Energy Monitoring Systems: value, issues and recommendations based on five case studies.

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SUMMARY

This paper investigates Energy Monitoring Systems (EMS) in five case study buildings. Specific examples in each of the buildings illustrate the value of these systems in identifying energy saving opportunities. The paper then discusses the issues encountered in the case studies in detail. The major findings were that although EMS data were used to improve energy efficiency in every case in which it was available, there are numerous issues with sensor specification and installation, software analysis, user-profiling, personnel resources, and data quality. The paper concludes with recommendations on how to address these issues using guidelines and a more coherent, integrated approach to the EMS design process.

INTRODUCTION

Energy Monitoring Systems (EMS) are commonly used in commercial and industrial buildings and consist of a number of sensors and meters that monitor energy use in a building. Usually, the majority of these sensors are electrical current transducers that are used to measure load on electrical panels. However, gas meters and flow meters (combined with temperature sensors to monitor energy flow) are also commonly included as part of this monitoring system. These sensors are connected to a central location for archiving through a wired or a wireless network. The resultant data is then analysed using visualisation and statistical software tools. Issues with the operation of building components and opportunities for possible retrofit or operational changes can be identified using these tools. Several articles to date prescribe the use of an EMS to monitor how energy is used in a building and to identify Energy Conservation Measures (ECMs) [1]. Numerous published case studies also quantify significant savings of 5-25% which were identified using data acquired from an EMS [2-7], but none were found that focused on office buildings, or that demonstrate the value of an EMS in detail.

This paper illustrates the value of EMSs by highlighting specific instances from five case study buildings in which EMS data was used to improve building operation. The issues regarding the specification, installation, and operation of EMSs based on the case studies are discussed and the paper concludes with recommendations on how to address these problems.

It should be noted that an Energy Monitoring System is distinct from an Energy Management System, Energy Management Control System (EMCS), Building Automation System (BAS) and Building Management System (BMS) in that actuators are not part of this system. In the context of this paper, an EMS is purely for *monitoring* energy use in a building (sub-metering), not for directly controlling aspects of building function. Of course, EMCSs, BMSs and BASs often monitor energy usage and hence, this paper also applies to these systems.

CASE STUDIES

The findings of this paper are based on five case studies investigated by the authors. Although each case study was performed with different objectives, an analysis of the energy performance of each building was a paramount objective. The private-sector buildings have been kept anonymous.

Case study 1: The Environmental Research Institute [8] is owned by the University College Cork in Ireland. It is a 3-storey research building containing offices, laboratories and a clean room. Completed in 2005, the building has a total floor area of 3,000 m^2 and was designed as an ongoing experiment in green building technology with a particular emphasis on an increased knowledge of downstream performance from green design. A state of the art BMS was installed to facilitate monitoring of the integrated aquifer heat-pump and solar thermal hybrid heating and cooling system, building energy use and indoor environmental conditions.

Figure 1: Case study 1 - The Environmental Research Institute

Case study 2: A 30,000m^2 office building in Ireland, constructed in 2003. This building consists of four floors with a kitchen and canteen on the ground floor, and open plan office space interspersed with conference rooms on the remaining three floors. The building supports a 24 hour manufacturing facility, but it is only partially (<10%) occupied outside of normal office hours. The HVAC system is a variable air volume (VAV) system served by on-site district hot and chilled water supplies. This building is very well instrumented; a detailed EMS was installed during the construction phase and is currently operational on-site. The aim of this case-study was to develop a calibrated building energy simulation model and to use it to identify ECMs, such as retrofits and system optimisation strategies.

Case study 3: A 5000m^2 office building located in the USA. This newly-constructed building consists of four floors with a gallery and restaurant on the ground floor, and tenant-occupied office space on the remaining three floors. The HVAC system is a novel combination of Underfloor Air Distribution (UFAD) and radiant hydronic slab systems. Low temperature hot water is supplied by a condensing boiler and chilled water is supplied by a cooling tower directly to the hydronic slabs and air handlers, removing the need for a chiller. Although a detailed EMS was originally included in the design, this was 'value-engineered' out of the project due to budgetary constraints. A case-study of this building is currently under way and aims to analyse the performance of this novel HVAC system.

Case study 4: A large pharmaceutical plant in Ireland. The plant has an annual energy consumption in the region of €20 million. Breakdown by cost is approximately 75% electricity and 25% gas. The drivers for energy management are financial, legislative (compliance with international medicinal drug production standards) and environmental. The plant currently complies with the ISO 14001 Environmental Management System. To further reduce environmental impact, energy management successfully implemented International Standard IS 393 (recently included in the ISO 16001) and was one of the first major industrial energy consumers to do so.

Case study 5: A 20,000m^2 manufacturing facility in Ireland which was constructed in the early 1970's. This single storey building consists primarily of office space with some clean room manufacturing areas and is occupied during normal office hours. The HVAC systems are a mix of constant volume air handlers with some VAV retrofits, and all hot and chilled water is supplied by an on-site district system. The building has undergone numerous changes of ownership and an EMS was installed recently (in 2006) as a retrofit measure as part of a company-wide drive towards energy efficiency. The aim of this case study was to investigate the difficulties involved in retrofitting an EMS into an old building, and to discuss the improvements identified using the resultant system.

ILLUSTRATION OF VALUE

Energy use in buildings can be broken down into two categories: 'independent' energy use, such as internal loads; and 'dependent' energy use, such as HVAC energy consumption, which is largely driven by the energy use of the former category. In the rare case when a BMS monitors energy consumption directly, it will only monitor 'dependent' energy use as part of a HVAC control strategy. This is despite the fact that internal loads are responsible for the majority of energy use in buildings [9]. However, EMSs explicitly monitor energy use in both categories, and thus can be used to identify and evaluate a different set of opportunities. Additionally, there are myriad downstream processes that benefit from the availability of detailed EMS data, such as: calibrated building energy simulation modelling, energy auditing, operational building performance rating schemes, Fault Detection and Diagnosis (FDD), Continuous Commissioning (CC), Measurement and Verification (M&V), Monitoring and Targeting (M&T), utility rate confirmation, sub-tenant and departmental billing. This section seeks to highlight specific instances where detailed EMS data was used to improve building energy performance and reduce operating costs. As the EMS was 'value-engineered' out of the building in case study 3, it is not included in this section and is discussed later in the paper.

Case study 1: Up to now the available EMS data for this building was not used. However, the building has recently become a centre of interest within several research projects and performance is now monitored. Figure 2 illustrates that the aquifer heat pump is quite inefficient. The data-points in this graph were calculated using heat meter and electrical

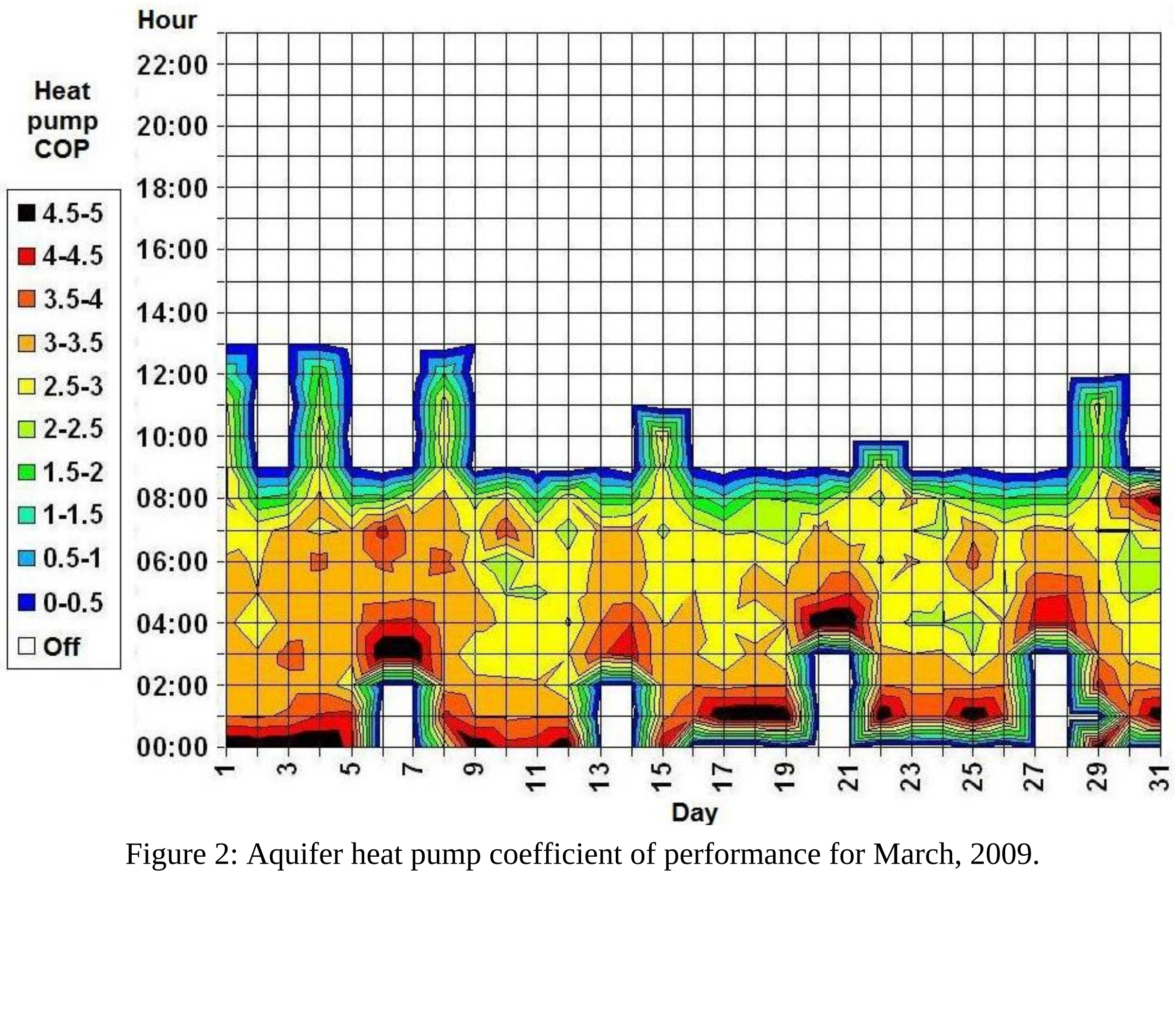

Figure 2: Aquifer heat pump coefficient of performance for March, 2009.

power meter EMS data. The average coefficient of performance (COP) is 2.98, compared to expected values of 3.5-4. It was also clear from the measured data that the heating system was operating erratically, due to the fact that BMS control of the system had been deactivated. Facilities personnel manually determine the start time for the heating system and hence improvements are currently under investigation.

Case study 2: A comprehensive system for Monitoring and Targeting (M&T) using EMS data is in operation in this building. The energy manager monitors the EMS data in order to identify unexpected and unnecessary energy use within the building, and through this process issues are identified and acted upon. As part of a project to develop a calibrated energy simulation model for this building, there were several specific instances in which the EMS was used to identify unnecessary energy use. Figure 3 illustrates an example of an unexpected increase in lighting load of approximately 12kW. This first occurred at 8pm on the 28th of June and corresponds to over €7000 per annum. This does not include the added cost of removing this heat energy from the building, which is also significant as the building is almost continually in cooling mode due to high internal loads and a deep floor plan. Upon investigation, it became clear that the lighting system schedules did not revert to their original settings after a temporary change was made.

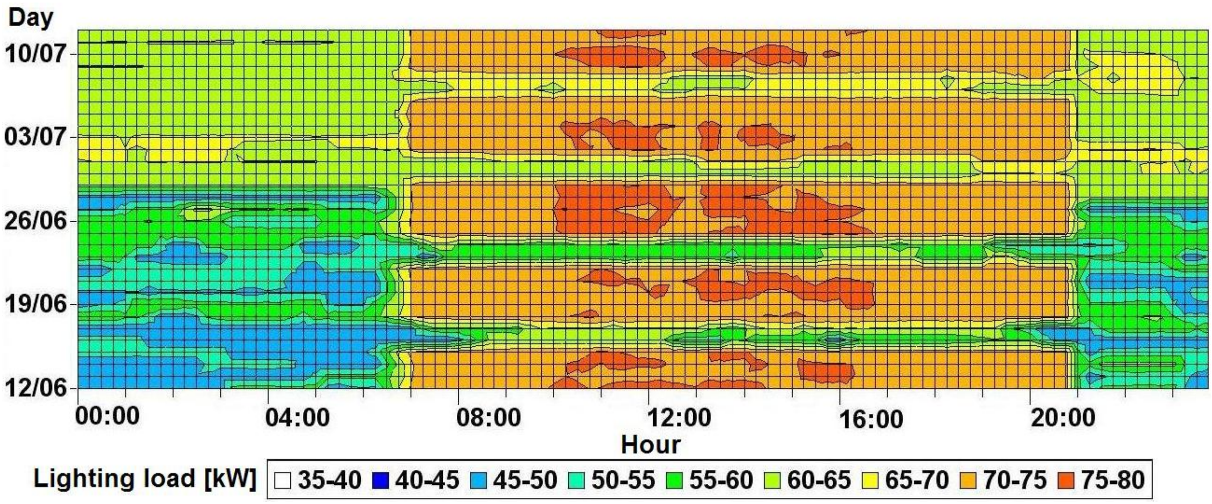

Figure 3: One month of lighting load data (kW) from the 12th June 2007.

Case study 4: Energy management perform monthly energy analysis and use a software package to store and access raw data. The energy manager manually extracts these raw sensor data from the software and converts them into informative metrics such as energy consumption values. Energy Performance Indicators (EPI's) underpin the analysis philosophy; which use six-sigma routines to validate that datum streams are within acceptable tolerance margins. Outliers require additional investigation and explanation [10,11]. In addition to this, energy management initiated a structured approach to energy reduction through a site wide energy audit. They identified the major energy consumers in order of consumption. These included e.g. wastewater treatment, thermal oxidiser, air compressors, chillers, boilers etc. The audit identified the components with the largest potential for gross energy savings and given priority for further investigation. Most importantly, the organisation allocated adequate resources for further analysis. Where possible the audit used the newly installed M&T system and identified that two low priority wastewater pumps were in fact the highest energy consumers on the site.

Case study 5: Data from the EMS software were used to identify numerous ECMs and evaluate them for cost effectiveness. Several areas of the building underwent lighting control upgrades, as well as a switch to long life bulbs with electronic ballasts. The average energy consumption during unoccupied hours of the compressed air system was monitored on a weekly basis and leak testing of the distribution network was performed when consumption exceeded a threshold value. A large AHU supplying an office area was retrofitted to operate on a time clock once the EMS data was used to identify that it was operating in unoccupied periods. Standby power settings were standardised on all networked computers according to recommended practice [12] after excessive plug loads during unoccupied hours were identified using the EMS data.

ISSUES

Now that the value of EMSs has been illustrated through examples from the case study buildings, this section reviews the issues that were encountered related their specification, installation and use.

Measurement framework: A lack of a complete, coherent, and well organised set of measurements was the most significant issue encountered in all of the case studies. Sensor locations are defined based on control requirements and do not consider the needs of performance analysts. Sensor locations are awkward even when monitoring is the primary purpose of the sensor. For example, in every building, electrical energy meters were installed in a unplanned manner, without a clear objective in mind. This caused piecemeal implementation in which varying levels of resolution of data were available. This significantly undermines the usefulness of much of the data, as similar resolution data is unavailable across the whole building. For example, in case study 5, the EMS was specified and installed in an arbitrary manner and thus energy consumption data for several systems and areas of the building was only available at a utility bill level. This included the majority of the AHU fans and pumps, along with plug and lighting loads for approximately 25% of the floor area of the building. This effectively rendered the EMS useless for analysing these systems and it is assumed that they use significant amounts of energy unnecessarily as they have never been investigated in detail. Case study 4 highlighted an example of newly installed sensors and meters on the primary energy consumers but not on the downstream energy end users, thus providing an incomplete picture for the analyst.

Electrical panel layouts: In each of the case study buildings, excluding case study 3 in which the electrical system was designed by an unusually innovative consultancy, the electrical panel schedules (layout of the electrical panels) were very disorganised from an energy monitoring point of view. In these cases, the usefulness of the data is severely reduced by the design of the electrical distribution system within the building. By clearly separating panels according to end use, consumption data measured at a panel level is much more useful as the user can instantly associate a change in consumption with a particular system. For example, in case study 2, there are numerous instances in which lighting loads and HVAC loads are served from plug load panels and where exterior lighting is served from interior lighting panels. Issues like these undermine the usefulness of the data, as any given change in consumption for these panels can not be immediately associated with a particular system. Resource-intensive spot-measurement or data-logging is then required to identify the system responsible for a change.

Visualisation and analysis software: A lack of adequate visualisation and data analysis tools was another very significant issue with the installed EMSs in the case studies. The most advanced visualisation capabilities of any of the 4 EMSs were simple line graphs and bar charts, and none of the software were capable of displaying carpet (or surface) plots. This is a very serious limitation, as it is not possible to adequately display the quantity of data involved in EMS applications using simple linear graphing methods. In addition, the software was often limited to only one data-stream per graph. Finally, each of the software tools had very rudimentary data analysis capabilities (i.e. basic mathematical functions such as averages, range, median, maximum and minimum values), and none included outlier analyses, cumulative difference calculations, or standard deviations. In case study 2, analysis of the data was performed using a spreadsheet developed by the energy manager as no dedicated software tool or graphical user interface (GUI) was available. The external energy analysts in case study 4 used a spreadsheet for all meaningful data processing, as the EMS software was primarily a data access tool.

'Value engineering': The concept of 'Value engineering' was a very significant issue in case study 3. This was an innovative building in almost every sense and a comprehensive monitoring system was specified in the initial design. However, as is often the case, the project overran its budget during the construction phase and many features were removed from the design just a few months before commissioning. Unfortunately the EMS was one of these, despite the fact that the electrical consultant had designed the electrical distribution so that each panel in the building served only one type of load - i.e. lighting, plug, HVAC, solar power, etc. Another example can be found in case study 1, in which the lighting monitoring and control system was 'value-engineered' out of the project at the last minute. The lights operate continuously, 24 hours per day, due to this omission.

The concept of 'value engineering' should not apply to aspects of the building function that are intended to save money over the long-term, as this does not make financial sense. In each of the buildings in which an EMS was installed, and in other case studies, the initial cost of installation was much lower than the savings over a reasonable investment period. For example, in case study 5, the total simple payback period was less than 18 months including both the cost of the EMS itself and the costs of the Energy Conservation Measure retrofits.

Data quality: In each of the case studies the fidelity of the archived measured data was quite low. Upon examination, there were numerous missing data-points and inaccurate time-stamps. This hinders any analysis, as the data must be repaired by interpolation before analysis. Also, there was a major issue with the proprietary software that came with the EMS in case study 5. The only access to the EMS data was through this software, forcing the analyst to make do with the inadequate visualisation and analysis techniques present in that tool. In addition to the problems previously outlined, it was discovered in case study 1 that a 15 minute recording interval was not sufficient for some detailed monitoring activities and that the inability to access multiple datum streams simultaneously also seriously hampered analysis. Best practice archives accurate data once every 60 seconds [13]. Furthermore, the building was never thoroughly commissioned and it was discovered that some of the flow meters (used to calculate heat flow) were not working correctly. For example, the boiler flow meter was oversized due to incorrect specification and that the resultant data was not usable.

Personnel resources: Another major issue encountered in all of the case studies was that inadequate personnel resources were allocated to energy management, despite the fact that the salaries associated with these personnel were much lower than the annual savings identified in all cases in which cost data were available. The authors identified additional ECMs in every case study, indicating that although data was available, the personnel allocated had insufficient time to review it and investigate. For example, in case study 2 there is just one energy manager for a site that includes numerous other buildings and covers several *hundred thousand square metres of conditioned floor area*. Thus, the M&T effectively operates at a target level [13], and only major discrepancies are investigated and acted upon. Also, the majority of EMSs were designed with inadequate or non-existent user-profiling [13] which often results in situations where EMS data is not utilised to its full potential.

RECOMMENDATIONS

In the short term, much can be done to ensure that adequate metering is provided to the building owner. There are numerous detailed specifications, standards and guidelines that discuss measurement in buildings which can be used on a new construction project today. Some of these specify in detail all necessary measurement for a given building, along with required through-system accuracy and archiving requirements [14]. Other guides are invaluable in the design of Energy Monitoring Systems in buildings [3]. The BuildingEQ project defines a present day, cost effective and practical minimum measurement set for all buildings [15]. Other sources detail the ideal set of measurements that enable meaningful building performance analysis, in three different levels of resolution [13].

In order to address issues in which an EMS is 'value-engineered' out of a design, and to get to the stage where finance is available to cover the initial cost associated with an EMS, the case must be made to the owner that they will save money and energy over the long-term. This is easier in owner-occupier projects, as the owner will benefit directly from the installed system and will recoup the initial costs. However, where buildings are built for the purpose of rental or resale, there needs to be a clear incentive for the installation of an EMS. Fortunately, in many cases there are financing mechanisms available to offset initial costs related to EMSs [16,17]. The developer can then advertise lower expected operating costs for the building, which should increase sale-value.

On a practical note, an integrated design process that informs the electrical design engineer of the requirements for the EMS is essential. From the beginning of the electrical design process, there must be a clear understanding that the electrical distribution layout is to be designed so that only one type of end-use is served from any given panel. This will minimise the number of sensors required and drastically reduce the cost of installing an EMS. It will also improve the ease-of-use of the system as the data analyst can easily and instantly associate a change in consumption with a specific system. Likewise, the consultant specifying the energy management strategy and EMS sensor locations should ensure that all energy consumption within the building is measured, at a consistent resolution based on the size of expected energy usage. The recommendation for how often to measure energy use vary up to a maximum of 50 kW rated power output, with higher resolutions (down to 10kW) recommended for end-uses that the building operator has significant amount of control over, such as Motor Control Centres (MCCs) [3]

Other considerations for the EMS consultant include that all EMS users are identified and profiled as part of EMS design. This ensures that the EMS is suited to its task and that adequate analysis tools are available to the user. It is essential to consider the skill set of the typical end-user, in order to tailor EMS outputs to their needs. In experience to date, most tools currently available are inadequate for the task, and significant software development is required. Specifications guides are essential to ensure that the quality of the archived data is very high. This must be thoroughly tested as part of commissioning. EMS software must include a facility to export in a commonly used format (such as comma-separated values, .csv) so that other tools can also be used as part of an analysis if necessary.

In the long term, the development of an accepted minimum set of measurements for every building underpinned by appropriate legislation would give analysts much of the information needed to improve energy efficiency in buildings. Standardised information would also facilitate the development and implementation of a comprehensive operational performance rating system for buildings. The minimum set should, at the very least, measure all energy use in a building, and must separately measure energy consumption based on type of end-use: lighting, plug, process, emergency power, external power, HVAC equipment, heating and cooling loads.

CONCLUSIONS

A properly designed and operating Energy Monitoring Systems enables more efficient building operation. This paper discusses the value of EMS and issues encountered in 5 case studies. The major findings were that although EMS data can be utilised to improve energy efficiency in every case, there are numerous issues with sensor specification and installation, software analysis, user-profiling and personnel resources, and data-quality. The paper concludes with recommendations on how to address these issues through the use of guidelines and a more coherent, integrated approach to the EMS design process. Structured, consistent and accessible EMS data facilitates efforts to reduce energy consumption across the building stock.

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