TAMPERE UNIVERSITY OF TECHNOLOGY

Reducing energy consumption with IoT prototyping

Reducing Energy Consumption with IoT Prototyping

Mika Saari*, Pekka Sillberg*, Jere Grönman*, Markku Kuusisto*, Petri Rantanen*, Hannu Jaakkola*, Jaak Henno**

*Tampere University, Faculty of Information Technology and Communication Sciences, Pohjoisranta 11A, 28101 Pori, Finland, mika.saari@tuni.fi, pekka.sillberg@tuni.fi, jere.gronman@tuni.fi, markku.kuusisto@tuni.fi, petri.rantanen@tuni.fi, hannu.jaakkola@tuni.fi

**Tallinn Technical University, School of Information technologies, Ehitajate tee 5, 19086 Tallinn, Estonia, jaak.henno@ttu.ee

Abstract: Nowadays, energy consumption and especially energy saving, are topics of great importance. Recent news regarding global warming has increased the need to save energy. In Finland, one of the major sources of energy consumption is housing. Furthermore, the heating of residential buildings accounts for up to 68% of housing energy consumption. Therefore, it is not surprising that apartment energy consumption and ways to save energy in housing are a popular research topic in Finland. In this paper, two different research areas are introduced: First, a literature survey is presented on the research subjects of energy saving in the area of real estate and housing. The goal is to gain overall knowledge of the current state of energy saving research. The overall conclusion is that knowledge of energy consumption improves efforts toward energy saving. Second, rapid prototyping with off-the-shelf devices and open source software are described. These devices are cheap to install, and a wide range of sensors are available. Consequently, it is important to deal with these topics together. The former studies provide knowledge about the usage of open hardware, open software, and open architectures with the development of prototype systems for gathering data. The literature survey gives us new information on the specialties of energy consumption measuring, offering a new area for modeling and developing prototype systems. These experiences will be taken forward and utilized in energy saving and environmentally sustainable solutions, such as Green Computing.

Keywords: IoT; Prototyping; Energy saving

1 Introduction

In the modern world, energy saving has become an important issue, in almost every aspect of life. Global warming is forcing people to search for low-energy solutions. It is important to be aware of the living comfort when thinking about the

low-energy solutions. For example, most people want the living temperature to be comfortable - not too low and not too high. Furthermore, the awareness of one's energy consumption has been proven to reduce overall energy usage. Thus, in the context of this paper, the research problem can be formulated as:

How to reduce energy consumption by collecting and serving suitable data?

For this problem, we are looking for a solution for two questions.

1) How to categorize the energy consumption related studies?

2) How to utilize free and open solutions in the energy consumption context preserving adequate living conditions?

In our use cases, we are especially looking for solutions that utilize open-source components and open hardware, architectures and interface specifications. This study belongs to the Internet of Things (IoT) research area and to studies focusing on Wireless Sensor Networks (WSN). In addition, one of the focus areas of this paper is rapid prototyping in the IoT world by using off-the-shelf devices. An example of rapid prototyping method was described by [1] for the automotive industry.

This paper introduces the application architectures and system models for IoT prototyping. Furthermore, sensors and sensor networks that collect data into the cloud are discussed, and more specifically, wireless sensor network (WSN) systems that can be utilized in testing data collection in rapid prototyping are of interest. In our use cases, the prototypes are built using off-the-shelf devices and tools. Additionally, Green ICT (Information and Communication Technology) should be part of the developing process when either the goal is to save energy or make systems which help to save energy.
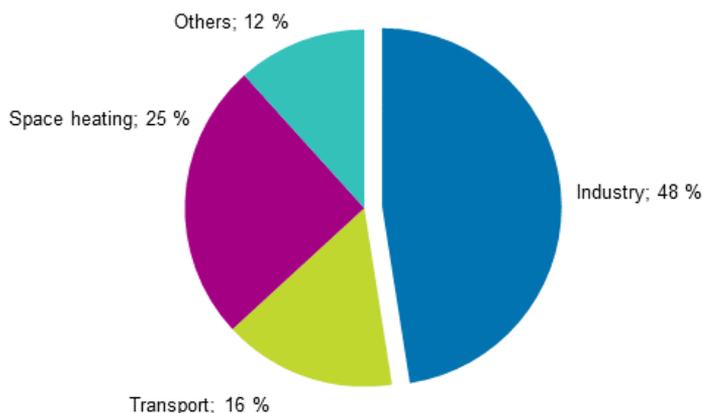

Figure 1
Finland's energy consumption by sectors in 2018 [2]

According to official statistics, collected and published by Statistics Finland, energy in Finland is produced mostly in three ways: wood, oil, and nuclear fission. These three sources combined add up to 66% of the energy produced in Finland. Various other sources of energy production include but are not limited to: coal, gas, water, peat, and wind. In their report, Statistics Finland [2] profile the Finnish energy consumption as shown in Fig. 1: Industry uses the most energy (48%) while heating comes in second place with 25% of energy consumed. Traffic is also a major consumer with 16% of the total energy used in Finland. Other sources then add up to the remaining 12%.

This research is focused on Finland (and further applicable in other northern countries), in which energy is often used for heating, instead of cooling (as is common in many other countries). The *Cold weather raised energy consumption in housing in 2016"* report by Statistics Finland [3] shows that heating residential buildings consumed 46 TWh of energy in Finland during 2016. Furthermore, the heating of residential buildings was reported to account for up to 68% of the total energy consumption of housing with the second largest consumer of energy being heating water, accounting for 15%. Other notable energy consumers in Finnish households were electrical appliances, saunas, and lighting. The most common source of energy for heating was electricity, at 34%. The next most common source of energy was district heating (29%) and the third most common heating energy source was wood, at 22%, followed by heat pumps, at 9%. The usage of heat pumps in Finland has grown significantly since the start of the millennium because of their efficiency, saving energy and money compared to direct heating sources. All together, these four sources of energy made up about 95% of the energy used for heating in Finland. The remainder was mostly heating oil at approx. 5%, with other technologies accounting for less than 1%.

Our former research focus has been IoT and prototyping. This preliminary research will show how existing studies could be applied to a new research area. The structure of paper follows the research process: Section 2 includes a brief introduction to studies related in energy consumption. Section 3 continues with further analysis and categorization of energy consumption papers. Section 4 will present our studies and those findings, which could be combined with energy consumption monitoring. Further, the combined ideas of reducing energy consumption and prototype developing are introduced. Finally, Section 5 concludes the study.

2   Related Studies in Energy Consumption

This section deals with studies related to energy consumption. One important point of view is the awareness aspect of energy consumption. In [4], it was found that dormitory residents reduced electricity consumption when exposed to real-

time visual feedback and incentives. This study examined electricity and water usage. In the study, two dormitories were equipped with automated monitoring systems that provided high-resolution, real-time feedback. The study showed that the residents' awareness, knowledge, and behavior regarding energy saving improved after they were provided with relevant information and exposed to campaigns.

The study [5] examined 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 the 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 performed an additional survey, which was conducted for women who were given energy-saving information and asked to participate in energy-saving activities after submitting the initial questionnaire. The results showed that energy-saving behavior improved after being provided with relevant information.

In the third study [6], 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 showed 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 study [7] focused on energy-saving awareness, by using In-Home Display (IHD) devices. These devices provide real-time data about the use of electricity in specific appliances. Also, the costs of these devices were shown, and the users had the opportunity to reduce their electricity consumption. The result of this study was that the direct feedback provided by IHDs encouraged consumers to make more efficient use of energy. In addition, active IHD users were able to reduce their electricity consumption by about 7%, on average.

All these studies show that knowledge of energy consumption improves efforts toward energy saving.

3   Literature Survey

The introduction posed the research question: how to categorize the energy consumption related studies? To answer this research question, a literature review was performed, in order to map the existing knowledge in this domain.

3.1   Research Approach

The literature review used the Systematic Literature Review (SLR) method for collecting relevant primary studies and followed the guidelines given by Kitchenham and Charters [8]. For the SLR, an electronic literature search was executed. The databases used were IEEE Xplore Digital Library (IEEE) and Google Scholar. The survey was started by using the main search term: "Energy consumption". During the pilot study and related research [4-7], 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 a combination of these keywords, a good coverage of potential studies was obtained. The target amount of related studies was a total of fifty publications, as this amount would provide enough information for categorization and determination of research trends. Of these fifty publications a small number of papers were selected, which were considered to include the most relevant papers for the energy consumption or energy savings.

3.2   Categories for Existing Studies

To get an overview of the existing studies, the papers included in the study were analyzed for common topics. Most of the papers were relatively distinctive in terms of research objective, methodology, and application. Ultimately, based on the analysis of the research papers, we selected four categories taking into consideration the variations in research themes. The reason for choosing a relatively small amount of categories was to enable the examination of the details of research papers falling under the same category systematically. Selecting too many categories would have made it difficult to compare the trends or research methodologies. It is worth noting that some of the papers could be classified into more than one category. The research categories identified from the source material are:

- Comfort

- Retrofitting

- Network APIs

- IoT

The categories are listed according to the importance of the background research. The category 'Comfort' contains studies that discuss the basic elements for living comfort, which are often considered to be more important than energy saving. In general, comfort is an important aspect of energy saving. Too much saving means that the comfort of the living environment, such as thermal comfort and humidity, decreases. The most important factor is thermal comfort, which is taken into

account in several studies [9-14] in this category. Most of the research addressed previous studies, but [9] in particular reviewed thermal comfort research work and discussed the implications for the energy efficiency of buildings.

In our use cases, focus is on existing building stock and therefore the 'Retrofitting' category contains the research on applications or solutions installed in existing buildings. A different approach is used for monitoring energy consumption monitoring in 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 old buildings, the main structure (e.g. the heating system) already exists, and the monitoring must fit this structure. This category consists of studies [15-20] where the presented application or solution was installed in existing buildings.

The study [15] 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 [16] 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.

The third category focuses on Application Programming Interfaces (APIs) and other methods that allow remote control or management of devices over networks. In addition, devices including a network API can provide (web) services usable by application developers or by client devices. A RESTful API is an architectural style for communications used in web service development, which was mentioned in [21] although the usage was not described in detail. The second study [22] present four RESTful services: one developed in Arduino and three mobile applications. A third study [23] 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 [24] 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.

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. This category is the widest and most of the papers could be included in it. Therefore, this research only introduces studies which: (*i*) collect the data in some way; (*ii*) save the data; and (*iii*) the saved data are then used or processed.

The survey [25] explored state-of-the-art control systems in buildings. The ref. [26] focused on intelligent control systems for energy and comfort management in smart energy buildings. The study [27] presented the wireless, smart comfort sensing system that they developed. This system consists of sensor nodes, which send data to a sink node that sends data to a PC. Another, lower-cost implementation was presented and discussed in [28], describing the hardware IoT infrastructure providing real-time monitoring in multiple school buildings. The sensor nodes and gateway node were based on Arduino boards or similar. A further study [29] also used low-cost devices in their HVAC and sensor system. IoT is also discussed in several studies [10], [13] and [21], which have been mentioned above.

Table 1
Breakdown of the papers reviewed

Category	Selected Studies	Author's Studies	Number of Studies
Comfort	[9-14]	[30]	7
Retrofitting	[15-20]		6
Network APIs	[21-24]	[30-36], [38]	12
IoT	[10], [13], [21], [25-29]	[30-31], [33], [37-40]	15

The results of the literature survey and the selected categories (Comfort, Retrofitting, Network APIs and IoT) can be seen in Table 1. The table also shows how the authors' own contribution related to the categories.

4   Prototype Systems and Models

This section gives a brief summary of our earlier studies related to rapid prototype development. The proof-of-concept demonstrations and prototype applications have been developed to illustrate how to utilize cost-effective, open, and modular solutions. The studies have been chosen based on their potential for including methods or technologies that could be transferred or exploited in the energy consumption monitoring or energy saving context.

4.1   Rapid Prototyping

In the context of rapid prototype development (and in the context of IoT devices in general), a working solution for gathering data needs:

- Hardware – a device or devices running the software
- Software to work with the data – collect, save, and transmit
- Technologies–choosing the right technologies for a use case makes things easier for both the developer and the user.

In our use cases, the prototype development has had more of software than hardware orientation. Data are gathered with embedded software, which controls the action of sensor devices. The data transfer to the cloud can be made in various ways and requires applicable software to control the sending and receiving of data. The WSN and sensor networks have several possible technologies for data transfer, for example: Ethernet [30], WiFi, ZigBEE [31] and LoRa [32]. In addition, power saving algorithms for WSN [33] and network topology related issues of Portable Fog Gateways [34] can be considered important topics.

The prototype systems gathered data which was saved to cloud-based services. In a basic example, the cloud service could be implemented with a Linux-based server and database [35], which has been modeled in [36].

Software development was carried out in several areas: data gathering software, data processing software, visualization of results, etc. The software development consisted of small-to-medium sized applications written in C/C++, Java, JavaScript or Python. The operating systems were generally chosen from the Open Source selection. For example, the Raspberry Pi is usually equipped with Linux–based operating systems (e.g. the Debian-based Raspbian). Also other software, such as databases, communication and web server software, was typically Open Source software.

Hardware development can be an integral part of prototype system development, but in our use cases the prototypes used off-the-shelf devices. In the past few years the price of microcontrollers, small computers and sensors has become much lower. At the same time, more and more features have been added to the off-the-shelf devices. These factors have made utilizing off-the-shelf devices both cheaper and easier, and it has also reduced the need to construct (or design) sensor or device packages from the ground-up using basic electronic components. Often used off-the-shelf devices include:

- Smartphones and tablets

- Single-board computers: Raspberry Pi, Beagle Bone, Intel Galileo, etc.

- Single-board microcontroller: Arduino Uno

- Sensors: Heat, humidity, pressure, movement, position, etc.

Using these off-the-shelf devices for the manufacturing and up scaling the number of prototype devices is more rapid than implementing a prototype based on printed circuit board design. In addition, the Raspberry Pi has been shown to be good choice for research projects and is a widely used device [37].

Furthermore, nowadays mobile phones have the ability to act as sensor devices. Even the basic Android smartphone has several of the following sensors: light, proximity, camera, microphone, touch, position (GPS, WiFi, Cellular), accelerometer, gyroscope, pressure, temperature, humidity. The data collection and processing can be handled in a smartphone. In addition, a basic smartphone

usually has more than adequate communication features: Bluetooth, WiFi, GSM, GPRS, 3G, 4G, etc. are often available.

4.2   Data Gathering with Sensor Network–Modeling, Piloting, and Testing

The sensor networks can be modeled as is illustrated in Fig. 2 [31]. The sensor nodes gather data and send it without processing to the master node. The master node may validate the received data, it may also process it, and send the data to the cloud. The data are usable from the cloud for various purposes.
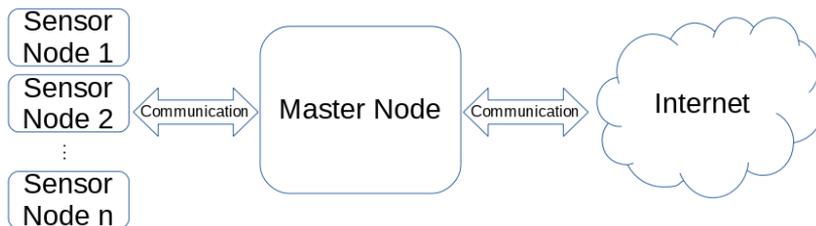
Figure 2
Basic model of sensor network [32]

This model was tested during the study [31], and a proof-of-concept solution was implemented and presented. Based on a survey of prototyping solutions that utilize Raspberry Pi the commonly used solutions were observed to adhere to this basic model even when no specific model was described in the studies [37]. However, the model shown in Fig. 2 has to be modified if smartphones are used as sensor nodes. Fig. 3 shows a combined presentation of the sensor node and master node model.
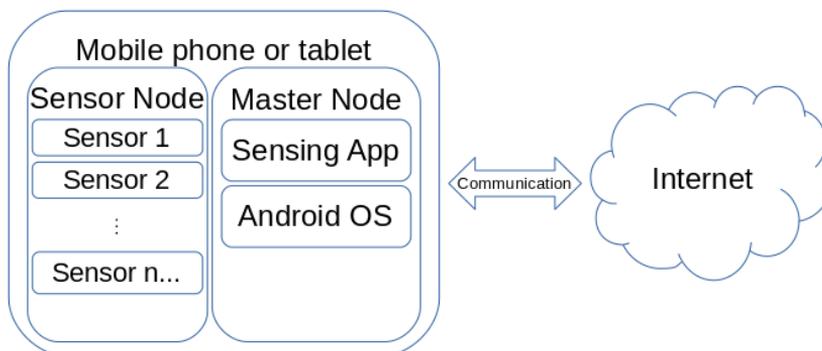
Figure 3
The combined sensor node—master node model for data gathering [36]

The model presented in Fig. 3 was developed especially for data collection with smartphones. The smartphone includes the necessary sensors, data storage, and communication channels for the data gathering prototype system. In addition, the Android operating system (OS) was used, which has enough capabilities to gather and store data. Also, the commonly used communication protocols are directly supported by the APIs provided by the OS. [36]

The studies [30-31] [36-37] show several important results:

- Study [30] introduced an example of how a cost-efficient single-board computer (SBC) can be used to gather sensory data, and how this data can be provided to the client over the public Internet. In addition, the use of standard protocols makes development easier, but not all development boards support all standards (in this case the I2C protocol).

- Study [31], mentioned that master nodes often have access to a constant power source, but one should carefully choose which components to use in remote sensors to minimize power consumption. In addition, most of the energy is consumed in the wireless transmission of data and consequently it is important to only send what is required (optimization of the nodes). The energy consumption issue was handled more specifically by [33].

- The survey about prototyping with Raspberry Pi was introduced in [37]. This paper shows that there is a lack of formalized approaches, methods, and tools in the research studies. Often only a single use case and a single system are described in the paper with a minimal use of testing practices and methods. The commonly used testing methods are software testing, software performance testing, and validation of data tests.

The conclusion from the results of the papers [30-31] [35-36] is that rapid prototyping with off-the-shelf devices is possible, but requires guidelines that include an architecture model of components—both software and hardware.

4.3 Prototype System: Road Condition Analysis and Visualization

Nowadays, almost everyone has a mobile phone and even the most basic smartphones often come embedded with a variety of sensors. In [38], smartphones were utilized to collect road condition data. The smartphone application developed during the research collects data from the phone's built-in sensors. The application can be installed in a common Android smartphone. This collected data could be further refined into more specific data, such as reports of bumps in the road, uneven road surfaces, roadworks, and so on. The data are sent to the cloud where they are processed. Fig. 4 shows the visualization of the captured data and the routes where the data were collected.
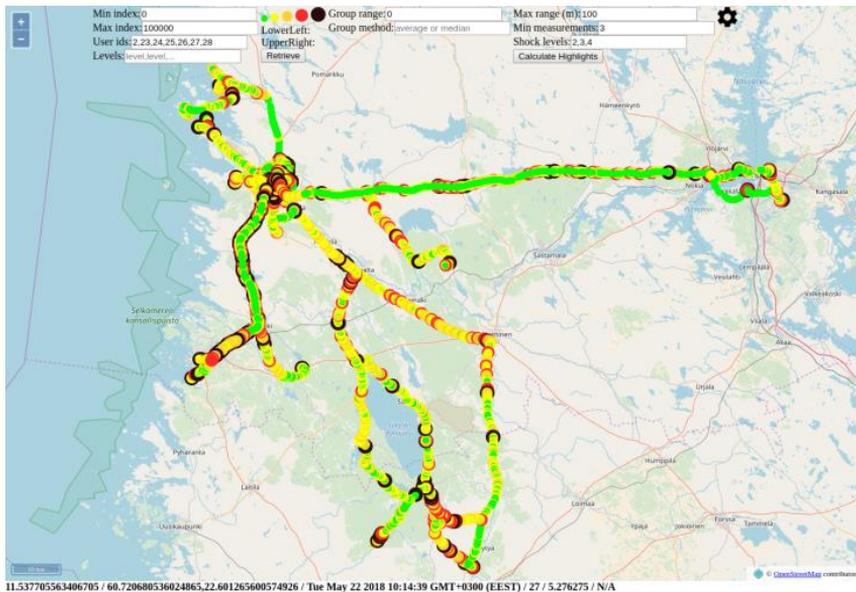
Figure 4
Visualization of the routes driven [38]

This research shows that it is possible to use a commonly used consumer product for data collecting. However, it turned out that, even though modern smartphones/devices are fairly similar by functionality, hardware differences can cause unexpected problems for implementation. Further, the embedded sensors are often not "calibrated" across devices and manufacturers. This can cause variances in the results and therefore comparison of data can be difficult if accuracy is of high concern. In addition, non-system-related effects and interference (environmental factors) may affect the final results e.g., when measuring shocks or vibrations different vehicles provide slightly different results. In addition, it is often necessary to perform pre-processing and filtering on-device, versus a fully service-implemented analysis.

A further result of this research is connected to the visualization of collected data. This is often no minor issue when measuring the quality of the user experience. Also, a fluent execution of visualization of a large dataset can be challenging, especially on a web browser.

4.4   Prototype: Approach to Image Data Collection

Customer complaints can be resolved by means of image and data collection. The research [39] introduces two prototypes installed in vehicles and a cloud service for autonomous collection of data. The first prototype—an Android application—

was implemented for a smartphone to take pictures of a bus as it approaches the bus stop. The second prototype was implemented for the Raspberry Pi single-board computer by using off-the-shelf devices such as a camera, GPS sensor, and 3G/4G wireless modem. The prototype was installed in a garbage truck to take pictures of recycling areas, as shown in Fig. 5.

Figure 5

Three pictures taken of a recycling area. Left: in daylight; center: at night; right: blocking obstacle [40]

The prototypes use a camera and GPS. The collected data—picture, location, time, etc.—were sent to the cloud server. The paper [39] discusses the differences and challenges faced in designing and implementing the two prototypes for different platforms.

The main conclusions were that mobile platforms (i.e., smartphones, tablets) can work as a quick starting point for rapid prototyping. These have embedded sensors, proper documentation, and the availability of examples, all of which support rapid prototyping. On the other hand, small computers like Raspberry Pi and microcontrollers offer a better option for use cases requiring remote management. Of course this has disadvantages, such as requiring more "hands-on" labor, and being more difficult to find examples or production quality code. In addition, both mobile platforms and small computers highlight the importance of environmental factors—such as the availability of electricity, telecommunications, and installation of the prototype [39].

4.5   Prototype: Counting Passengers from Image Data

The research [40] was the result of a real-life need for counting passengers. In the summer of 2018 a large public event was organized in the city of Pori, Finland. The event had free-to-ride buses and the organizer wished to collect statistics about the bus passengers: Where they got in and where they got out. The use case utilized cost-effective and off-the-shelf components such as the Raspberry Pi 3 computer, position sensors, and cameras. In this use case, the software used was Open Source Computer Vision Library version 3.

Figure 6
An example of the detection area of the bus, as seen by the device [40]

During the research, a prototype system was developed, consisting of hardware and software components. The prototype takes pictures, as shown in Fig. 6. The pictures are processed by the system, which was based on image analysis and shape detection. The data are processed in the Raspberry Pi and the results of the processed data are sent to the cloud server. [40]

4.6   Toward Reducing Energy Consumption with IoT Prototyping

An important part of achieving energy usage reductions is a reliable way of collecting data about current environmental conditions. The research presented in this section (Section 4) illustrated simple models that could be used when implementing a sensor network for collecting data. Furthermore, Section 4.2 illustrated certain pitfalls related to currently used approaches and highlighted the lack of existing model for rapid prototyping in the IoT domain. Sections 4.3 and 4.4 showed advantages of using smartphones as tools for data collection. Modern smartphones contain a huge variety of built-in sensors and the available devices range for low-cost affordable models to more expensive high-end devices. Today, almost everyone already has a smartphone, and thus, the cost of using smartphones for environmental monitoring can be negligible. Additionally, even the low-end devices are capable of running simple applications, that can be used to show statistics about current living conditions, and at least in theory, to provide the user with interfaces for controlling the environment. Unfortunately, there are challenges related to installing devices to real-life scenarios, such as, creating solid, durable packaging for the sensors and the availability of electricity and

telecommunications. Specifically when dealing with rapid prototype development and actual locations, there can be unexpected challenges, even when not considering the interoperability issues with existing structures and systems. More advanced scenarios can be realized with customizable devices. Section 4.5 described how Raspberry Pi could be used to monitor passenger ridership, an approach that could be easily expanded to energy consumption domain. Detecting whether rooms or buildings are occupied can have huge effect on the cooling and heating requirements. Furthermore, all of the presented prototypes use free and open software and low-cost modular components proofing that rapid prototyping with off-the-shelf devices is possible.

Conclusions

One of the initial research questions for this study was "How to categorize the energy consumption related studies?" Based on the literature review carried out, the existing studies can be roughly divided into four distinct categories: studies related to measuring and ensuring occupant comfort in buildings; research on how to extend existing systems with modern sensor and optimization solutions (retrofitting); studies on the usage and description of network-based APIs; and studies on IoT-based devices in general. All of these categories—comfort, retrofitting, network APIs, and IoT—include a wide array of existing research and provide numerous examples of applications and systems for monitoring and optimizing energy consumption. Several conclusions can be drawn from the results of the literature review, and from our previous experience in prototype development in the various research projects presented in this paper.

Our second research question was "How to utilize free and open solutions in the energy consumption context preserving adequate living conditions?" In the scope of this paper, the solutions for this question answered more on the basic technical problems. The paper gave insights on available software and hardware options, but the aspect of preserving living conditions was given less focus, and would require more extensive research.

In existing studies, IoT often consists more of "proof-of-concept" style research. The studies present a use case, various testing methods, and results, but often no formal model for testing or benchmarking is described. Without further studies it is difficult to say why there is an apparent lack of a standardized or *de facto* model for rapid IoT prototype development, but research on developing such a model or applying an existing model for the IoT context could be one potential direction for future studies.

Mobile devices (i.e., smartphones, tablets) can work as a good starting point for prototype development—they are ubiquitous, and they come embedded with various built-in sensors. Documentation and application examples are, in general, easy to find, and the utilization of mobile devices can be combined with off-the-shelf devices to create more complex systems. Off-the-shelf products—such as the Raspberry Pi single-board computer and wide multitude of available sensors—

have become much cheaper in recent years and offer adequate performance with a relatively good set of features and expansion capabilities. The market has also seen an increase in cheaper commercial sensor products targeted at consumers (end users). This price and market development has caused an increase in research utilizing cost-effective off-the-shelf devices as opposed to building and designing devices (e.g., sensor nodes) from the "ground up". Additionally, the increase in commercial products has enabled people with lesser technical knowledge to buy and set up sensor devices in their homes. Unfortunately, the interoperability of existing systems (air conditioning systems installed in older buildings, commercial products lacking proper interfaces or APIs, etc...) is often less than seamless and connecting the systems to available off-the-shelf devices can be challenging. With more barebone devices (Raspberry Pi, Arduino, etc.), packaging, designing a case, and installing the sensor node in a real-life environment or for outdoor use can pose further difficulties.

Finally, the paper attempted to answer the question: "How to reduce energy consumption by collecting and serving suitable data?" Based on the existing studies, the availability of energy consumption information can have a huge effect on people's habits, and properly presented usage statistics can lead to energy savings. In existing systems, the information is often limited to simple statistics (numerical details, graphs). Unfortunately, meaningful visualization can be challenging: How to select what is "meaningful"? How detailed should the statistics be? And how should the information be presented? In some cases, the user cannot affect the energy consumption and occupant comfort as desired. The user may not have access to the building's air conditioning or the building may not have devices capable of altering the indoor air quality (i.e., CO_2 levels, humidity, temperature, etc.)—should these statistics still be shown to the user? Furthermore, a building seldom has only a single occupant, and taking the possibly conflicting preferences of the users fully into account may in practice even be impossible. One potential research topic could be how to tackle the aforementioned issues, perhaps by utilizing A.I. or modern smart devices.

Acknowledgements

References

[1]   Dubar, I. G., Bogdan, R., & Popa, M. (2017) External rapid prototyping validation system for the automotive development cycle. Acta Polytechnica Hungarica, 14(6), 41-57, https://doi.org/10.12700/APH.14.6.2017.6.3

[2]   Official Statistics of Finland (OSF): Energy supply and consumption [e-publication] ISSN 1799-7976. 4th quarter 2018, Helsinki: Statistics Finland [referred: 24.6.2019] Access method: http://www.stat.fi/til/ehk/2018/04/ehk_2018_04_2019-03-28_tie_001_en.html

[3]   Official Statistics of Finland (OSF): Energy consumption in households [e-publication] ISSN 2323-329X. 2016. Helsinki: Statistics Finland [referred: 24.6.2019]   Access   method: http://www.stat.fi/til/asen/2016/ asen_2016_2017-11-17_tie_001_en.html

[4]   J. E. Petersen, V. Shunturov, K. Janda, G. Platt, and K. Weinberger, "Dormitory residents reduce electricity consumption when exposed to real-time visual feedback and incentives," International Journal of Sustainability in Higher Education, Vol. 8, No. 1, pp. 16-33, 2007

[5]   N. N. Kang, S. H. Cho, and J. T. Kim, "The energy-saving effects of apartment residents' awareness and behavior," Energy and Buildings, Vol. 46, pp. 112-122, 2012

[6]   G. M. Huebner, J. Cooper, and K. Jones, "Domestic energy consumption - What role do comfort, habit, and knowledge about the heating system play?" Energy and Buildings, Vol. 66, pp. 626-636, 2013

[7]   A. Faruqui, S. Sergici, and A. Sharif, "The impact of informational feedback on energy consumption - A survey of the experimental evidence," Energy, Vol. 35, No. 4, pp. 1598-1608, 2010

[8]   B. Kitchenham and S. Charters, "Guidelines for performing Systematic Literature Reviews in Software Engineering Version 2.3," EBSE Tech. Rep. EBSE-2007-01, 2007

[9]   L. Yang, H. Yan, and J. C. Lam, "Thermal comfort and building energy consumption implications – A review," Applied Energy, Vol. 115, pp. 164-173, 2014

[10]   D. Marković, D. Vujicic, Z. Jovanovic, U. Pesovic, S. Randik, and D. Jagodic, "Concept of IoT system for monitoring conditions of thermal comfort," in International Scientific Conference "UNITECH 2016," 2016, November

[11]   M. Taleghani, M. Tenpierik, S. Kurvers, and A. van den Dobbelsteen, "A review into thermal comfort in buildings," Renew. Sustain. Energy Rev., Vol. 26, pp. 201-215, Oct. 2013

[12]   F. Salamone, L. Belussi, C. Curro, L. Danza, M. Ghellere, G. Guazzi, B. Lenzi, V. Megale, and I. Meroni, "Integrated Method for Personal Thermal Comfort Assessment and Optimization through Users," Sensors, 2018

[13]   L. Ciabattoni, F. Ferracuti, G. Ippoliti, S. Longhi, and G. Turri, "IoT based indoor personal comfort levels monitoring," in 2016 IEEE International Conference on Consumer Electronics (ICCE), 2016, December 2015, pp. 125-126

[14]   A. Ghahramani, F. Jazizadeh, and B. Becerik-Gerber, "A knowledge based approach for selecting energy-aware and comfort-driven HVAC

temperature set points," Energy and Buildings, Vol. 85, pp. 536-548, Dec. 2014

[15]   Y. Obuchi, T. Yamasaki, K. Aizawa, S. Toriumi, and M. Hayashi, "Measurement and evaluation of comfort levels of apartments using IoT sensors," IEEE International Conference on Consumer Electronics (ICCE), 2018, pp. 1-6

[16]   T. Niemelä, R. Kosonen, and J. Jokisalo, "Cost-effectiveness of energy performance renovation measures in Finnish brick apartment buildings," Energy Build., Vol. 137, pp. 60-75, Feb. 2017

[17]   B. E. Medina and L. T. Manera, "Retrofit of air conditioning systems through a Wireless Sensor and Actuator Network: An IoT-based application for smart buildings," IEEE 14th International Conference on Networking, Sensing and Control (ICNSC), 2017, pp. 49-53

[18]   S. R. West, J. K. Ward, and J. Wall, "Trial results from a model predictive control and optimisation system for commercial building HVAC," Energy and Buildings, Vol. 72, pp. 271-279, Apr. 2014

[19]   S. Gupta, M. S. Reynolds, and S. N. Patel, "ElectriSense: single-point sensing using EMI for electrical event detection and classification in the home," in UbiComp, 2010

[20]   C. A. Björkskog, G. Jacucci, L. Gamberini, T. Nieminen, T. Mikkola, C. Torstensson, and M. Bertoncini, "EnergyLife: Pervasive Energy Awareness for Households," in Proceedings of the 12th ACM International Conference Adjunct Papers on Ubiquitous Computing - Adjunct, 2010, pp. 361-362

[21]   M. Weiss, A. Helfenstein, F. Mattern, and T. Staake, "Leveraging smart meter data to recognize home appliances," IEEE International Conference on Pervasive Computing and Communications, 2012, pp. 190-197

[22]   L. Özgür, V. K. Akram, M. Challenger, and O. Dağdeviren, "An IoT based smart thermostat," 5th International Conference on Electrical and Electronic Engineering (ICEEE), 2018, pp. 252-256

[23]   M. Weiss and D. Guinard, "Increasing Energy Awareness Through Web-enabled Power Outlets," in Proceedings of the 9th International Conference on Mobile and Ubiquitous Multimedia, 2010, p. 20:1-20:10

[24]   N. Morimoto, Y. Fujita, M. Yoshida, H. Yoshimizu, M. Takiyamada, T. Akehi, and M. Tanaka, "Smart Outlet Network for Energy-Aware Services Utilizing Various Sensor Information," 27th International Conference on Advanced Information Networking and Applications Workshops, 2013, pp. 1630-1635

[25]   B. L. Risteska Stojkoska and K. V. Trivodaliev, "A review of Internet of Things for smart home: Challenges and solutions," J. Clean. Prod., Vol. 140, pp. 1454-1464, Jan. 2017

[26] P. H. Shaikh, N. B. M. Nor, P. Nallagownden, I. Elamvazuthi, and T. Ibrahim, "A review on optimized control systems for building energy and comfort management of smart sustainable buildings," Renewable and Sustainable Energy Reviews, Vol. 34, pp. 409-429, Jun. 2014

[27] A. Kumar and G. P. Hancke, "An Energy-Efficient Smart Comfort Sensing System Based on the IEEE 1451 Standard for Green Buildings," IEEE Sensors Journal, Vol. 14, No. 12, pp. 4245-4252, Dec. 2014

[28] L. Pocero, D. Amaxilatis, G. Mylonas, and I. Chatzigiannakis, "Open source IoT meter devices for smart and energy-efficient school buildings," HardwareX, Vol. 1, pp. 54-67, Apr. 2017

[29] S. Godo, J. Haase, and H. Nishi, "Air conditioning control using selfpowered sensor considering comfort level and occupant location," in IECON 2015 - 41st Annual Conference of the IEEE Industrial Electronics Society, 2015, pp. 002497-002502

[30] M. Saari, P. Sillberg, P. Rantanen, J. Soini, and H. Fukai, "Data collector service - practical approach with embedded linux," 38th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), 2015, pp. 1037-1041, IEEE

[31] M. Saari, A. M. Baharudin, P. Sillberg, P. Rantanen, and J. Soini, "Embedded Linux controlled sensor network," 39th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), 2016, pp. 1185-1189, IEEE

[32] M. Saari, A. M. bin Baharudin, P. Sillberg, S. Hyrynsalmi, and W. Yan, "LoRa — A survey of recent research trends," 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), 2018, May, pp. 0872-0877, IEEE

[33] A. M. bin Baharudin, M. Saari, P. Sillberg, P. Rantanen, J. Soini, and T. Kuroda, "Low-energy algorithm for self-controlled Wireless Sensor Nodes," International Conference on Wireless Networks and Mobile Communications (WINCOM), 2016, pp. 42-46

[34] A. M. bin Baharudin, M. Saari, P. Sillberg, P. Rantanen, J. Soini, J. Jaakkola, W. Yan, "Portable Fog Gateways for Resilient Sensors Data Aggregation in Internet-less Environment," Eng. J., Vol. 22, No. 3, pp. 221-232, Jun. 2018

[35] I. Ahmad, P. Rantanen, P. Sillberg, J. Laaksonen, S. Liu, "VisualLabel: An Integrated Multimedia Content Management and Access Framework," in Proceedings of the 27th International Conference on Information Modelling and Knowledge Bases, EJC 2017, 2017, pp. 332-353

[36] P. Sillberg, M. Saari, J. Grönman, P. Rantanen and M. Kuusisto, "Interpretation, Modeling and Visualization of Crowdsourced Road Condition Data", IS-TRIA2019, Submitted

[37]   M. Saari, A. M. bin Baharudin, and S. Hyrynsalmi, "Survey of prototyping solutions utilizing Raspberry Pi," 40th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), 2017, pp. 991-994, IEEE

[38]   P. Sillberg, J. Gronman, P. Rantanen, M. Saari, and M. Kuusisto, "Challenges in the Interpretation of Crowdsourced Road Condition Data," International Conference on Intelligent Systems (IS), 2018, pp. 215-221

[39]   J. Grönman, P. Rantanen, M. Saari, P. Sillberg, and H. Jaakkola, "Lessons Learned from Developing Prototypes for Customer Complaint Validation," in CEUR Workshop Proceedings, 2018

[40]   J. Grönman, P. Sillberg, P. Rantanen, and M. Saari, "People Counting in a Public Event—Use Case: Free-to-Ride Bus," 42th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), 2019, IEEE