The National Building Controls Information Program

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ABSTRACT

The National Building Controls Information Program (NBCIP) has been established at the Iowa Energy Center with initial support from the United States Environmental Protection Agency. The NBCIP was established on the premise that properly functioning control systems are a significant contributor to energy efficiency, and problems associated with building controls and operation are a primary cause of energy inefficiency. The objective of the NBCIP is to develop a source of manufacturer-specific performance information as well as broad-based best-practice information on building controls and related components that will promote energy efficiency in buildings.

This paper describes the motivation and background for establishing the NBCIP, outlines the first year efforts of the NBCIP, and summarizes findings from tasks already completed. In particular, findings are presented from a literature review of case studies reporting inefficient energy use linked to control-related problems. Control problems associated with input devices, software programming, and operator interference had the highest rate of occurrence among the subcategories of problems identified. Findings from a roundtable discussion in which controls experts were asked to help identify the source and energy impact of control-related problems are also presented. The results from the roundtable support those from the literature review and identify problems stemming from software programming as the subcategory of control problem having the largest energy impact. These findings and those from other scoping activities to be carried out in the first year of the program will be used to help prioritize NBCIP efforts.

Introduction

Energy use of buildings represents 36% of the total primary energy consumption in the United States (BTS 2000, 1-1). Often this energy is used inefficiently and the inefficiency can be linked to the control/operation of the building. Hardware failures, software errors, and human factors related to difficulty of use and understanding of control products all conspire to prevent buildings from achieving the energy efficiency that is expected. The first step toward correcting this underperformance is to better understand the cause of problems with building controls. The second step is to develop information that will help solve these problems and to disseminate the information to building owners, facility managers, design engineers, controls consultants, and manufacturers of control components and systems.

The National Building Controls Information Program (NBCIP) was created at the Iowa Energy Center (IEC 2002a) with sponsorship from the United States Environmental Protection Agency to address the need for building control system information. The NBCIP was established on the premise that properly functioning control systems are a significant contributor to energy efficiency, and problems associated with building controls and operation are a primary cause of inefficient energy usage.

The objective of this paper is to provide an overview of the NBCIP and to present findings from tasks already completed in the first year of the program. The findings include a summary of case studies of real buildings that document problems with control systems and a summary of a roundtable discussion with building controls experts addressing the topic "What's Wrong with Building Controls?"

Why a National Building Controls Information Program?

It is commonly understood among heating, ventilating, and air-conditioning (HVAC) professionals that direct digital control (DDC) systems can improve the energy performance of a building (ASHRAE 2000). Hicks and von Neida (2000) found that the 1999 Energy Star office buildings had an average site energy intensity that was 44% lower than the market average determined from office buildings in the Commercial Building Energy Consumption Survey (CBECS) database. (EIA 1998) The Energy Star buildings typically employed energy management and control systems (EMCS), variable speed drives (VSD), economizers, and energy efficient equipment.[1] However, these same technologies were also found to be prevalent in the least energy efficient CBECS buildings. Thus, while control systems can be a significant contributor to energy efficiency, EPA staff concluded that technology alone cannot deliver this efficiency. In referring to the findings of Hicks and von Neida (2000), Lupinacci (2001) concluded that operation and practice, as well as strong management commitment, were common threads that could be found in buildings exhibiting superior energy performance.

The CBECS buildings considered by Hicks and von Neida (2000) illustrate that the mere presence of a DDC system does not ensure superior energy performance. Numerous studies supporting the premise that problems with building controls are a primary cause of inefficient energy use can be found in the literature. One study estimates that failure rates of economizers are 50% and higher, with resultant energy waste far exceeding energy savings that can be achieved when they operate properly (Lunneberg 1999). Another study estimates that about one-sixth of Oregon K-12 schools have "dysfunctional DDC systems" leading to energy waste in excess of $1 million per year (Churchill 2000). A study of 60 buildings found that 50% of the buildings had controls problems, 40% had HVAC equipment problems, 25% had energy management systems, economizers, and/or VSD that were not functioning properly, and 15% had missing equipment (LBNL 2002). Claridge et al. (1994) estimated potential energy savings of nearly $4,000,000 per year due to operations and maintenance measures in 132 buildings, of which 77% of the savings could be achieved through correcting controls problems. Brandemuehl and Bradford (1998) performed a number of commissioning activities primarily involving changes to the software and hardware of the control system of a building constructed in 1991. The changes, completed in 1996, produced electrical energy savings of 16% compared to 1995, and 25% compared to 1994. This study is an example of just how well and how poorly a building can perform because of its control system.

[1] The terminology DDC system and EMCS are often used interchangeably by the building controls industry. In this paper, EMCS is used only when referring to a study that used this terminology.

These studies demonstrate that control-related problems can be a significant contributor to energy waste in buildings. While the problems tend to be diverse in nature, experience indicates that the underlying cause is often a lack of understanding of building control systems among the individuals who design, install, and operate them. This should not be interpreted as an indictment of these individuals' abilities. Instead, it is recognition that building control systems are a complex technology that changes rapidly. This makes it difficult to get informed and stay informed of their capabilities. Owners often lack an understanding of the attributes and shortcomings of various manufacturers' control systems and control components, so cost becomes the only decision criterion. Designers often do not comprehend the energy impact of various control strategies, so efficient strategies are not specified. Specifiers are often unaware of the importance of strategic sensors. Operators are often uninformed of the intent of control sequences and receive inadequate training on the use of the control system, so when problems arise, they develop a "work-around" and unknowingly create energy waste.

Increasing the level of understanding of building control systems among all the stakeholders is the first step toward good decision-making, and with good decision-making will come improved energy efficiency. An unbiased source of information on building control systems would serve to increase the level of understanding. The NBCIP was established to provide this information. Other resources such as publications of professional societies and trade journals (e.g., HPAC 2002) provide useful information on building controls; however, that is not their primary mission. The next section examines the NBCIP more closely.

About the National Building Controls Information Program

Program Objectives and Overview

The overall objective of the NBCIP is to develop a source of manufacturer-specific performance information as well as broad-based best-practice information on building controls. Within the context of the NBCIP, building controls and control systems refer to the input devices, controllers, and controlled devices that are components of DDC systems that operate buildings. Pneumatic controllers are considered outside the scope of the NBCIP because DDC systems do not typically incorporate them.

As evidenced by the program title, the primary deliverable of the NBCIP will be information. Demonstrating a commitment to the dissemination of information related to building controls, the Iowa Energy Center funded the creation of the *DDC Online* resource and introduced it to the industry at the 2000 ASHRAE Winter Meeting (IEC 2002b). *DDC Online* provides manufacturer reported information translated into a common format and architecture to allow comparisons across brands. The NBCIP will build on this effort to disseminate unbiased information related to building control systems. The basis for obtaining the information and the nature of the information will take various forms, including but not limited to the following: 1) reports providing independent testing results of comparable products from different manufacturers; 2) reports describing best-practice energy efficient control algorithms tested against conventional and/or alternative algorithms; 3) white papers addressing control issues of pressing importance; and 4) updates to *DDC Online*.

The NBCIP is being modeled after the National Lighting Product Information Program (NLPIP) that is managed by the Lighting Research Center at Rensselaer Polytechnic Institute (LRC 2002). A program of this nature requires a sustained effort. The following section outlines the approach that is being taken in the first year of the program to accomplish the goals of the NBCIP.

Approach

Scoping activities. Much of the work in the first year of the program will involve activities aimed at understanding the link between DDC systems and inefficient energy use in buildings. The objective of these activities is to identify what are the most prevalent building control problems, where they exist, and what is their impact on energy use.

The initial effort for the NBCIP has been to undertake a literature review of case studies of real buildings to define the relationship between energy consumption in buildings and control-related problems. The findings of the review are summarized later in this paper.

A related effort is targeted at researching existing databases to summarize commercial building demographics as they relate to energy use and control systems. The effort will seek to: 1) correlate energy use in commercial and institutional buildings to control system type as well as other factors, such as building type, HVAC system type, etc., that impact the characteristics of the control system; and 2) identify opportunities where improvements in building controls and their components are most needed and can lead to significant energy savings and pollutant reductions.

One of the best sources of information concerning control-related problems is the individuals who design, specify, trouble-shoot, and live with the systems on a day-to-day basis. Roundtable discussions and interviews are being conducted with controls experts (excluding controls manufacturers) to help identify the most common control problems that impact building energy use and to help identify information needs to address the problems. A summary of the first roundtable discussion is presented later in this paper. As described in the next section, a separate forum will be conducted with controls manufacturers to introduce the NBCIP and to invite manufacturer feedback.

The final scoping task involves the development of supplementary case studies of Energy Star buildings to identify the impact of control performance problems on energy use. Activities in the first year of the program are focused primarily on identifying the number and type of buildings to be examined and the information to be sought for each case study. In subsequent years, case studies would entail interviews with building operators and owners to identify known control problems, and monitoring of building systems to identify scheduling problems (e.g., lighting and air-handling units left on during unoccupied times), sensor problems, simultaneous heating and cooling, inappropriate static pressure set points resulting in excessive fan energy use, inappropriate economizer operation resulting in excessive use of outdoor air or unnecessary use of mechanical cooling, and other common control problems.

Defining testing procedures and infrastructure. Another important aspect of the first year efforts will be to lay the groundwork for the implementation of the product-testing program. Two key tasks have been identified. The first involves a face-to-face meeting with controls industry representatives to inform them of the program, describe the vision for the information gathering, testing, and reporting aspects of the effort, and solicit their feedback for consideration in program design. The second involves identifying (or establishing) processes and identifying test apparatus necessary for conducting the testing. The processes to be addressed include a risk management policy patterned after the NLPIP policy, as well as industry standards for methods of test of control system components. In the absence of a standard method of test, the NBCIP will develop the test procedure and utilize external reviewers with relevant expertise to establish the validity of the procedure.

Testing and reporting. Reporting manufacturer-specific product information and testing results is a central aspect of the NBCIP. *DDC Online* has become a recognized source of information on DDC systems. In its current form, it contains product information as reported by manufacturers. This effort will continue by means of updates to *DDC Online* that reflect new product introductions and revised product lines. In future years this information will be supplemented with information generated through the independent testing program.

The first product testing of the NBCIP will involve duct mounted humidity transmitters. Relative humidity sensors are frequently used to monitor supply and return conditions from air-handling units, monitor conditions in occupied spaces, and control humidification and dehumidification processes as well as economizer cycles. In the latter case, relative humidity and temperature measurements of outdoor and return air conditions are used to compute the enthalpies of the two airstreams, with the result determining the amount of outdoor air that is allowed to enter the building. If one or both of the computed enthalpies is erroneous, extreme energy penalties can result from the introduction of too much or too little outdoor air.

Capacitive type and resistive type humidity sensors dominate the current HVAC market. The sensors are integrated with a transducer and sold as a humidity transmitter. Products from approximately seven manufacturers representing the two major sensing technologies will be tested using a benchtop-scale two-pressure humidity generator. Accuracy will be assessed by comparing outputs of the transmitters to the output of the precision humidity generator for a range of temperatures and relative humidities. This pilot testing effort will be used to refine testing and reporting procedures and define testing procedures for humidity transmitters in the second year of the program and beyond.

Outreach. The final activity in the first year is aimed at program outreach. The NBCIP is envisioned as a long term, multi-sponsor program. The scope and complexity of the issues to be addressed mandate the development of a robust, sustained effort in order to have meaningful impact. A national program to address the issues is appropriate because of their pervasive nature. Program sponsors will have an opportunity to help guide the program by suggesting projects of importance to the goals and efforts of their organization, and through the selection of the work to be carried out. Program sponsors will also benefit by leveraging their funding support with that of other sponsors. To maintain credibility, sponsorship will not be accepted from the building controls industry.

Findings to Date

Some of the scoping tasks aimed at understanding how control problems impact building energy use are already completed. Summaries of the literature review of case studies citing inefficient energy use linked to controls problems are presented in the next section.

This is followed by a summary of the findings of a roundtable discussion with controls experts.

Literature Review of Case Studies

Numerous studies citing the link between energy waste and control problems were cited in a preceding section. The challenge now is to better understand the nature of the control problems that produce energy waste. With this understanding, a course can be set to alleviate such problems. The literature review of published technical documents described below is a first step towards gaining that understanding.

About the review. The initial effort of the NBCIP has been to undertake a literature review to define the relationship between energy consumption in buildings and control-related problems. The review included an extensive survey of HVAC trade publications, proceedings of building and HVAC-related conferences, and reports from federal, state, and university-based energy laboratories and agencies as well as private companies offering building services. This effort culminated in a report prepared for the NBCIP (Ardehali & Smith 2001). The focus of the review was on case studies of real buildings. In all, more than 40 studies were considered, in which the control-related problems of more than 70 buildings were described. Over 450 control-related problems were reported.

One of the objectives of the review was to categorize the control problems as much as possible. To that end, the following first-level categories were defined:

1. Hardware related control problems
2. Software related control problems
3. Human factor related control problems

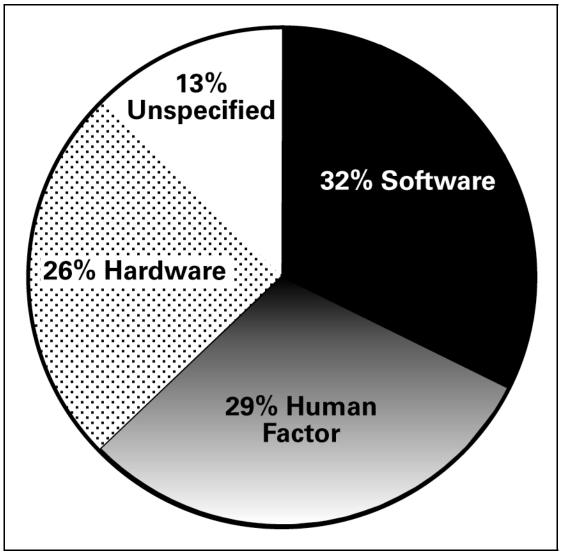
A fourth category labeled "unspecified" was defined to accommodate control problems lacking sufficient detail for assignment in the other categories. Problems in the actual HVAC equipment (e.g., chiller, pump, air-handling unit, etc.) were not considered.

Findings. The literature review produced the following findings (see Figure 1):

- 32% of the problems were software related,
- 29% of the problems were human factor related,
- 26% of the problems were hardware related, and
- 13% of the problems were unspecified.

It should be pointed out that there is uncertainty in the findings. Many studies cited economizer problems without indicating whether the problems were predominantly hardware related (e.g., broken damper linkages), software related (e.g., unstable control loop caused by the use of incorrect tuning parameters), or human factor related (e.g., outdoor air damper propped open with a two-by-four). Undiagnosed problems of this type were placed in the unspecified category. Uncertainty also exists within the hardware, software, and human factor categories, stemming mainly from the challenge of distinguishing a problem from a symptom. For instance, a symptom might be a broken linkage in a damper actuator, while the

Figure 1. Categorization of Control Problems



real problem might be a poorly tuned control loop causing premature failure of the linkage. If the problem cited was a broken linkage, it was assigned to the hardware category instead of the software category.

The first level categories are quite broad and greater specificity would be helpful in identifying the true nature of control problems. Therefore, the subcategories described below were established. The abbreviations HW, SW, and HF following the subcategory titles indicate the category (hardware, software, or human factor) to which they belong. One or more examples of typical control problems that would be assigned to each subcategory are also provided.

Input Device (HW) – Refers to problems associated with sensors, transducers, wiring, and related devices used for measuring some condition and transmitting information regarding that condition to the controller. Example: a control problem stemming from a sensor that is out of calibration.

Controller (HW) – Refers to problems associated with the hardware device that receives sensor input data, applies control logic to those data, and causes an output action to be generated. Example: an electronic failure of a circuit board.

Controlled Device (HW) – Refers to problems with the device that receives output signals from controllers and changes the state of an end device. Examples include valve operators, damper operators, electric relays, fans, pumps, compressors, and variable speed drives. Example: a leaking control valve.

Communications (HW) – Refers to problems associated with the hardware necessary for data transmission between controllers in the control system (e.g., between an application specific controller and a supervisory level controller). Example: a control problem stemming from delays due to excessive traffic on the control network.

Input/Output Implementation (SW) – Refers to problems arising with the control software that occur prior to delivery of the building to the end user. Example: incorrect point addressing, conversion factors, gain coefficients, etc.

Programming (SW) – Refers to problems arising from incorrect or inappropriate control logic. Example: improper reset control strategies.

Operation (SW) – Refers to problems arising after system start up and while the building is in operation. Example: loss of control set points and/or parameters due to a power outage.

Data Management (SW) – Refers to problems associated with data monitoring, display, alarming, logging, and downloading, as well as problems with software compatibility. Example: overwriting a file while downloading resulting in the loss of parameter settings.

Operator Error (HF) – Refers to unintentional changes to the control system made by the operator during routine operation and maintenance that result in improper operation of a system.[2] Example: failing to release an operator override that was implemented to allow system maintenance.

Operator Unawareness (HF) – Refers to control problems arising from an operator's lack of understanding or familiarity with the control system due to inadequate training. Example: changing control logic to compensate for a problem, only to have the changes produce additional control problems.

Operator Interference (HF) – Refers to intentional changes to the control system made by the operator causing interference with the normal operation of the system. Example: disconnecting controllers, obstructing control devices, and disabling control points through software or hardware changes.

Operator Indifference (HF) – Refers to any number of control problems stemming from an operator's apathy toward operation and maintenance.

Using these descriptions, control problems classified in the hardware, software, and human factor categories were assigned to one of the subcategories. Because of the uncertainty and subjectivity of the classifications, the results are presented in a qualitative manner in Figure 2. Figure 2 illustrates that problems stemming from input devices, programming, and operator interference have the highest rate of occurrence. Problems associated with input/output implementation, operator error, and controlled devices are also prevalent.

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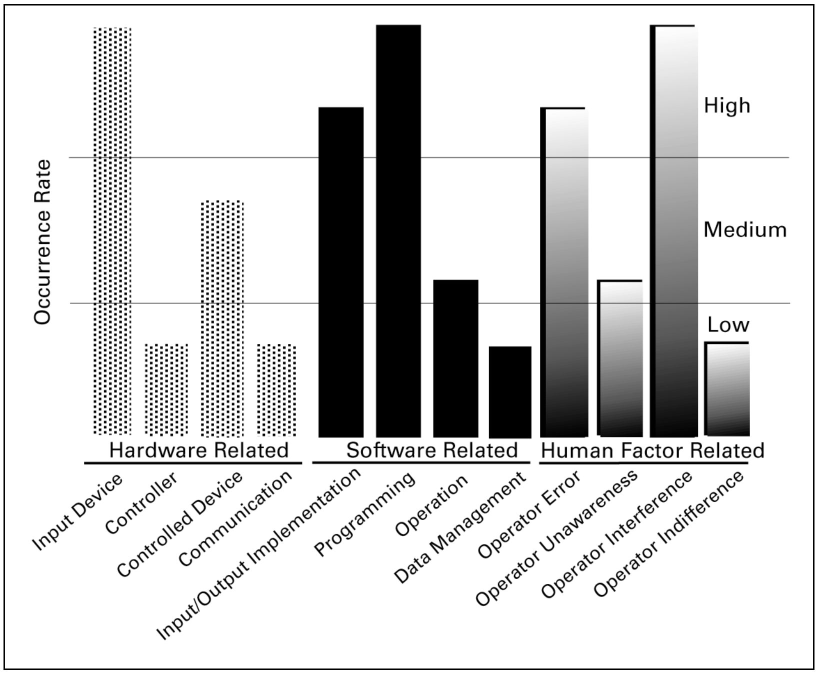
[2] The operator is the individual or individuals responsible for monitoring the day-to-day operation of the control system. The operator responds to alarms, diagnoses HVAC system problems and performs routine maintenance tasks. In general, the operator has not received the specialized training or experience necessary to create input/output points, modify control logic, or perform related tasks that would ordinarily be done by a DDC systems technician, service contractor or controls contractor.

Figure 2. Qualitative Representation of the Occurrence Rate of Control Problems Based on a Review of Case Studies



The findings of the review shed considerable light on the types of control problems that occur most frequently; however, the energy impact of these problems is more difficult to ascertain. In general, the case studies reviewed did not provide sufficient information to determine the percentage of energy savings that could be achieved through a reduction or elimination of control problems stemming from the individual categories and subcategories. Quantifying the energy savings potential requires information from additional sources. These sources may include: 1) new case studies conducted specifically to determine the energy impact of control problems in various categories and subcategories; 2) simulation studies wherein normal operation of HVAC equipment is altered to account for control problems and energy use is compared to baseline energy use for normal operation; and 3) control systems experts. The next section presents findings from a roundtable discussion in which controls experts were asked to help complete this picture.

NBCIP Roundtable: What's Wrong with Building Controls?

The first NBCIP roundtable discussion entitled *What's Wrong with Building Controls?* was held in January, 2002. The objective of the roundtable discussion was to gather feedback from participants regarding the types of control problems that are most prevalent, the types that have the largest energy impact, and the types that lend themselves to improvement. The participants in the roundtable were invited because of their extensive experience in the application of DDC systems to HVAC equipment. The group consisted of seven consultants from across the country, two facilities engineers (one at a major university and the other at a government institution), and a technologist from a large utility company. In this paper the group is referred to as the "controls experts".

Rate of occurrence of control problems. One of the main objectives of the roundtable was to assess the rate of occurrence of control problems based on participant experience. The purpose of this exercise was to establish the degree to which the experience of the roundtable participants was consistent with the findings from the case studies. To do this, individuals were given 12 votes and asked to vote for a subcategory as an indication of how frequently control problems of that nature occur based on their experience. The maximum number of votes that any individual could apply to a subcategory was four. Note that the subcategories of control problems are the same as those identified in the review of the case studies and used in Figure 2. The results of this exercise are shown in Figure 3 and are strikingly similar to the results from the case studies (see Figure 2). In each case, the software programming and operator interference subcategories have the highest rates of occurrence. The experts considered problems with software input/output implementation to have a slightly higher rate of occurrence than problems with input devices and problems stemming from operator error.

Energy impact of control problems. To prioritize efforts of the NBCIP, it is necessary to have some measure of the energy impact of control problems from the individual subcategories. In general, the case studies reviewed for the NBCIP by Ardehali and Smith (2001) did not contain sufficient detail to enable such an assessment and, therefore, another important objective of the roundtable was to perform an energy impact assessment based on expert experience. Roundtable participants were asked to indicate whether the energy impact of control problems from each subcategory was low, medium, or high. A weighted voting scheme was used.

Results from this exercise are shown in Figure 4. The results in Figure 3 and Figure 4 are very similar. In general, the subcategories of problems perceived to have the highest rate

Figure 3. Qualitative Representation of the Occurrence Rate of Control Problems Based on the Experience of Experts

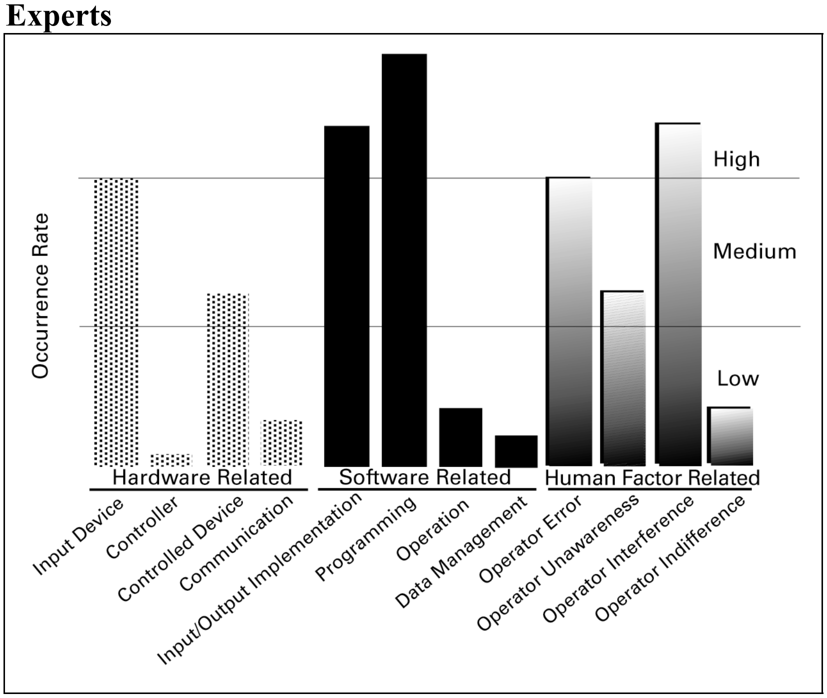
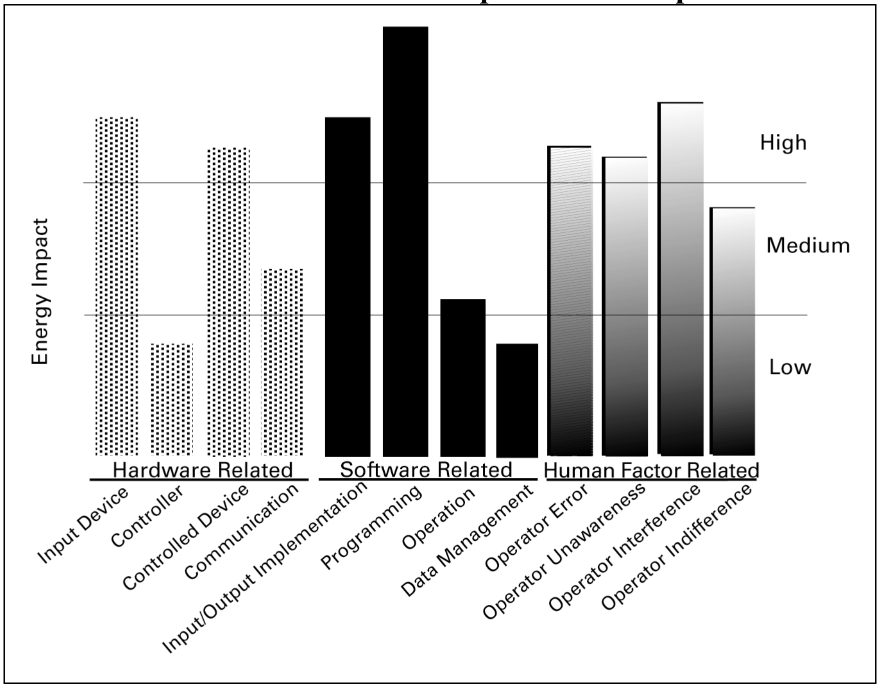


Figure 4. Qualitative Representation of the Energy Impact of Control Problems Based on the Experience of Experts



of occurrence are also perceived to have the highest energy impact. Control problems stemming from software programming were considered to have the highest rate of occurrence and the highest energy impact of all subcategories. It is also interesting that all four categories of problems associated with the operator are among the top eight categories in terms of energy impact.

Achieving improvement. The final objective of the roundtable was to conduct a brainstorming session with the goal of identifying how the NBCIP can help achieve improvement in the energy efficiency of buildings through the development and dissemination of information related to DDC systems. The specific question posed was "What information is needed to improve the performance of DDC systems?" Following the brainstorming session, the ideas were reviewed and categorized. The two primary categories are product characteristics (e.g., clear, easy to use programming interfaces) and process improvements (e.g., better control design and engineering). The latter category encompasses all ideas that are related to the process of designing, installing, commissioning, operating and maintaining DDC systems. The subcategories under process improvements and a summary of needs identified by the group for each subcategory follow:

- Design – The need for proven control strategies and sequences was a pervasive sentiment in the group.
- Documentation – Needs identified in this subcategory ranged from the early planning stages of control design to the as-built documentation and owner's manuals. Examples of ideas offered were the need for: 1) a master planning guideline for owners; 2) a standard specification template; and 3) an effective way of conveying design intent.

- Training/Education/Certification – Needs in this subcategory included: 1) training for owners, installers, and operators; 2) the development of college curricula for engineers on control system design; and 3) certification of operators.
- Performance Verification – The need for standard field tests, protocols, and performance acceptance criteria.
- Operation and Maintenance – The need for troubleshooting tips and a field calibration guide.
- Dialogue – The need for improved communication among controls manufacturers, designers, installers, and end users.

Clearly, solving the problems with building controls was not the goal of the roundtable. Identifying avenues that can help solve these problems was the goal, and the brainstorming session provided an excellent perspective on how these experts would approach the challenge. These ideas and results from other year one efforts will be used to shape the agenda for future NBCIP efforts.

Conclusions

The National Building Controls Information Program (NBCIP) was established on the premise that properly functioning control systems are a significant contributor to energy efficiency, and problems associated with building controls and operation are a primary cause of inefficient energy usage. The objective of the NBCIP is to develop a source of manufacturer-specific performance information as well as broad-based best-practice information on building controls and related components that will promote energy efficiency. Efforts in the first year of the program include scoping activities aimed at understanding the link between DDC systems and inefficient energy use in buildings, defining testing procedures and infrastructure necessary for product testing, testing of duct mounted relative humidity transmitters and reporting new and/or revised product information on *DDC Online*, and outreach.

Results from two scoping activities were reported in this paper. A review of case studies in the literature revealed that control problems stemming from input devices, software programming, and operator interference had the highest rate of occurrence among the subcategories defined. A roundtable discussion with controls experts supported these findings to a large degree and identified software programming as the subcategory having the largest impact on energy use. The controls experts also considered problems stemming from software input/output implementation, input devices, controlled devices, and all human factor subcategories to have significant impacts on energy use. The controls experts also offered numerous suggestions concerning what information is needed to improve building controls. In addition to needs related to product characteristics, process needs in the areas of design, documentation, training/education/certification, performance verification, operation and maintenance, and dialogue were also identified.

Having credible information is the first step toward good decision-making and good decision-making in the building controls industry offers the opportunity to improve energy efficiency. The goal of the NBCIP is to provide information to owners, operators, installers, designers, and manufacturers that will enable better decision-making. As this information becomes broadly available, it will increase the transparency of the building controls industry and support further enhancements that will improve energy efficiency in buildings.

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