EEB HUB — Energy Efficient Buildings Hub

RUTGERS

THE STATE UNIVERSITY OF NEW JERSEY

Preliminary user needs assessment and responses to a novel human-machine interface for a building control and diagnostics system

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Executive Summary

As part of the Energy Efficient Buildings Hub Year 3 subtask on occupant behavior and decision making, a research team performed a user needs assessment and a preliminary evaluation of the effectiveness of a novel human-machine interface (HMI) for a building control and diagnostics system. The HMI was developed by a different research team at the Hub, and the two teams worked closely together in a highly iterative process of design-and-feedback that allowed rapid progress from concept to pilot implementation. Funding for this project ended sooner than expected on January 31, 2014, so there is more that could be done regarding implementation and evaluation. If resources become available in the future, then field deployments of the HMI could be evaluated and the resulting information used to further refine the interface.

1. Introduction

As part of the Energy Efficient Buildings Hub Year 3 subtask 6.4 on occupant behavior and decision making, a research team from Rutgers University performed, first, a user needs assessment, and, second, a preliminary evaluation of the effectiveness of a novel human-machine interface (HMI) for a building control and diagnostics system. The HMI was developed by a different research team at the Hub under subtask 4.4, and the two teams worked closely together in a highly iterative process of design-and-feedback that allowed rapid progress from concept to pilot implementation. This report summarizes the needs assessment and preliminary evaluation.

2. Assessing Control System HMI Needs

Introduction

This section summarizes a pair of focus groups that assess the needs of building operators for information on energy performance and fault diagnostics in their buildings. This needs assessment, concluded June 30, 2013, provides guidance to researchers at the Energy Efficient Buildings Hub who are designing new Human-Machine Interfaces (HMIs) for building management systems. It is part of an ongoing process to scope, design, deploy, and evaluate better HMIs for existing commercial buildings.

Research Questions & Objectives

- Considering typical facility constraints, how to present complex information to facility staff in order to enable efficient user-system interaction that leads to energy-saving?
- How to engage facility managers with control and diagnostics capabilities
- What actionable information can help facility managers identify energy saving

The research design was organized around a multi-step participatory design framework intended to (1) characterize the experiences of facilities personnel with existing systems designs, (2) propose solutions to the needs that were identified with interfaces, (3) implement the proposed solutions through a series of mock ups of, and (4) evaluate the response of managers and operators to the design implementation and the process of engagement. Along each step of the

process is nested an iterative participatory process by which facilities personnel could offer their responses and ideas to interface systems design and operation. Overall objectives were to demonstrate energy Human-Machine Interface (eHMI) to <u>engage facility staff</u> with advanced supervisory control and diagnostics technology that supported effective management of systems for maximizing energy efficient operations. This report summarizes step #1 in the research process.

Methods

Participants were recruited through a "snowball" sampling process by which the Subtask members reached out to their primary contacts within the facilities community to request their assistance with identifying individuals who would be knowledgeable of interface dynamics could participate in focus groups. Two groups then were convened in a local university campus setting and at the Hub Icon Lab and included managers and operators from both private and public sectors from university campuses, commercial office buildings, and non-profit facilities. Participants signed IRB-approved informed consents that safeguarded their confidentiality while authorizing the recording of the session. Notes were captured at the focus group meetings and recordings were transcribed and maintained on a secure server at Rutgers University. Each group was conducted for approximately 90 minutes.

Results

Due to confidentiality provisions in the human subjects protocol governing this research, verbatim transcripts are not shared in this report. Instead it summarizes key findings. Analysis of the focus group comments produced a number of overarching themes relevant to energy savings through improved human machine interfaces:

1. Facility staff must integrate complex information in a manner to promote efficient user-system interaction that leads to energy-saving responses.

   Increase information in system notifications. More information is needed on the monitoring screens and in emails to help the operator or manager know what's going on.

   <u>Prioritization of alarms</u>. Facility personnel overwhelmingly identified the need to prioritize and categorize alarms. A glut of alarm notices, especially those associated with VAV boxes, are triggered when systems cycle: routine start, stop, start again alarms can lead to overlooking "critical" alarms. Alarms should provide notification of onset of potentially sharp changes in operating levels, performance. Alarms also don't trigger when areas are too hot or too cold, reducing opportunities to affect energy consumption; e.g., triggers can zero in on zones with color codes or be channeled as "high" or "low" alarms to catch bad meters.

   <u>Monitoring activities.</u> Graphics depicting conditions by floor and color coding by temperature are convenient, and notification of manual overrides would provide information for managers to more quickly identify locations of areas potentially requiring attention. Systems should notify managers what is going on, e.g., if mechanical cooling, free cooling, or reheating is underway there should be information on the screen. Status reports, for example, on VAV boxes that are operating 100% and not satisfied can lead to further investigation and improved performance. Cost savings can be realized if there are indicator

lights where problems exist and can facilitate diagnosis and reduce time by repair service provider to locate the problem.

Strengthen human capital. A good deal of employee effort is spent managing the systems, particularly where load shedding / demand response efforts at energy efficiency are engaged.

Education. BMS is the norm now in many buildings but operator training hasn't caught up. Not everyone has the education to analyze systems for the greatest amount of energy savings. Training should be provided on an ongoing basis to provide reinforcement for existing programming and orientation for updates. Training that starts in advance of implementing systems may help personnel feel comfortable, reassured, and empowered with the expectation that systems function efficiently and are not "an enemy." Videos that include a Q & A component and a step by step orientation beginning with simple points first can also help build confidence and reduce defensiveness. Small segments of time, such as lunch & learn sessions may be more easily tolerated while extensive blocks of time, e.g., 8-hr sessions can "lose people".

- The interface system should also teach the user by incorporating a logic function to help guide next steps for the operator. A help screen can offer check points so that the system helps and does not overwhelm the operator.

2. Engaging facility managers with control and diagnostic capabilities that improve efficient energy use as well as energy savings. Facilities personnel have pointed to a number of areas to be integrated into a systems approach to enhanced their abilities to manage efficient energy use:

Coordinate placement of room appliances, equipment, and activity settings with locations of energy management devices. Room electronics, windows, and locations of planned activities can conflict with locations of thermostats, returns, and vents to create conditions for either erroneous readings or uncomfortable occupants demanding changes in settings that may not best reflect optimum energy use. For example, the heat from a large monitor placed near a thermostat can provide readings not consistent with the majority of the occupancy space.

"Measurement is key". Facilities personnel need meaningful and "readable" feedback of information in order to make informed decisions.

Occupancy sensors. There is a need generally for better occupancy sensor data and specifically for the ability to compare percent of occupancy activity to kWh.

Flexibility. Operators speak often of desiring systems that are flexible. Comments defined this flexibility in terms of:
- Reporting. Personnel with varying degrees of knowledge should be able to design their own reports from an intuitive menu system that permits different configurations of reporting queries. Exception reporting should be enabled with

fewer time (day, week, month, etc.) and parameter constraints. For multi-tenanted buildings this might include a function or "button" for each tenant.

- Settings & Controls. Lab environments typically require 24/7 temperature stability but other spaces should be designed for separate night setback settings. Meeting building needs in an energy efficiency capacity requires an ability to vary controls in an iterative process where the operator makes an adjustment, receives feedback from settings, and can make a later adjustment based on changes in the weather or other influences. Feedback is also needed on repairs that have been made, through a work order history,

Technology systems must be integrated.
Integrating legacy systems. Retrofit buildings in particular will often have a patchwork of systems that have been installed during different phases of the life of the building or buildings. Plug-n-play components can often facilitate communication between systems.

Submetering. Panels that have been divided by the contractor submetering can be an effective means of tracking energy use. Submetering data should be capable of rolling up to one overall usage number.

Improved monitoring. BAS monitoring typically goes through one screen and may be improved by using multiple screens to monitor every meter in the building such that every condition is submetered. Right now gathering that data is a manual process.
Integration with organizational systems. Building or organization-wide energy policy is important for communicating objectives and expectations to occupants and tenants as well as to prioritize investments to the systems, including dedicated facilities staff, to maximize energy savings. Typically, energy savings features are the first to be cut in value engineering.

Facility personnel need basic information about building systems. Some meters are still being read manually. A building may or may not have been commissioned as it is costly especially for small fit-outs. When available, however, information on performance indicators is useful to facilities personnel expectations. An equipment history is important especially where there are multiple systems in place. Load shedding and other operational applications must factor in the needs of the tenants which must be defined. In addition, there is a need to have readily available information such as the forecast and time of day, the presence of sun, and the time of day when changes that will affect building conditions might be expected.

3. Actionable information is needed to help facility managers identify energy savings. Energy management systems can save in two ways: reduced labor and increased service – but they need better fine tuning ability.

   Avoid trade-off with comfort. The decrease in achievable kWh needs to be balanced with a reasonable comfort level for occupants. Operators find themselves responding to

both BMS systems as well as phone calls from occupant stakeholders and tenants who are unhappy with comfort levels. Many facilities personnel are necessarily "in the business of comfort" while others, such as those in academic or research environments recognize some areas (e.g., labs) require steady state environments with thermal comfort the next priority. Flexibility in settings and identification of occupant needs can facilitate energy savings.

BMS interfaces should help diagnose the problem, offer steps for correction, and report back on the fix.

Wireless access needs improvement. Not all systems respond to the same platform. Better technology is needed with less interference.

This mid-project assessment of the eHMI (energy Human-Machine Interface) initiative to engage facility staff suggested that a number of advantages could be achieved through improvement of BMS communications with facilities personnel. Fundamental to this initiative is an ongoing iterative design-user process by which operator needs can be identified, design and organizational solutions might be proposed, and feedback is obtained again from operators on the fitness of the solutions toward energy efficient operations.

Next steps were to propose design mock-up design solutions and obtain feedback from facilities personnel on the effectiveness of the solutions in addressing facilities personnel needs and achieving energy saving building performance.
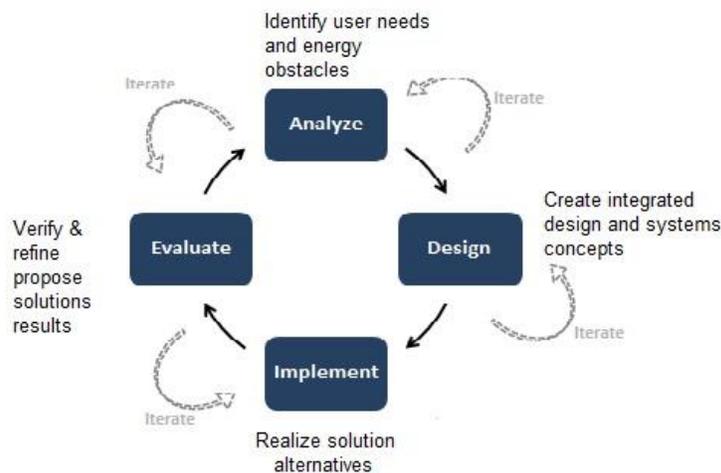

Figure 1

3. Assessing eHMI Effectiveness via Participatory Design Feedback Sessions

Introduction

This section summarizes additional progress made for greater understanding and improved building information system human machine interfaces (HMI) toward increasing facilities operators' energy management capacity. Through a participatory design process, initial

activities focused on engaging facility managers and operators to learn more about their responsibilities, priorities, gaps in information, and needs for improving building energy performance and transforming this information into a usable design-applicable format. Following the needs assessment, designers have taken this on-the-ground, inductive specification of key affordances and constraints to energy savings operations and developed mockups or 'wireframes' for further feedback by individual participants and enhanced precisions on proposed solutions to these constraints. The subsequent feedback on the initial prototypes was then reviewed and modifications were made to produce an upgraded and final "Look-and-Feel" prototype also delivered as screen images prior to development of the demonstration model.

This section summarizes the participatory design process and the responses of facilities participants to the proposed design changes as of October, 31, 2013. Specifically, we discuss:
- What are the primary features to be included for effective human machine interface (HMI) assisted energy management?
- How do the design mockups address the different skills of users?
- How can HMI best balance energy savings information with other facilities' priorities, such as comfort?
- What is still needed, where do gaps and limitations lie?

Assessment Protocol

During this phase of the project, feedback sessions were conducted in response to two successive design prototypes: The first design was a wireframe mockup intended to provide a visual response to some of the needs identified by the Phase I focus groups. Because this first stage of the Phase III process required more one-to-one intensive review of the 'wireframe' screen contents, only individual feedback sessions were conducted either onsite or via webex. The second design was to enhance precision of the HMI usability just prior to development of the demonstration prototype and included focus group and individual interactive interviews. Participants were recruited from earlier Phase II feedback sessions.

For the first wireframe mockups, 2 sessions were conducted through separate onsite visits to 2 facilities managers who also participated in the earlier Phase II focus groups (see Quarter 2 report) and thus were familiar with the objectives of the participatory design process. As a way to reduce time and costs for investigators and also to test the efficacy of introducing this material by remote electronic communications, two additional sessions were conducted as a webex presentation and discussion, with otherwise the same format as the onsite presentations. Individuals were asked to comment on the strengths and weaknesses of the interface images, how often they thought they might use the information displayed, clarity of the interfaces, essential and less important features, and the need for improvements or additions.

Final "Look-and-Feel" feedback sessions were also held through a focus group format to obtain reactions from individuals with various facilities operations skills levels, and via a webex presentation for a more in-depth review with an individual facilities manager.

Objectives for inclusion in the mockup feedback and discussion sessions focused on:

- Normalized energy usage/system performance comparison in a flexible and reconfigurable manner (Monitoring)
- Automated diagnostics and root-cause analysis of alarms (Diagnostics)
- Fault prioritization based on criticality, safety, energy and comfort impact (Diagnostics)
- Ability to visualize and control energy-saving vs comfort trade-off (Control)

Findings

Findings for these sessions are organized according to the page objective (i.e., home page for monitoring, diagnostics, control) and the feedback issues or topics.

Wireframe Mockup

As noted earlier, Phase III feedback sessions included two successive mockups to assess the usability of proposed HMI conceptual models. For the first mockup, one-to-one presentations were made to 4 participants to explain the capabilities and objectives behind the static images on power point slides. All 4 participants were in managerial roles.
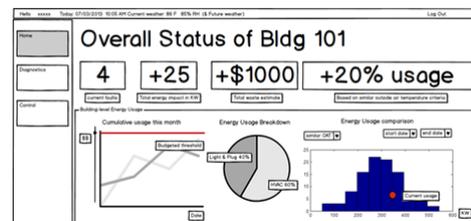

Home screen with overall status:

Figure 2. Home page of wireframe mockup.

1. Prioritizations**.** Generally, participants reiterated their priorities as follows:
   - comfort and life safety over property protection and energy management,
   - preferences for data on comfort impacts to be available on the same page as energy information, and
   - having easy access to the data to maximize usability

   Because managers are often asked to produce reports on the data that is available to them, they would also like the ability to

   - run queries on safety, comfort, and energy conditions

2. Monitoring. A number of comments focused on both the appearance and the function of the Home Page:
   - Combination of graphics and text were both useful for individuals oriented to different forms of communication.

   - Breakdown of information was extremely helpful.

   - While participants found everything on the screen helpful, there was a general preference to be able to call up different items at different times, and not to have all information on screen all of the time.

- There was also an interest in having information on the underlying assumptions behind calculations readily available, and

- having widgets that list different function abilities and are associated with user profile

3. <u>Diagnostics</u>.   Participants expressed an advantage to having fault information and how the system is being negotiated all in one place and identified a number of affordances that they would like to see mapped to the diagnostic pages, including

- Integrating hot and cold calls into the database, and

- both comfort and energy impacts incorporated into fault alarms;

- provisions for separate categories for faults, e.g., current, suspended and closed with no ability to close out faults indefinitely so as to drive a repair protocol;

- a history of fault patterns to help support decision-making for repair or replacement;

- an ability to reprogram defaults, critical values;

- a list of widgets for zone level issues to help immediately identify problems with highly critical equipment, e.g., compressors down; and

- an ability to access notes and actions taken to address fault correction

The diagnostic pages were thought to be particularly useful for daily monitoring during heat waves and to back off energy use when conferences and other large gatherings were not scheduled.

4. <u>Energy Management</u>.   Again, the diagnostic pages were thought to be most useful where comfort impacts were integrated into energy adjustments:

- They were "spot on" with the display

- "Bringing out comfort management the way energy management was brought would hit a home run"

- Data available on a real time or even hourly basis could offer important feedback on the effects of actions taken by operators without having to wait 24 hours. The information could mean the difference in missing energy targets.

Participants' frequency of use for the page might be motivated by
- Their concern with multilevel zones in multitenanted buildings
- The ability to get what is needed in a few clicks, when "high tech buildings go bad quickly"

- Issues that arise with submetered tenants

Look-and-Feel Mockup

The more advanced mockup to be reviewed prior to the demonstration design was presented to 5 focus group participants representing a variety of facilities operational skills based in a university system. In additional individual session was also held with a facilities management representative from a large multitenanted, private commercial buildings.

1. Overall Building Status. The response to the visually engaging template was generally positive,
   - "gives user what they need, not what you think   they need";
   - "an awesome idea": canned screen that can be customized,
   - The different ways to compare data were well received, with some formats more appropriate for use during the summer than to winter.

Figure 3 Look-and Feel-Mockup home page

The interface was thought to be particularly relevant to managers and individuals who were responsible for monitoring but perhaps not well versed in the area.

Information "I" icons in the corners of the reported quantities revealed underlying assumptions upon which the calculations were based.

2. Diagnostics. Similarly, the diagnostics visuals were considered an advantage for overall management responsibilities:

- "When humans intervene incorrectly, managers can look at this screen and id patterns and solutions to increase efficiency"

- "From an energy consumption standpoint, this screen is really important, helping to diagnose the problem"

- "…Managers, operational engineers, higher level will be thrilled to see this - helps them figure out alarms but also alerts you prior to reaching critical alarm state."

- Graphics provided a helpful visual for identifying exceptions to normalized operations

- The ability to close out tabs that are acknowledged but no longer needed is helpful.

There were also a number of additions identified by participants that would enhance the usefulness of the interface:

- Basic information is needed, such as everyday scheduling equipment and monitoring how it is running, which has been long neglected in energy management systems.

- A floor plan diagram with VAV boxes and their efficiencies might be another way to communicate whole-building operations

- An easier way to monitor operators; run reports on high alarms, setpoints, and schedules; and know how many faults are being reset on a regular basis that need to be addressed.

- Wet bulb readings would be especially helpful in the summer.

- The ability to set alarms and pre-alarms to alert operator when the temperature deviated a small amount and a large amount from the setpoints.

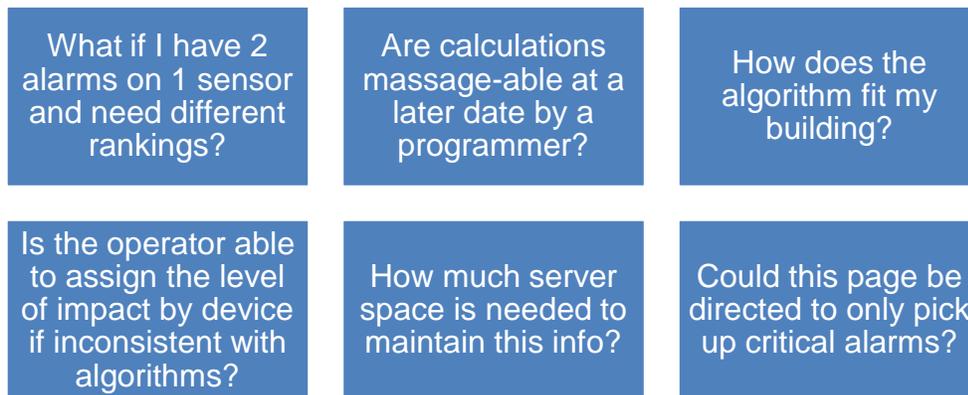The detail in the interface also raised additional questions:

What if I have 2 alarms on 1 sensor and need different rankings?	Are calculations massage-able at a later date by a programmer?	How does the algorithm fit my building?
Is the operator able to assign the level of impact by device if inconsistent with algorithms?	How much server space is needed to maintain this info?	Could this page be directed to only pick up critical alarms?

Figure 4

3. <u>Overall Control and Relevance to Systems</u>. Several comments raised other questions about constraints in integrating the proposed "eHMI" overlay into existing systems:

- Most existing systems may not have the external feedback mechanism to make the determinations demonstrated. Systems overlay is dependent on older systems that won't be able to make the system produce the information demonstrated.

- Information is most relevant to managers, who would need time to filter down the data to operators. It would take the average engineer some time to get comfortable with this level of information.

- Standard energy management information used 75% of the time by operators would need to be incorporated

Finally, there was some debate on the current availability of the interface capabilities through other providers and the ability to integrate this system into legacy systems, although it seemed apparent that the ease and thoroughness of the interface layout presented was an advantage.

Presentation Format

The WebEx format used for the individual presentations was well received by participants, including those who had participated in one-to-one on site presentations. Recall that these participants were managers. All agreed that, while the media format worked very well for them, personnel with fewer skills and those relying on introductory materials would require in-person demonstration where they could stop, discuss, and make references to previous material for maximum comprehension.

Summary

The eHMI mockups offered an important opportunity for facilities personnel to examine prototypes and offer feedback to designers of building management systems (BMS) control interfaces prior to significant financial investment into software design. Not only does this kind of participatory design strategy save on cost, but also it provides designers with information on affordances and constraints to help produce the most effective – and usable - application of the interface.

Many of the comments by facilities personnel served to provide a list of preferences for customized interface capability. While all comments could not be incorporated into design parameters for obvious reasons, there were number themes that had a great deal of overlap among participants' feedback and several that were able to be incorporated into the second prototype for comment. For example, participants were emphatic that energy management functions be intrinsically linked to comfort impact assessments. Reports that are just a few clicks from the data are also particularly important to managers. The final interface was well received with its "spot on" display, interchangeable widgets and combination of graphics, text, and easily accessible information icons. Specification for fault criteria was more intricate and a system to maintain a record of fault patterns was proposed.

Concomitantly, the interface seemed particularly geared to managerial roles and potentially less relevant for average skill operators. A number of comments offered suggestions as to what might be included to offer this tool to a broader user group.

Finally, the question about the potential performance of the eHMI as an overlay to some underlying BIS systems was an overriding concern. Participants pointed out that existing legacy systems might not have the capability to support the data needs and operation of the proposed interface.

The participants' feedback to the mockups provided the best opportunities to work out or work in some of the user-defined features needed for successful energy management. An assessment of actual use of the demonstration models should be very helpful in determining how successful the interface can be in mapping to users' concerns and overcoming obstacles to greater building energy performance.

4. Additional feedback from a pilot user

On January 29, 2014, there was an opportunity to meeting with a subject who operates a building. This was a voluntary effort and the subject was able to stop at any time. No recordings were made of the interview.

The research team presented the interface and explained the major functions and solicited feedback. The user did not ask any questions comparing this interface to current systems, but the subject volunteered a lot of comparisons anyway. Major pieces of feedback included:

-Yes, the subject is a user of a current system.

- The subject was first skeptical that this system had possibly caused a problem he had experienced in the previous week. I explained that the interface was not turned on, so nothing it did would actually affect the building, though the information was live.

-"This is more user friendly than using the current system."

-"This would be my first choice." (Comparing wanting this as a tool instead of the current system as if he had to pick one.)

-"This would be 50% faster and easier than [the current system]" (with respect to fixing problems).

"The [current system] is – you have to know it to operate it" (with reference to difficulties encountered in trying to use the current system to diagnose problems.)

-"It's much simpler and direct and to the point." (With reference to faults instead of using the graphs to diagnose problems.) The subject relayed that when something is wrong in the current system, there are many possible explanations, where the diagnostic capabilities of the new interface points directly to root causes.

-The subject felt the sorting features were useful when trying to figure out why certain things had happened. For instance, when looking at why a transformer blew out due to increased load, the subject felt sorting by energy cost would help identify a possible cause. (I am skeptical that this is actually how the system would work, but that a question for an HVAC engineer.)

-I think the subject felt a little bit like the feedback was negative towards the current system, because the subject added "Don't get me wrong, when the current system was introduced it did wonders for the way it was before."

-Having access to this would be a big plus from any computer rather than just from a specific computer. I explained that it would work from any phone or tablet, and that was well-received.

-The subject felt that having access to the interface would result in "less service calls" and that it would help with a "self-service approach" rather than having to call support for various pieces of equipment.

-Overall the subject was impressed with the "graphics, results, and answers – information – [available] before trying to figure [a problem] out."

5. <u>Conclusions</u>

Funding for this project ended sooner than expected on January 31, 2014, so there is more that could be done on this project. If resources become available in the future, then field deployments of the HMI could be evaluated and the resulting information used to further refine the interface.