Optimization of building energy consumption

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Abstract

Abstract goes here

Dedication

To mum and dad

Declaration

I declare that..

Acknowledgements

I want to thank...

Contents

Chapter 1

Introduction

The developed world's dependency on fossil fuels to power growth and prosperity is becoming an increasingly unsustainable and unfeasible situation. The world will eventually run out of fossil fuels, and the dependency on it means that vital infrastructure is depending on politically unstable regions. What is perhaps even more concerning is the damage our environment suffers from our burning of fossil fuels. Energy efficiency is a major step away from the dependency on fossil fuels, and towards a society powered by economically and socially sustainable energy.

In March 2012 a new Energy Agreement was reached in Denmark, with goals to have approximately 50% of electricity consumption supplied by wind power, and more than 35% of final energy consumption supplied from renewable energy sources in 2020. The final goal is to have 100% renewable energy in the energy and transport sectors by 2050[1].

Buildings in Denmark have over the last decades become more energy-efficient as a result of advances in engineering and the ongoing strengthening of requirements for new buildings. However, around 40% of the total energy consumption is used in buildings making them the largest contributor to energy usage in Denmark[2]. Therefore retrofitting buildings with energy efficient technology is important, if Denmark is to fulfill the energy agreement and reach it's goals. The field of Energy Informatics has recently attracted much attention as large energy efficiency improvements remains to be realized, by utilizing the field to better understand, predict and optimize energy consumption efficiency in buildings[3]. This field is a cornerstone for realizing the visions of smart buildings and smart cities. In southern Denmark, the Municipality of Odense (henceforth referred to as OM) has come one step closer to these visions, by putting data regarding energy consumption of approximately 550 public buildings on the

[1] Energy Efficiency Policies and Measures in Denmark 2012; Page 3.

[2] http://www.kebmin.dk/klima-energi-bygningspolitik/dansk-klima-energi-bygningspolitik/byggeriet-danmark/bygningers

[3] Energy Informatics -DOI 10.1007/s12599-013-0304-2

roadmap to becoming Open Data[4]. This data contains hourly measurements of raw consumption for electricity, heating and water in a building. The availability of such data is a crucial step, but the raw data is of little use, unless it is transformed into useful information that can be represented in an intuitive manner to various stakeholders.

This project has worked with OM to find potential use cases of the consumption data, and explore what kind of useful information can be extracted from the available data. The aim was to develop a functioning prototype website capable of highlighting various trends, correlations, odd events, odd buildings etc. The scope for this project was not limited to researching and theoretically proving the applicability of various data processing methods, but included understanding and applying state of the art statistical methods to solve real problems for OM. Thus the challenges faced by this project were also those of a software development project, in which a software system suiting the clients' need had to be developed and delivered. The project utilized an iterative development approach, to identify needs and problems related to building energy consumption in OM, design and evaluate prototypes and develop the final software solution.

The problems OM is facing and which the developed software attempts to solve, are rooted in issues relevant to the entire energy management domain. Those issues include how individuals and organizations can gain a better understanding of their energy consumption, and be motivated to save energy. How to identify odd consumption patterns and get a quicker response time to leakages. How to benchmark buildings to guide investments in renovations to yield optimal results. How to optimally support the workflows of building energy managers, while minimizing operation and maintenance efforts of such a system. How to more precisely predict energy consumption. Thus anyone working with those or related issues might be interested in the results and findings of this project.

[4]http://odensedataplatform.dk/

Chapter 2

Background

Odense Municipality (OM) is the third greatest in Denmark with an size of 304 km^2 and a population of nearly 200.000 people. In order to reach the goals of the national environmental policy, OM has created the directive "Environmentally friendly construction - requirements and recommendations", which as the directive states will: "concretise the environmental policy and objectives, so that future building projects in the municipality contributes to the up-filling of the overall vision of Odense as Denmark's most sustainable city."[1]. This directive sets energy efficiency requirements for newly constructed buildings and also for renovated ones.

OM owns approx 850 buildings, which are used for different purposes like schooling, administration, care centers and cultural institutions. OM is responsible for paying suppliers of water, heat and electricity for the consumption in these buildings. This is done on basis of billing meters which measure the consumption, and are installed in each building. Depending on the size of the building, there might be a number of internal meters (so called distribution meters), which measure the consumption in different parts of the building, but are not used as billing meters.

Each public building has an appointed energy manager who has the responsibility of performing the manual tasks involved in reading and checking the meters. The energy manager logs reading internally in a control book or scheme and reports them on the last weekday of the month through a web portal. If reading deviate more than +/- 10 % from the budget forecasts, the manager must submit possible causes for this. As the document "Energy efficiency in the municipality of Odense" states, both types of meters must be often checked to avoid energy leakages. In buildings less than 1.000 m^2, meters must be checked at least once a week and for larger buildings the frequency is at least once a day. OM has started installing meters which automatically report their readings on an hourly basis. Those are not yet installed in all buildings, but OM has plans to do so. Depending on the concrete building and setup there is a delay from

[1] Miljørigtigt byggeri – krav og anbefalinger

around 1 to 7 days before readings from the automatic meters are visible in OM's energy management system 'Energy Key'[2].

2.1 Current limitations

Through interviews with the head of OM's Energy and Maintenance department, the current practises in the domain of energy and building management have been investigated. This analysis revealed a number of areas in which improvements could be made. Before 2013 each building's energy consumption was monitored on site by appropriate staff, and energy bills were paid from the budgets of the organization residing in the building. However building managers on site had no real tools or means of monitoring their consumption, making it difficult to identify high usage or leakages. This function has now been centralized in the department of Energy and Maintenance which owns the buildings and is responsible for monitoring and paying for energy consumption, as well as renovation and maintenance of the buildings. The organizations residing in the buildings will then just rent the building for a fixed price. This centralization should give OM a better control and overview of the municipality's energy consumption, but a number of new issues have arised. The task has scaled with the number of buildings that now needs to be monitored, and the problem analysis showed that OM's Energy and Maintenance department does not have the needed staff nor the proper tools to complete it effectively. The problem analysis resulted in the identification of 5 main issues, which has been the focus points of this project.

System and data maintenance

Maintaining accurate data about a building's size, age, type, associated meters etc. can seem like a seemingly small effort, but has scaled to become an overwhelming task when considering the amount of buildings. If the primary data is imprecise, erroneous or inconsistent, the value of data analysis and anything that depends on it will decline. OM's current energy management system Energy Key has no way of telling the user when certain data has last been verified and by whom, nor is there any easy way for users to update incorrect data entries. This makes it difficult to work with the data, because the users are often unsure about the validity of it, and it causes redundant work for multiple users that need to both verify the same data. There are currently no procedures for how often a building's consumption should be checked and validated, nor does Energy Key support such continuous maintenance tasks in any way. Additionally OM struggles with poor data quality and many missing values regarding consumption figures, which according them is because the energy suppliers' systems are simply not built for sharing data with clients.

[2] http://www.emtnordic.com/da/energykey-energistyringsprogram

Visualization of buildings and consumptions

Energy Key allows users to view electricity, water and heat consumption data for individual meters, but the possibilities to visualize and represent data in meaningful formats seems limited. The user can view diagrams depicting consumption over time, and histograms that compare a building's reported consumption with the budget. Other than this, the system does not summarize important key features and energy statistics for a given building. It does not analyze the data to provide new insights nor does it provide any tools for users to do so. The lack of meaningful information and visualization of consumption patterns makes it hard to understand a building's energy usage. This makes it more difficult to motivate users and building managers into making better decisions that lead to energy savings, because they do not know how their behaviour influences the consumption. Furthermore it is not possible to easily see what kind of motivation works, and for how long the effects of energy saving campaigns lasts.

Fault detection, diagnosis and resolution

Energy Key has an automatic fault detection feature which can raise an alarm when consumption goes above or below a given percentage of what is budgeted. OM's Energy and Maintenance department has tried experimenting with this system for a single building, and the results were that 37 false alarms were received in 2012 and 34 in 2013. When considering all buildings the amount of false alarms becomes overwhelming. The large amount of false alarms combined with the fact that tasks involved in diagnosis and resolution of faults are not supported in Energy Key, has lead to the alarms being completely ignored. Better visualization of buildings and consumptions would allow users to more easily diagnose what caused the alarm. Even if a user can verify that an alarm is valid the fault might be neglected, as there no standard procedures to follow in order to resolve the fault, nor is there any personnel assigned as responsible. Energy Key provides no support for diagnosis and resolution of faults, as an alarm can not be associated with a set of tasks assigned to relevant users. It is not possible to track status and progress of its resolution and users can't make comments to coordinate efforts between them. Another type of fault which is currently not detected by the system is when meters suddenly go offline and stop reporting data.

Budgeting

Currently energy consumption and budgets for each building are estimated by looking at the same building's consumption in previous years. Estimations have monthly granularities, meaning that the energy consumption estimate for a given month depends on the consumption reported the same month previous years. This approach does not allow one to properly predict consumption under changing circumstances (people usage, environment, building changes etc.). A better model for a building's energy consumption would allow for better predictions and more exact budgets. When information about a building is changed in Energy Key, the previous information is lost making it is difficult to use the previous consumption patterns to plan future budgets as there is no historic data to show under which conditions the previous consumption was produced. Because of the issues with maintaining data in Energy Key, information like how many people are using a building is stored and maintained in excel files, meaning budgets are created only on basis of the very basic building features stored in the system.

Selecting buildings for renovation

In 2015 OM's Energy and Maintenance department has budgeted 200 million dkk to renovation of public buildings. As the directive Environmentally friendly construction - requirements and recommendations[3] says all renovations must be done with the most energy efficient solutions. The department now faces the task of finding the set of buildings for which renovations would bring down energy usage the most. Currently a taskforce is screening through the available data manually, and more or less takes educated guesses about which buildings are inefficient and can be optimized. This is a difficult task as there is a large amount of buildings and no visualization of the data in a meaningful manner resulting in consumption pr. square meter being the only parameter considered in this manual process. The current system is unable to perform any sophisticated benchmarking or ranking of buildings, making it nearly impossible to verify that the most energy inefficient buildings have been found. However, identifying energy inefficient buildings is only the starting point, as a vast range of economical and political parameters also have to been considered before a building is selected for renovation.

[3]See Appendix 01 -Environmentally friendly construction

Chapter 3

Requirements

Based on the initial problem analysis and identification of OM's current limitations, a quick low fidelity horizontal prototype system was created[1]. This prototype was evaluated through an interview with a representative from OM's Energy and Maintenance department[2]. Based on this interview the problem analysis was deepened and a final backlog of requirements was for the system to be developed was specified. The full requirements list can be found in Appendix 05 -Requirement Specification, while this section will give an outline of how the requirements solve the identified issues.

3.1 System and data maintenance

Any client of a new software system would require that the servicing efforts are minimal, but the problem analysis uncovered that for OM this is of critical importance. OM's Energy and Maintenance department has had a large increase in workload without a proportional increase in resources or personnel. This means that the department simply does not have the time or resources to maintain a new system if the required servicing effort is too high. A number of steps to prevent this have been taken, resulting in formal requirements which can be measured and evaluated.

Firstly, in long term, the new system should replace OM's existing system, but changes in an organization's processes, workflow and technology comes with the expense of time and money. In order to minimize the expenses, a gradual adoption of the new system will be in focus. Requirement R18, ensures data consistency in a such adoption phase where multiple systems work on the same data. This ensures further, that maintenance in an adoption phase will remain the same as in the existing system.

Secondly, to minimize the effort needed to maintain large amounts of building information (such as type, age size and so forth), requirement F2-06a and F2-

[1]See Appendix 04 -Website Alpha Prototype.zip

[2]See Appendix 02 -Meeting with Kim Allan 29-4-15

06b make sure it is possible to easily update and validate these general building informations. The effort associated with maintaining the data is minimized by informing the user when data was last validated and if it is time to re-validate. Thus the user needs not spend time investigating validity of data every time it is needed. Also as opposed to the current system it will be possible to easily update data when a building is viewed anyway, and then offering the user the choice to validate it now. This solution ensures that even building managers for the different buildings will participate in keeping the information correct. This is additionally supported with requirement F15 and F17, which will allow the assignment of maintenance tasks to the building managers thus distributing the maintenance effort.

3.2 Visualization of buildings and consumptions

Requirements F2 and F9 together with the respective sub requirements state that it should be possible to view and compare information about buildings and their energy consumption. The requirements formulate a number of concrete aspects of the energy consumption that must be visualized to the user. In contrast to OM's existing system this will give users better information and support better decision making. Requirement F2-02 gives concrete examples of a number of energy features that must be extracted and visualized from the raw consumption numbers. Those are for instance peak loads, standby usage and daily average consumptions.

Besides pure consumption figures, the visualization of consumption patterns can further enhance a manager's understanding of the buildings consumption. The consumption patterns of a building may be viewed in different levels of granularity, like for instance patterns on a micro scale (dayly) and patterns on a macro scale (yearly). Depending on the user's task, he might be interested in patterns on different scales. The three requirements F2-03a to F2-03c describe how consumption patterns on a micro scale is to be visualized through so called daily consumption profiles. Requirement F2-04 requires that a buildings seasonal variation in consumption is visualized which might be considered a macro scale pattern.

From looking only at the consumption of a single building without a context or reference point, it can be hard to identify faults or even verify the that everything is as it should be. Therefore requirement F9 and its sub requirements aim to give the user a way to visualize a building in comparison with others, to have a reference point when evaluating a building[3].

[3] Requirement F9 and comparing buildings is further discussed in the Selecting of buildings for renovation section

3.3 Fault detection, diagnosis and resolution

Requirement F3, addresses the fault detection, and here the aim is to build a fault detection system which is more accurate and allows for diagnosing the feature which caused the flaw.

Requirements F3-02, F3-03 and F12 (handling of alarms) will try to make sure alarms are not ignored or forgotten by establishing a process/workflow for how they should be handled. The system will provide an easy overview of alarms, and requirements regarding task management (F15-17) will contribute to the creation of a “standard” procedure of handling alarms.

3.4 Budgeting

Requirement F14 states that the system is should implement functionality regarding creating and maintaining a budget. The system must support the user in creating precise budgets, by being able to accurately forecast the expected consumption of a building as stated in requirement F13.

3.5 Selecting buildings for renovation

Selecting buildings for renovation is a decision process with many political and economical parameters which would be impossible for one system to fully implement. However the system will be able to support the process by giving users the ability to quickly identify potential candidates. This is done by implementing requirement F11, which will make the system come up with various rankings of buildings, making the worst ranked buildings potential candidates for renovation. It will be considered to map the benchmarks of buildings to the national energy labeling scheme[4].

3.6 Other requirements

The environment in which the application is to be used, spawns quality requirements for the systems portability and scalability which needs to be meet in order to develop a successful application.

The users from OM’s Energy and Maintenance department work both from their offices and from various locations when visiting buildings to inspect. This need is met by requirement XX, which addresses the portability of the system and states the application must work on a tablet.

This project has focused on the municipality of Odense, but other municipalities in Denmark could potentially have similar requirements for an energy management system. Based on this, there is a requirement that the application is scalable. Another scenario is that the system is expanded to not only public

[4] http://www.ens.dk/forbrug-besparelser/byggeriets-energiforbrug/energimaerkning

buildings. In that case the number of buildings handled would be an order of magnitude more, and the system should be able to handle this.

3.7 Prioritization of requirements

All requirements have been prioritized using the MoSCoW-prioritization technique. The prioritizations do not reflect the wishes of the client, but are based on what is within this project's scope and boundaries. For instance a task management system is out of scope for this project and therefore requirements F16 and F17 have been prioritized as $WON'T$ have. If a finished product was to be made, these requirements are essential for the user and should therefore be implemented.

Chapter 4

Related Work and Methods

Within recent years numerous research papers have emerged showing successful applications of various methods to real word problems like detecting faults, benchmarking, classifying, predicting or recognizing patterns in the energy consumption of buildings. Most of the applied methods rely on theories rooted in the fields of statistics, machine learning and data mining to analyze and interpret the data. To successfully apply such methods to real word problems one must be familiar with the nature of the data, and have working knowledge of the methods being applied. This section will explore some of these methods and the current literature that applies them to various problems related to energy management.

4.1 Decomposing time series

The most visible pattern that emerge from time series data of building energy consumption is the daily rise and fall in consumption, which loops every 24 hours following the daily cycles of building users. Also a weekly cycle can be noticed, as different days of the week tend to have different consumption profiles. If looking at several years of data, the yearly cycle following the seasonal changes in environmental conditions can be seen. These cycles form the basis for the components that can be found when decomposing a time serie, and which could be used to reconstruct the original by combining the components. For instance considering the weekly cycles and yearly seasonal change, it would be possible to make a decomposition into a Cyclical Component, and a Seasonal Component. Additionally [REF wiki] suggests that the decomposition produces a Trend Component and an Irregular Component. The Trend Component reflects the long term progression irrespective of any cycles and seasonality, while the Irregular Component is the noise in the original time serie which could not be explained with the other components. Figure XX shows an example of a decomposition:

Appendix A

Appendix awesome

This is a nice appendix thing

Appendix B

Appendix not so awesome

This is a nice appendix thing