Design Recommendations for Smart Energy Monitoring: a Case Study in Italy

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Abstract

In the era of green energy and smart grids, the ability to access energy information and effectively analyze such data to extract key performance indicators is a crucial factor for successful building management. Energy data can in fact be exploited both in long-term policy adaptation and in shorter term habits modification, providing the basis for stable improvements of the overall efficiency of buildings and dwellings. To reach the ambitious goal of actually improving how buildings consume energy, four main challenges emerge from literature: (a) lack of skills and experience of energy managers, (b) complex and disparate data sets, which are currently blocking decision making processes, (c) mostly-manual work-flows that struggle to find relevant information into overwhelming streams of data sourced by monitoring systems, and (d) lack of collaborations between organizational departments. This paper provides deeper insights on these challenges, by investigating the kind of analysis currently performed by energy managers (in Italy) and the expectations they have if required to reason about systems that will be available within the next five years, and proposes design recommendations for next generation energy intelligence systems.

Keywords: Energy Management, Energy Intelligence, Smart Energy Monitoring

1. Introduction

According to recent surveys and researches carried by both academia and industrial analysis firms, the ability to effectively access, process and transform energy consumption and production data into actionable knowledge is a crucial factor for a successful building management, fostering major changes in long-term policy planning and in shorter term occupants' energetic behavior.

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One of the fundamental players in this information analysis and delivery process is the availability of appropriate support tools, mainly based on information and communication technologies (ICT) as in [1, 2, 3]. Such tools should help building and energy managers to unveil the full potential of field data delivered by monitoring systems, e.g., through semantic sensor networks [4] or other state-of-the-art solutions. According to a research carried by the Aberdeen Group in 2011 [5] and confirmed by several other research papers [6, 7], four main challenges need to be addresses for better energy management at the enterprise level:

1. insufficient (human) resources with necessary skills and experience;

2. complex and disparate data sets that present a significant road block to improving decision making;

3. manual processes making difficult to find relevant information for decision makers;

4. lack of collaboration among different enterprise departments.

The work presented in this paper aims at better understanding the issues and challenges related to data handling and analysis (items 2 and 3), with a strongly experimental approach that builds upon living "needs" emerging from the main users of energy management systems, i.e., the energy managers. The final goal is to start tackling the emerging issues at *design* time, with a set of *recommendations* to follow for achieving improved effectivenesss of energy management processes.

In building or site-wide energy management, effective data handling generally emerges as a particularly strong issue, involving the ability to analyze and summarize complex, heterogeneous data sets and the capability to progressively replace manual and error-prone processes with automated procedures. This process involves two main aspects: *data cardinality* and *data analysis*. The data cardinality aspect is mostly cross-domain and can effectively be tackled by exploiting emerging solutions for real-time processing of huge data streams and sets (also known as Big Data). The data analysis perspective, on the other hand, requires specific and careful adaptation of well-known techniques (e.g., data mining, machine learning, business intelligence, etc.) to the energy management domain. In such a context, business intelligence, as an example, has already proven to be useful for improving energy information extraction and management [8].

While data cardinality requires a typically technology-centered approach, where the end user is almost "isolated" from data collection issues, data analysis must be strongly driven by energy management needs, and therefore must adopt a strong user-centered approach. In such an approach, the final users (i.e., energy managers, in our case) are continuously involved in the design process, starting from the elicitation of their needs and the analysis of the current context and situation, with the aim to identify the tasks and the operations carried out by the users. A viable way to successfully pursue the initial phases of this approach is to extract some *design recommendations*, accounting for both the current situation of energy management and the actual needs and expectations of energy managers.

This paper specifically aims at defining an initial set of publicly accessible recommendations for designers of Energy Intelligence Systems (EIS), e.g., business intelligence systems applied to the energy domain. First, the paper tries to get deeper insights on the current energy management habits and needs, in Italy, by presenting the outcomes of a web survey subministered to all certified energy managers, and aiming at capturing the technologies, the kind of analysis currently adopted by Italian energy managers and the solutions they would adopt if they were available. Secondly, results from the survey are compared with data analysis capabilities of current worldwide-available energy dashboards. Finally, design recommendations for energy intelligent systems able to fulfill the data analysis requirements emerging from the survey are distilled, and integrated with possibly missing aspects highlighted by the analysis of the existing systems.

The reminder of the paper is organized as follows: Section 2 reports related works in literature. Section 3 addresses survey design choices and interview modalities, whereas Section 4 reports the survey results and the lessons learned. Section 5 presents results from the secondary investigation on visualization dashboards already in-use in various companies and educational institutes worldwide and discusses their relation with results from the main survey. Section 6 defines design recommendations for energy intelligence systems by building upon the survey outcomes, while Section 7 draws the final remarks and proposes future works.

2. Related Works

Investigating the gap between state-of-the-art data analysis solutions and actual adoption of such techniques in the field of energy management is still a quite neglected research topic in the Computer Science and Smart Grid community. Although some preliminary work start to emerge, this particularly challenging topic lies at the boundaries of several disciplines and few works can be cited who precisely aim at tackling this issue under a computer science and human-computer interaction point of view.

Curry et al. [8], propose a new Enterprise Energy Management system aimed at enabling full citizenship of energy data in enterprise management systems, through the adoption of a Linked Dataspace for Energy Intelligence. Their work shares with this paper the underlying feeling that business intelligence and data analysis techniques could be better exploited to offer enhanced and more efficient energy management in buildings and enterprises. With respect to the presented survey, the Curry's approach is more targeted at realizing an innovative energy management system rather that at identifying the needs that the system should tackle and the, possibly bad, habits that the same system should foster to change. In a sense, our work should ideally precede the one of

Curry et al., helping to better deploy provided analysis and interactions. On the other hand, as their system is modular and quite adaptable to different adoption cases, it might also be considered as a base platform upon which implementing solutions for the energy management shortcomings emerging from this survey.

Jain et al. [9], investigate the usage and design of eco-feedback interfaces with respect to the goal of improving energy efficiency in buildings. Their work involved an empirical study with 43 participants using a prototype eco-feedback interface. Although non directly related to the presented survey, their work, and many others involving the impact of feedback on energy consumption behaviors [10, 11] and relative management issues, are crucial to gain a better understanding of this survey outcomes and to effectively tackle the subsequent step of designing data analysis systems able to support energy managers in their daily activities.

The Sustainable Energy and Business Management communities already investigate the topic of efficient energy management in buildings and enterprises, but with an approach more targeted to the management, energetic and economical issues of the problem, again neglecting the human factor, crucial for successful exploitation of available systems.

In this context, the work of Bunse et al. [12] provides a quite detailed analysis of the existing gap between industrial needs and scientific literature in the domain of energy efficiency performance in production management. Although biased towards a management standpoint, the analysis they carry highlights the existence of a sensible gap between tools currently investigated in computer science, and in particular involving data management, analysis and information extraction, and actual industrial needs. Such a gap can be easily reconciled with the outcomes of the presented survey, although in this work we mostly focused on identifying habits and needs that information communication technologies should address for better supporting energy efficiency in buildings and dwellings.

3. Survey Design

In order to investigate the current landscape of energy management in Italy, we designed a web survey aiming at capturing the technologies, the kind of analysis currently adopted by Italian energy managers and the solutions they would adopt if they were available. To address this double purpose, we organized the overall survey in different sections, each aimed at harvesting homogeneous subsets of information either referred to current or future systems. The general structure of the questionnaire underwent several reviews and was firstly subministered to the energy manager of our institution for initial validation and subsequent fine tuning. Obviously, data obtained through such a preliminary interview are not included in the analysis.

3.1. Survey structure

The survey, subministered in Italian for lowering language-related issues, involves 3 main areas including personal details (only limited to not-sensible data as the questionnaire is completely anonymous), currently adopted monitoring processes, tools and kinds of analysis currently performed. Monitoring processes are analyzed in terms of observed quantities, sampling frequency and granularity, only. Tools are investigated with the aim of distilling an up-to-date overview of currently adopted techniques and methodologies, whereas analysis carried by energy managers are investigated to understand at which degree they can be improved by applying business intelligence and data analysis solutions.

More in detail, four different sections have been identified for the survey, aiming respectively at:

1. Characterizing respondents in terms of age, gender, education, working position, etc.;
2. Checking whether sampling rates and granularity needed and/or used for a set of measures typically monitored by energy managers are handled differently depending on the kind of measured quantity, or not;
3. Getting an overview of currently adopted tools and methodologies;
4. Identifying typical analysis currently carried by energy managers.

The survey sections mainly involve closed-answer questions, plus some sorting tasks. Open questions were limited to topics not directly addressed by the survey, e.g., for including/suggesting additional measures to consider. Each question was tested with a group of 5 persons, out of the target user sample, for optimizing readability and understandability, and with the aim of maximizing the effectiveness of the published survey. The total survey duration was around 10 minutes and follow-up techniques were adopted to maximize the rate of response.

3.2. Subministration modalities

We subministered the survey to all certified energy managers reported in the national registry maintained by the Italian Federation for Rational Use of Energy (FIRE) on behalf of the Italian Ministry of Economical Development (Law 10/91 and subsequent Decree Laws). Given such a registry we collected the available mail addresses of listed managers and we contacted them individually, by e-mail. Over 200 managers have been contacted within a week and they were invited to participate to the on-line survey we set up using the well known Lime Survey tool[1]. Participation to the survey did not include any payment or reward.

We applied follow-up techniques for increasing the number of responses: a month after the first invitation, a new mail was, in fact, sent to the selected users for inviting them to fill-up the survey in case they had not participated yet. As the survey was anonymous, follow-up messages were sent to all users

[1] http://www.limesurvey.org, last visited on April 08, 2014

and formulated carefully to foster new participation while not bothering energy managers who already contributed their opinion.

We allowed submission for a 3 months time span, after which we closed the online survey and started the data filtering and elaboration phase.

3.3. Results overview

Even by applying follow-up techniques the total amount of complete responses was quite low due to several reasons. Among the 200 collected e-mails, 26 were not up-to-date and either resulted unreachable or the corresponding mailboxes resulted full. Moreover some candidate participants did not contribute to the survey, even if reachable by email. Eventually, a total amount of 40 responses were collected, of which only 34 complete. With respect to the initial sample size of 200 participants we scored a rather low participation rate of 17%. Filtering out unreachable email addresses and full mailboxes, and considering complete responses only, the overall sample coverage increases up to 19.5%.

Being aware that such a low rate of response might lead to non-significant results, we verified the actual sample distribution by comparing its composition in terms of gender / employment areas with the original sample of 200 energy managers. Results, reported in Tables 1 and 2 reflect a similar distribution thus supporting the validity of survey findings, although not formally.

Table 1: Comparison between employment areas of contacted users, respondents and full respondents.

	Public sector	Private companies
Original sample	168 (84%)	32 (16%)
Respondents	35 (87.5%)	5 (12.5%)
Full respondents	29 (87.9%)	4 (12.1%)

Table 2: Comparison between gender of contacted users, respondents and full respondents.

	Males	Females
Original sample	186 (93%)	14 (7%)
Respondents	38 (90,5%)	4 (9,5%)
Full respondents	30 (90,9%)	3 (9,1%)

4. Survey Results

4.1. User characterization

The first section of the survey aims at providing a "slow" engagement preparing users to subsequent sections, and, at the same time, at extracting some information about survey participants in terms of age, experience, education, size of companies for which they work, and market areas in which their companies operate. Collected data provides 3 main insights on the sample composition. First, survey participants are aged between 36 and 65 (see Table 3) and they are almost uniformly distributed in three bands: 36-45, 46-55 and 55-65 years old. This result confirms that the energy manager position mostly involves mid-senior figures, due to responsibilities associated to this role, in Italy.

Table 3: Age of survey participants

Age	Percentage
< 25	0%
26-35	0%
36-45	33.3%
46-55	27.3%
56-65	39.4%
> 65	0%

In most cases the education level of energy managers is high, with more than 80% of participants holding a master degree, with technical specializations clearly prevailing with respect to others (Table 4). Moreover, the remaining 20% of non graduated people, is composed by over 75% of persons holding a technical bachelor degree, thus confirming the energy manager as a typical technical position.

Table 4: Education level of participants

Degree	Percentage
Mechanical engineering	21.2%
Industrial BSc (Perito Industriale)	15.2%
Civil engineering	12.1%
Electrical engineering	9.1%
Electronic engineering	9.1%
Nuclear engineering	6.1 %
Engineering (not specified)	6.1%
Management engineering	3%
Mining & underground engineering	3%
Industrial engineering	3%
Chemistry	3%
Environmental sciences	3%
Architecture	3%
Other	3%

As expected, companies employing the interviewed energy managers are medium-large (see Table 5), respect to the Italian average enterprise size (mostly in the small and medium size range), thus suggesting that the selected user sample works in the context of activities in which energy assets are crucial under the economical standpoint.

Table 5: Size of companies employing the interviewed energy managers.

Size (# employees)	Percentage
< 10	3.0%
10-50	0.0%
51-100	6.1%
101-1000	42.4%
> 1000	48.5%

Due to the partial bias towards the public sector emerged from the FIRE directory of managers composition, the economic sector data obtained from the survey was not really relevant, providing an incomplete overview of the energy management domain where public administration, universities and public health facilities cover 75% of survey respondents. Similarly, data about experience level of energy managers is quite variable and shows an average value of 11.61 years of experience in energy management with a standard deviation of 7.84 years. No conclusions can be driven on the basis of such evidence and more investigations are needed to get a more realistic representation of the current experience-level of Italian energy managers.

4.2. Energy monitoring needs

The second section of the survey aims at identifying monitoring habits and needs of energy managers in terms of granularity and sampling frequency. Both current and near future solutions are analyzed, by explicitly requiring participants to express their needs regardless of the features of currently adopted systems.

The main focus is on electricity, gas or fuel, and water consumption, however users were also allowed to suggest other quantities to monitor, e.g., geothermal energy. In particular, we wanted to understand to which degree different quantities (e.g., electric consumption, water consumption, etc.) need different sampling granularity and frequency, and, secondly, which quantities are considered relevant for getting a useful representation of the environment being managed.

Results show a clear need for quantity-specific sampling frequency and granularity (expressed by over 70% of the respondents, Table 66). More in detail, the survey findings show that electricity typically needs higher sampling frequencies and finer granularity with respect to water and fuel consumption. This is mainly due to the different time constants of observed phenomena: while electrical loads may vary in very short times, often lower than a second, heating and water consumption data slowly change thus enabling slower acquisition.

More specifically, the quantity-specific analysis shows a quite clear scenario for both water and fuel consumption with most users (more than the 80% of respondents) preferring sampling frequencies between 30 minutes and 1 hour. On

Table 6: Need for quantity specific sampling frequency and granularity.

	Yes	No
Frequency	24 (72.7%)	9 (27.3%)
Granularity	25 (75.8%)	8 (24.4%)

the converse, monitoring of electric consumption shows a more varied landscape, almost split in two parts preferring sampling periods lower than 30 minutes, and between 30 minutes and 1 hour, respectively. See Table 7 for more details.

Table 7: Required sampling frequency.

Frequency	Electricity	Gas / Fuel	Water
< 30”	2 (8.33%)	1 (4.17%)	1 (4.17%)
30” – 1’	1 (4.17%)	0 (0.0%)	0 (0.0%)
1’– 10’	3 (12.5%)	1 (4.17%)	1 (4.17%)
10’ – 30’	5 (20.83%)	2 (8.33%)	1 (4.17%)
30’ – 1h	13 (54.17%)	20 (85.71%)	21 (87.50%)

Spatial granularity data shows a slight preference for building-level data about fuel and water consumption, whereas department / office detail is typically needed for electricity (see Table 8). Differently from the sampling frequency case, the granularity data shows a more smoothed distribution among the alternatives offered in the survey, hinting at a certain degree of non uniformity between energy managers needs.

Table 8: Required spatial granularity.

Granularity	Electricity	Gas / Fuel	Water
Group of buildings (e.g, campus / plant)	1 (4.00%)	1 (4.00%)	1 (4.00%)
Building	8 (32.00%)	17 (68.00%)	15 (60.00%)
Department	15 (60.00%)	10 (40.00%)	12 (48.00%)
Office / Room	9 (36.00%)	3 (12.00%)	2 (8.00%)
Other	1 (4.00%)	0 (0.00%)	0 (0.00%)

4.3. Available Tools

The third section of the survey aims at harvesting the current state-of-the-art of data analysis and visualization tools adopted by interviewed energy managers and at identifying possible places for improvements and/or open research challenges. Involved questions, therefore, gather data about: (a) the kind of visualization and reporting tools managers use in their daily working routine,

(b) the data processing solutions they adopt and, (c) the needs they feel as not yet addressed.

According to survey answers (Table 99), most of the users build their analysis on the basis of simple tables of consumption data, and only in few cases dashboards, or more interactive interfaces, are adopted, e.g., by allowing dynamic data drill-down as in typical Business Intelligence (BI) systems.

Table 9: Data visualization and analysis tools.

Tool	User count	Percentage
Dashboard	1	3%
Report	5	15.2%
Tables	19	57.6%
Dashboard and reports	0	0.0%
Dashboard and tables	1	3.0%
Reports and tables	4	12.1%
Dashboards and reports and tables	3	9.1%
Other	0	0.0%

To better classify the perceived efficiency of currently adopted tools we designed subsequent questions to extract specific aspects of analyzed data and of desired analysis features. We firstly asked the managers to describe the kind of data they exploit in their analysis, given the above landscape of tool adoption. Responses show a rather clear lack of customizable analysis and data detail and most activities are limited to operation on aggregated data (not always customizable, see Table 1010).

Table 10: Kind of data used for routine analysis.

Kind of data	User count	Percentage
Only customizable aggregations	13	39.4%
Only preset aggregations	12	36.4%
Only raw data	4	12.1%
Customizable aggregations and raw data	3	9.1%
Preset aggregations and raw data	0	0.0%
Customizable and preset aggregations	0	0.0%
Customizable and preset aggregations, raw data	1	3.0%
Other	0	0.0%

While operations on aggregated data are typical in energy scenarios where raw data is often too dense for being of any use, there are, however, situations, typically faults or anomalies, that would be better addressed if raw data could be retrieved for arbitrary time intervals, in which the anomaly occurs. To check whether this hypothesis is confirmed by the managers engaged in the survey, we proposed a specific question asking "Would you consider valuable the availability of tools able to drill down energy data to raw measures on arbitrary time intervals?". Results (Table 1111) show that such a feature is actually perceived as a need (by 94% of the managers) even if not yet supported by data analysis procedures in use.

Table 11: Results for the "Would you consider valuable the availability of tools able to drill down energy data to raw measures on arbitrary time intervals?", on a 5-point Likert scale.

Value	User count	Percentage
1 (useless)	1	3.0%
2	1	3.0%
3	3	9.1%
4	12	36.4%
5 (must have)	16	48.5%

4.4. Measures and Dimensions of Analysis

The latest section of the survey is aimed at identifying the aspects (analysis dimensions) considered by energy managers when extracting meaningful information from monitoring data. To reach this goal, the first question requires to identify most relevant aspect to consider throughout data analysis, by selecting multiple options among a predefined set of alternatives (14 + 1 free to fill). The second and third questions, instead try to get a deeper understanding of adopted aggregations, by requiring users to sort, according to their preferences, the dimensions considered for data analysis (as defined in the first question), and the kind of aggregate measures to adopt.

By analyzing answers to the first question, it is easy to notice that most important aspects to consider for managing energy data are: the kind of activities performed in the involved architectural spaces, the usage scope (heating, lighting, etc) of energy, the occupancy level and the time (calendar) of use. Most of these aspects are typically accounted in the ICT infrastructure of companies, including Enterprise Resource Management (ERP), Supply Chain Management (SCM), etc., which however is not designed to explicitly account energy consumption / production as a "relevant" asset [13, 14].

Data about predicted events, room position in the building, room exposure to sun, etc., are, on the converse, deemed as less important than other factors. Table 12 summarizes the survey outcome on this topic.

Typical aggregated measures are average (for power consumptions), sum (for energy data), minimum and maximum values whereas other aggregations more frequent in statistics such as the median or the standard deviation are considered less important. This information reflects the fact that performed analysis are typically not very sophisticated and that further research should be carried to understand why more complex performance indicators defined in the energy management literature (e.g., in [15]) are not applied by energy managers (this might denote a lack of currently available tools).

Table 12: Dimensions to consider for energy consumption analysis.

Dimension	Percentage (*)
Usage scope of Energy (heating, lighting, etc)	78.8%
Kind of activities performed in architectural spaces	75.8%
Occupancy	66.7%
Geometric dimension of spaces	66.7%
Usage frequency	60.6%
Working hours / days	60.6%
Energy billing schema	57.6%
Environmental conditions (e.g., outside temperature)	57.6%
Local production of energy	54.5%
Exposure to sun	48.5%
Position inside the building	45.5%
Time of the day	42.4%
Number of openings (windows, doors, etc.)	30.3%
Predicted events	24.2%
Other	3.0%

* multiple selections were allowed

The third question of this section required participants to sort aggregated measures by dimension of analysis. According to the question answers, most relevant dimensions are time, space and usage scope of energy (the average position was around 2), whereas weather, occupancy and local energy production typically get lower scores (average position of 4).

Eventually, typical correlations analyzed by energy managers have been investigated, requiring participants to interconnect dimensions of analysis considered in the energy management process. It must be noted that only 60% of respondents actually performs correlation analysis whereas the remaining part would perform it if supported by analysis tools. Results are reported in Table 13 and show that correlation analysis mainly involves weather and occupancy conditions whereas other dimensions deserve a lower interest ($\leq 20\%$).

Table 13: Dimensions to consider in correlation with energy consumption data.

Dimension	Percentage (*)
Weather / Environmental conditions	45%
Occupancy	35%
Time of the day / working hours	20%
Kind of activities performed in architectural spaces	20%
Energy billing schema	15%
Local production of energy	5%

* multiple selections were allowed

5. Visualization Dashboards

In order to better define the context and scope of results emerging from the survey, and to identify potential issues not emerging from a national survey, we performed an additional state-of-the-art survey on publicly accessible, energy visualization dashboards currently adopted by both public and private institutes worldwide.

The main goal of such an investigation is to confirm the findings of the primary survey in terms of granularity and frequency of energy data, and of dimensions used for the analysis (visualization, more specifically). It must, however, be clear that some bias in the conclusions on granularity data could have been introduced as we were limited to publicly available information, only. While in public access dashboards data is typically provided at low granularity, in private (and thus not accessible) interfaces, in fact, much more details might be available.

We analyzed 55 different dashboards (see Table 19) published by a variety of institutions including universities, public and private companies.

The macro distribution in the three categories is reported in Table 1414.

Table 14: Institutions offering public energy dashboards.

Type of institution	Percentage of analyzed dashboards
Public companies	16.4%
Private companies	25.5%
Educational institutes	58.2%

The dashboard analysis confirms the kind of measures considered for energy consumption analysis, showing almost the same ranking of energy types emerging from the primary survey, with electricity holding the first position (94.5%) followed by heating, ventilating and air conditioning (HVAC, 38.2 %) and water consumption (30.9%), as reported in Table 15.

Table 15: Considered consumptions.

Consumption type	Percentage of analyzed dashboards.
Electrical consumption	94.5%
HVAC	63.7%
Water	30.9%
Local energy production	29.1%
Gas / fuel	10.9%
Other	5.5%

By analyzing the drill-down capabilities of considered dashboards we gathered the spatial and temporal data granularity offered to energy managers. Results show that the typical spatial granularity is the *department level* whereas the most common temporal granularity is the *hour*. Since in this secondary investigation we could not separate granularity data by considering different energy types, results can only be compared with the outcomes of fuel and water consumption analysis performed in the primary survey, showing an almost perfect fit. Tables 16 and 17 offer more details on data granularity.

Table 16: Spatial granularity.

Granularity	Percentage of analyzed dashboards.
Group of buildings	23.6%
Single Building	54.5%
Department	78.2%
Piano	9.1%
Room	5.5%

Table 17: Temporal granularity.

Granularity	Percentage of analyzed dashboards.
1 hour	76.4%
15 minutes	20.0%
1 minute	3.6%
$<$ 1 minute	1.8%

Data aggregation capabilities exposed by the analyzed dashboards have also been investigated (see Table 18), with respect to the achievable granularity and to the degree of results personalization. Typically, energy data can be browsed at predefined aggregation levels, respectively referred to monthly, weekly, and daily granularity. Only in few cases the aggregation period is customizable by end users (21.8% of analyzed dashboards).

Table 18: Aggregation granularity (temporal).

Granularity	Percentage of analyzed dashboards.
Fully customizable	21.8%
Year	60.0%
3 Months	9.1%
1 Month	72.7%
1 Week	100.0%
1 Day	72.7%

Also in this case, a quite good match could be observed with the results of the primary investigation (see Table 10), highlighting that the lack of advanced interfaces for energy data analysis is probably crossing the nations boundaries and affects the energy analysis domain worldwide. The degree at which such features are lacking, and the needs that must be addressed by energy management interfaces, at a worldwide level should however be further investigated.

6. Design Recommendations

Results emerging from the primary survey, and supported by the outcomes of the secondary dashboard survey, identify at least 3 different layers of needs to be addressed by energy intelligence systems (EIS), e.g., business intelligence systems applied to the energy domain. They can be identified as: (a) the data sampling, (b) the data handling, and (c) the presentation layers.

The *data sampling* layer involves recommendations derived from the analysis of currently adopted sampling frequencies, spatial granularities, and sources. It builds upon the "desired" features emerging from the presented survey and mainly describes requirements for systems that "feed" data into energy intelligence tools. Recommendations are organized as a set of guidelines to follow when designing or selecting building energy monitoring systems.

The *data handling* layer encompasses all recommendations referred to how data should be handled by energy intelligence systems, including typical aggregations, comparisons and computation of relevant key performance indicators (e.g., see [12]). It describes requirements on the energy intelligence back-end, driven by requirements extracted from the survey, at the presentation layer.

The *presentation layer*, finally, represents the interface between end users and the underlying information system. It defines the requirements and needs that must be satisfied by an energy management system to successfully tackle the issues emerging from the presented survey.

6.1. Data sampling layer

According to the survey outcomes, *data sources* should go beyond simple inclusion of "pure" consumption and must include contextual information such as: weather conditions, occupancy, working calendars, activities performed in spaces, billing and dynamic pricing, relative position of rooms / departments, system operational data, control schedule, etc. Particularly important is the ability to add, handle, and integrate additional data sources during system operation, in a demand-driven setting. For all available measures (present and future), it clearly emerges a need for systems to handle different sampling frequencies. In particular, the sampling frequency should be higher than 1 sample every 30 minutes, and possibly should go up to 1 sample every 30s for electric measures (and the like). On the other hand, water, fuel and thermal consumptions should be sampled at a much lower pace, around 1 sample every 30 minutes. Similarly, the *spatial granularity* should be different for different measures, with electricity requiring a little more granularity than other measures, i.e., room vs. department. According to the survey results, in fact, electricy should be collected at least at a room-level, while water, fuel and thermal consumptions can be typically considered with a departement-level granularity. Room and department granularity represent the *minimum acceptable level* that EIS designer

Table 19: Surveyed Dashboards.

Company/ Institution	URL
University of Arizona	http://www.fm.arizona.edu/energydashboard
University of Massachusetts Amherst	http://www.bedashboard.com/kiosk/20
Cornell University	http://dashboard.heb.emcs.cornell.edu/
Milwaukee Area Technical College	http://www.bedashboard.com/Kiosk/2
Northern Michigan University	http://www.bedashboard.com/Kiosk/5
Onondaga Community College	http://www.bedashboard.com/Kiosk/17
Texas AM University	http://www.bedashboard.com/Kiosk/19
Western Kentucky University	http://www.bedashboard.com/Kiosk/25
University of South Carolina	http://www.bedashboard.com/Kiosk/29
University of Wisconsin Oshkosh	http://www.bedashboard.com/Kiosk/39
Kent State University	http://www.bedashboard.com/Kiosk/45/
University of Hawai'i	http://www.bedashboard.com/Kiosk/49/
Delaware State University	http://www.bedashboard.com/Kiosk/54/
Virginia Commonwealth University	http://buildingdashboard.com/clients/vcu/
Phillips Academy	http://buildingdashboard.com/clients/phillips/
Southern Methodist University	http://buildingdashboard.com/clients/smu/
St. Lawrence University	http://buildingdashboard.com/clients/stlawrence/
Yale University	http://buildingdashboard.com/clients/yale/ http://buildingdashboard.net/yale/#/yale/
Elon University	http://buildingdashboard.net/elon
Harvard University	http://buildingdashboard.net/harvard/
Stanford University	http://buildingdashboard.net/stanford/
Princeton University	http://buildingdashboard.net/princeton
Western University	http://wes-utilities.buildings.uwo.ca/
University of British Columbia	https://ubc.pulseenergy.com
McGill University	https://mcgill.pulseenergy.com/
Simon Fraser University	https://my.pulseenergy.com/sfu/dashboard
Green Mountain College	http://sagetcv.greenmtn.edu/tcview.website/home.php
University of California Berkeley	https://us.pulseenergy.com/UniCalBerkeley/dashboard/
University of North Carolina at Chapel Hill	https://itsapps.unc.edu/energy/
University of Victoria	https://my.pulseenergy.com/uvic/dashboard/
UC San Diego	http://energy.ucsd.edu/index.html
University of California Merced	http://cem.ucmerced.edu/content/home
Johnson Controls	http://www.bedashboard.com/Kiosk/1
Deutsche bank	http://www.bedashboard.com/Kiosk/46/
Southface	http://buildingdashboard.com/clients/southface/
IBM	http://www.bedashboard.com/Kiosk/23
Edwards Lifesciences	http://buildingdashboard.com/clients/edwards/
NewAge Industries	http://buildingdashboard.com/clients/newage/
Ferraro Choi and Associates	http://buildingdashboard.com/clients/ferrarochoi/
California Water Service Company	http://buildingdashboard.com/clients/calwater/
Alabama Power	http://buildingdashboard.com/clients/alabamapower/
Bernards	http://buildingdashboard.com/clients/bernards/
Yahoo	http://buildingdashboard.com/clients/yahoo/
Google	http://buildingdashboard.net/google/
Facebook	https://www.fbpuewue.com/prineville https://www.fbpuewue.com/forest-city
EMD Serono	http://buildingdashboard.com/clients/emdserono/
City of Bloomington	http://buildingdashboard.com/clients/bloomington/
Florida State	http://buildingdashboard.com/clients/florida/
Imagination Station Science Museum	http://buildingdashboard.com/clients/imaginationstation/
GR Dodge Foundation	http://buildingdashboard.com/clients/grdodge/
Kresge Foundation	http://buildingdashboard.com/clients/kresge/
Woodruff Arts Center	http://buildingdashboard.com/clients/woodruff/
David Brower Center	http://buildingdashboard.com/clients/brower/
Portola Valley Town Center	http://buildingdashboard.com/clients/portolavalley/
Maui Ocean Center	http://buildingdashboard.com/clients/mauioceancenter/

should account for, while supporting a finer granularity is encouraged but is left to the designer's judgment. Table 20 summarizes the design recommendations at the data sampling layer.

Table 20: Design recommendations at the data sampling layer.

Title	Description
1. Sources	1.1 "Pure" consumption data (i.e., electricity, water, fuel, thermal, etc.) 1.2 Weather data 1.3 Occupancy data 1.4 Working schedules 1.5 Performed activities 1.6 Energy billing and pricing 1.7 Relative position of rooms / departments 1.8 Additional sources (e.g., system operational data and control schedule)
2. Frequency	2.1 Electricity $\leq$ 0.033Hz (1 sample / 30s) 2.2 Water, Fuel and Thermal $\leq$ 0.005Hz (1 sample / 30 minutes)
3. Spatial Granularity	3.1 Electricity $\rightarrow$ single room or finer granularity 3.2 Water, Fuel and Thermal $\rightarrow$ department or finer granularity

6.2. Data handling layer

The capability to extract, summarize and correlate energy consumption information (also including contextual data, e.g., weather) is crucial for providing easy to access, actionable knowledge of energy-relevant processes and activities in a building. Survey outcomes, can be exploited to get a better understanding of the actual needs of energy managers and may be formalized as a set of guidelines for future energy intelligence systems. Such guidelines encompass recommendations on data aggregation, data comparison and key performance indicators extraction.

Raw data stemming from the monitoring processes feeding an EIS is seldom usable, unless for precise analysis of faults or critical situations. Instead, the daily operations performed by energy managers involve aggregated measures, which typically[2] include: average, sum, minimum and maximum over pre-defined time windows. Nevertheless customizable aggregations, or time

[2]According to the survey results.

windows, are a plus. This provides an hint on the kind of data handling processes that an EIS must provide. It should, in fact, support efficient computation of typical aggregations, e.g., by using Complex Event Processing techniques [16, 17], and at the same time it must exploit an efficient persistence policy, to enable run-time computation of custom aggregations. Moreover, an EIS should be able to automatically compute, and keep updated, a customizable set of high-level metrics (key performance indicators, KPI) to provide an immediate overview of the current system performances, tailored to the end users, be they technical people carrying maintenance, energy managers or administrators [8]. These KPIs seem quite neglected in the current energy management landscape, in Italy, however as demonstrated by related researches [12] they are crucial for better informing the stakeholders involved directly or indirectly (e.g., the end users) in shaping the energetic building efficiency. Finally, raw and aggregated data must be stored efficiently and should enable complex analysis involving comparison of different data sources in different time frames, on-demand drill-down, etc., e.g., by applying Business Intelligence solutions.

Table 21 summarizes the design recommendations at the data handling layer.

Table 21: Design recommendations at the data handling layer.

Title	Description
1. Aggregations	1.1 Average over a time window 1.2 Sum over a time window 1.3 Maximum over a time window 1.4 Minimum over a time window
2. Data processing	2.1 Stream processing of predefined aggregations 2.1 Stream processing of KPIs (if applicable) 2.2. On-demand computation of custom aggregations
3. Data Storage	3.1 Support to high data cardinality 3.2 Quick response to custom operations on raw data 3.3 Quick response to predefined operations on raw data 3.4 Ability to support business intelligence (e.g., through data warehouses)

6.3. Presentation layer

By analyzing the outcomes of the primary survey, the most relevant aspects to consider at the presentation layer involve effective data visualization, easy creation of customized views and comparisons, ability to explore different aggregations and to compose complex analysis involving more than one measure at time, especially including context information such as occupation or weather conditions. Moreover, the survey clearly highlights a gap between state-of-the-art information visualization and processing and real tools available to the energy managers, which mainly include static tables or reports.

In this context, design recommendations at the presentation layer are aimed at filling this gap and at unveiling the full potential of information management and visualization to the energy management domain. This involves the ability to present data in different ways, complementing traditional tables and reports with charts, time-lines, heat-maps[3], etc; the capability to support online tuning of temporal granularity as well as of spatial granularity; the possibility to access raw data at any point in time; the support to easy construction of custom visualization and comparisons[4], the ability to compose informative dashboards tailored at different end-users, etc. Comparisons, should possibly involve any of the available data although a particular focus emerges on comparison between time periods, between different meters and between consumption measures and weather data.

Table 22 summarizes the design recommendations at the presentation layer.

Table 22: Design recommendations at the presentation layer.

Title	Description
1. Data visualization	1.1 Tables
	1.2 Reports
	1.3 Bar and Line Charts
	1.4 Time-lines (events, occupancy, etc)
	1.5 Heat maps
	1.6 Other
2. Customizable visualizations	2.1 Granularity
	2.2 Composition of different sources (including KPIs) in the same visualization
	2.3 Comparison of different data sources in different time frames
	2.4 Dashboard creation
3. Customizable data aggregations	3.1 Ability to create custom KPIs and metrics
	3.2 Ability to create custom aggregations

[3] As in http://modi.mech.columbia.edu/resources/nycenergy/, last visited on June 17, 2014.

[4] As in Bamboo (http://bamboo.io), last visited on June 17, 2014.

7. Conclusions

This paper presented a survey on the kind of analysis currently performed by energy managers (in Italy) and the expectations they have if required to reason about systems that will be available within the next five years. The survey response rate was lower than expected, as only 19.5% of respondents fully completed the survey, however received responses are from a subset of the original sample having almost the same gender and age distribution, thus supporting the validity of survey findings, although not formally.

Results have been discussed, with respect to the current state-of-the-art of worldwide energy management dashboards, and design recommendations have been distilled to guide the design and development of the next generation energy intelligence systems. Three different levels of recommendations have been identified and discussed: the data sampling, data handling and presentation layers. The *data sampling* layer involves recommendations derived from the analysis of currently adopted sampling frequencies, spatial granularities, and sources. The *data handling* layer encompasses all recommendations referred to how data should be handled by energy intelligence systems, including typical aggregations, comparisons and computation of relevant key performance indicators. The *presentation layer*, finally, represents the interface between end users and the underlying information system.

Future works will evolve in two different directions. On one hand, further investigations will be carried to mine the features and needs that must be addressed by energy management systems, worldwide. On the other hand, the authors will be working on the creation of an EIS prototype, according to the provided recommendations, and based on classical business intelligence engines (e.g., Pentaho[5]). Such a prototype will be validated with energy managers and results will be compared with this paper outcomes.

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