Monitoring & Targeting Energy in Practice: A Field Study

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Abstract

This paper summarizes a field study of Industrial Energy Monitoring & Targeting (M&T). Despite the enduring popularity of M&T methods, the experiences of practitioners remain undocumented. By contrast, in residential energy conservation domain, field studies have been influential and well-cited (Kempton, Willett & Montgomery 1982, Kempton, Feuermann, McGarity 1992, Kempton, Willett & Layne 1994). This suggests an un-met need for direct descriptions of industrial energy management practice to complement existing instructional materials and "success stories". Non-practitioners such as researchers, software engineers, or policy developers would benefit from case studies of M&T work.

The field study included eight weekly energy interpretation sessions and two interviews with five participants: two from an energy analytics company, two from an institutional site, and one from an industrial manufacturer. Results include qualitative and quantitative categorized observations and interview responses, such as:

- Participants without direct control authority envisioned software tools to help persuade colleagues and enhance credibility. By contrast, the participant with direct control authority emphasized informing daily control decisions, and attempted to adapt the M&T software to meet these needs.
- Participants spent roughly equal time assessing the trustworthiness of energy data and models as they did seeking efficiency opportunities. Assessing data and model quality was not well-supported by the software.
- All participants relied primarily on Cumulative Sum of Differences (CUSUM) charts, despite being uncertain about the underlying models.
- CUSUM charts were difficult to interpret, even for experienced analysts.
- On-site workers couldn't assess energy performance models and over-attributed their sophistication.

Findings underscore opportunities for innovation in Energy M&T software and management processes. We hope it will motivate a discussion of challenges in energy management practice.

Introduction

Monitoring and Targeting (M&T) energy use is a business analytics practice, developed after the energy crises of the 1970s (Technological Economics Research Unit, 1979). First introduced in the British sheetboard, paper, and textile industry (Gotel, 1989), it proved an effective way to measure energy efficiency, quantify performance changes, and help businesses improve operations & maintenance practices (Harris, 1989). Energy M&T is still a standard practice today, and has been incorporated into modern Energy Management Information System (EMIS) software (Hooke, Landry, & Hart, 2003) and energy management standards such as ISO 50001 (ISO Technical Committee 242, 2011).

However, given the well-established benefits of energy M&T, why do many businesses still not monitor their energy use, requiring incentives from government and power utilities (BC Hydro, 2010)? Perhaps some have concluded that the labor cost of examining energy use will outweigh the benefits of detecting energy-saving opportunities. Others may have tried M&T and found it too difficult. It is difficult to know because, while new instructional, motivational, and prescriptive literature on energy M&T continue to be published (Capehart, Turner, & Kennedy, 2008; Carbon Trust, 2008; Efficiency New Brunswick, 2010), none document the experiences of people practicing energy M&T in real work situations.

Energy conservation in the residential sector is much better understood. Public policy planners have a wide literature of descriptive studies to consult (Kempton, Feuermann, & Mcgarity, 1992; Kempton & Layne, 1994; Kempton & Montgomery, 1982; Kempton, 1986; Lutzenhiser, 1993) that identify user needs and frustrations.

These studies also inform the design of mass-market energy monitoring tools (Darby, 2000; Hargreaves, Nye, & Burgess, 2013). Why haven't there been similar exploratory studies in the larger and more economically feasible commercial, institutional, or industrial sectors?

Building on an interview study of energy managers in heavy industry (Hilliard, Jamieson, & White, 2009), this paper describes interactions between an M&T software vendor and two light industrial and institutional clients. Both clients were medium-sized enterprises that could not support a dedicated energy manager, but saw benefit in a bundled package of consulting services and an Energy Management Information System (EMIS).

We expected that interactions between the consulting energy analysts and novice clients would provide a controlled contrast to illuminate the commercial M&T customer's "energy analysis environment" (Kempton & Layne, 1994). We hope that better understanding the work challenges that M&T practitioners face will help software developers improve EMIS tools to be more useful, usable, and time-effective.

Method

This work follows two theoretic orientations. First, researchers followed an ethnographic orientation, to visit participants in their environment, listen to their point of view, and describe their understanding of their personal and social situation (Fetterman, 1998). Secondly, researchers used Human-Computer-Interaction methods of recording participants at a computer-mediated task and describing their activities in terms of goals and mental representations (Hutchins, 1996; Vicente, 1999; Wickens, Gordon, & Liu, 2004).

Recruitment / Sites

We collaborated with an energy software / analytics company and two of their clients, as described in Table 1.

Table 1: Participating institutions and workers

Site	*Approximate yearly utility consumption*	*Participant pseudonyms*
Client Site A: Light Industrial	5 GWh electricity 8 Mm^3 natural gas	Anna
Client Site B: Institutional	25 GWh electricity 4Mm^3 natural gas	Boris Bill
Energy Management Information System Supplier		Carl Chris

Recruitment comprised 5 participants: 2 energy analysts, 2 client energy managers (one from each client), and an electrical operations manager from the institution Site B. An operations manager from Site A was not available.

The researcher visited each participant at their place of work. Energy analysts were observed at the software company, client energy managers at their respective institution / industrial site. Eight task observation sessions were conducted on a more-or-less weekly schedule, as shown in Tables 2 and 3. All participants experienced some non-negotiable demands on their time that required cancelling or postponing some researcher visits.

Participants were asked to evaluate their site's energy performance, but self-directed their use of the EMIS. Analysts were mainly responsible for their corresponding site (Carl with Site A, Chris with Site B), but were asked to inspect both clients' energy use.

Table 2: Study dates for participants at Site A.

Participant	*Interview 1*	*Week 1*	*Week 2*	*Week 3*	*Week 4*	*Week 5*	*Week 6*	*Week 7*	*Week 8*	*Interview 2*
Anna	6-Oct	11-Oct	18-Oct	25-Oct	1-Nov	8-Nov	15-Nov	22-Nov	29-Nov	8-Dec
Carl	4-Oct	-	17-Oct	25-Oct	1-Nov	8-Nov	15-Nov	22-Nov	29-Nov	12-Dec
Chris	4-Oct	13-Oct	-	-	1-Nov	8-Nov	15-Nov	22-Nov	29-Nov	12-Dec

Table 3: Study dates for participants at Site B.

	Interview 1	*Week 1*	*Week 2*	*Week 3*	*Week 4*	*Week 5*	*Week 6*	*Week 7*	*Week 8*	*Interview 2*
Carl	4-Oct	17-Oct	21-Oct	1-Nov	4-Nov	-	25-Nov	2-Dec	9-Dec	12-Dec
Chris	4-Oct	13-Oct	-	28-Oct	4-Nov	10-Nov	25-Nov	2-Dec	8-Dec	12-Dec
Boris	14-Oct	14-Oct	21-Oct	28-Oct	4-Nov	11-Nov	25-Nov	2-Dec	8-Dec	9-Dec
Bill	14-Oct	14-Oct	21-Oct	28-Oct	4-Nov	11-Nov	25-Nov	2-Dec	-	9-Dec

Apparatus

The EMIS that participants used was a commercial product developed by our collaborating software company. It had been designed to support M&T best practice (ASHRAE Guideline Project Committee 14P, 2002; Gotel, 1989), and supported popular graphing formats including line, stacked bar, and pie charts, as well as some specialized charts such as a load duration curve. The EMIS interface was implemented as a web browser application, and the display was user-configurable with customizable 'widgets'. In-house energy analysts and client users had access to the same EMIS features, though analysts supplemented it with Excel spreadsheets.

Observation Tasks / Methods

Participants were asked to 'think aloud' (Chi, 1997; Ericsson & Simon, 1992) as they worked. Researchers would occasionally interject to encourage participants that had fallen silent, or to ask clarifying questions.

Interviews were conducted before and after the longitudinal observation period. Questions were semi-structured and addressed participants background, work experience, motivation, past successes, action opportunities, and difficulties.

Interviews were audio recorded and transcribed, and the researcher took handwritten notes. In task observation sessions, client participants' computer screen was recorded with a video camera. Analyst participants' computer screens were captured by software, and discussion by audio recorder.

Interpretation

Because of the small sample size (5 participants) and open-ended / self-directed sessions, results are interpreted qualitatively, anecdotally (Kempton & Layne, 1994; Sanderson & Fisher, 1994).

Interpretation sessions were summarized and time-tagged by one researcher, with the intent of distinguishing time spent navigating within the EMIS, context sources consulted, and the object of participants' investigation. However, inter-rater-reliability testing of these codes produced only moderate agreement, so they are not reported in detail.

Results were interpreted in terms of opportunities to improve EMIS usability, and reported to the software developer. They were also interpreted in terms of design opportunities for EMIS tool development.

In this paper we will focus on describing the people, environment, and M&T behaviour observed.

Results

We will first introduce the participants as stereotypical personas, by summarizing their responses to Interview 1. Personas are a useful representation for software developers (Cooper, 2004). Next, we present a subset of related observations from the longitudinal study, and conclude with participants' responses to Interview 2.

Participant Personas / First Interview

For anonymity, we address participants by pseudonyms. Their backgrounds, experience, and opinions differed greatly, and reflect some of the prototypical users that designers might consider when anticipating user needs.

Anna – Site A Energy Specialist

Anna was a recently graduated chemical engineer hired at Site A, a chemical processing plant. She had been given (among other duties) the job of monitoring site electricity, gas, and water efficiency performance and had been doing so from time to time over 2-3 months.

Her main motivations were to stay aware of whether the site was "winning or losing" at energy performance, diagnose savings and prove that they were due to ongoing energy efficiency equipment investments and operational strategies. Over the past months, Anna had noticed a few interesting features in the energy record, but hadn't taken any direct actions.

Being a junior engineer, Anna wanted to quantify the cost of savings / losses and "prove that what you were proposing is actually working." Anna would have liked to use EMIS results more, but was concerned that she didn't understand enough about the quality of the EMIS data collection and processing to feel credible challenging her more experienced operations colleagues, such as during production team meetings.

Boris – Site B Energy Specialist

Boris was a certified steam system operator, with over two decades of experience in running boilers. He had worked many jobs including nuclear power plant operator and incinerator site manager. He joked that he had "retired" to managing operations and maintenance at Site B, a downtown institutional building. For three years, Boris had led the site technical operations team responsible for all facility services including HVAC, steam boilers, air conditioning chillers, building repairs, and so on. Two years prior, Boris had supervised a major energy efficiency retrofit to the site's heating and cooling systems. Energy monitoring had mainly been implemented to verify the savings rate for contractual payments, and Boris was happy to have gained energy analyst services to monitor weekly energy performance.

Like Anna, Boris' most important reason for monitoring energy was to save money. However, being a site manager, Boris also had to make informed operating decisions, so wanted to go beyond "whether we're staying on track" to be better able to estimate "the real cost of running" Site B both in labour and energy terms. Boris was interested in discovering more efficient ways to schedule equipment operation, and was considering engaging in utility-sponsored electricity demand response programs. While he couldn't recall any specific energy monitoring findings in the past month, in the recent past the EMIS had helped diagnose a major supply transformer failure, and quantify the cost of idling air conditioners, unrepaired equipment, and an emergency change to heating ventilation.

Boris's main complaint was that diagnosing energy performance changes was too uncertain with the current EMIS, that there wasn't a "stupid-proof indicator" of energy waste. He suggested that either better modelling (through quantifying the customer/visitor loads on the institution) or closer integration with the building automation system (such as known equipment start/stop times) would help him better direct and support his operations team.

Bill – Site B Operations Supervisor

Bill had worked for over 20 years as a power systems electrician before being promoted to electrical operations supervisor at Site B. He hadn't been involved in energy monitoring as he didn't feel it yet informed his daily work of dispatching and supervising site electrical maintenance staff, but was curious to see if he could learn anything about the site's electrical performance trends. More so than Boris, Bill was not very experienced or fluent in using computers, but was enthusiastic to learn.

Carl – Energy Analyst assigned to Site A

Carl had been hired as an energy analyst only two weeks prior to starting the trial. His prior experience included a Masters degree in mechanical engineering, and previous employment in machine design.

As an energy analyst, he felt his role was to "help the client save money", but also to "develop a history" of energy-related data. Having only been on the job a few weeks, he hadn't yet made any discoveries of energy waste through M&T, though he had learned the importance of assessing energy data and model quality.

In the future, he hoped to learn how to better diagnose clients' energy performance problems so as to develop credibility as an energy analyst. So far, the only actions he'd taken in response to suspected energy waste were to search for additional data records. He felt that if he were to contact a client with concerns over their energy performance, he would need to trust the energy data more so as to be confident in making a diagnosis or suggested course of action. Carl felt that the more clients perceived him as adding to their workload, the less they would attend to his suggestions.

Chris – Energy Analyst assigned to Site B

Chris, like Carl and Anna, was also a young engineer. He had been hired only a few weeks prior to Carl, but had more energy analysis and statistics experience, having worked previously as an energy efficiency auditor.

Besides helping clients save money, Chris found personal satisfaction in solving mysterious energy consumption patterns. While he hadn't yet found anything of interest in his clients' energy data, he attributed this in part to not yet being statistically certain of the precision or accuracy of the existing energy performance models. He felt he limitations of energy models "are hard to learn if you didn't make the model yourself". Like Carl, Chris felt his only options for action were to investigate remotely, or to contact the client.

In his experience so far, he found clients were always "busy with other things", sometimes "too busy to care". This presented a challenge to balance "not being annoying" with missing out on opportunities to be helpful. He felt that being more specific and correct in analyzing causes of energy performance changes would help bolster his credibility in the eyes of clients.

Observations from longitudinal study

To summarize the 14 hours of observations from the 50 sessions, we will organize selected observations by theme.

Navigation and time demands

Navigating the menus and reports of the EMIS consumed on average about 15% of participants' time, and seemed a barrier to efficient use. This is an underestimate as it omits Bill the Site B electrical supervisor, who found navigating the EMIS very burdensome. Bill was the only participant who needed to read in detail the descriptions of the charts and data presented. Having little computer experience, he was puzzled by cases where the EMIS showed zeroes and couldn't explain the discrepancy in terms of missing data.

His frustration led the experimenter to offer to navigate the EMIS at Bill's direction. Bill accepted this offer, being curious to see the effects of electrical maintenance operations that he had recently coordinated. Inspecting 5-minute-interval electric meter data at Bill's direction, he recognized the effects of both electrical maintenance jobs. Bill was unique in being able to explain these events – Carl detected one through the CUSUM charts the subsequent week, but could only speculate at its cause.

Boris was more successful at navigating the EMIS than Bill, but expressed concern that too much time was required to inspect charts. As Boris put it, given how busy building staff are, "5 minutes is a long time" to ask. Boris fondly recalled Chris's predecessor energy analyst who saved him time by making concrete suggestions such as "I think you have a problem with this particular equipment", and directing him exactly what to "go out on-site and look for".

Interruptions at client sites

While Anna's work environment was a private office, Boris and Bill worked in a shared meeting space for Site B operations staff. The competing demands for Boris' time were evident in the office whiteboard which read "Big Stuff to Fix: Steam Leaks, Freshwater Pumps, Roof Leaks". Boris and Bill were interrupted during four of fifteen site visits, at least twice on each occasion. Interruptions included fire alarm testing, employee family emergencies, and a Site B visitor getting locked in a washroom. Boris expressed on one occasion that the experimenter's visit was "the most time I've had to sit down all day", and remarked that he would welcome a mobile device EMIS report so that he wasn't "tied to my computer".

EMIS and managing staff

Boris hoped that an EMIS could help him better manage his team of operators. On one occasion he remarked that while his boiler and chiller operating staff "know their own equipment", he felt they "control the site from different silos" and that he hoped energy M&T could serve as an indicator for whole-system optimization. A weakness in the existing EMIS was that it was retrospective - Boris needed *predictive* indicators to schedule staffing and equipment start-ups at least two shifts in advance. He suggested that the EMIS could use weather forecasts or other indicators to give at least day-ahead indications of energy-saving opportunities.

Anna, while hesitant to present model-derived energy performance metrics to colleagues, found 5-minute-interval electric meter data useful. On one occasion she documented the exact time of an equipment stop/start for downtime reporting management.

Data availability

As expected, client participants had access to more detailed records and data about site operations than remote analysts. The speed with which Anna could retrieve site records, however, was surprising. On two occasions she fetched shift reports in less than 30 seconds to investigate and explain energy use at a given date/time. This was faster than the response time of the EMIS for some complex charts.

However, such local data was not reliably communicated with energy analysts. Energy under-consumption that Carl studied at some length, Anna quickly dismissed as being due to a known shutdown. However she did not use the note-taking feature built into the EMIS to record her observation on the chart. The under-use of such features may have been due to usability problems. Even measured data such as weather temperatures required some navigation to access, which may have contributed to Anna, Boris, and Chris on occasion explaining suspicious energy consumption "because of cold weather" without verifying their guess against weather data.

Verifying/cultivating data & model record

Carl and Chris were responsible, as energy analysts, for maintaining the quality of energy and driver data in the EMIS, and spent at least five sessions almost exclusively assessing data quality. Missing data and unit conversion problems at Site A were the two main difficulties observed during the study period. Questions of measurement error weren't yet considered.

Carl and Chris updated energy models for Site A and B during the course of the study period, as they familiarized themselves with the site data record and developed their personal modelling practices. However, the EMIS did not display any notification when models were updated, and on two such occasions Boris interpreted completely revised historic energy performance charts without noticing that they had changed from the previous week's session.

Diagnosis strategies

Though it is difficult to draw conclusions about participants' thought processes, their spoken comments suggested a few general strategies. All participants relied largely on the energy over/underconsumption CUSUM charts (Harris, 1989) generated by comparing energy performance models and actual consumption.

On noticing a deviation, Chris and Carl would often navigate within the EMIS to check fine-timescale meter and driver data, being unsure if either might have data gaps. Anna also checked data to verify energy and driver values, often quoting her estimates of what "normal" consumption for a given day's operation should be, and inferring on one occasion that "when this plant area is shut down, we get savings".

Anna, Carl, and Chris seemed to try to explain periods of over/underconsumption in terms of events that happened at the same time. However, Chris realized that this rule was not always valid, as in Site B, major additions to the building complex had been completed in mid-fall, which plausibly explained increased gas consumption arising several weeks later in early winter.

Boris, being closely involved in site operation, seemed to use the EMIS with the intent of confirming the effects of known changes rather than to try and diagnose unexplained changes.

Time reference frames

As all the charts in the EMIS were time-series, and a frequent diagnosis strategy was to recall plausible simultaneous events, participants often spoke about dates and times. The most common time reference frame for explaining energy use were calendar weekdays/weekends and holidays, which were not marked on all EMIS charts. Participants often used standalone software calendar aids or paper calendars.

Carl expressed interest in being able to rearrange charts according to dates when large equipment was started or stopped to search for common patterns in startup and shutdown energy consumption. Chris kept notes to remind him of important dates at Site B, such as when a transformer had failed, or when new building construction started, both of which affected energy performance throughout the study period.

Unit reference frames

Charts in the EMIS displayed consumption and drivers in fixed measurement units (e.g. kWh or m^3), which were not easily changed, even by Carl and Chris. During some M&T sessions, these units seemed to interfere with participants' navigation or diagnosis.

For example, energy quantity (e.g. kWh) is the standard basis for metering, as it sums across even irregularly metered time periods. However, on two occasions when Chris zoomed in to examine energy charts at 5-minute timescales, the change in Y-axis scales (300kWh / h becoming 25 kWh / 5min) disoriented him. Expressing consumption in terms of average power (kW) would preserve unit magnitude across timescales. Converting consumption to average power was also mentioned by Carl as a useful diagnosis or client communication aid, specifically by using Imperial units of equipment capacity familiar to maintenance staff (e.g. horsepower of electricity for motors, million BTU/h of gas for boilers). Describing an overconsumption of "about 25hp" seemed to Carl to be better understood by clients and helped them imagine likely causes to narrow their search.

Other units suggested to describe over/underconsumption were financial cost, and for accumulated consumption the equivalent number of 'typical' days' use (e.g. two "free" days per month).

EMIS for more than monitoring

On the second-last session of the field study, Boris announced that he wanted to answer a very important question. Because of the new building construction at Site B, heating demand was increasing as evident from the EMIS energy performance charts. Boris wanted to determine if there was a risk of running out of steam heating capacity on an extremely cold day, and estimate his margin of operating safety. The EMIS was not designed to answer equipment capacity questions, and it took 25 minutes for Boris to reach a conclusion that satisfied him.

In pursuing this question Boris tried to determine the building's relationship between temperature and gas consumption, and relate it to the boiler performance of gas consumption versus steam generated. To determine how much the new building had increased the heating load, he used the EMIS to plot a time-series line chart of temperature and gas consumption. He then selected a cold day in the previous winter, and compared it to a recent day with similar temperatures, to estimate how gas consumption had changed. Next, he tried to learn the relationship between gas and steam production, which was more difficult. Boris consulted boiler logbooks to assess steam production on the same cold date, and then double-checked his estimate using thermodynamic principles, converting from steam production to gas capacity required, by way of looking up the energy capacity of natural gas and the equipment boiler efficiency.

Boris seemed to be uncertain about how conclusive his estimate was, but claimed to be satisfied for the moment.

Second Interview Responses

Questions in the second interview asked participants about their experiences over the study period, and probed their understanding and explanation of site and EMIS functionality.

Reflexivity

The first interview question addressed reflexivity – the tendency for participants in a research study to change their behaviour in response to observation. Both Carl and Chris stated that they probably spent more time and looked more in-depth at weekly data than they would have otherwise. However, all three client participants said they hadn't changed their behaviour.

Participants couldn't suggest any of their energy interpretation practices that the researcher hadn't asked about, except for Boris who suggested that several months prior he had used the EMIS "more in-depth" to diagnose manage a electrical transformer failure at Site B.

Summary findings of Energy performance

Site A

No participant reported having found any important changes in the site's energy performance during the study period. The site had transitioned from 24/7 production to a period of weekend shutdowns, which Carl, Chris, and of course Anna noticed. However, none could distinguish whether this changed production energy performance.

Anna and Chris did notice a period of gas overconsumption, but interpreted it differently. Chris was fairly confident in it being unexplained, but didn't have enough knowledge to call it "waste". Anna explained the gas overconsumption in terms of colder weather, but didn't seem to consider to what degree the existing energy performance model accounted for weather effects. Anna was satisfied to describe site monthly consumption values as being 'normal', again without reference to energy models.

Site B

Both Energy Analysts identified that Site B had had a large electric overconsumption on the 10th of October, which Chris suspected was related to the new Site B building having been commissioned on the 3rd of October, being too coincident to be coincidence. Neither reported any gas overconsumption, though this may have been due to charts having changed with a newly updated gas model that Chris had implemented the previous day.

Like Anna, Boris didn't reference energy model-corrected performance in explaining site energy consumption. He described recent Site B energy performance in terms of his day-to-day coordination of heating and air conditioning operation and maintenance. Boris did reference EMIS as being useful in estimating critical winter cold temperatures that might exhaust the capacity of Site B's steam plant.

Bill was pleased at having found signs of his electrical maintenance events in the EMIS's 15-minute timescale energy data, but didn't feel he could judge site energy performance.

Overall, participants did not report gaining much insight into either Site A or B through eight weeks of energy monitoring.

Mental Models

Participants were asked to explain, in their own opinion, how they thought the following EMIS elements worked:

Site Equipment, Metering, Operation, Energy-consuming Processes

Anna described Site A in terms of process units: assemblies of equipment designed to support chemical manufacturing processes. She described processes in terms of which groups of equipment had to be running to perform them, and in terms of an associated process power draw, for example "when that [process unit]'s down I can see a major drop in electricity".

Boris described Site B's heating and cooling equipment in more abstract terms, as moving "mass" and "energy", the only participant to use such abstract terms. He described site processes in terms of energy 'drivers', some of which were measured and incorporated in the energy model, others (such as visitor demand) that he expressed a desire to quantify. Boris described operations in terms of the difficulties he had experienced in scheduling operation of air conditioning and heating equipment during the unpredictable fall season.

The only process that Bill described was the effect of outside temperature on heating & cooling requirements. He listed electrical equipment on-site sorted by largest power draw (air conditioning chillers), and summarized occupant loads as “miscellaneous”.

Energy analysts Carl and Chris, lacking first-hand knowledge of their clients’ sites, seemed to use an alternate strategy. They both described sites in terms of processes modelled in the EMIS (electricity & gas consumption, heating, cooling, pumping), and seemed to deduce from stereotypes what equipment the site most likely had (e.g. Site A as “A chemical plant with distillation”, requiring a steam boiler, Site B as an institution “probably with a central chiller rather than air conditioners”). Neither Carl nor Chris knew exact equipment or configuration at either site, aside from a few details they had learned through specific discussions with Anna or Boris.

Meter & Driver Data Collection

Carl and Chris had no difficulty describing how energy and weather data was collected. However, Anna was the only one to mention the complexity of how production data was recorded and calculated within Site A’s process departments, possibly due to her experience in compiling this data for uploading to the EMIS.

At Site B, neither Boris nor Bill had any guess as to how data was collected, aside from a rooftop temperature sensor whose installation Bill had overseen.

M&T Energy Baseline Models

When asked to explain energy performance models (Carbon Trust, 2008), participants agreed only that they were based on historic energy performance data. As anticipated, client participants had a less detailed understanding than energy analysts.

Anna agreed with Carl and Chris on the importance of selecting “driver” variables based on an engineering understanding of energy-consuming processes. She interpreted baseline energy models as meaning “if everything's operating the way it should... with regular conditions, this is how much [energy] you should use", and concurred with Boris that a baseline model could be used to reveal the effects of energy projects or changes in production.

However, both Anna and Boris misunderstood the ordinary-least-squares statistical regression relationship used to fit energy models. Anna believed models were calculated by an analyst selecting a base load, then specifying "chunks of energy consumption" for each "department" of Site A. This is consistent with her explanation of energy use as “normal” with respect to which parts of the factory were operating. Boris understood modelling as similar to benchmarking, taking into account not just long term historic data, but also a site audit of major equipment, building age, space utilization, and normalized per square foot of building space.

In contrast to client participants over-attributing the sophistication of models, analyst participants were cautious in describing energy model quality. Both Carl and Chris warned that the historical data used to train an energy model limits the conditions the model can represent and predict. Carl cautioned that the regression process assumes a linear relationship between drivers and energy, and Chris described models as only “our best guess of what the [consumption] should have been”.

Lessons learned

Despite not having discovered energy savings opportunities during the study period, participants reported having learned more about the behaviour of Sites A and B. Anna expressed having a better sense of typical power consumption of each plant unit in the facility. Bill admitted finding the EMIS difficult to use, but was gratified to be able to see the effects of his maintenance work and quantify the energy consumption increase from Site B’s new building. Boris credited his telephone discussions with Chris for helping him learn more about how energy models were updated to correct for large site changes.

However, Boris mused that the experience of using an EMIS wasn’t “a matter of being fed little chunks of information... 'use chunk X to look at graph Y and it'll give you answer Z’. The whole thing is a bit more kind of holistic. You have to think 'system', you know?"

Discussion

The relatively modest energy conservation findings after 8 weeks of energy monitoring were somewhat disappointing to the researchers. However, the work difficulties we observed may be more informative in exposing difficulties with energy M&T software tools and practice.

Observations were consistent with our two hypotheses: remote analysts had poorer understanding of site equipment, processes, and conditions than client practitioners, and remote analysts showed a more accurate understanding of M&T data collection and statistical practice. Participants reported appreciating the discussion and interaction between clients and analysts, though Carl did note that Anna and Boris were exceptionally active and engaged clients.

Clients and analysts agreed on the need to find cost savings, but differed in their other motivations for energy monitoring work. One difference seemed to be between participants with control authority and those without – Anna and the analysts seemed preoccupied with personal credibility and correctness, while Boris was much more confident in his personal authority, and described the EMIS as a tool for personal education. Another motivation difference was between analysts' desire to maintain data and solve mysteries, and Anna, Boris, and Bill's time-pressured environments which left little time for curious exploration.

These pressures and observations from the study suggest that given the interruption-prone, colleague-dependent M&T work pressures of clients, an EMIS should be designed to:

- Deliver summary reports at weekly and monthly timescales
- Be capable of communicating energy performance insights in less than 5-10 minutes
- Universally translate between units such as energy, power, money, or "folk" units
- Convert between multiple time reference frames such as weekdays, weekends, or holidays, facility operating schedules, worker shift schedules, etc.
- Support forecasts or user-entered estimates to produce predictive indicators (Hooke et al., 2003)

The motivation for these features should be to support *diagnosis* of energy performance deviations. Diagnosis was cited as important by all users – Anna because of her uncertainty in challenging colleagues, Boris because of his limited time to investigate, and Carl and Chris because of their need for client credibility. Because diagnosis is social in large work environments, EMIS should support users in suggesting concrete observations and diagnosis rules for explaining abstract model – actual energy deviations.

Diagnosis is difficult because of the constant change present in complex business systems. Both sites experienced large changes - Site A experienced a production schedule change from 7 to 5 days, Site B dealt with both a new building commissioning and an ongoing transformer failure. In the 7^{th} session, Boris complained about the difficulty of learning and keeping up to date with the state of site equipment & controls for such a large facility with so many contractors and site workers. Without knowledge of the specifics of site changes, Carl and Chris did their best to update both sites' models during the course of the study. However, for good model quality, a year of consistent energy data is recommended (ASHRAE Guideline Project Committee 14P, 2002), leading Chris to observe a paradox of more energy performance improvements leading to worse energy performance indicators.

The effort of maintaining models to match system change may encourage use of one model for multiple purposes. Depending on the audience, however, energy performance models may be used to:

- Interpret recent energy use, as a purpose-specific problem solving aid
- Verify energy savings, as a legally binding accounting instrument
- Substantiate "success stories" for management, as a performance metric
- Motivate behaviour from co-workers, as a control signal

The binary "Baseline / Target" description of model purposes introduced in classic M&T texts (Gotel, 1989) seems inadequate to these uses.

The EMIS displayed very little information about energy model quality, calculation process, or the intended meaning of performance indicators. The only display 'widget' available on the main view was a pie chart listing relative contribution of baseload and energy drivers, and a 3 sentence summary. Client participants had difficulty noticing model changes, misunderstood models' capabilities, and while they used model-calculated performance charts, more often expressed their findings in terms of 'normal' energy use or known operating conditions.

Nevertheless, when asked about energy consuming processes, client participants seemed to describe the processes used in the energy models, suggesting that energy models might serve as a 'scaffold' for participants to build their understanding of site energy consumption. EMIS designers might consider whether their reporting systems match or enhance participants' mental models of energy use.

Finally, Boris's boiler size estimation task suggests that EMIS have the potential to be a flexible problem-solving tool. Unfortunately, the chart representations Boris needed to estimate the coldest temperature that Site B's boilers could manage were not available in the charting software used. With two adjacent scatterplots, one relating temperature to gas consumption (from the energy model) and the other gas consumption to steam production limits (from the boiler operating logs), Boris could have sketched an estimate by interpolating between the charts with three ruler lines. A list of tasks that EMIS designers should anticipate is an opportunity for future work.

Conclusion / Future Work

This field study provides a descriptive account of energy M&T in practice, and a first step towards an empirically-based work analysis of M&T. Just as descriptive analyses of energy auditing form a basis for tool design (Owens, 2013), this study can inform design of Energy Management Information Systems.

This field study is limited to relatively novice users, and was conducted over a fairly short period, so the results may not generalize beyond Canadian customers and the collaborating software company.

However, in the author's experience, the EMIS product used in this study was typical of contemporary M&T software tools. Its features seemed designed to support official M&T work practices (Carbon Trust, 2008; Gotel, 1989; Hooke et al., 2003), which we found do not completely describe M&T work needs.

The experiences of participants in this study suggest opportunities to develop innovative EMIS that:

- Can adapt to use terminology familiar to the user, whether Euros, Joules, or folk units.
- Use familiar metaphors to build users' understanding of energy use.
- Support M&T data quality monitoring and model diagnostics, and make this crucial work accessible to novice users.
- Encourages work not observed in this study: visiting the equipment in-place, with mobile support for in person monitoring and "good housekeeping" work.

As a first step, we have proceeded with a design project to explain energy models and support diagnosis with a novel M&T statistical method (Hilliard & Jamieson, in review, 2013).

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