions and ground water temperature. The range of performance data that will be collected is highly dependent on the technology, risk areas, and research questions that must be addressed, but electricity savings, comfort impacts, and cost data will be tracked for all projects.

The specific monitoring approach will be tailored to the systems and research goals at each building, though basic methods and devices will be kept as uniform as possible across field monitoring efforts. Figure 5 provides a high-level diagram of the monitoring methods and systems described in this section.

To the greatest extent possible, the monitoring systems and sensors used in the baseline monitoring periods will continue to be used in the retrofit monitoring periods at each site. Data will be collected from both wireless and wired sensors by one or more dataloggers. The dataloggers will securely transmit data over the internet through a program-supplied cellular modem independent from the site internet service.

Two basic types of dataloggers may be used: customizable and programmable dataloggers (e.g. dataTaker, Campbell Scientific, etc.) or dataloggers that are part of residential and commercial energy management systems (EMS) (e.g. SiteSage, inView, and Ecobee). All custom dataloggers and most EMS dataloggers will provide some on-site data storage to prevent data loss due to internet connection issues and power outages.

Figure 5: Frontier Energy Monitoring System.



EMS dataloggers will send data over a secure connection to a cloud server operated by the respective EMS providers. These EMS systems provide additional benefit to field test site owners and occupants, who will be provided access to any available EMS features. Some EMS systems also provide data visualization both at an aggregate level for use in the Energy Marketplace and at an individual site level to assist with equipment commissioning and troubleshooting.

The Frontier Energy Monitoring Server (FEMS) will centrally manage and collect monitoring data from all data sources for all monitoring sites. The FEMS is a secure industrial computer system with redundant data backup and redundant secure internet connections. It automates data collection by retrieving data from field monitoring sites, checking retrieved data for errors and common equipment issues, and automatically notifying key personnel about possible problems detected. The FEMS also tracks the internet connection status of monitoring equipment and sends weekly data summaries to key personnel.

The FEMS can be set up to retrieve data in any file format from any datalogger at any specified interval. Data from EMS dataloggers are automatically downloaded through a secure login to the EMS cloud server and typically retrieved daily. Custom dataloggers communicate directly with the FEMS over a secure connection, uploading data files directly to the FEMS secure FTP server. The FEMS provides secure storage for all retrieved data by project and by site. In addition to retaining the raw data files, the FEMS automatically combines all data for each site into a site-specific binary data file for use in analyses. Direct access to the FEMS is kept limited to specific personnel for security and reliability reasons. Access to data collected by the FEMS will be provided to other Team members via Frontier Energy's SharePoint service as necessary.

Site Close-out

At the conclusion of the field test period, all instrumentation will be removed, and the condition of the building will be returned to its original state, except for the efficiency measures themselves, which will remain unless the building owner is dissatisfied with measure performance. In such cases, the original equipment will be re-installed if the complaints are well-founded, but it is expected that this scenario will be uncommon because of the careful risk-reduction strategies employed by the Team.

Building Energy Simulation

Energy simulation is an important supplement to most field test activities. Because field tests are conducted with uncontrolled occupant behavior and weather conditions, it is usually necessary to normalize energy use data before and after the retrofit. The energy savings can then be calculated under standard operating conditions and compared across test sites or to expectations based on manufacturer specifications. The most accurate method for this normalization process is the use of a whole-building model informed by field test measurements and occupant surveys, with adjustments made to uncertain inputs when necessary to align with measured data. This process can be time-consuming and expensive, especially when the retrofits involve numerous measures for which energy savings must be disaggregated. Models of commercial buildings are more difficult to create, but operating conditions tend to be more predictable than residential buildings, reducing the number of uncertain parameters. Weather data used for modeling can either be collected directly with an on-site weather station or downloaded from one of several providers of historical weather data. Modeling tools will be selected based on the research questions and technologies to be analyzed for each applied research project. Once validated through comparisons with measured data, the models can be used to estimate the energy savings potential for the technology in other building applications and climate zones, which is important for developing sector targeting strategies and quantifying state-wide program impact. The models can also identify positive and negative systems interactions with other measures, which will help guide measure bundling strategies used in the Energy Marketplace.

Modeling can be supported by laboratory testing when controlled conditions are needed to develop input parameters or performance maps for use with more complex modeling tools like EnergyPlus. These laboratory-validated algorithms can provide greater confidence in whole-building models during the subsequent field test phase. However, installed equipment performance cannot always be predicted based on laboratory testing, especially when the technology relies on occupant interactions or complex control algorithms. Daylight harvesting is an example of a technology where the Team expects to encounter some surprises when moving from the laboratory to occupied buildings.

For Lead Locally, the Team expects to use energy models informed by field test data for most of the research and technology demonstration projects that involve multiple retrofit measures. The energy savings for single-measure projects, such as phase change materials (PCMs) and induction cooking, may be calculated analytically using direct measurements and simple normalization equations. The details will be discussed in the technology-specific sections of the research and technology demonstration plans. These plans will be based on current expectations of the technologies and equipment that will be included in the lab and field test program, but early test results may open up new research questions and the plan must be adaptable when necessary to address all performance uncertainties before large-scale deployment is pursued.

Success Criteria

Each technology measure will have defined specific success metrics for both the lab testing and field testing stages which will need to be met in order for the technology to progress to the next stage and eventually be included in the Energy Marketplace. During the lab testing stage, success could take many different forms depending on the specific objectives and research questions being addressed. At the field test stage, success will primarily be evaluated in terms of costs and benefits for each measure. Specific criteria will depend on the technology and application under consideration, but will be defined using the following metrics:

Table 3: Cost Benefit Analysis criteria

Costs	Benefits
Administration/permitting	Gross site electricity savings %
Equipment costs	Normalized site electricity savings
Installation costs	Gross site electrical demand savings%
Bill increases (electricity and gas)	Normalized site demand savings
Maintenance costs	Bill reductions (electricity and gas)
	GHG reductions
	Load shifting
	Tax credits
	Non-energy participant benefits
	Non-energy social and environmental benefits

Electricity Savings

The technologies being evaluated are expected to notably improve the existing baseline site electricity consumption, moving it towards the portfolio level target of 10% site electricity reduction for the residential sector and 20% for the commercial sector. To contribute to the overall targets, there will be an expectation of significant system level savings for each technology and this is specifically outlined in each technology section. Where appropriate all measure(s) will be also compared to the existing building requirements of Title 24 (Part 6) Standards that are applicable at the time of permit issue. Energy savings for each measure or combination of measures will be evaluated both individually and in combination.

Economic Benefits

Technologies will be evaluated in terms of their benefits and applicability for wider adoption across the entire SCP territory of over half a million customers and further across the State of California through IOU EE programs. Success of the initial trials will likely also highlight contractors' skills and capability gaps, which will allow for SCP to strategize development of a Workforce Education and Training delivery program to increase scaling through the Energy Marketplace. The development of territory-wide EE programs that include the successfully verified innovative technologies will have long-lasting positive economic benefits to the residents of Mendocino and Sonoma counties.

Cost effectiveness of measures will be evaluated from two different standpoints. Firstly, that of the homeowner whose home is being retrofitted, utilizing metrics such as simple payback and return on investment. Secondly, data will be collated to support the evaluation of the overall program in conjunction with the CPUC framework for cost effectiveness, which will be needed for future inclusion of the measures in rate payer funded Energy Efficiency programs. Installed costs at different scales will be evaluated for different technologies and retrofit packages.

Non-energy Benefits

The Team will monitor and record baseline non-energy factors such as indoor air quality, thermal comfort and acoustic levels to be able to identify and track any changes due to the introduction of a measure in the participating property. Project completion will include a comprehensive occupant acceptance procedure inclusive of a building owner questionnaire that will identify any issues requiring further improvement prior to the measure being included in the Energy Marketplace. Where feasible, preference will be given to subcontractors with local presence in the SCP service territory to allow for rapid rectification of any installation issues. In addition, materials and products will be sourced through California based companies to mitigate possible delays associated with out-of-state procurement. In the event a technology yields unsatisfactory results, or upon a reasonable request from the building owner, the offending technology will be removed, and a mutually agreed upon alternative will be re-installed.

CHAPTER 3: Radiant Panels with Air-to-Water Heat Pumps

Locating ductwork in unconditioned attics and crawlspaces has been standard practice in California for at least 50 years due to low installation costs, but this approach results in significant distribution losses. Radiant ceiling panels are one potential cost-effective and retrofittable method to reduce distribution losses. Recent work has shown that radiant ceiling panels with an energy efficient air-to-water heat pump (AWHP), can provide comfort superior to high performance forced air systems with ducts in conditioned space, while consuming comparable amounts of energy (Haile, P.E., et al., 2018).

This applied research project will be completed in three primary phases:

1. **Laboratory Testing** – Develop sizing methods for radiant panels by developing a dataset of downward heat transfer coefficients for a range of flow rates, inlet water temperatures, and design conditions.
2. **Field Testing** – Evaluate the laboratory-developed sizing method by retrofitting radiant systems to existing homes. The field tests will also quantify electricity and natural gas savings, retrofit costs, and payback periods for radiant ceiling panels. These results will also be compared to moving ducts into conditioned space, using the mini-split heat pump (MSHP) retrofit houses monitored under task 6.5.4. Through a series of post-installation surveys and monitoring, occupant behavior and satisfaction with the radiant ceiling panels will also be compared to ducted systems.
3. **Model Development** – Using the laboratory and field test data, performance curves of the radiant ceiling panels will be developed for use in modeling software.

Partners for this project include:

- **Frontier Energy Inc.** (Frontier), formerly Davis Energy Group (DEG), has over 35 years of experience evaluating residential technologies. Through a national workshop series presented in 1984, DEG helped inspire a resurgence of radiant technologies. Key Frontier Energy staff on this project include James Haile, P.E. and David Springer.
- **Energy Docs Home Performance** is a licensed General Building Contracting company in Redding, CA specializing in performing comprehensive home performance retrofits to existing homes. Mike MacFarland, owner of Energy Docs, has over twenty-five years of construction experience, as well as extensive research experience.
- **Rick Chitwood, BSME**, owner of Chitwood Energy Management, is an expert in energy-efficient residential building construction and a leader in building science-based design. Rick's work on research projects in California has contributed to each revision of the California Building Energy Efficiency Standards since 2001.

Technology Overview

Bringing ducts into conditioned space is a cost-effective solution to reduce distribution losses in new construction but can be costly and challenging in retrofits. Radiant systems offer an alternative solution to reduce distribution losses, while providing equal or superior comfort compared to forced air systems.

Radiant systems use large heated or cooled surfaces, typically panels containing tubes to transport heated and chilled water, to directly serve thermal loads through radiative heat transfer. Traditional forced air systems instead use heated and cooled air distributed by ducts to indirectly serve thermal loads through convective heat transfer.

Figure 6 provides a representation of heat transfer effects in a room with a radiant ceiling during cooling operation. Objects inside the room radiate heat to the ceiling panel surface, which is cooled by chilled water circulated through channels in the panel. Some heat is also transferred to the panel surface via natural convection where rising warm air meets the panel surface. Ceiling panels are preferred over floor panels in cooling dominated climates. Ceiling panels benefit from increased natural convection in cooling and the ceiling surface isn't typically blocked by carpeting or furniture. Because radiative heat transfer is more direct than convection, comfort can be delivered at higher cooling setpoints and lower heating setpoints, which can translate to improved equipment efficiency.

Figure 6: Heat transfer effects in a room with radiant ceiling panels in cooling mode.

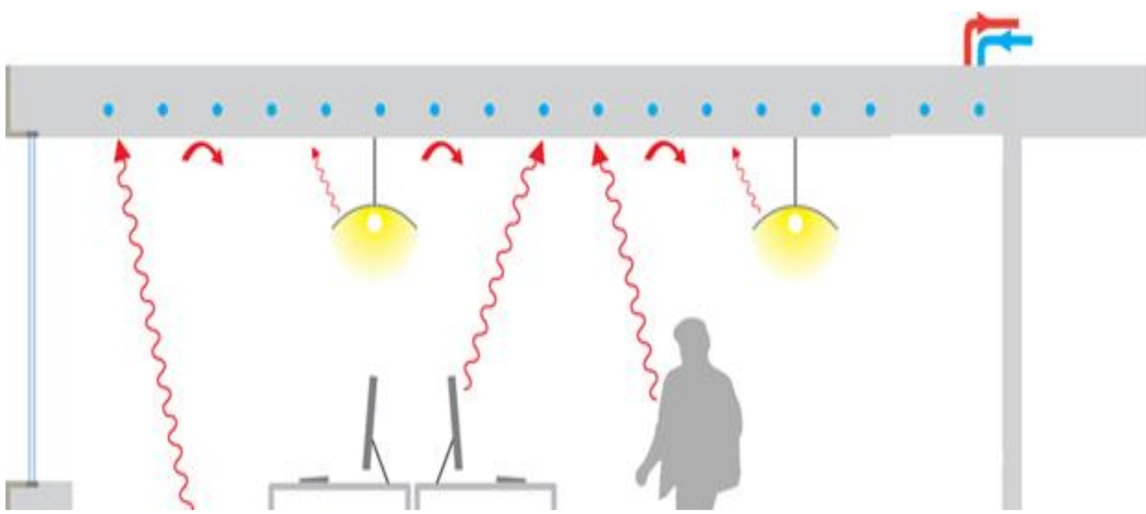


Image credit: Caroline Karmann, Center for the Built Environment at UC Berkeley.

Radiant ceiling panels are heated using either a heated fluid or electric resistance cables, but can only be cooled using a chilled fluid, typically water in the 50 to 60˚F range. Because of the large heat transfer surface, radiant systems deliver comfort at more moderate temperatures than hydronic fan coils, which use water temperatures around 140-160˚F in heating and around 45˚F in cooling. The moderate temperature translates to improved equipment efficiency, particularly with AWHPs as the heated and chilled water source.

AWHPs are a practical source for both heated and chilled water and keep system designs simple. AWHPs are not covered by DOE equipment standards and California has no minimum performance requirement. Beginning July 2016, the Energy Commission began listing AWHPs under Title 20 in the Appliance Database. As of writing, there are 10 AWHP units listed compatible with residential electrical service (California Energy Commission, 2017).

Existing Test and Evaluation Standards

Delivery effectiveness is the ratio of the quantity of heating or cooling energy delivered to the conditioned space over the total energy provided. There are no existing methods for determining radiant panel delivery effectiveness, such as ASHRAE Standard 152 provides for air-to-air systems (ASHRAE, 2004). An estimate of delivery effectiveness is necessary to properly size panels for a particular building. There are several laboratory testing standards for radiant panels, but none of these provide a method to estimate delivery effectiveness that is accessible to contractors and designers and compatible with existing industry practice.

In the absence of usable and accessible standards for evaluating radiant panel systems, radiant systems are typically evaluated by comparing the performance of the AWHP to the comfort performance of the whole system using ASHRAE Standard 55 and ACCA Manual RS (Haile, Springer, & Hoeschele, 2016). ACCA RS is a set of criteria for acceptable deviations from setpoints, allowable temperature differences between rooms and floors, and allowable humidity ranges (ACCA, 1997). ASHRAE Standard 55 is a more complex standard that considers operative temperature, relative humidity, air velocity, and clothing (ASHRAE, 2010).

Radiant Ceiling System Benefits

Radiant ceiling systems with AWHPs reduce distribution losses and maintain comfort at lower setpoints in winter and higher setpoints in summer due to their effect on mean radiant temperature (MRT). This means radiant systems have the potential to reduce electricity use while improving comfort and providing a host of other benefits to the homeowner, the HVAC industry, and the utility.

The primary homeowner benefits are obvious: improved comfort and reduced utility bills. Other benefits to the homeowner include reduced maintenance of the system (no more air filters), increased interior and attic space, quiet operation, and improved aesthetics (no registers). Additionally, refrigerant lines into the house are eliminated, improving the efficiency of equipment and reducing the potential for refrigerant leakage. Reducing refrigerant leakage, to the atmosphere or the interior space, is good for the environment and the homeowner's health, and reduces the need for periodic refrigerant recharge maintenance calls.

Hydronic systems in general present significant potential benefits to utility load shifting and demand response programs. With the addition of sufficient chilled water storage, hydronic systems can be used to shift the entire cooling electrical load to off-peak periods without sacrificing comfort and potentially without sacrificing performance.

Radiant ceiling systems with AWHPs also provide a host of potential benefits to HVAC contractors and designers by being easier to work with and allowing a significant degree of architectural and system design freedom. Components take up very little indoor space. Water piping is easier to install and much more conducive to zoning than ductwork. Factory charged AWHPs reduce installation defects, such as achieving proper sizing, adequate airflow, and refrigerant charge, common to forced air systems which have been widely documented (Downey & Proctor, 2002) (Heinemeier, Hunt, Hoeschele, & Weitzel, 2012) (Proctor, Chitwood, & Wilcox, 2011). All of this reduces design and installation time, potentially improving profit margins.

Radiant Ceiling System Performance Uncertainties

There are some uncertainties about radiant system performance that will be evaluated in this applied research project.

The lack of a usable sizing method has been a significant market barrier for radiant ceiling systems. Typically, sizing is performed by sizing an AWHP to the ACCA Manual J estimated sensible load and installing as much panel as there is ceiling space. Though this results in the AWHP being right-sized for the interior sensible load, it is often oversized for the volume of water in the panels. This disparity can be overcome by installing a buffer tank sized to increase the system volume enough to prevent AWHP short cycling. This is not cost effective, however, as it results in installing excess panel, oversized AWHPs, extra water storage, and requires an additional water pump. The laboratory tests will develop a sizing method based on the per square foot downward (into the space) heat transfer rates of the panels for different levels of insulation, above panel (attic) conditions, and panel water supply temperatures and flow rates. With that dataset, a designer could take a design condition and determine the best balance of supply temperature, flow rate, and panel area for cost effectiveness. Buffer tanks may still be necessary for low volume systems. The dataset would also allow developing performance curves for panels that could be mapped to existing performance curves for AWHPs for modeling.

Though radiative heat transfer is more direct than convective, radiant panels can be slow to reach operating surfaces temperatures. This is only an issue if an occupant uses a setback on their thermostat. Using a setback with radiant panels may result in temporary discomfort while the radiant surfaces are brought to operating temperature post-setback. This adds a comfort loss to the well-documented efficiency losses associated with using thermostat setbacks with heat pumps. However, these issues can be addressed by maintaining a buffer tank during thermostat setback and operating a hydronic fan coil post-setback until the radiant surfaces reach operating temperature.

Additionally, in conventional air conditioners, the evaporator coil operates at temperatures near 40°F, providing continuous latent cooling and humidity control. Radiant panels, however, only provide sensible heating and cooling. If indoor humidity runs high while the system is operating in cooling, condensation can occur on the panel surfaces. This could result in damage to the radiant surfaces, which is why radiant systems have historically been the most popular in dry or heating only climates. However, this can be addressed through dynamic humidity controls (adjusting the water temperature provided to the panels based on humidity), providing proper ventilation (in accordance with ASHRAE Standard 62.2), and/or by providing supplemental dehumidification (preferably using a hydronic fan coil).

Potential Inclusion in the Energy Marketplace and EE Programs

Broad deployment of radiant systems is inhibited by several market barriers:

- Lack of builder awareness of radiant panel systems.
- Home buyer risk aversion to invest in homes that incorporate non-traditional systems.
- Lack of design professionals familiar with hydronic systems.
- Installing hydronic systems requires skills common to both plumbing and mechanical trades, but a single subcontractor needs to be responsible for the entire system.
- Lack of case studies demonstrating the value of radiant panel systems and AWHPs.
- Limited availability of radiant panels through mainstream distribution channels.
- Radiant systems and the part-load performance of variable capacity AWHPs are not adequately modeled by the 2016 Title 24 Alternative Calculation Method (ACM).

Pending successful laboratory and field tests, strategies to overcome these barriers for radiant panels will be tested in the Energy Marketplace and hopefully in wider EE Programs in California. The overall impact of the technology will depend on the following factors:

- Achieving success metrics during both Laboratory Testing and Field Testing.
- Achieving electricity savings potential, as identified by the literature review.
- Contributing energy savings toward the overall portfolio site electricity savings targets of 10% for residential and 20% for commercial buildings. Savings will be isolated to the measure level. In most cases, successful measures will be bundled as a retrofit package.
- Existence of a local supply chain for radiant system components.
- Positive feedback from participating homes during the Technology Demonstration stage.

Laboratory Testing

The laboratory tests of radiant ceiling panels will be conducted in the environmental chambers in the Frontier Energy Building Science Research Laboratory (BSRL). Testing will determine downward heat transfer coefficients as functions of the amount of "above panel" insulation at standard design conditions. This will allow estimating the delivery effectiveness of the panels for a wide range of applications. Results will be used to size the radiant systems for the field tests, and field test results will be used to evaluate the accuracy of the sizing methods. Results will also be used to develop performance curves for use in modelling software. Using these curves with performance curves available for AWHPs will allow easier sizing of AWHPs for radiant systems and allow more accurate modeling of radiant panel and AWHP systems.

Research Questions and Success Metrics

The goals of the laboratory testing are to determine the downward heat transfer rate per square foot of panel area as a function of the amount of "above panel" insulation for multiple design conditions. Research questions include:

1. What is the downward heat transfer rate for each insulation level?

2. Do the panels provide sufficient capacity at typical insulation levels?
3. What is the temperature distribution across the surface of the panels for each flow rate?

The primary success metric to advance radiant systems to the field test stage is that laboratory tests must indicate that the panels can provide sufficient downward capacity at typical insulation levels used in attic retrofits (≥R-38) to meet design loads in Sonoma and Mendocino Counties.

Test Facility

BSRL has two environment simulation chambers: one larger chamber for simulating outdoor conditions and one smaller chamber for simulating indoor conditions. Currently, the conditions inside the chambers are controlled using a prototype high-performance commercial HVAC unit developed by Frontier Energy's predecessor, Davis Energy Group, called the HyPak. Controls and data logging are currently provided on an ad hoc basis using dataTakers and ADAM modules communicating with a computer using Modbus.

Of the laboratory resources available to the project team, BSRL is the best option for the required laboratory testing of radiant panels and AWHPs. The environmental chambers afford the opportunity to precisely simulate design conditions at a steady state, allowing development of heat transfer coefficients for the radiant panels. BSRL is also in closest proximity to the project team, is the only facility available to the team with environmental chambers large enough for the radiant panel tests that is located in California, and is the most conducive to the modifications necessary for conducting the radiant panel tests.

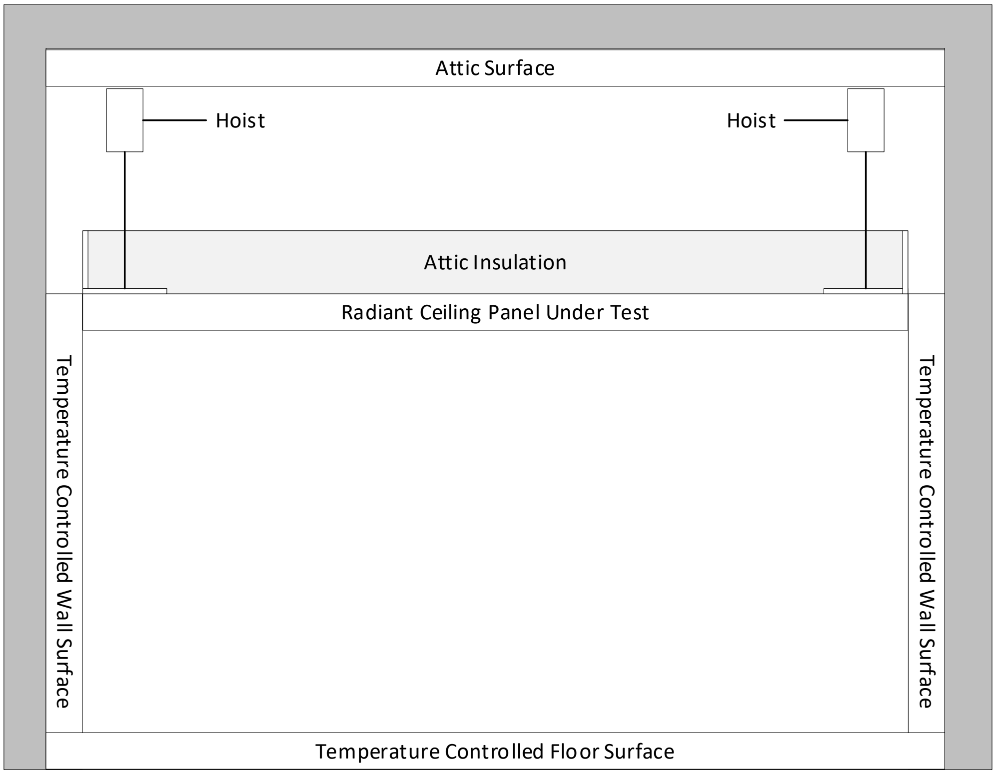
Modifications to BSRL systems and the instrumentation in the environment chambers required to perform the laboratory work include the following:

- Temperature controlled surfaces on all interior surfaces of the indoor environment chamber.
- A simulated attic section in the indoor environment chamber, which will include a removable ceiling for adjusting the insulation level at the back of the panel under test.
- Fine-resolution and high-sample rate data acquisition systems and instrumentation.

A National Instruments CompactDAQ system and high-performance liquid cooled industrial computer with a redundant data backup system will be used for data acquisition and controls.

Figure 7 provides an illustration of what the indoor environment chamber will look like with the temperature-controlled surfaces and separate attic space.

Figure 7: Diagram of planned modifications to the BSRL indoor environment chamber.



The middle horizontal surface will be the radiant ceiling panels under test. This horizontal surface will be lowered using remote controlled electric hoists, allowing adjustments to the level of insulation in the simulated attic. A small ductless fan coil head may be added to the attic if time and budget allows. This would allow simulating both sealed and vented attics. The upper horizontal temperature-controlled surface will be used to control the simulated attic temperature. The five other temperature-controlled surfaces will be maintained at specific surface temperatures, simulating the exterior load on a house with R-19 walls in the specified climate zones. Each surface will be heated or cooled independently.

These modifications will also be utilized by other laboratory experiments performed under Lead Locally, such as planned tests for PCM insulation, which will utilize the simulated attic space. Other grant-specific laboratory work done at BSRL, including laboratory work for mini-split heat pumps and heat pump water heaters, will also benefit from these upgrades and the improved data acquisition and controls systems.

Test Matrix

The goal of the radiant ceiling panel laboratory testing is to determine the downward heat transfer rate per square foot of panel area as a function of the amount of “above panel” insulation for multiple design conditions. This will be done by measuring the steady state downward heat transfer rate of the panels for a range of operating conditions:

- Design conditions for California Climate Zones 2, 12, and one of 3, 11, or 16. Developing radiant panel performance data for these climate zones will allow accurately sizing panels for most of Northern California and will provide three design conditions for extrapolation to other California climate zones.

- Attic insulation R-values of 30, 38, and 49.
- Panel entering water temperatures from 46 to 58˚F in cooling and 90 to 140˚F in heating.
- Water flow rates between 0.1 and 5 gpm.

The general test procedure will be as follows:

1) Adjust level of insulation above the panels.
2) Set attic space temperature and surface temperatures to simulate the design condition.
3) Set entering water temperature.
4) Set flow rate.
5) Wait for steady state.
6) Repeat steps 4 through 5 for each flow rate.
7) Repeat steps 3 through 6 for each entering water temperature.
8) Repeat steps 2 through 7 for each design condition.
9) Repeat steps 1 through 8 for each insulation level.

Steps 2 through 8 will be fully automated. The BSRL data logging and control systems will be programmed with target values for inlet water temperature, flow rate, and interior space surface temperature. Once steady state is achieved, BSRL systems will maintain steady state for one hour.

Data points collected will include:

- Inlet and outlet water temperatures.
- Water flow rates.
- Surface temperatures of all surfaces.
- Ambient air temperatures and humidity in both the simulated attic and interior spaces.
- Heat flux at the interior panel surface and at the back of the panel.

Sensor data will be collected at a high resolution. This will provide sufficient data at steady state to determine the downward heat transfer rate for each condition. Tests for each insulation level are expected to take approximately one month, requiring three months of laboratory testing in total for the three planned insulation levels.

Field Testing

Field tests will be performed in multiple single-family houses that currently have central heating and cooling, with ducts in a vented attic. Multiple houses are necessary because occupant behavior and comfort considerations have a significant effect on the operation and perceived performance of radiant systems. Home energy audits and envelope improvements will be performed prior to monitoring to limit differences between the houses. Six months of monitored baseline data will be collected prior to the retrofits, followed by one year of monitored data collection post-retrofit. Data will be collected on system performance, as well as occupant comfort and behavior. The costs of each retrofit will be recorded in detail. Eligible homeowners will be asked to complete a quarterly survey, provide access to their utility data, and allow technicians to enter the residence for data collection or repairs with reasonable notice.

Retrofit costs, performance data, and utility bills will be used to estimate payback periods for the two approaches. Occupant surveys, thermostat setting data, occupancy sensors, and window operation data will be used to evaluate occupant behavior both before and after retrofits are performed. Any comparisons of energy use will adjust for differences in occupant behavior that could distort the results.

Research Questions and Success Metrics

The specific research questions for the field tests include:

- How does the indoor comfort performance and energy use provided by the Retrofit systems compare to the Baseline systems for each house and in aggregate?
- How does the indoor comfort, performance, and energy use in the field tests differ from modeled expectations?
- How does the indoor comfort performance and energy use provided by the Retrofit systems compare to the MSHP systems being evaluated in Task 6.4.5?
- What are the annual cost savings and the payback period for the Retrofit system, based on the energy use of the Baseline system and billing data? How does this compare to the MSHP systems being evaluated in Task 6.4.5?
- What was learned about radiant panel heating and cooling capacity, and what are the implications for system sizing?
- What was learned about occupant behavior relative to the Retrofit system? How does behavior impact performance?
- What home, climate, or occupant behavior factors led to the greatest savings potential for the Retrofit systems?

Whether or not the technology is ready for larger deployment and inclusion in the Energy Marketplace will be based on the results of the evaluations above and feedback from occupant surveys. The technology will be considered a quantitative success if it is able to produce comfort and energy performance results better than those of the Baseline systems and comparable to those of other technologies that have already achieved inclusion in the market place (mini-split heat pumps). The technology will be considered a qualitative success if occupant feedback from the field tests is positive, and cost-effectiveness appears achievable in at least a few applications. In the event of an overall success, the occupant feedback will also be used to help inform customer decisions while they shop for retrofit systems in the Energy Marketplace.

Test Sites

Test sites will be located within Sonoma and Mendocino counties and will be selected from among SCP customers. Desired criteria for the field test locations are outlined in Table 4. These are research criteria constrained by project goals and resources and so should not be taken as limits of the technology. Results from these houses will be extrapolated to other conditions. These criteria are weighted by desirability as follows:

- Essential –Criteria must be met to be a candidate field test location for this project.
- Important – Criteria is flexible but would aid research goals.
- Desired – Criteria to be used only in an abundance of candidates. Locations that meet all criteria including "desired" would be considered "near perfect" candidates for the work.

Table 4: Field test site selection criteria.

Category	Criteria	Criteria Value	Criteria Weight
Occupant	Occupied?	Yes	Essential
	Owned by current residents?	Yes	Essential
	Occupants will remain for 2 years?	Yes	Essential
	Full time residence?	Yes	Essential
	Retired Residents?	No	Desired
	Resident Smokers?	No	Essential
	Anticipated change in occupancy?	No	Essential
	Employees of Energy Industry?	No	Essential
Site	Year Built	1978 < x < 2005	Essential
	Dwelling Type	Single family detached	Essential
	Number of floors	1	Desired
	Sq. Ft. of conditioned living Space	< 2000	Essential
	Attached Garage	Yes	Desired
	Utility Data available	Yes	Important
Building Envelope	Foundation Type	Slab on grade	Important
Mechanical	HVAC system functional?	Yes	Essential
	Cooling Type	Split system AC or HP	Essential
	Central Cooling?	Yes	Essential
	Heating Fuel	Electric	Desired
	Propane Heating?	No	Essential
	HVAC Age	10+ years	Essential
	HVAC Indoor Location	Garage or Attic	Important
	HVAC Duct Location	Attic	Essential
	HVAC Asbestos Ducts	No	Essential
	Water Heater Location	Garage or Exterior	Desired

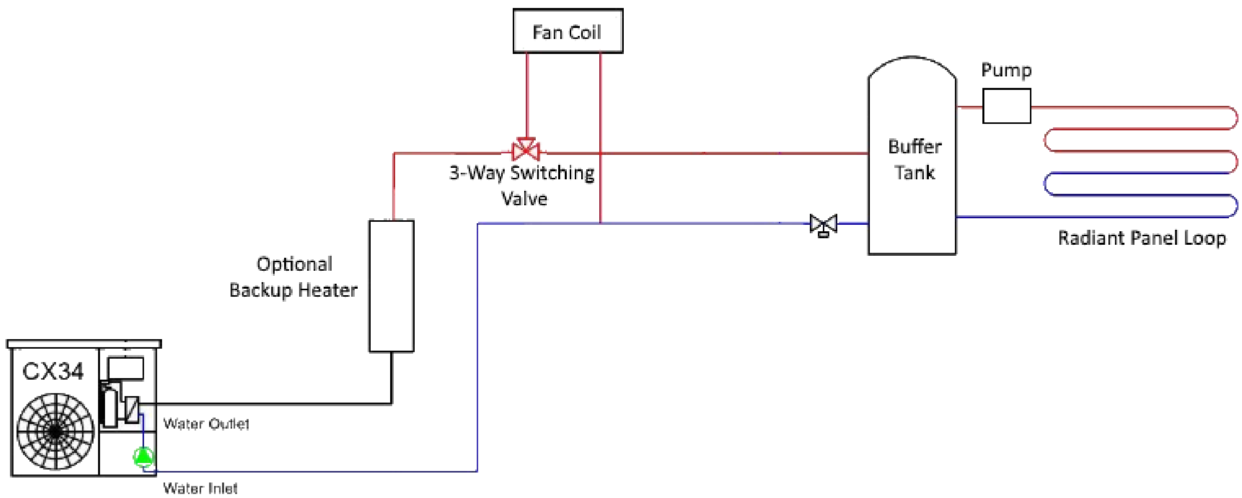
Once candidate test sites have been selected, the existing condition of each site and its systems will be evaluated in greater detail using standard field verification and diagnostic testing techniques. Heating and cooling loads will also be estimated by room using industry standard methods in ACCA Manual J (ACCA, 2011). The information collected will be sufficient to document the existing conditions and produce a detailed EnergyPlus model of each house and to produce home energy audit reports for each final test candidate. These reports will include summaries of the energy performance of the existing conditions and recommended renovations in a format that will be easily digestible for the homeowner.

The field verification and diagnostic tests to be performed will include envelope leakage, duct leakage, insulation levels, thermal images of interior surfaces of exterior walls and ceilings, supply and return airflows, ventilation airflows, and equipment power draws.

Retrofit Systems and Equipment

The retrofits systems being evaluated in the field tests include hydronic radiant ceiling panels fed heated and chilled water by an air-to-water heat pump. Hydronic systems in general afford the option of relatively low-cost customization, including advanced zoning, energy storage, etc. However, for these field tests, the simplest and lowest-risk hydronic radiant system designs will be installed and evaluated. An example diagram of a simple hydronic system incorporating radiant panels is shown in Figure 8.

Figure 8: Example of a simple hydronic system using an AWHP, fan coil, and radiant panels.



The following will be incorporated into each radiant system design to minimize complexity and minimize risk of occupant dissatisfaction with the system:

- Radiant ceiling panels in every room, balanced at a home-run manifold, fed water by a secondary pump from a buffer tank.
- Only one to three zones (likely Bedrooms, Communal Rooms, and Kitchen or Bath), depending on loads and other site-specific issues.
- A ductless hydronic fan coil in a central room to serve latent loads in cooling and allow for faster system response to setpoint changes.
- ASHRAE Standard 62.2 compliant indoor air quality ventilation will be installed (if not already present).

The following sections provide additional detail about significant components of the retrofit systems.

Radiant Ceiling Panels - Warmboard-R

The radiant ceiling panels planned for use in these field tests are manufactured by Warmboard, Inc. Warmboard, Inc. is located in Aptos, California and has manufacturing facilities in Northern California. Warmboard-R (Figure 9) is a 2'x4'x13/16" press-board panel with grooves for ½" nominal diameter cross-linked polyethylene (PEX) tubing spaced 12" on center. The interior-facing surface of the panel, with tubing grooves, is laminated with 0.025" thick 1060 Aluminum. A typical installation process includes removing the existing ceiling, attaching the panel without tubing to the ceiling, inserting PEX tubing for the hydronic circuit into the grooves, and then covering the assembly with standard drywall. Panels can be cut to allow fitting almost any geometry. Gaps between the panels and the walls can be filled using standard ceiling materials. The panels can also be installed on top of existing ceilings, walls, and floor, though use as a replacement is recommended.

Figure 9: Diagram of a Warmboard-R panel.

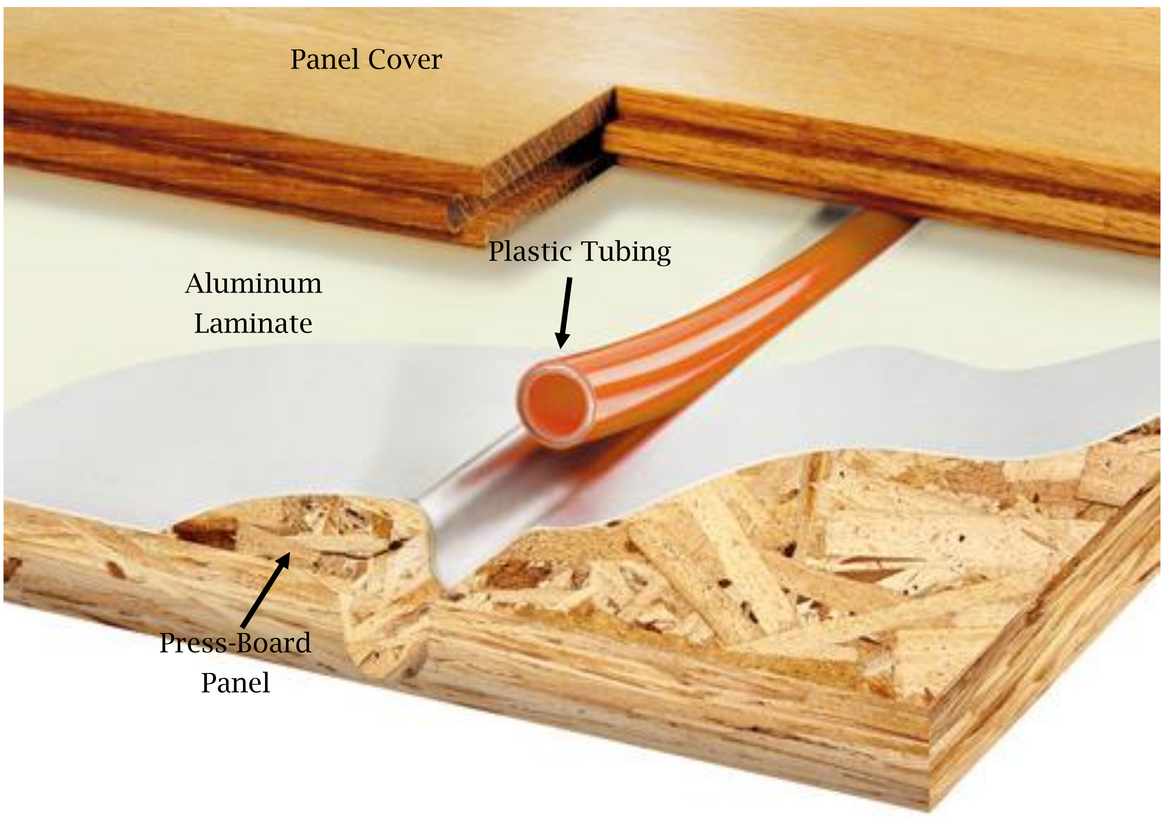


Image credit: Warmboard, Inc

Though Warmboard-R is primarily marketed for use as floor panels, it is light enough for use as ceiling and wall panels. Its overall heat transfer characteristics as a floor panel is documented by the manufacturer, but its downward heat transfer as a ceiling panel has never been evaluated. Laboratory tests discussed in the preceding section of this plan will determine those characteristics for sizing the required panel area for retrofit systems.

Air-to-Water Heat Pumps – Chiltrix CX34

The AWHPs planned for use in these field tests are manufactured by Chiltrix, a United States manufacturer based out of Chesapeake, VA. The Chiltrix CX34 (see Figure 10) uses a variable speed compressor, pump, and fan to vary system capacity based on a desired entering water temperature and water temperature difference across the heat exchanger. The CX34 is certified under UL 60335-2-40 and CSA 22.2 and is AHRI-Certified and is listed in the California Energy Commission Appliance Database.

Figure 10: A research installation of the previous revision of the Chiltrix CX34 (left), and a promotional image of the most recent revision of the Chiltrix CX34 (right).

Image credit: James Haile (left); Chiltrix, Inc (right)

General Test Strategy

There will be two periods of data collection during field test monitoring: Baseline and Retrofit. Retrofit systems will be evaluated relative to the baseline systems, as well as the MSHP systems evaluated in task 6.5.4. These evaluations are described generally below:

- **Energy Use:** Energy consumption of all electrical components of the Retrofit and Baseline systems will be monitored using electrical power and/or gas meters.
- **System Performance:** Radiant system performance will be monitored using BTU meters installed in pipes serving the panels, fan coil, and the inlet and outlet of the AWHP. These data points, along with energy use, will be used to calculate total heating or cooling delivered and AWHP efficiency. AWHP health (component status, internal temperatures, etc.) will be monitored using the AWHPs built-in Modbus port. If possible, baseline system performance will be estimated using supply and return temperature and relative humidity sensors with one-time airflow measurements.

- **Comfort Performance:** The comfort performance will be measured using room temperature and relative humidity in major rooms and evaluated using the methods provided in ACCA Manual RS for deviation from setpoint and ASHRAE Standard 55. Outdoor conditions will be monitored using data from nearby weather stations.
- **Occupant Behavior:** Occupant behavior will be monitored in both the Baseline and Retrofit periods by monitoring occupant interactions with the systems using logging thermostats, occupancy sensors, etc.

Model Development

Using the laboratory and field test data, performance curves of the radiant ceiling panels will be developed and documented, allowing their use in various building simulation tools. Using these curves with the performance curves available for AWHPs will allow easier sizing of AWHPs and better modeling of how they perform in combination with radiant panels.

Baseline conditions collected during the energy audits will be used to develop detailed EnergyPlus models of the field test houses. Results from the models using the actual meteorological year data covering the Baseline period will be compared to the actual monitored performance.

Radiant and AWHP systems will then be sized using these models. After the Retrofit monitoring period, results from the sizing model will be compared to the monitored performance. If the predictions of the models are reasonably accurate, the validated model will be published, utilized in a parametric modeling analysis to extrapolate system performance for other design conditions, and recommended for inclusion in compliance software.

The results of the laboratory tests, field monitoring evaluations, and parametric analysis will be used to develop general rules of thumb for use by field technicians and contractors and to provide additional detail in the Radiant Design Guide deliverable under Task 4.3 of the Project.

Project Timeline

Table 5 shows the high-level project milestones and deliverables with anticipated completion and due dates.

Table 5: Anticipated project schedule for research on radiant panels with AWHP.

Project Milestones	Completion/Due Date
Laboratory Tests	Mid-April 2019
Laboratory Test Report and Preliminary Sizing Method	May 2019
Field Tests - Site Screening/Selection	December 2018
Field Tests - Energy Audits	February 2019
Field Tests - Design Retrofits	June 2019
Field Tests - Baseline Monitoring	November 2019
Field Tests - Retrofit Monitoring	February 2021
Program Participant Satisfaction Questionnaire for Homeowners	April 2021
Model Development	May 2021

Draft Radiant Design and Installation Guide	July 2021
Final Radiant Design and Installation Guide	August 2021
Draft Radiant and AWHP Report	October 2021
Final Radiant and AWHP Report	November 2021

CHAPTER 4: Commercial Daylighting Retrofits

Interior lighting remains a large component of electricity use in non-residential buildings. In California, electric lighting has both a direct effect on peak load, and an indirect effect by increasing cooling requirements during summer peak hours. Effective daylighting combined with electric lighting dimming controls can directly offset electric lighting energy by reducing lighting levels when necessary to reduce the load on the cooling system. However, in existing buildings where glazing area and location are likely to be fixed, there are a limited number of proven methods available for enhancing the level and quality of daylighting. Commercial buildings are generally better candidates for energy-saving daylighting improvements than residential buildings, because lighting is a much larger fraction of daily electricity use, and the demand for lighting by occupants is more closely aligned with daylight availability (i.e. during the day instead of the evening).

To address the challenge of enhancing and effectively utilizing daylight in commercial buildings, the Team will create and implement a multi-pronged project to assess the potential energy savings for several promising daylighting technologies. These technologies will reduce lighting electricity use by a minimum of 20% when packaged into an optimal combination for typical buildings in Sonoma and Mendocino Counties, while targeting even higher savings for ideal building sectors (e.g. schools or office buildings). CLTC will perform laboratory testing of innovative daylight harvesting technologies that show promise for cost-effective retrofits in commercial buildings. Lab-verified control technologies will be further tested as part of a field evaluation of alternate daylighting retrofit technologies in three non-residential buildings. The approach will include the implementation of several techniques for extending daylighting into dark interior spaces at two field test sites. In similar test buildings or occupied spaces with substantial existing daylight, CLTC will verify the ability of advanced control algorithms to manage the operation of the lighting system to optimize the overall energy efficiency of the building and reduce peak demand. Any comfort or operational issues will be identified through surveys of building owners, occupants and facility managers.

The following sections provide a high-level overview of the research strategy that will be employed to evaluate innovative daylighting measures for Lead Locally. The specific plans for the enhanced daylighting project will be addressed in more detail as part of the Phase 2 Research, Instrumentation, and Monitoring Plan under Task 3.2.

Technology Overview

Recent advances in commercial daylight harvesting technologies and control algorithms have opened the door to greater integration with related building systems and optimized overall performance, offering the potential for significant energy savings in the commercial retrofit market. However, some of these technologies require further evaluation individually and in combination before lighting designers will feel comfortable including them for commercial building retrofits. Specific technologies that will be investigated include dimmable light-emitting diode (LED) lighting with motion and photo-sensor-based controls and integrated communication technologies. In addition, daylighting management technologies will be considered to help realize electric lighting savings and provide additional HVAC energy savings through automated management of solar heat gain and possibly natural ventilation and cooling. These technologies include automated Venetian blinds, roll-down shades, electrochromic glazing, tubular daylighting devices, sun-tracking skylights with mirrors and/or optical fibers, along with motion and photo-sensors for determination of occupancy and potential for glare from direct solar penetration. Examples are shown in Figure 11 and Figure 12.

Figure 11: Sun-tracking Skylights with Mirrors

Image credit: Ciralight Global, Inc.

Figure 12: Parans Fiber Optic Systems

Image credit: Huvco Daylighting Solutions

A literature review will be performed at the start of the project to investigate manufacturers claims and learn from previously completed research and demonstration studies for each daylighting technology. The Team will estimate the lighting and HVAC energy savings that can be experienced through enhanced daylighting technologies that integrate automated operation of electric lighting, dynamic fenestration systems and HVAC. Opportunities for reducing peak electricity demand will also be an important topic of study.

Enhanced Daylighting Benefits

Economic benefits that could be experienced from commercial daylighting applications include cost savings through reduced energy requirements, lower lamp replacement costs, and reduced commissioning and operational costs. Health and comfort benefits may also be felt by building occupants, such as improved effects on circadian rhythms, less sensitivity to illumination levels and reduced glare potential, lower solar heat gains, radiation asymmetry, and better acoustic insulation performance.

Enhanced Daylighting Performance Uncertainties

Key performance issues and uncertainties that may be expected with the mentioned technologies include delayed response times, decreased occupant acceptance, stricter maintenance and cleaning requirements, and dependency on climate and fenestration orientation. Installed costs for many of the technologies may be uncertain as well.

Potential Inclusion in the Energy Marketplace and EE Programs

The inclusion of enhanced daylighting technologies in the Energy Marketplace and in further wider EE Programs will depend on the following factors:

- Achieving the specific technology Success Metrics during both Lab and Field Testing.
- Achieving electricity savings potential, as identified by the literature review for the technologies.
- The successful delivery of energy savings towards the overall portfolio level targets of site electricity savings of 20% for commercial buildings. For the applied research part of the project savings will be isolated to the measure level. In most cases the wider rollout of successful measures will be through specific technologies bundled as components of retrofit packages.
- Local supply chain capable of delivering the technology products for fast installation turnaround following order.
- Positive feedback from participating commercial building occupants during the Technology Demonstration stage (e.g. savings benefits, improved comfort and quality of installation).

Research Questions

The Lead Locally Team will look to answer the following research questions as part of the laboratory and field test activities:

- Do technologies perform as expected in the laboratory under controlled anticipated daylight and occupancy conditions?
- Do technologies perform as expected in the field?

- How do occupants feel about these technologies in terms of their automated operation and the harmonization with manual override?

The following questions will be addressed through modeling/analysis:

- Can existing daylighting and energy modeling tools predict the dynamic behavior of the daylight harvesting technologies effectively?
- How do modeling results compare to actual performance in the laboratory and in the field?
- What is the estimated annual performance of the daylighting technologies in different applications in terms of occupancy, climatic conditions and fenestration orientation?

Additional questions may arise as more information is discovered during the early stages of the project. These additional questions may result in potential future research work to discover better uses or applications of these technologies.

Laboratory Testing

Laboratory testing of all commercial daylight harvesting technologies will be performed at the CLTC Daylight Harvesting Laboratory (DHL) located in Davis, CA (see Figure 13). The CLTC DHL is a full-scale laboratory associated with the University of California, Davis Campus with capabilities in research and development, prototyping, and product testing of various lighting applications. The DHL is highly adaptable to research needs, and can accommodate virtually any combination of windows, skylights, blinds, shades, electric light fixtures, and lighting controls.

Figure 13: CLTC Daylight Harvesting Laboratory

Image credit: CLTC

The CLTC DHL facility will be modified to accommodate the commercial daylight harvesting technologies being evaluated, and to identify any issues related to installation, commissioning, integration, and operation of these technologies. The selected spaces within the lab will be modified to test the performance of daylighting technologies under real sun and sky conditions. For each laboratory test, a broad range of lighting parameters will be monitored, including power and energy consumption, illumination levels, glare potential, response times, and harmonization of manual and automated operation.

The success of each daylighting technology relative to the following metrics will determine its readiness for field testing in occupied buildings:

- Potential for effective installation, commissioning and operation
- Potential to realize expected energy and peak demand reduction
- Potential to realize comfort and cost benefits

Field Testing

Site Selection

Site selection requirements for all daylighting technologies include the following:

- Building owner to approve window and/or skylight changes and/or installation of new skylights and tubular daylighting devices.
- Spatially fixed work stations within the approved sites, such as office and classroom spaces, with year-round occupancy between 7 am and 6 pm, 5 days/week.
- At least two similar spaces with significant daylighting potential, only one of which will receive daylighting retrofits. This will allow side-by-side evaluation of the daylighting measures in spaces subjected to very similar weather and operating conditions.
- LED lighting with occupancy and photo-sensor controls capable of communicating through standardized protocols, such as BACNET IP, manually operated Venetian blinds or rolling shades, and a T-bar drop ceiling.

Requirements for spaces with windows include:

- Window orientation should be South, ranging from SE to SW and those windows should have an unobstructed view of the sky.
- Window-to-wall ratio of at least 40%, and high-performance glazing, in a space deeper than two window-heights from the window wall.

Requirements for spaces away from windows and skylights include:

- Essential that the space is in the top two floors of the building and supports penetration through the roof and ceiling. (Basements can be considered depending on ease of penetration access to such spaces)
- Unobstructed view of the sky hemisphere above the roof.

Retrofit Design

The retrofit design will be performed in collaboration with industry partners that manufacture or market the selected technologies, and the owner and facility manager of the facility. Lead Locally team members, including SCP, Frontier, and DNV-GL, will be consulted prior to the installation of retrofits to help determine the best approach for each building.

Instrumentation Plan

Pre-retrofit instrumentation will be focused on determination of energy consumption, peak electricity demand, illumination levels and potential for glare introduced by daylight. The pre-retrofit test duration will be limited to about 3 months, which should provide sufficient data to understand the general quality of existing daylighting and the general usage patterns for the space. The Baselines for the project will include similar spaces within the same buildings that are not retrofit. These spaces will be monitored simultaneously with the enhanced daylit spaces for a period of at least one year. This side-by-side evaluation of the daylighting measures will provide a more meaningful evaluation of the technologies and a better estimate of electricity savings, because the relevant spaces will be subjected to very similar weather and operating conditions.

The retrofit implementation will follow the retrofit design specifically selected for each site. The post-retrofit instrumentation will match the pre-retrofit instrumentation to the extent possible in order to facilitate comparative evaluation. Pre-retrofit and post-retrofit data will be analyzed comparatively to evaluate the performance of the daylighting technologies in terms of energy, cost and comfort.

Simulation

Simulations (including spreadsheet tools and/or whole building simulation) will be performed to estimate annual energy performance of the commercial daylight harvesting technologies under standard operating conditions, and to extrapolate results to other building types and climates. Any daylighting models developed under this project will be validated against measured lab and/or field test data.

Success Metrics

Performance relative to the following metrics will be reviewed and ultimately determine which daylighting technologies are ready for deployment to the broader retrofit market in Northern California:

- Verification of expected performance in the field in terms of energy savings and peak demand reduction.
- Ascertaining a positive response from the facility manager and space occupants in terms of overall lighting quality.
- Understanding of design and installation challenges, and methods for overcoming them.
- Recommendations for cost-effective applications in the commercial building sector.

Project Timeline

Table 6 shows the high-level project milestones and deliverables with anticipated completion and due dates.

Table 6: Anticipated project schedule for research on enhanced daylighting.

Project Milestones	Completion/Due Date
Laboratory Tests	June 2019
Laboratory Test Report	July 2019
Field Tests - Site Screening/Selection	March 2019
Field Tests - Baseline Monitoring	Mid-July 2019
Field Tests - Design Retrofits	August 2019
Field Tests – Retrofits Installation	November 2019
Field Tests - Retrofit Monitoring	November 2020
Model Simulations	November 2020
Program Participant Satisfaction Questionnaire for Owners and Occupants	December 2020
Draft Report	December 2020
Final Report	January 2021

CHAPTER 5: Conclusion and Next Steps

This Phase 1 Research, Instrumentation, and Monitoring Plan (Plan) establishes clear methodologies for evaluating two applied research technologies: radiant heating and cooling with air-to-water heat pumps and commercial daylighting retrofits. These technologies are high priorities for Lead Locally because they reside on the critical path for the program. Key subcontracts related to this research effort are in place, and those subcontractors have provided significant feedback to ensure that the scope and milestones are achievable within the budgetary, staffing, and administrative (permits, prevailing wage) constraints of the Lead Locally grant.

Specific details on the make/model, locations, and accuracy of the instrumentation package will be provided in Monthly Progress Reports for the grant as they are defined based on the characteristics of the retrofit packages, the realities of the test sites, and the criteria established in the Phase 1 EM&V Framework. An effective research program must be adaptable to changing circumstances and unexpected challenges that may be encountered during the execution of the project. As a result, the emphasis of this Plan is to document the decision-making process and overall strategies that will guide the choice of test sites, selection of research questions, and approaches to answering those questions in accurately and completely. Ultimately, this Plan supports the important Lead Locally project implementation goal of expanding the range of retrofit technologies with proven performance and cost-effectiveness in Northern California.

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GLOSSARY

Term	Definition
ACCA	Air Conditioning Contractors of America
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
AWHP	Air to Water Heat Pump
BSRL	Building Science Research Laboratory
CEC	California Energy Commission
CLTC	California Lighting Technology Center
CPUC	California Public Utilities Commission
DHL	CLTC's Daylight Harvesting Laboratory
EE	Energy Efficiency
EM&V	Evaluation, Measurement and Verification
EMS	Energy Management System
EPIC	Electric Program Investment Charge
FEL	Frontier Energy Laboratory
Framework	Phase 1 EM&V Framework
FSTM	Food Service Technology Center
HVAC	Heating, Ventilation, and Air Conditioning
IOU	Investor Owned Utility
LED	Light-Emitting Diode
MRT	Mean Radiant Temperature
MSHP	Mini-Split Heat Pump
PCM	Phase Change Materials
Plan	Phase 1 Research, Instrumentation, and Monitoring Plan

SCP	Sonoma Clean Power
Team	All Lead Locally Program Partners
TRL	Technology Readiness Level