Survey of Applications for Apartment Energy Consumption Monitoring

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***Abstract*—Nowadays energy consumption and especially energy saving are hot topics. The news about global warming has increased the need to save energy. In Finland, one of the major energy consumers is housing. The heating of residential buildings accounts for up to 68% of housing energy consumption. The second largest consumer of energy is heating water, at 15%. Therefore, it is not surprising that apartment energy consumption is a popular research topic in Finland. In particular, this study tries to find ways to increase energy savings - without forgetting comfortable living. This paper introduces the results of a study exploring the research subjects of energy saving in the area of real estate and housing. The research methodology is a literature survey and primary articles were selected by means of a systematic literature review. This study presents a way to categorize research papers with diverse themes. In addition, the survey reveals the most recent trends in research and practical applications of energy saving as well as efforts toward energy saving in the area of real estate and housing.**

Keywords—Energy consumption, Energy saving, Systematic literature review, Sensor Networks, IoT, Sensors and Monitoring, API, Network API

I. Introduction

Nowadays, energy saving is an important issue of everyday living. Global warming is encouraging people to think about low-energy solutions. Consequently, in this study we present a set of research studies, which aim at minimizing energy consumption - heating consumption and electricity consumption. Real-time monitoring issues are also included in this research.

This study belongs to Internet of Things (IoT) related research, carried out by the Software Engineering and Intelligent Systems (SEIntS) group at Tampere University (TAU), Pori. In our earlier studies [1-4], we focused on wireless sensor networks (WSN) by building and testing data collecting prototypes. These prototypes were mostly built using off-the-shelf devices. In addition, the system architecture included a data collecting device, network or internet connection, and cloud for saving data. Mostly in these prototypes the data processing was done in the cloud.

As a result of the previous studies, this research was executed, which focuses on designing and developing methods and technologies that can assist in finding and achieving the property- and situation-specific "energy minimum" - a situation where the minimum amount of energy is used while still preserving a comfortable environment within the building. In the KIEMI ("Vähemmällä Enemmän – Kohti Kiinteistöjen Energiaminimiä", or "Less is More: Towards Energy Minimum of Properties" in English) project, proof-of-concept demonstrations and prototype applications are being developed that illustrate how cost-effective, open, and modular solutions can be utilized to improve the energy efficiency of buildings.

This paper includes the results of the study exploring the research subjects of energy saving in the area of real estate and housing. The goal of this study is to gain overall knowledge of the current state of energy consumption monitoring research. The results of this study will be used when designing the future research activities in one of our projects, KIEMI, and overall in this research area.

Our interest is focused on energy consumption monitoring in general. Parts of our research problem have already been discussed in our earlier papers [1-4]. As a continuum to these, we defined the research question for this study as follows:

RQ: What are the main research subjects of energy consumption monitoring?

Statistics Finland collects and publishes the official statistics of Finland. Their report [5] "Energy Consumption in households 2016" shows that heating of residential buildings consumed 46 TWh of energy in 2016. The most common sources of energy for heating were district heat, wood, and electricity, accounting for 85 percent. The next most common energy source was heat pumps. The use of these in Finland has grown significantly since the start of the millennium because of their efficiency, which saves energy and money compared to direct heating sources. Furthermore, the heating of residential buildings was reported to take up to 68% of the total energy consumption of housing and the second largest consumer of energy was heating water, accounting for 15%.

The structure of this paper is as follows: In Section II we introduce some related studies that take a similar approach to ours. In Section III, we introduce the research approach used in this literature study. In Section IV, we present the analysis of the findings and categorization of studies. Section V includes a discussion and conclusion, which summarizes the study.

II. Related studies

During the background study for this research, we found several studies that could be mentioned as similar general research to our survey. The four selected studies do not directly fit our categories, but nevertheless are worth mentioning. One point of view is the awareness of energy consumption. In one study [6], it was found that dormitory residents reduced electricity consumption when exposed to real-time visual feedback and incentives. This study examines electricity and water usage. In the study two dormitories were equipped with automated monitoring systems that provided high resolution, real-time feedback. This shows that the residents' energy-saving awareness, knowledge, and behavior improved after they were provided with relevant information and exposed to campaigns.

Another study [7] examines the effects of energy-saving by analyzing the changes in the awareness and behavior of apartment residents after the promotion of energy-saving activities and their proper usage and provision of relevant information. In this study, the questionnaire included topics such as energy awareness and the knowledge and practice of energy conservation. In addition, this study used a second survey, which was conducted for women who were given energy-saving information and asked to participate in energy-saving activities after submitting the first survey. The results showed that energy-saving behavior improved after being provided with relevant information.

In the third study [8], the focus was on the meaning of comfort and comfort practices, barriers to and motivators for saving energy, and knowledge about the heating system. Data were collected from social housing tenants and university staff using surveys, interviews, and monthly energy meter readings. This study shows that warmth was mentioned most often as the meaning of comfort. In addition, comfort practices were to a large extent defined as temperature-related actions that were low in energy consumption. This study also found that willingness to change behavior was the greatest when the motivation was to save money.

The last related study [9] focused on energy-saving awareness by using In-Home Display (IHD) devices. The device gives real-time data about the use of electricity in specific devices. Also, the costs of these devices were shown and the user had the opportunity to reduce the electricity use. The result of this study was that the direct feedback provided by IHDs encouraged consumers to make more efficient use of energy. In addition, the active IHD users were able to reduce their electricity consumption by about 7 percent on average.

These related studies show that knowledge of energy consumption improves efforts toward energy saving.

III. Research approach

To answer our research question, we decided to perform a literature study in order to map the extant knowledge in this domain. We decided to use the Systematic Literature Review (SLR) method for collecting relevant primary studies and followed the guidelines given by Kitchenham and Charters [10].

For the SLR, we executed an electronic literature search. The databases used were IEEE Xplore Digital Library (IEEE) and Google Scholar. The survey was started by using the main search terms: "Energy consumption", which was set by the European Regional Development Fund. During the pilot study and related research [6-9], several other research terms arose such as "Temperature comfort", "Learning temperature comfort", "Apartment temperature comfort", "Smart home communication", "Real-time energy consumption monitoring," and "Energy apartment sensor". With these keywords, we received good coverage of potential primary studies. The target amount of related studies was about fifty, because this amount would provide enough information for categorization and research trends.

In the second phase, we determined several reasonable categories and classified the papers into those categories. The reason for this classification is that most of the papers published are relatively distinctive in terms of research objective, methodology, and application. For the sake of simplicity, we selected four categories of papers without ignoring the variations of themes. This way, we systematically examined the details of research papers falling under the same category whereas too many categories would have made it difficult to compare the trends or research methodology logically. In this phase, we also made the selection of studies so that no one category would become too dominant. Please note that some of the papers could be classified into more than one category.

In the remaining sections of this paper, we will first present the categorization of the key studies in section IV. This is followed by conclusions in section V, where we summary the research.

IV. Categories

In this section, we introduce the categories we chose for this research. The criteria for these categories were determined in the early phase when we studied the topic by referring to source material chosen from the findings of previous studies. These studies were described in the introduction section. The research categories of the selected studies are:

- Comfort
- Retrofitting
- Network APIs
- IoT

The categories are ordered according to the importance of the background research. As mentioned before, this research was the pilot study in the KIEMI project, and the goal was to gain overall knowledge of the current state of research. The category of Comfort gives us the basic elements for life comfort, which can often be considered to be more important than energy saving. This pilot focuses on the existing building stock and therefore the Retrofitting category contains the research on applications or solutions installed in existing buildings. The third category focuses on Application Programming Interfaces (APIs) and other methods that allow remote control or management of devices over networks. The last category, IoT, includes the studies which do not fit in any of the other categories but are nevertheless related to our focus area.

Next, the categories are described with the selected studies. These studies give an overall description of the categories.

A. Comfort

Comfort is the important aspect of energy saving. Too much saving means that living environment comfort, such as thermal comfort and humidity, decreases. The most important is thermal comfort, which is taken into account in several studies [11-16] in this category.

Most of the research studies addressed previous studies, but one study in particular [11] reviewed thermal comfort research work and discussed the implications for the energy efficiency of buildings. The study [12] discussed the term thermal comfort and how it represents a set of microclimate conditions in which a person feels comfortable in their living environment. User preferences to maximize occupant comfort, especially in office buildings, are dealt with in the study [17].

Indoor comfort has been regulated with several standards, which specify indoor air quality, thermal environment, lighting, and acoustics. For example, the European standard EN 15251 has been reviewed by [13] and [14]. Salamone et al. [14] also present a case study about the integrated method for personal thermal comfort assessment and optimization through users' feedback, IoT, and machine learning.

Applications and systems have been developed in several studies. Ciabattoni et al. [15] present a low-cost IoT-based system able to monitor acoustic, olfactory, visual, and thermal comfort. This system is provided with different ambient sensors, to monitor acoustic, olfactory, visual, and thermal comfort levels. Another study [16] introduced a knowledge-based approach to improving heating, ventilation, and air conditioning (HVAC) system operations through coupling personalized thermal comfort preferences and energy consumption patterns. Murakami et al. [18] propose a new system to control air-conditioning systems, lighting systems, etc. via occupants' requests. This system collects occupants' requests from their own personal computers and controls the air-conditioning system with logic that balances the needs of the occupants with energy consumption.

Thermal comfort levels were evaluated in one study [19] by recording subjects with thermographic cameras. This is a non-invasive method to automatically model human thermal comfort in transient conditions. Office temperature, relative humidity, exposed skin temperature, and clothing temperature were automatically measured for over approximately 27 minutes per subject, using remote sensors and avoiding any contact with the subjects.

Energy consumption was combined with comfort in a study by Dalamagkidis et al. [20]. The study addressed the issue of achieving comfort in buildings with minimal energy consumption. Specifically, a reinforcement learning controller was developed and simulated using the Matlab/Simulink environment.

B. Retrofitting

There is a different approach to energy consumption monitoring between new buildings and old buildings. In new buildings, monitoring applications and systems are included in the design phase of the building. For example, the heating system could be selected by weighing up the energy aspects. In the old buildings, the main structure, e.g., the heating system already exists, and the monitoring must fit this structure. This category collects the studies where the presented application or solution was installed in existing buildings.

The study by Obuchi et al. [21] focused on the problems of buying or renting a house. The potential purchaser or renter of the property does not know its living comfort factors such as temperature and lighting. This study introduced IoT sensors for the evaluation of the comfort levels of real estate properties. Another study [22] focused on studying and determining the cost-optimal renovation measures to decrease both the supplied and primary energy consumption of the building. This study encouraged apartment building owners to conduct thorough renovations toward nearly zero-energy apartment buildings.

HVAC systems were the focus of two studies. The first [23] proposed a technology which provides an alternative and low-cost solution capable of improving conventional HVAC system intelligence by making use of a network of wireless sensors and actuator mesh. The second [24] presented the results from two real-world trials of an optimized supervisory model predictive control system for HVAC in two office buildings.

The energy consumption of electrical devices was the subject of two studies. The first [25] introduced the ElectriSense system for automatically detecting and classifying the use of electronic devices in a home from a single sensing point. The results show that ElectriSense can identify and classify the usage of individual devices. The second study [26] combined gamification and energy awareness by using data collected by wireless sensors. The feedback, such as awareness tips and consumption feedback, is given by mobile devices. This research does not mention any results.

C. Network API

Network API describes the possible device connections in the related world. The connections could be programmable interfaces - the possibility for the developer to make applications by using the interface. Also, remote access and furthermore the ability for control are enabled. In addition, devices including a Network API commonly offer services and furthermore web services. A RESTful API is an architectural style for communications used in web service development, which was mentioned in [27] but the usage was not described in details. Özgür et al. [28] present four RESTful services: one developed into Arduino and three mobile applications. A third study [29] integrated smart power outlets into the web and facilitated the development of extensions and novel features. They were implemented in a web user interface and a mobile phone interface for demonstration purposes. In addition, this was confirmed with a 12-month pilot deployment.

The study by Morimoto et al. [30] described the construction of a smart outlet network as a system for automated energy-aware services utilizing humidity, temperature and light sensors and motion sensor data. The sensors were installed on smart outlets and the appliances were under policy-based automatic control. This study also presented the deployed system in real-life environments.

D. IoT

The IoT category was chosen as a result of our previous studies. This category is the widest and most of the papers could be included in it. Therefore here we introduce only the studies which were not mentioned in any of the other three categories. The common issue for all these chosen studies is that data are collected in some way, saved, and the saved data are used or processed. All these papers discuss or mention IoT, connected devices, sensors, etc.

The survey by Risteska Stojkoska and Trivodaliev [31] explored state-of-the-art control systems in buildings. This was quite a large survey, but the focus of the study was more on computational intelligence.

Smart home management was discussed in another study by the same authors [32]. This study introduced a holistic framework incorporating different components from IoT architectures/frameworks. They also integrated smart home objects in a cloud-centric IoT-based solution. Also, Shaikh et al. [33] focus on intelligent control systems for energy and comfort management in smart energy buildings.

Kumar and Hancke [34] present their developed wireless, smart comfort sensing system. This system consists of sensor nodes, which send data to a sink node. The sink node sends data to a PC. Another, lower-cost implementation was presented and discussed in [35], describing the hardware IoT infrastructure that provides real-time monitoring in multiple school buildings. The sensor nodes and gateway node were based on Arduino boards or similar. A further study [36] also used low-cost devices in their HVAC and sensor system.

IoT is also discussed in several studies [12], [15], and [27], which have been mentioned above.

V. Conclusions

This study answered the research question through the lens of the presented categories. The most important factor in the comfort category is the comfort of the resident, such as thermal comfort and humidity. The retrofitting category shows that existing systems, e.g., HVAC systems, can be developed further to save energy. The Network API category gives examples of implemented web user interfaces and mobile phone interfaces. The last IoT category consists of sensor applications. Together, the categories of Retrofitting, Network APIs, and IoT provide numerous application and system examples of monitoring energy consumption.

This paper introduced the pilot study of the KIEMI project. This pilot study showed that energy saving is widely focused on research implementations of various kinds. The research methodology - a literature survey - revealed the primary articles. This study presented a way to categorize research papers. In addition, this survey revealed the most recent trends in research and practical applications of energy saving.

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