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# Through the looking glass: analyzing barriers to adoption of advanced rooftop unit controls through human-centered observational research

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# Through the looking glass: analyzing barriers to adoption of advanced rooftop unit controls through human-centered observational research

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## ABSTRACT

The US Department of Energy has estimated that sensors and controls systems could lead to 29% annual energy savings across all building types (Fernandez et al. 2018). This can be achieved by better matching system operation to building occupancy and outside air conditions and enabling real-time adjustments to temperature setpoints and schedules. However, only 13% of small to medium buildings have adopted technologies capable of providing these functions. Based on anecdotal evidence, there are challenges associated with installing, maintaining, and using rooftop unit (RTU) controls that may contribute to this missed opportunity. To better understand the importance of human-technology interaction, we use non-participant, observational research methods in conjunction with technology performance evaluations to gain real-world insight into installation, integration, configuration, commissioning, and use of RTU controls. Doing so highlights barriers to adoption and perceived value of RTU controls and also provides valuable feedback to manufacturers and workforce regarding pressure points. In this paper we describe the methodology and initial results from observations conducted by the research team. Key outcomes in three main areas are also discussed - market conditions, peoples' perception, and the technology itself. As with other emerging IoT building control technologies, themes such as unclear and unintuitive manufacturer documentation, complicated software interfaces, difficulty in IT security and access issues, and lack of perceived value by owners and users continue to be barriers to adoption. Finally, we provide recommendations to address deployment barriers of RTU controls that prioritize economic and technical accessibility to small businesses and organizations.

## 1. Introduction

In the United States, heating, ventilation and air conditioning (HVAC) is a major energy intensive end use in the commercial building sector in the US, amounting to 52% of the total energy use (EIA 2022). Small- and medium-sized buildings make up to 94% of all commercial buildings. Most of these buildings are conditioned with rooftop units but lack building automation systems (BAS) (<40% of the floor area) (EIA 2018). This section describes the current status of RTUs and gives an overview of the past work to estimate the energy savings potential in small commercial buildings. This study aims to tap into the savings potential by studying the human factors which affect the uptake of RTU controls in small commercial buildings. Roof-top units (RTUs) serve ~60% of commercial floor space and account for 150 TWh of annual electrical usage (Wang et al. 2016), corresponding to 20% of total commercial building energy use (DOE 2017a). There are approximately 15 million RTUs in the US (Deru et al. 2021) and in the past decade they have been the focus of national and state initiatives aimed at improving their efficiency. For example, DOE launched the Advanced RTU campaign (ARC) in 2013-2019 which was successful in saving 3.8 billion kWh of energy and about $400 million in cost through deployment of high-efficiency RTU controls (DOE 2017a, DOE 2017b).

Recent studies have shown that when RTUs with gas furnaces are retrofitted with advanced controls such as multi-speed fan control, integrated economizer controls and demand-controlled ventilation (DCV), it can yield energy savings between 24% and 35% (Wang et al. 2013). Simulation results from Woldekidan, Studer, and Faramarzi (2020) showed that upgrading RTUs with a variable-speed compressor and switched reluctance motor (SRM) supply fan can provide annual energy savings between 3% to 23%. Comparing between the two-stage and variable-speed compressor RTUs, there was an average of 1.5% extra total building energy savings. In addition to building energy savings, the simulated upgrades also resulted in peak demand (kW) reduction as high as 11%. Several features contribute to the savings, such as variable- or multi-speed fan control, integrated economizer control, demand-controlled ventilation, advanced thermostat control with optimum start and predictive cooling with smart economizer controls, remote monitoring and communication, fault detection and diagnostic capabilities, condenser fan control, and compressor variable-capacity control (Milan, Deru and Gable 2014). More broadly, advanced RTU controls can include a variety of energy efficiency measures, from networked thermostats with advanced scheduling features to hardware components such as multi-speed fan controls, integrated economizer controls, or DCV. Additionally, software platforms allow for remote access, management, and troubleshooting of the networked devices (LBNL 2023). These studies showed that deploying advanced RTU controls to enhance efficiency could serve as a significant strategy for reducing carbon emissions, while also proving advantageous for building owners economically and increasing occupant comfort.

Despite the potential benefits, the market adoption of advanced RTU controls remains small. Successful, scalable deployment of advanced controls as a retrofit on existing RTUs involves overcoming several barriers, some of which are well-known. First, the cost of retrofit can vary significantly depending on the readiness of the existing system and the IT requirements of the site. Some advanced control solutions may require changes to the mechanical and/or electrical systems such as implementing a variable speed drive or multi-speed fan. The mechanical systems may also need to be re-commissioned, and faults found in the system fixed. Additional costs may be incurred due to the downtime of the equipment. These costs must be weighed against the promised comfort improvements and energy savings from the proposed retrofit. Another barrier is the interconnectivity and compatibility of the different devices and software platforms. For example, installation of a desired smart thermostat may not be possible if it is incompatible with the RTU's on-board controller. Lack of interoperability between these newly installed devices and the legacy equipment or between different brands of new devices often represents a technical challenge and increases integration cost. Other barriers are hypothesized but not well documented. For example, on-going requirements for firmware and software updates can present additional challenges to realizing full value from the controls, and to more wide-spread adoption due to technology reputation and perceived risks. Installation, integration maintenance and use of these controls are not well studied in the literature and can constitute an important practical barrier to adoption. This is a category of problems that are hard to uncover unless they are observed in real time because installers and operators often downplay them, assuming they are case-specific rather than evidence of systemic problems.

In the past, DOE efforts such as the Next Generation Lighting Systems (NGLS) project used observational research to figure out the human perspective contributing to the slow rate of adoption of connected lighting systems (Collier, Taylor, and Matteson Bryan 2021). The details of the NGLS project and how observational research can be deployed to identify these barriers and support uptake are discussed in the Methodology Section below. For this study, observational research methods will be used to explore the human factors associated with advanced RTU controls from understanding design decisions through installation and beyond. This will result in identification of technology-specific barriers and best practices that will be communicated to product manufacturers, installing contractors, and building owners or managers in order to increase the successful adoption of networked RTU controls, capture energy savings, and improve occupant comfort. More specifically, this work is focused on the perspective of small commercial buildings (<50k sq.ft.), many of which lack a centralized BAS.

This paper shares the outcomes of the work to date after observing three installations of advanced RTU controls in California. The sections in the paper are outlined as Methodology, Preliminary findings from the field, Lessons learned and themes emerging from the research and Conclusion.

## 2. Methodology

In contrast to measurement and verification research methods, observational research provides insight into the "why" or "how" behind the research questions, which are typically related to the subject's behavior. As an example, researchers conducted a study to examine the contributing factors of a well-known occupational health hazard, lead exposure. The authors collected blood samples to objectively measure lead levels in workers before and after their shift. They also observed workers before, during, and after spending time at the jobsite. The objective blood samples confirmed that the workers had higher lead levels in their blood after leaving the jobsite. However, it was only discovered through observing the workers that incorrect use of the decontamination unit as well as poor personal hygiene habits posed a greater risk to workers than their time on the jobsite (Sen, Wolfson, and Dilworth 2002).

In the case of building technologies, there are similar complexities related to people and the installation and operation of advanced building systems that warrant observation to further understand the confusion surrounding product literature, the thought process behind a particular design decision, or the unchecked box during system programming. The process of designing, constructing, and using a building is inherently complex and difficult to understand. These behaviors are often left out of energy estimates because they are challenging to accurately predict, model, or simulate. Observational research methods involve the research team carefully watching and recording the behaviors that lead to an eventual outcome, thereby exposing the complexities of human interactions with people and technology that may influence the ultimate success or failure associated with a technology or building system.

In order to uncover complexities related to advanced RTU controls, the team leveraged the observational research methodology as presented by Collier, Taylor, and Matteson Bryan

(2021). An overview of the methodology as applied to RTU controls for the current study is provided in Figure 1.


Figure 1. Research methodology overview.

## 2.1 Technology and Site Selection

As previously stated, advanced RTU controls were selected for evaluation because they are networked (IoT) and emerging building technologies with significant energy savings potential. Specifically, there is opportunity to evaluate emerging products serving small commercial applications such as retail spaces and stand-alone community services like post offices or libraries that do not have a BAS or a dedicated facility manager. In coordination with other DOE RTU control programs, three technology categories of advanced RTU controls were identified for evaluation: Networked thermostats, Advanced RTU Control (mechanical upgrades), and Light Commercial BAS (LBNL 2023). Details regarding each technology category are shown in Figure 2. The team leveraged their existing network of partners and established new connections with utility programs and contractors to identify sites implementing these technologies. Each site chose specific products based on their own interests and context, and the team refrained from influencing these decisions.

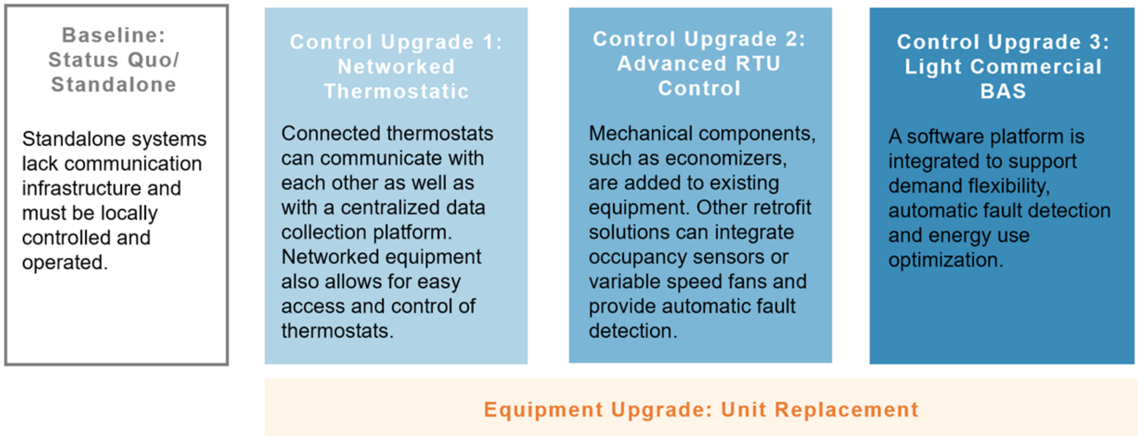



Figure 2: Descriptions of each control upgrade categories. Each site selected for observation was installing RTU control equipment that fits into one or more of these categories.

To date, the team has completed three initial pilot observations which are summarized in Table 1. The first set of pilot observations were conducted on the LBNL campus as an opportunity to refine the approach, including the documentation templates described in step 5b in Figure 1. Here, networked thermostats were installed in two conference rooms, as well as a laboratory support space. While it is best practice and of most interest to observe naive installers, the LBNL installation was managed by their experienced facility staff. The other two observations took place at a jewelry store and in a municipal building serving a small city in Northern California and were completed by typical HVAC technicians or contractors (referred to as ICs, installing contractors, hereafter). Each installation took place over one or two days. All of the sites were retrofitting existing controls with advanced RTU controls and all three sites decided to install devices from the same smart thermostat vendor. Five researchers observed the installation at LBNL over two days and there was one researcher each at the jewelry store and municipal building installation. Both of these installations were completed over a single day. At every observation the experiment completion rate was 100%, since all installers at each site successfully completed the installation and configuration of the new thermostats. It is important to note that the small sample size of the current set of observations is to provide only an illustrative understanding of the control upgrades and is not statistically representative of the upgrades made in small commercial buildings.

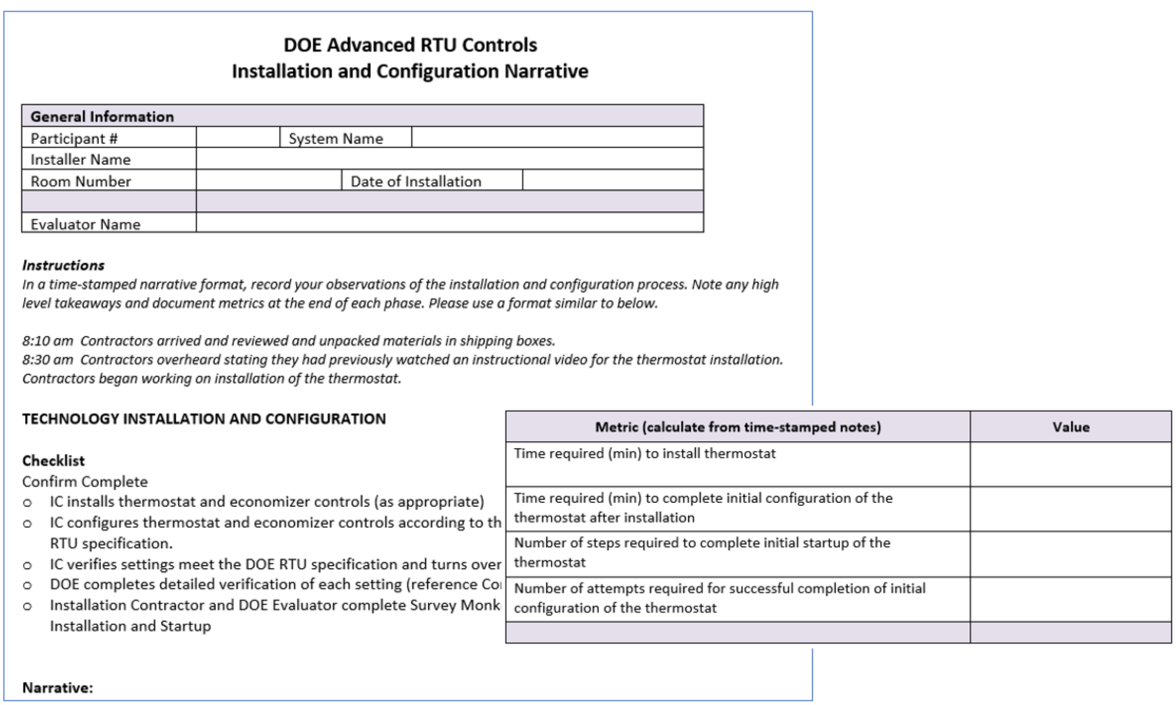
Table 1. Site characteristics selected for observation.

| # | Observed sites | Date and Duration of installation | People involved | Product (technology category) | Space type |
|---|---|---|---|---|---|
| 1 | PILOT - Lawrence Berkeley National Laboratory | 26 June, 2 days | 3 IC (Facility Staff, acted as site representatives)<br>5 Evaluators | 4 Smart thermostats<br>1 Add-on economizer control<br>1 Repeater and Gateway<br>(Category 1 & Category 2) | (2) Conference Room, Lab Support Space |

| | | | | | |
|---|---|---|---|---|---|
| 2 | Jewelry Store | 8 August 2023, 1 day | 2 IC<br>1 Evaluator | 4 Smart thermostats<br>1 Gateway<br>1 Add-on economizer control<br>4 Temperature sensors (Category 1 & Category 2) | Retail - Strip Mall |
| 3 | Municipal building | 15 November 2023, 2 days | 1 IC<br>1 Evaluator<br>4 City Staff | 4 Smart thermostats<br>1 Repeater and Gateway<br>12 Temperature sensors (Category 1) | City Hall |

## 2.2 Evaluations

To evaluate installation and configuration, each observation included the installing contractor or contractors, and one or more Evaluator from the research team. Apart from LBNL, each site hired contractors they would typically hire to perform the installations. The Evaluators were primarily responsible for observing and documenting the installation and configuration activities, however, they also ensured proper procedures and protocols were followed throughout the process. An instruction sheet and structured project checklist, shown in Figure 3, are provided to each Evaluator. Following the same process for each observation ensures rigorous data collection including predetermined quantifiable metrics such as time required to install each thermostat, or number of steps required to complete the initial start-up.


**DOE Advanced RTU Controls**
**Installation and Configuration Narrative**

| General Information | | | |
|---|---|---|---|
| Participant # | | System Name | |
| Installer Name | | | |
| Room Number | | Date of Installation | |
| | | | |
| Evaluator Name | | | |

***Instructions***
*In a time-stamped narrative format, record your observations of the installation and configuration process. Note any high level takeaways and document metrics at the end of each phase. Please use a format similar to below.*

*8:10 am Contractors arrived and reviewed and unpacked materials in shipping boxes.*
*8:30 am Contractors overheard stating they had previously watched an instructional video for the thermostat installation. Contractors began working on installation of the thermostat.*

**TECHNOLOGY INSTALLATION AND CONFIGURATION**

**Checklist**
Confirm Complete
- IC installs thermostat and economizer controls (as appropriate)
- IC configures thermostat and economizer controls according to th RTU specification.
- IC verifies settings meet the DOE RTU specification and turns over
- DOE completes detailed verification of each setting (reference Co
- Installation Contractor and DOE Evaluator complete Survey Monk Installation and Startup

| Metric (calculate from time-stamped notes) | Value |
|---|---|
| Time required (min) to install thermostat | |
| Time required (min) to complete initial configuration of the thermostat after installation | |
| Number of steps required to complete initial startup of the thermostat | |
| Number of attempts required for successful completion of initial configuration of the thermostat | |
| | |

**Narrative:**

Figure 3. Sample data collection template for consistency between evaluators.

While the evaluators were not allowed to answer questions posed by the installers, they were able to ask the installers questions about their process, actions, or reactions in the moment to provide an accurate record. Evaluators recorded observations in the form of a time-stamped narrative. When more than one evaluator was present, their narratives were collected independently and discussed and synthesized at the conclusion of the observation.

Although the research team remains actively engaged with each observed site, there were very few to no outstanding issues left to troubleshoot at the end of installation and initial system set up. Thus far, functional tests to verify correct operation has been a typical part of the installing contractor's routine. Evaluators documented the outcomes of this procedure, which typically included operating the thermostat past heating and cooling setpoints and waiting for the system to respond, but did not perform any further performance evaluations. Lastly, no end-user assessments have been completed at this time.

## 3. Preliminary findings from the field

Observing the installation of networked thermostats and associated RTU control equipment such as economizers or sensors in several small commercial applications provided insights into the human factors related to the adoption, installation, and initial setup of advanced RTU controls. All three sites elected to use technology from the same manufacturer; however, each site's approach to controls provides a unique perspective to the project.

### 3.1 Motivation and Technology Selection

While each owner had their own reasons for installing advanced RTU controls, a common interest was increased access and visibility into operation. LBNL upgraded thermostats and other RTU control equipment as part of an internal pilot project. The LBNL Facilities team evaluated different networked technologies in some of the campuses smaller and non-networked spaces that are not connected to a central BAS to increase their ability to monitor operation. Similarly, the ICs completing the upgrade at the jewelry store suggested that the store owners install networked thermostats to gain remote access and control when they are not physically in the space. The networked thermostats used in this installation are part of a system that includes a management system which facilitates remote access. The management system also allows the ICs to create a user profile and access the system remotely, which can be a helpful troubleshooting tool without physical access to the site.

At City Hall, the poor conditions of the existing RTU controls pushed City staff to replace controls. The existing controls were too complex - staff were unsure how to use or adjust the controls, equipment was not commissioned properly when installed and therefore operating incorrectly, and they had to rely on the manufacturer to troubleshoot any issues. The ongoing cost of software updates and annual service contracts for the existing system were also of concern to the City. After several years of poor performance of existing systems, the City allocated money for another controls upgrade. But they ran into another barrier when they did not get any responses from local contractors to complete the work. The City had to expand the search geographically to find a controls contractor available to complete the upgrade.

### 3.2 Installation

Overall, the observations demonstrated that the installation of networked thermostats and associated control components can present challenges, and that experience and familiarity with these systems is very helpful in mitigating installation issues. Using their experience and the provided written documentation, the ICs were able to quickly resolve any issues they had during the installation process. It took approximately 15 minutes for an IC to remove the existing thermostat and rewire the new thermostat. Installation hurdles were typically related to uncertainty surrounding the existing conditions. Generally, ICs would wire the thermostat considering the previous wiring configuration and written documentation. Next, the ICs tested the heating and cooling operation to verify that the wiring was completed correctly. Two of the thermostats installed at LBNL took slightly longer to test operation and adjust the wiring, but the issues were resolved and correct operation was confirmed within 3 attempts or less. In a conference room, the IC took a photo of the existing wiring configuration for reference after the thermostat was disconnected. Through several rewiring attempts, the IC determined that the previous thermostat was wired incorrectly and therefore an incorrect reference for the new thermostat. At the jewelry store and at City Hall the ICs wired the thermostats correctly on the first attempt. Both ICs had spent time walking the site and reviewing the existing equipment prior to beginning the upgrade. A summary of evaluation metrics comparing each installation and initial system setup is provided in Table 2.

Table 2: Installation metrics from 3 field observations.

| Evaluation metric | Observation 1<br>LBNL Pilot | Observation 2<br>Jewelry Store | Observation 3<br>City Hall |
|---|---|---|---|
| Time required to install hardware | Thermostat: 20 - 60 minutes<br>Economizer: 3 - 4 hours | Thermostat - 15 minutes | Approx. 15 minutes |
| Number of attempts required to verify performance of heating/cooling operation | 1 - 3 | 1 | 1 |
| Time required to complete initial setup of the system after installation (minutes) | 10 - 20 | 25 | 15 |

At LBNL, the installation of the economizer controller also presented installation challenges. The IC could not establish a connection to the newly installed economizer controller and spent roughly 45 minutes troubleshooting the issue. When the team returned the next day, the IC had determined through manufacturer documentation that the new economizer controller was not compatible with the other equipment. Luckily, the compatible component was already on site and the ICs were able to install and calibrate the economizer, but this added time to the initial 45-minute installation and troubleshooting process. Photos from the installation are shown in Figure 4.

Figure 4. Images of the installation and troubleshooting process at LBNL.

### 3.3 Initial System Setup

The last step in the installation process is to start up the system and other communication devices like a gateway, which facilitates communication between the networked thermostats and the web portal. The web portal allows the IC or the owner to configure detailed schedules, generate alerts, and review operational data, among other capabilities. For evaluation purposes, the initial system setup included:

- Start-up of gateway and connection to a network
- User profile creation and account setup
- Schedule creation
- Calibration of economizer controllers, as appropriate

Similar to the installation of the networked thermostats, the ICs found the initial system setup to be straightforward. As the ICs had installed the same system before, it only took between 10 and 25 minutes to complete these tasks. Prior to the installations, the ICs at LBNL went through an extensive vetting process with the IT department and discussed which network to install the devices on to ensure security. The IT department did not want the devices connected to the central LBNL network and decided to use a guest network for the pilot installation. At the conclusion of LBNL's pilot, IT will create a new, isolated network for these devices. Even though the initial system setup didn't take a lot of time, the ICs at LBNL noted that some settings were not easy to find within the organization of the web portal. Less experienced installers or others responsible for the daily use and maintenance of the system may find the unintuitive interface to be a barrier. The lead IC at LBNL set up a user account and invited their team to join. One schedule was created after the first thermostat was installed and was assigned to all thermostats. Lastly, the system installed at LBNL offers an automated calibration procedure for the economizer controller. The calibration procedure failed and alerted the ICs that there was an issue, which was resolved by changing the wiring at the economizer controller. The calibration was successful on the second attempt and took less than 5 minutes to complete.

The ICs at the jewelry store were employed by a regional installer who completed work for locations across the jewelry brand in their area. The gateway was operational in 15 minutes and it took the ICs about 10 minutes to create a schedule for the space. Since the ICs had worked with the client before, they understood how to connect to the network and how to manage account access on the web portal. The ICs also received a common schedule that was applied across the portfolio of jewelry stores.

Because of the existing control issues at City Hall, the City asked the IC to educate staff members on the installation and management of the system. However, during the installation the IC largely completed the work on his own, without the assistance of city staff. Several staff members were assigned, but seemed to be uninterested or completing other work. The following day, four individuals from the City attended a web portal training session hosted by the IC but did not show much interest in the training topics or learning about the newly installed system. The IC invited the City staff to contact him with any questions or trouble operating the system.

## 4. Preliminary lessons learned

The lessons learned during the observations have been grouped under the categories of 'Technology', 'People' and 'Market' to discuss respectively equipment or network issues; perspectives of different stakeholders; and issues arising due to proprietary systems and costs. As shown in Figure 5, the intersection of each category offers a way to improve the process from the initial decision making through operation and use of the control upgrade. These include:

- appropriately setting objectives and expectations for all the involved stakeholders at the beginning of the process,
- continuing communication throughout the process, and
- maintaining clear and thorough documentation for future maintenance and system users.

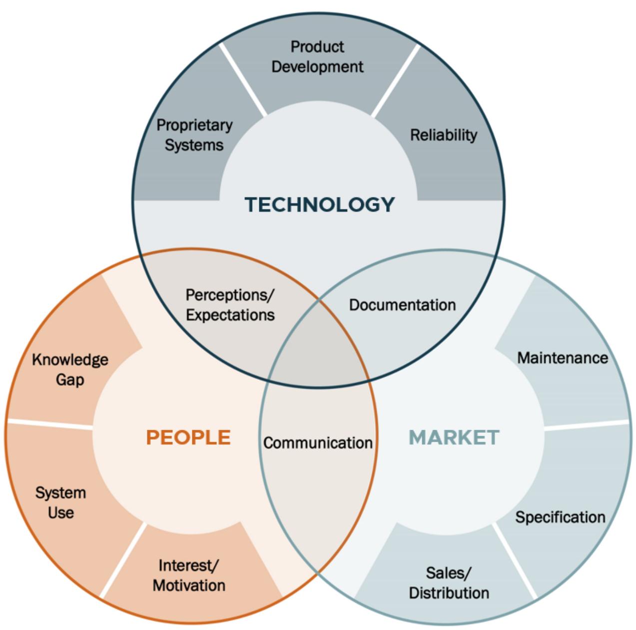



Figure 5: Human factors related to the adoption of advanced RTU controls and emerging building technologies.

### 4.1 Technology

**4.1.1 Networked components and user portals are still cause for concern, but are getting better.** Installing networked and potentially wireless control devices raises concerns for some owners regarding cybersecurity and network access, as well as simple logistical issues like maintaining user permissions and locating passwords. As seen with the existing system installed in the city buildings, software updates can also create hurdles during system use. The general anecdotal evidence is that IT teams are hesitant to give network access to the installers to install new devices. At LBNL for example, the IT department did not want the devices connected to the central LBNL network so they instead gave access to use a guest network for the pilot installation. The access process is often lengthy since IT teams want to ensure that the new device is not a threat to their network. During observations at the jewelry store and LBNL, the installers talked about how they had received access to the network prior to the installation day to register the gateway to make sure that the installation process was smooth and could be completed in a timely manner. Access to the network before installation allows installers to address any potential issues or compatibility issues beforehand, reducing the likelihood of delays or complications during the installation process. Overall, addressing these logistical issues related to network access and cybersecurity is essential for the successful deployment and operation of IoT building systems like HVAC controls. Collaboration between IT professionals, installers, and building owners is key to overcoming these challenges and ensuring smooth implementation.

**4.1.2 Unclear manufacturer documentation and unintuitive software interfaces lead to slowdowns.** Anecdotally, unclear documentation and software interfaces impact the installation and programming process and increase installation costs. However, contrary to typical situations, LBNL contractors found the product documentation to be very clear and comprehensive. However, they did note that a lot of the important settings and features were buried within the "Admin" section of the web portal which was unintuitive and also time consuming to find. The installers at LBNL believe it would be valuable for the control manufacturers to provide training for their systems and have suggested this to the vendor. During the interactions, we also learned that many manufacturers charge for training about $5,000 or more which can be counterproductive to the goal of more installers offering their equipment. This can affect the adoption of devices as installers might find it cumbersome and costly to invest in expensive trainings.

**4.1.3 Complexity of integrating new HVAC equipment.** Installing, integrating and commissioning new HVAC components with existing equipment can be complicated mostly because:

1. Wiring, distribution and equipment may be hidden or difficult to access. According to LBNL installers, since a thermostat is the end node to a complex and hidden HVAC system it complicates troubleshooting and rewiring of thermostats. Experienced installers capable of problem solving in unknown situations will be valuable to navigate these issues on site.
2. Vendors often use proprietary software and hardware that are not easy to replace with equivalent products from other vendors. At LBNL, a new economizer controller was installed and integrated with a new thermostat with DCV capability. While the older installation was

hardwired, the new system was wireless. This led to communication issues between the new module and the economizer which could only be resolved after a discussion with the new vendor's technical support team. The setup took much longer than expected and the team had to return to the site for a second day to resolve this issue. This issue is further discussed in the 'Market' sub-section.

3. Due to a high number of interacting components and slow dynamics, the commissioning processes for HVAC controls is long and tedious. In all of the observations we conducted, configuration of thermostats, especially the ones that provided additional capability (i.e., demand-controlled ventilation or occupancy sensors) took the longest time. To address these issues, a simplified and clear commissioning process can reduce the time and effort required to configure and commission new devices. Images in Figure 6 show ICs inspecting thermostat wiring.

Figure 6. Images of ICs installing networked thermostats.

**4.2 Market**

**4.2.1 Proprietary systems prevent interoperability or seamless expansion when connecting different devices** (particularly over time). Aside from the wiring of the thermostat to traditional RTUs, many products use unique software or hardware interfaces that are incompatible with other vendors' equipment. While manufacturers may benefit from locking customers into proprietary systems and service contracts, this limits the range of economically viable options when upgrading a system or replacing components. Integrating proprietary systems with other BAS may also require custom development or middleware solutions. It can also lead to delays in installation which can be frustrating for both the installers and building owners. The installers faced such an issue while upgrading the economizer module and DCV enabled thermostat at LBNL.

**4.2.2 High upfront cost and lack of perceived value is a significant barrier.** While it is expected for any user group to be cost conscious, this is particularly pronounced for small and medium commercial building owners. They have fewer resources and smaller budgets so they want to reduce the capital expenditure when replacing HVAC units. Advanced RTU control technologies have high upfront costs which when combined with their 'lack of perceived value' deters the small building owners from investing in them. Beyond providing remote access, buyers do not perceive their value to be greater than cost of installation and equipment. The actual cost savings and benefits from high efficiency units are unclear. Due to improper maintenance these benefits are not always realized which further reduces the intent to invest in these expensive measures. Installers at the municipal building and jewelry shared that the incentives to cover some of these costs are usually insufficient and unevenly split between different parties (owners vs renters). While the owners are the ones buying the equipment, the additional expense of an inefficient equipment is passed on to the renter.

### 4.3 People

**4.3.1 Users are not motivated by energy efficiency.** The preliminary observations confirmed that users do not care as much about energy efficiency as they care about increased bills or passed-on energy upgrade costs. This has led us to expand the research to incorporate users' perspective as well through surveys and interviews to understand their interactions with the installed technology over time. This will help to gain people-focused insights on operation and performance of RTU controls to determine if and how energy efficiency capabilities are being utilized over time.

**4.3.2 Absence of existing schedules and poor system configuration.** Installers highlighted gaps which affect seamless installation and successful adoption. All installers from the three observations emphasized that it was critical to have access to existing HVAC schedules. Often these schedules were not available to the installation team which limits their ability to configure the system to suit the needs of the building occupants. This leads to poor utilization of the system and discontent among the building users about the effectiveness of the newly installed technology. Another learning from the observations was that in addition to installation of efficient devices, efficient controls can make a substantial difference – correct programming is key! Experienced installers found networked thermostat installation and setup to be straightforward and fast.

**4.3.3. Lack of motivation in system upgrade and maintenance.** In the City Hall building, the existing RTU controls had been upgraded before but because they were too complex for the city to operate and maintain, the system was not being used properly. The controls had also been programmed incorrectly and in some cases were physically disabled. Without a depth of knowledge in HVAC controls, their only option was to rely on the manufacturer for support and troubleshooting which they felt was too time consuming. As a result of many unresolved issues, the system was no longer functional and conditioning spaces adequately. The city staff searched for a different solution which involved installing new systems and getting training for their staff who could learn to operate and maintain these upgraded devices. Overall, there was a lack of interest in the installation of the new upgrades and the city staff showed little interest in understanding system operation and maintenance The local CCA electricity provider failed to send any technicians for training and some of the city staff left the training before completion. In addition, the IT department, which initiated the project, also didn't attend training.

## 5. Conclusions and next steps

The observational research allowed the team to identify human factors hindering the installation of advanced RTU controls. The lessons learned from the three pilot observations were captured under the broad themes of technology, market and people to organize the barriers to adoption of energy efficient RTU controls and capture broadly applicable outcomes and recommendations to mitigate these barriers. Some key findings and recommendations based on these initial observations are summarized below:

1. Addressing logistical issues related to network access and cybersecurity is essential for the successful deployment and operation of IoT building systems like HVAC controls. Collaboration between IT professionals, installers, and building owners is key to overcoming these challenges and ensuring smooth implementation. Access to the network before installation allows installers to address any potential issues or compatibility issues beforehand, reducing the likelihood of delays or complications during the installation process.
2. It would be beneficial for manufacturers to design software interfaces with usability in mind; by ensuring that important settings and features are easily accessible and clearly labeled within the software interface. In addition, a clear and comprehensive documentation using diagrams and detailed instructions can be an easy and cost-effective way to fix this issue.
3. Standardization of HVAC equipment, interfaces and protocols can simplify integration efforts by ensuring interoperability between different vendors' systems. Addressing interoperability issues by encouraging adoption of open communication protocols and standards within the HVAC industry, mandating interoperability requirements for HVAC systems in building standards and developing interoperable devices and solutions could lead to higher adoption of energy efficient new devices.
4. In case of upgrades in city owned and operated buildings, we recommend establishing a comprehensive project team early on in the process. Such a team could include a manufacturer representative, an IT staff member, a maintenance staff member, a finance representative from the business office as well as the project manager. This helps set expectations and roles of different stakeholders involved in the decision-making process and also increases all parties' accountability.

As the nature of building systems and technologies continue to become more capable, connected, and integrated, evaluation of human-technology interactions can help us better design technologies which would be effective for adoption and use. As next steps in our work, we plan to expand our research to understand more people-related issues affecting the adoption and deployment of these controls. We will study more complex systems such as hardware upgrades and optimization platforms in small commercial buildings to capture barriers associated with their adoption. We will also conduct system performance and user evaluations to understand how the system aligns with user expectations over time. We will also be conducting interviews of different stakeholders (owners, managers and users) to learn about the decision-making process for purchasing energy efficient RTU controls. Gaining these people-focused insights will help us understand the barriers to advanced controls adoption from different perspectives and make more comprehensive assessment of the current situation, as well as make recommendations to address the existing barriers.

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