DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR PROACTIVE ENERGY AND MAINTENANCE MANAGEMENT DECISIONS

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Energy efficiency of commercial and institutional buildings is a topic that has continued to gain interest as sustainability, green and high performance buildings gain the attention of building owners, facility managers, engineers, architects and other professionals within the built environment. To support this area of interest, tools are needed. The aim of this paper is to summarize the development and testing of a decision support system that links energy and maintenance management to help facility managers make proactive energy and maintenance management decisions to help achieve sustainability and energy efficiency goals for heating, ventilating and air-conditioning (HVAC) systems. The decision support system was developed using a multimethodlogy, mixed methods approach. Three case studies and a questionnaire were used as the foundation to develop the rules to code the decision support system. The decision support system was tested by 56 industry participants and evaluated by 38 of the test participants. Overall, the evaluations revealed that the decision support system was helpful to very helpful and useful to very useful. It is concluded that the decision support system can be an effective tool to help facility managers make combined energy and maintenance management decisions to meet sustainability goals and transition more proactive energy and maintenance management practices.

Keywords: action research, decision support, energy efficiency, facility management, maintenance

INTRODUCTION

Energy efficiency is a core focus of sustainability in the built environment, as evidenced by building rating systems such as the BRE Environmental Assessment Method (BREEAM) in the United Kingdom, the United States Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED), the Canadian-based Green Globes and the Green Star Australia rating systems (Portalatin *et al*, 2010). In order for energy efficient heating, ventilating and air-conditioning (HVAC) equipment installed within a building to remain energy efficient over the life cycle of the building, the equipment must be properly maintained. By definition, maintenance is the work required to preserve or restore equipment to the original condition or a condition that it can effectively be used for the intended purpose (BSI, 1993; APPA, 2002). Although designing systems to reduce maintenance requirements can be beneficial, over time belts slip, bearings wear, sensors drift out of calibration and filters become filled with particulate (as evidenced by ASHRAE, 2008).

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Thus, it can be suggested for energy efficient HVAC equipment that there is an interdependent link between energy efficiency and maintenance (Figure 1) (Lewis *et al*., 2011b). This interdependency is commonly not applied in practice, especially within large organizations (Lewis *et al*., 2010; Lewis *et al*., 2011b). As a result, energy and maintenance managers often use different, often non-integrated, software and management practices (Sapp, 2008; Lewis *et al*, 2010). Within academic research, the topics of energy and maintenance are generally studied independently, as evidenced by energy efficiency research (including Piette *et al*., 1996; Claridge *et al*, 1996) and maintenance management research, (including Lam *et al* (2010); Chandrashekaran *et al* (2008); Lavey *et al* (2008)). Furthermore, maintenance management is an area identified to be under researched (Jones *et al*., 2007; Wood, 2005).

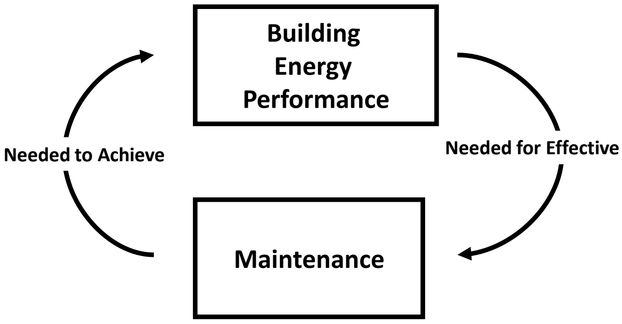

Figure 1: Interdependent link between energy efficiency and maintenance

As a result of these observations, a decision support system was developed as part of the PhD research A Framework for Improving Building Operating Decisions. The aim of this paper is to summarize the methodology and methods used to develop the decision support system and to summarize the results of testing and evaluation of the decision support system.

METHODOLOGY AND METHODS USED TO DEVELOP A DECISION SUPPORT SYSTEM

Facility management, by definition is interdisciplinary and multifaceted. Facility management is defined as "a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, process and technology" (IFMA, 2011). As stated in Lewis *et al*. (2011a), a multi-methodological approach from a classical epistemological point of view can be beneficial when conducting facility management research. Thus, the research described within this paper takes both a positivist and phenomenal epistemological focus, while taking an objectivist ontological point of view.

As discussed below, to work towards the aim of the research, a mixed methods approach was used. First, three case studies were completed to look for trends and patterns in practices, needs and challenges of facility management teams. Second, a questionnaire was developed to test a research hypothesis and ten propositions developed from observed trends and patterns from the case studies. Third, rules were written from the results of the hypothesis and proposition testing to support the coding of the decision support system.

Overview of the case studies

The first phase of the research was to complete three case studies using action research. The purpose of each case study was to understand the challenges faced by facility management teams while also providing a case study report that could benefit each facility management organization. The three facility management project teams managed different building types: a community college district, a laboratory building at a college campus and a hospital. The aim of the community college district case study was to identify how energy and maintenance management practices were identified and quantified across the district through semi-structured interviews. The aim of the laboratory building case study was to identify how the collection of energy and building operations data can be automated. The aim of the hospital case study was to identify how to convey energy efficiency information to a facility management team when patient life safety is also important. Further discussion, including results and a summary of synthesized findings of the case studies can be found in Lewis, Elmualim *et al*, 2011b.

To compare and synthesize the findings of the three case studies, content analysis was performed. To complete the content analysis, the Integrated Building Process Model (IBPM) for building operations (Sanvido *et al*., 1990; Guvenis, 1989) was adapted to classify the content. Classifying the data using the IBPM allowed the data from the case studies to be systematically and consistently organized.

After the content of the case studies was classified, research propositions were written considering the results of the case studies and existing literature. To test the hypothesis and propositions, a questionnaire was developed.

Overview of the Questionnaire

A web-based questionnaire was developed to test the ten research propositions and the research hypothesis. Further discussion of the development and results of the questionnaire, including a table of the propositions and hypothesis can be found in Lewis *et al*. (2010).

DEVELOPMENT OF A DECISION SUPPORT SYSTEM

A decision support system is a model developed using management science concepts (Markland, 1989) that can be used to analyze past activities and help make decisions that require assessment, analysis and/or planning (Kroenke and Auer, 2010) to help make timely and relevant decisions (Markland, 1989). The decision support system discussed within this paper is used to synthesize energy, maintenance and human factors management practices and goals to help the user make prioritized decisions.

The decision support system includes three parts: a question set, processor and a Recommendations Report. By answering a set of multiple choice questions the user received a Recommendations Report that includes three one-page Best Practice Recommendation Sheets and a Proactive/Reactive Score to help the facility management team improve their energy, maintenance and human factors management practices. Within this paper, human factors represent the interactions of humans with energy and maintenance management systems and processes. As defined by Wickens *et al*. (1998), human factors includes both brain and body interaction with a system. Examples of human factors specific to this research include facility management and organizational strategy, and training of building operators and building occupants.

To develop the question set, the findings of the content analysis were reviewed to determine what activities within the synthesized IBPM analysis where not standard practice for the three case studies. Questions were written for all activities that were not standard practice. After writing the initial question set, the questions were pre-tested by six industry participants. The participants were asked to review the questions for relevance, clarity and organization, as well as suggestions for improvement. The group of participants was selected based on their current knowledge or involvement with the study, ability to provide critical review of the content, professional expertise and ability to provide timely feedback. The pre-testing process was limited to six because each participant provided an exhaustive review and the feedback provided were refinements, not suggestions for major revision.

Rule Development

The results of the questionnaire testing were used to develop a set of rules to code the decision support system. The rules were used to link the questions within the question set to the Best Practice Recommendation Sheets (BPRs) and to determine the Proactive/Reactive Score. Using the rules, first pseudo code was developed using flow charting concepts. The pseudo code and a processing structure developed from the pseudo code provided a standardized method to process the responses to the questions within the question set; merging a normative (theoretical) model, the IBPM, and a descriptive (reality) decision model.

Development of Best Practice Recommendation Sheets

A Best Practice Recommendation Sheet (BRPs) is a one-page summary of a best practice that could be implemented at a facility. The 35 BPRs developed provide a structured, interactive, economical and quantifiable summary of a method to meet the needs identified within the Recommendations Report. The Best Practice Recommendation Sheets include:

- Tool format: Checklist, flow chart, score card, planning guide, spreadsheet or informational brochure
- Description of a specific best practice, highlighting key components
- Benefits of the specific best practice
- Tips to help develop a business case for the use of the best practice

The goal of the BPRs is to provide an overview of an action a facility management in-house or consultant team could implement to transition to more proactive energy, maintenance and human factors management processes. The development of a complete database of detailed implementable tools, including the review of all tools within the public domain that could be recommended by the decision support system, is beyond the scope of research.

Development of a Proactive/Reactive Weighting Scale

As the researcher developed the concepts for the decision support system, insight was gathered from industry practitioners about what would be useful and helpful for inclusion within the tool. One repeated request was a simple graph that quickly identified how proactive or reactive the practices at the facility were. To include this idea, the researcher developed a bar graph from negative five to positive five for each of the three categories: maintenance management, energy management and human factors: the Proactive/Reactive Weighting Scale. A value of negative five indicates the facility is nearly to entirely reactive and positive five indicates the facility is proactive at a world class level. A qualitative value is assigned at each 1.0 interval.

Decision Support System Coding

Nine different software options were evaluated to determine what software to use to transform the pseudo code into computer code to link the question set to the Best Practice Recommendation Sheets and generate the Recommendations Report. The evaluation determined that the use of LAMP (Linux, Apache, MySQL and PHP) used with a commercially available survey tool would best meet the needs for the project. Using a commercially available survey tool for the question set was valuable because the user interface is generally familiar to many computer users and a familiar, easy to use interface is important to the adoption of new tools. LAMP was selected because it provided the flexibility necessary to support a web-based output (the Recommendations Report), supports commonly used databases (such as MySQL), and PHP (hypertext preprocessor) is a commonly known computer language used by software developers for web-based applications.

DECISION SUPPORT SYSTEM TESTING, EVALUATION AND RESULTS

After the programming and debugging were complete, the decision support system was tested by 56 industry participants. Thirty eight of the test participants completed an evaluation of the decision support system through a web-based questionnaire.

To recruit testing participants, the researcher established a contacts database over the duration of the research by interacting with industry professionals at conferences and posting the research to a website, www.improvebuildingperformance.com. Additionally, the researcher posted information about the testing process on multiple professional networking sites and listservs. This effort resulted in, 20 test participants (34 percent) from the contacts database and 38 test participants (66 percent) from listservs and networking sites.

The testing process found that it took an average of one hour and 21 minutes to complete the question set. However, it is possible that the actual time to complete the question set is actually lower because the nature of facility management requires multitasking and facility managers are often interrupted while completing other tasks. This is concluded because several of the participants stated that the web-based tool had timed out while completing question set, indicating that the question set was left idle while other tasks were attended to. The important finding from this data is that the completion of the question set was less than several hours. This is important because other tools that have some similar features can take between eight hours and one week to gather the data before a recommendation can be made. Thus, the decision support system developed within this research requires much less time (and money) before a recommendation to improve building operations can be made. This allows the planning and implementation process to start sooner.

Evaluation of the Decision Support System

A web-based questionnaire with 30 questions was sent to the 56 test participants. Thirty-eight (58 percent) of the test participants completed the evaluation. The goal of the evaluation was to determine how helpful and useful the decision support system was to industry participants. Within the evaluation, helpful was defined as the amount of assistance the system provided to the decision making process and useful was defined as the amount of practical and/or beneficial use of the decision support system. The evaluation of the decision support system was limited to the use of a questionnaire because the quantification of measurable energy and/or cost savings would take at least one year of data to validate, due to variations in weather and collect data at a meaningful interval for facility management teams. The collection of quantitative energy and/or cost savings data would be further complicated because it would be difficult to differentiate changes in energy and/or maintenance management practices as a result of using the decision support system, compared to other factors. Thus, determining quantitative energy and/or cost savings is beyond the scope of this research.

The researchers also acknowledge that questionnaires can result in a positive bias. However, an adequate response rate can help to reduce bias, considering the population, practical limitations and the questionnaire topic (Neuman, 1994), all which were addressed in selecting the sample size. Furthermore, other academic researchers who have developed construction management tools have used questionnaires to evaluate tools (Song *et al*, 2005; Udeaja *et al*, 2008). (Studies cited had eight and 18 test participants, respectively).

Demographics of Evaluation Participants

Four questions within the evaluation were used to collect demographic information: the role of the participant within the industry, type of service(s) provided, if the testing process was completed for a single building or campus of buildings and the type(s) of building(s) the testing process was completed for.

The participants represented ten industry roles, including facility managers, mechanical engineers, energy engineers, facility management consultants, maintenance technicians, commissioning agents, architects and maintenance service providers. Fifty percent of the participants were facility managers. The second and third largest roles represented were mechanical engineers (13 percent) and energy engineers (10 percent). The services provided by the participants included energy management or commissioning (36 percent), maintenance (33 percent), construction (15 percent), design (15 percent) and various types of consulting services (one percent). Fifty percent of the participants completed the testing process for a single building, while the other fifty percent of the participants completed the testing for a campus of buildings. Fifteen different building types were evaluated using the decision support system during the testing process, including office, public assembly, college/university, laboratory, medical office building, manufacturing and dormitory/barracks. Offices (not medical) represented 31 percent of the building types, while the other types of buildings represented between two and 11 percent of the total.

Results

Overall, the results of the testing process revealed that decision support system was rated as helpful to very helpful and useful to very useful by industry evaluators. Additionally, the information conveyed by the decision support system was generally communicated clearly or very clearly.

To evaluate how helpful the decision support system was for combining energy and maintenance management decisions a question with a five point scale ranging from not at all helpful to extremely helpful was used. As shown in Figure 2, all participants found the decision support system to be at least helpful (53 percent), 40 percent found the decision support system very helpful and seven percent found the decision support system to be extremely helpful to when combining energy and maintenance management decisions within the same process.

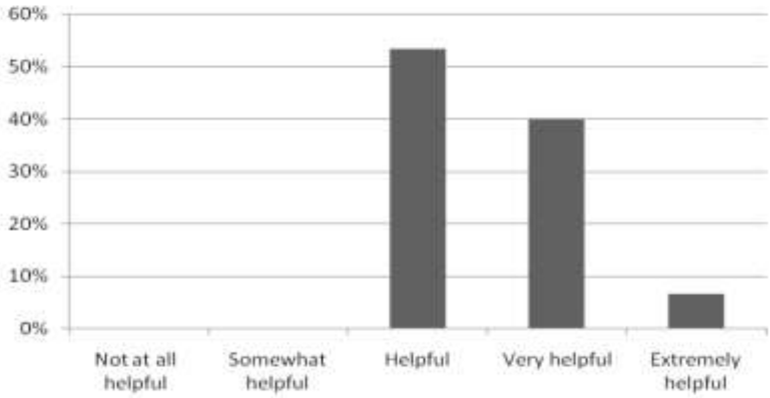

Figure 2: Helpfulness of the decision support system to support combined energy and maintenance management decisions

The decision support system was also evaluated to determine how useful it was for moving from reactive to proactive energy, maintenance and human factors management practices, using a five point scale. As shown in Figure 3, the decision support system was found to be either useful or very useful for moving from reactive to proactive energy, maintenance and human factors management practices by most of the evaluators.

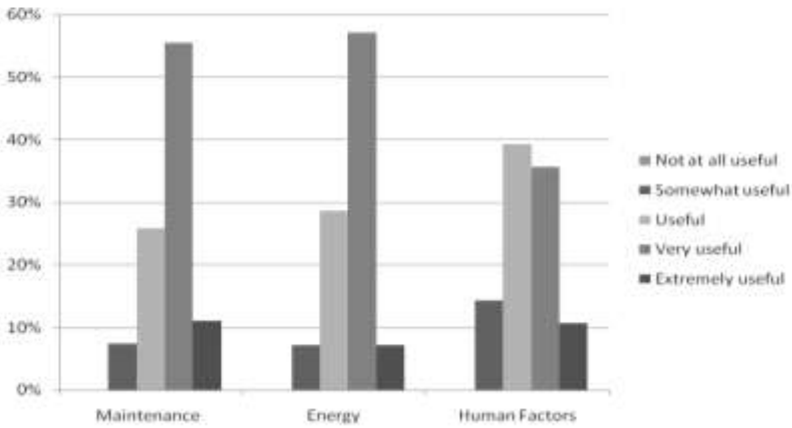

Figure3: Usefulness of decision support system to transition from reactive to proactive energy, maintenance and human factors management practices

The evaluators were also asked to select what the most useful part of the decision support system was (Figure 4). Evaluators were to select one of the following full Recommendations Report, Proactive/Reactive Scores, rank ordering of the Best Practice Recommendation Sheets, information contained on the Best Practice Recommendation Sheets (BPRs), user guide and question set. The full Recommendations Report received the highest percentage of responses, 39 percent. This demonstrates the decision support system as a whole is useful to industry practitioners because the full Recommendations Report includes the rank ordered list of BPRs, information on the BPRs and Proactive/Reactive Scores. The set of questions and user guide provide the structure for the user to receive and understand how to use the full Recommendations Report.

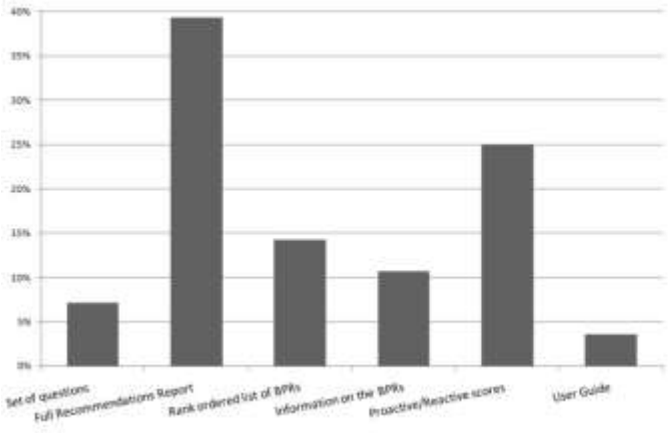

Figure 4:Usefulness of decision support system components

The information on the Best Practice Recommendation Sheets was selected as the most helpful by the least number of evaluators because the information on each Best Practice Recommendation Sheet was limited to only one page. Although the Best Practice Recommendation Sheets were not selected as the most useful component of the decision support system, most of the evaluators found the Best Practice Recommendation Sheets to be either useful or very useful (Figure 5).

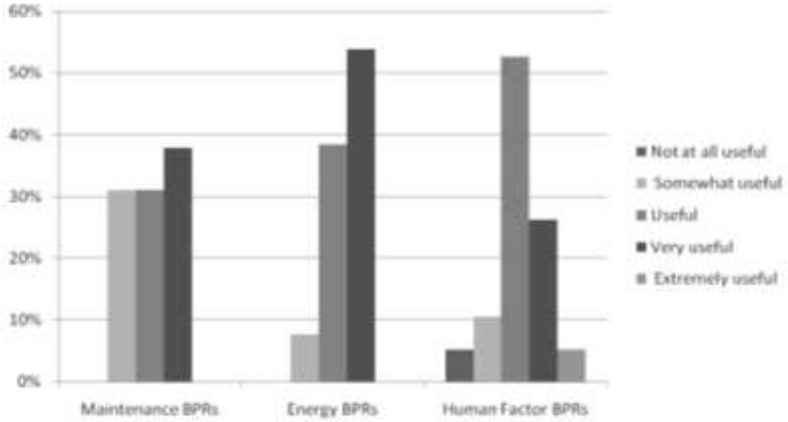

Figure 5: Usefulness of Best Practice Recommendation Sheets (BPRs)

A five point scale was provided for the evaluators to state how clear the information of various components of the Recommendation Report was communicated (Figure 6). The evaluators generally found the decision support system to convey the information presented clearly or very clearly for all four of the components evaluated. None of the evaluators found the four components evaluated to be very unclearly communicated.

Evaluators were also asked about the likelihood they would use the decision support system again and if they would recommend the use of the tool to a colleague. Forty-eight percent of respondents would likely use the decision support system again and 10 percent would very likely use the decision support system again. In contrast, only three percent would be unlikely to use the decision support system, while 10 percent would very likely use the decision support system again. Forty-three percent of respondents would likely recommend the decision support system to a colleague and 21 percent would very likely recommend it. In contrast, only four percent would unlikely recommend the decision support system to colleague and seven percent would very unlikely recommend it.

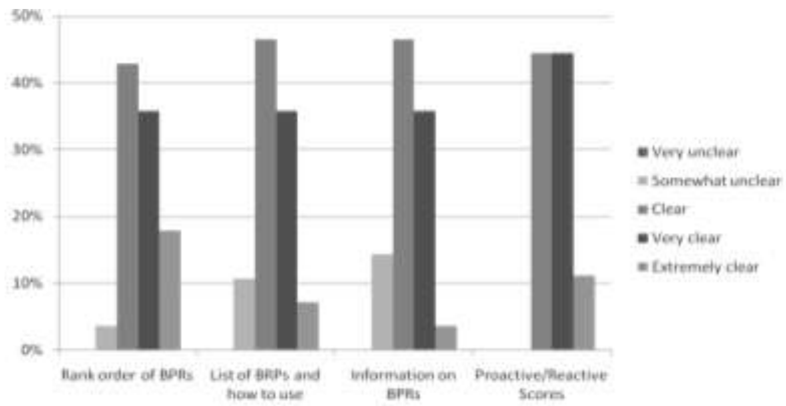

Figure 6: Clarity of contents of Recommendations Report

Qualitative feedback was also requested as part of the evaluation. Some of the comments received included:

- "The [decision support system] takes advantage of easily accessible technology to acquire, contain and analyze information about a particular [facility] ... thus joins the user to colleagues in helping to set priorities."
- It "can provide some valuable guidance for facility management groups that utilize" it
- "A fee or donation or donation for use could certainly be acceptable" for use

Overall, the qualitative comments received were supportive and multiple comments suggested that value could be added to the tool through further development of the Best Practice Recommendation Sheets and refinement of the question set.

CONCLUSIONS

A decision support system was developed using a multimethodological, mixed methods research approach to align two interdependent concepts that are often researched and applied in practice separately. By researching maintenance management within the context of energy efficiency, the body of maintenance management research is increased. The main contribution to knowledge resulting from the development of the decision support system is that it can be helpful for facility management teams to combine energy and maintenance management decisions when seeking to move from reactive to proactive energy and maintenance management practices for heating, ventilating and air-conditioning systems.

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