Chapter 1

Introduction

The world-wide energy system is facing serious challenges because of problems caused by fossil fuels and efforts to be less dependent on them. The energy consumption by households forms a significant part of the energy usage and can potentially play an important role to address these challenges. The domain of this dissertation is the energy consumption and production in houses. It is studied how computational approaches can be used to understand, simulate and influence the energy consumption in houses.

The overall aim is to use computational techniques for a more sustainable energy system. Our computational studies cover four aspects of this general theme: A. Reduction of energy usage for heating by using heat pumps. B. Optimizing local solar energy production. C. Reduction of energy usage by understanding and improving the characteristics of a house. D. Adapting the time of energy usage.

This chapter discusses the motivation and the necessity of such research, and is split into five subsections. First, some background is described. Then the challenges that energy grids are facing are discussed. The third section is about possible solutions in the residential sector. The next section talks about the methodology and explains how computational techniques can be helpful to achieve a more sustainable society. Finally, the research questions behind this dissertation are outlined.

1.1 Background

This section discusses the characteristics of energy production and usage worldwide and specifically addresses the domestic section.

In the last decades, the worldwide energy consumption has increased rapidly, and it has caused serious problems for us. Most of these problems are due to the fact that the
main sources of used energy are fossil types of fuel. Figure 1.1 shows the global energy consumption, from different sources.

![Figure 1.1: Primary energy world consumption 2015 (million tonnes oil equivalent), [1]](image)

The residential sector, besides transportation and manufacturing, is one of the main sectors of energy usage. Around 30% of the world energy consumption is used in this sector[2]. But where do people use energy in their houses? The answer to this question is depended on many factors, for example, the type of residents, the age of the building, the climate, the location of the house. Figure 1.2 shows for what purposes is energy used in European houses on average:

- It becomes clear that most of the energy in houses is used for heating purposes, including water and space heating.

### 1.2 Problems / challenges

There are a number of challenges in the energy domain, we will discuss some of them below.

**Limited availability and increasing need**

As we know, the sources of fossil fuels are limited. It is predicted that if our usage increases with the current pattern, then the resources will finish in the coming decades. On the other hand, it is very likely that we will see an increased need for energy sources in the near future. Some studies show a strong relation between the average of energy usage in countries and the indexes of quality of lives and indexes of development. The graph in figure 1.3 shows the relation between the Human Development Index, and the primary energy use.
1.2 Problems / challenges

Figure 1.2: Household energy consumption by end-use in the EU-2015 [3]

The Human Development Index, also known as the HDI, is an evaluation of several different indicators that shows achievement in human life and well-being overall. This index is an overall view of human development and shows whether a country is developed, developing, or underdeveloped. Generally, having a high HDI is linked to a high quality of life. Indicators for HDI include measures of GDP, life expectancy, adult literacy, and school enrollment.

The quality of life in many countries, especially in developing countries, is growing, which will likely lead to more energy usage per capita in these countries. High-populated countries like China and India, are growing and developing very fast. Not only the population, but also the energy usage per capita is growing fast in these countries. Therefore, it can be predicted that in the near future their energy demand will increase a lot, which has a strong effect on the world energy consumption.

Environmental problems

The use of fossil fuels for fulfilling this energy need comes with many different problems for the environment, human kind, and other creatures: burning and using coal, oil and gas as the main fossil fuels cause many serious pollutions.

Climate change is a significant problem related to energy usage. The main aspect is the rise in the average temperature of the earth’s climate system, and its related problems. In addition to global warming, anticipated effects include rising sea levels, changing precipi-
Introduction

Figure 1.3: Human Development Index VS. The primary energy use per capita in different countries [4]


The largest influence of climate change has been the emission of greenhouse gases such as $CO_2$, and Methane. The next graphs show the Global Greenhouse Gas Emissions by Gas and the Annual Global Carbon Emissions by Fossil-Fuel.
As can be seen, \( \text{CO}_2 \) is the dominant greenhouse gas. Over the past 20 years fossil fuels burning has caused about three quarters of the increase in \( \text{CO}_2 \) from human activity, and its emission is rapidly increasing in the last decades.

Air and water pollution is another problem caused by fossil fuels. Cities with many cars, power plants and factories, which burn fossil fuels, suffer from high level of pollution.

**Matching the demand and energy production**

As a response to the problems that are caused by using fossil fuels, different countries set targets to promote renewable energy and reduce dependency on fossil fuels using more renewables to meet its energy needs and to make the production more sustainable. As an example, the EU’s Renewable energy directive sets a binding target of plus 20% final energy consumption from renewable sources by 2020. And EU countries have already agreed on a new renewable energy target of at least 27% of the final energy consumption in the EU as a whole by 2030 as part of the EU’s energy and climate goals for 2030 [7].

Increasing the proportion of renewable energy in the grids might cause problems with the balance between production and demand. A critical limitation on the energy systems (especially for electricity grids) is the continuous balance between demand and response sides [8]. Traditionally, for electricity grids it is assumed that the demand side is not controllable, but (to a certain extent) predictable. It means that even though it is not possible to control the amount of energy usage, but it is possible to forecast it based on its history. So, it was always the case to keep the balance of the energy grid by predicting the demand from one side and controlling the production from the other side.

As is clear, the production of renewable energy from sun and wind is not controllable. Therefore, it is not possible to keep the demand-response by steering at the production side. Thanks to modern ICT developments and the available ICT infrastructure (like internet, IoT, smart sensors, smart controllers, etc.) it might be possible to control the demand side to some extent. The research in this thesis aims to provide solutions related to this aspect.

### 1.3 Possible solutions

Given the challenges, we need to reduce energy consumption, increase renewable production, and provide solutions for matching demand and production.

There are many different ways in which we can tackle aforementioned challenges. Most researchers believe that the discussed problems would not be solved, except by using and combining all possible solutions[9]. In this thesis, we focus on computational approaches to support solutions that are mostly related to houses and the domestic section.
Introduction

(a) Using more efficient devices that are less dependent on fossil fuels. For example: heat pumps instead of gas- or oil-based heating, . . .

(b) Producing more energy through decentralized energy production systems, e.g. PV systems to generate electricity in houses

(c) Making residents more aware about their energy usage. This can be done by for example understanding the thermal characteristics of the house, which can lead to improvements such as better insulation of houses.

(d) Shifting energy usage to times when there is more energy available. Through substantial progresses in ICT infrastructures, it becomes possible to inform the residents at the consumer side about the availability of energy and encourage them to shift their usage to times when there is more energy available; for example, by lowering the prices in a time-dependent manner.

The first three solutions (a, b and c) can contribute to the first two problems mentioned before, as they reduce the need of energy in general and for fossil fuels specifically. Solution c is also useful for matching the demand and production. Finally, d can contribute to the balance between demand and supply.

1.4 Methodology

The main aim of this thesis is to investigate how computational methods and modeling can contribute to the problems mentioned above. Computational modeling approaches can play an important role to tackle the mentioned challenges. There are many different aspects and parameters that influence the energy usage in a house. We can use models for different aspects involved in the energy process. For example:

• Technical aspects of production facilities

• Technical aspects of energy consuming devices

• Characteristics of the house

• Behaviour of inhabitants

• Dynamic of prices

• Dynamics of the environment
1.4 Methodology

Figure 1.5: Dependencies of the main variables relating to the energy required to heat a house

As an example, Figure 1.5 shows the parameters and aspects that affect the energy that is required for space heating purposes in a house by an air-source heat pump.

Computational models can help us to understand the processes. In addition to that, such models can be used for simulations experiments to evaluate different alternative choices and find the optimal solutions. Different steps are relevant in the use of models.

1. Creating the models. To do so, we first need to clarify the causal relations between different aspects. As is illustrated in figure 1.5, different aspects and variables have effect on each other. We can translate this into a network of causal relations of all the aspects that are relevant for energy usage in a system.

However, we are usually interested in more specific questions, for example, how changes in one aspect affect other aspects. For example, how do dynamic price strategies lead to changes in the behaviour of people? How do changes in the thermal characteristics of a house affect the energy usage? How do changes in the temperature of the ambient air lead to the changes in the performance of an air-source heat pump? To use the computational models to investigate these effects, it is necessary to apply data driven methods.

2. Setting the parameters: A computational model includes a number of parameters, e.g., representing characteristics of the house, heat pump, and the human mental processes and behavior. By applying data analysis approaches we can understand and estimate the different parameters.

Eventually, the models can be used for actual investigation of the effects.
3. Running simulations: to find optimal setups and for evaluating alternatives, computational modeling and simulation can be very helpful. Different scenarios can be tried out through the simulations and different variables and parameters can be manipulated to find the optimal setup in the sense of energy efficiency and costs.

In this thesis, we have used different types of computational methods:

1. Dynamic causal models: in this type of models, the effect of different aspects on each other are modeled. We have used this type of modeling in several chapters of this thesis, specially to model the performance of heat pumps and PV panels. We also used these models in simulations to study the effect of the changes in different aspects and comparing different alternatives. Temporal causal models were obtained by translating the causal models into differential equations. This type of modeling is introduced in [10]. We have also used temporal causal models for the cognitive states of a person. This model is used to simulate the process of forming and changing the behaviours.

2. Data driven approaches: in some chapters, we used a data analysis approach to estimate the parameters of the models. Moreover, in one chapter we illustrate how a data driven approach can be used to make the inhabitants more aware about their energy usage.

3. Time series modeling: in one chapter of this thesis, we used time series modeling techniques to study the changes in the performance of PV panels.

1.5 Research questions

Following the motivation as set in section 1.2, the research challenges addressed in this thesis focus on analyzing, understanding and modeling the energy consumption and production in a house.

Main research question:

How can computational methods contribute to a reduction in the use of fossil fuel in the residential sector?

This question is split into four sub-questions; each is the subject of one part of this thesis. The first sub-question is addressed in Part I.

RQ1: How can we use computational models to apply heat pumps more smartly and thus reduce their electricity usage?
In designing new houses and also in renovating old houses a common aim nowadays is to achieve a net zero house. A net zero house is a house which energy consumption is not more than its energy production on an annual basis. As it is seen in figure 1.2, heating is an important issue to achieve a net zero house.

To achieve this, in addition to good insulation of a house, also heating systems are to be considered that are less depend on fossil fuels and electricity. Often heat pumps are suggested as an environmentally friendly alternative. It reduces the need of primary energy because as it gets most of its energy out of ambient environment as a heat source.

A heat pump is a device that can be used in winter time, to transfer the heat energy from a source of heat to houses. A heat pump takes most of its energy from the ambient environment (i.e. ambient air, water, or the ground) and its performance factor depends on different factors.

The majority of heat pumps in residential sector use ambient air as the heat source, so they are called Air Source Heat Pump (ASHP). An important challenge for efficient usage of heat pumps is adapting the timing of the heat pump to both the outdoor temperature and indoor energy demand in order to minimize the electricity usage or the costs.

Such a system should work efficiently and economically, thereby taking into account comfort for the residents, with minimal human intervention.

To reduce the energy used in residential sectors for heating purposes by using heat pumps, computational modeling that can be very useful for simulation. These models can help us to forecast the situation (e.g., taking into account the weather), predicting the performance of a ASHP, and also to find the optimum heating set-up for a house or the optimal time for using the ASHP.

**RQ2:** How can computational methods be used in designing efficient PV systems?

To make a net zero energy house, in addition to reducing its energy usage, it is important to increase its energy production, which is usually done by systems of photovoltaic solar panels (PV systems). The production achieved by such solar energy production systems strongly depends on different aspects including their location and orientation.

Nowadays, there are many houses which are equipped by PV systems to produce solar energy; they generate part of (or all of) their own energy demand. However, for optimal production the positioning and their environment is important.

The focus of Part II is on domestic PV systems, and approaches are investigated addressing what is the best place and the best orientation to install PV panels. We investigate how a computational model can be used for prior analysis of a PV system, to choose the best location(s) and orientation(s) to install it, before it is actually built. Moreover, the effect of
Introduction

The dynamics of the environment on the degradation rate of PV systems are studied.

**RQ3:** How to understand the thermal characteristics of a house and the heating system by analyzing temperature and energy usage data?

Thermal simulation is a common way to study the effect of different changes on the energy usage in a house.

As mentioned, a computational simulation of the thermodynamics of a house can be a powerful tool to study the effect of different changes on the energy usage and optimize the energy usage in a house. Moreover, it is possible to optimize different aspects (i.e., time of operation of the heating system, the size of a new thermal storage) to minimize the cost or energy usage. However, to do such a simulation, it is required to have knowledge about the thermal characteristics of the house.

Measuring the thermal characteristics of a house can also be used to find out the best ways to prevent or minimize energy waste in houses. This information can also be used to compare thermal characteristics of houses with similar situation (size, the number of residents, etc.) to motivate the residents with high usages to reduce their usage. Usually, precise thermal experiments are performed to determine the thermal characteristics of a building. In this part, we investigate whether it is possible to do some conjectures based on data gathered by a (smart) thermostat.

This question is investigated in Part III of this thesis. Moreover, it is addressed how they can be used to detect malfunctioning of the heating system of a house. By using the investigated techniques, it would be possible to further extent the possibilities of a smart thermostat.

**RQ4:** How to use computational modeling and simulation to support people to their energy usage time?

What is the role of knowledge about the behaviour of residents to shift the consumption time to when more energy is available? Load balancing is a critical topic in smart grid systems. The behaviour of customers in a household is an important factor that influences the effectiveness of any balancing/pricing strategy. In many types of research about dynamic pricing, it is assumed that individual households adopt their usage pattern based on prices. However, the actual behavior of consumers in a house is an uncertain factor that might influence the efficiency of pricing strategies. In Part IV, the focus is on the behaviour of residents and dynamic pricing. On the one hand, it is investigated that to what extent the knowledge about human behavior can be used to produce better control strategies, in the sense of energy efficiency and costs. On the other hand, a computational-cognitive model of
forming and changing the behavior is presented, which simulates the dynamics of mental and cognitive states of a human during forming and changing his behavior. A computational model is suggested to simulate the role of advertising on behaviour change.

1.6 Dissertation outline

The work presented in this thesis is a collection of various papers. Most of these papers have been published, or were accepted for publishing in journals or proceedings of conferences. It should be noticed that since each chapter is an independently published paper, there is some overlap between chapters. On the other hand, it is not necessary to read all chapters, or it is not necessary to read different chapters in the order presented here. Reflecting the research questions addressed in the section above, this dissertation is divided into four parts (in addition to this introduction and the conclusion part). Each part contains a few papers as its chapters. Table 1.1 shows the structure of this thesis.
<table>
<thead>
<tr>
<th>Part I</th>
<th>Computing a Sustainable Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 1</td>
<td>Introduction</td>
</tr>
<tr>
<td>Chapter 2</td>
<td>An Analytical Model for Mathematical Analysis of Smart Daily Energy Management for Air to Water Heat Pumps</td>
</tr>
<tr>
<td>Chapter 3</td>
<td>Analysis of Electricity Usage for Domestic Heating Based on an Air-To-Water Heat Pump in a Real World Context</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>Comparative Evaluation of Different Computational Models for Performance of Air Source Heat Pumps Based on Real World Data</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>Comparative analysis of the efficiency of air source heat pumps in different climatic areas of Iran.</td>
</tr>
<tr>
<td>Part II</td>
<td>Generate more by PV systems</td>
</tr>
<tr>
<td>Chapter 6</td>
<td>Analysis of the Performance a PV System Based on Empirical Data in a Real World Context</td>
</tr>
<tr>
<td>Chapter 7</td>
<td>Analysis of the Performance a PV System Based on Empirical Data in a Real World Context</td>
</tr>
<tr>
<td>Part III</td>
<td>Estimating house thermal characteristics</td>
</tr>
<tr>
<td>Chapter 8</td>
<td>Agent-Based Analysis of Annual Energy Usages for Domestic Heating based on a Heat Pump</td>
</tr>
<tr>
<td>Chapter 9</td>
<td>An Analysis Method for a Smart Thermostat to Make Humans Aware of their Heating Energy Efficiency</td>
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<tr>
<td>Chapter 10</td>
<td>A Data Analysis Approach for Diagnosing Malfunctioning in Domestic Space Heating</td>
</tr>
<tr>
<td>Part IV</td>
<td>Role of Residents’ behavior</td>
</tr>
<tr>
<td>Chapter 11</td>
<td>The Role of Knowledge about User Behaviour in Demand Response Management of Domestic Hot Water Usage</td>
</tr>
<tr>
<td>Chapter 12</td>
<td>A Computational Model for the Role of Advertisement and Expectation in Lifestyle Changes</td>
</tr>
<tr>
<td>Chapter 13</td>
<td>Conclusion</td>
</tr>
</tbody>
</table>
The rationale behind each part is as follows.

1.6.1 Part I: Addressing research question 1

The focus of this part is on understanding and modeling the performance of heat pumps used for domestic purposes. These models can be helpful to control a heat pump more smartly. Moreover, it is investigated why in some countries people are not financially motivated to use this technology.

This part contains 4 chapters, explained in Table 1.2
# Table 1.2: Table of Content, Part I

<table>
<thead>
<tr>
<th>Chapter 2</th>
<th>Chapter 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Title</strong></td>
<td><strong>Title</strong></td>
</tr>
<tr>
<td>An Analytical Model for Mathematical Analysis of Smart Daily Energy Management for Air to Water Heat Pumps</td>
<td>Analysis of Electricity Usage for Domestic Heating Based on an Air-To-Water Heat Pump in a Real World Context</td>
</tr>
<tr>
<td><strong>Publication</strong></td>
<td><strong>Publication</strong></td>
</tr>
<tr>
<td><strong>Brief explanation</strong></td>
<td><strong>Brief explanation</strong></td>
</tr>
<tr>
<td>In this paper, an analytical model is presented that can be used to mathematically analyze how to use energy more efficiently for space heating of a house. The energy usage of an air-to-water heat pump of a house according to a particular heating program is calculated. The final result is a mathematical formula that can calculate the daily energy usage of the heat pump based on inputs like characteristics of the house and the parameters of the heating program.</td>
<td>In this paper, an analytical model is presented to estimate the daily electricity usage of a heat pump, which used for both space and water heating in a house. This model can be used to perform simulation on energy usage of the heat pump day by day for arbitrary time periods (e.g. seasons or years). Such a model includes a number of parameters representing characteristics of the house, the heat pump, and the human behavior. In this paper, it is shown how appropriate values can be found for these parameters based on actual data of an existing house. Based on this simulation results, it is possible to decide the specifications for further renewable energy production system to be installed, in order to obtain a net zero house.</td>
</tr>
<tr>
<td><strong>Own contribution</strong></td>
<td><strong>Own contribution</strong></td>
</tr>
<tr>
<td>- Performing a substantial part of the mathematical analysis</td>
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<tr>
<td>- Comparing the analytical model to a simulation model</td>
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<tr>
<td>- Writing part of the paper</td>
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<tr>
<td>- Involving in defining the model</td>
<td></td>
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<tr>
<td>- Doing a substantial part of mathematical modeling</td>
<td></td>
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<tr>
<td>- Tuning the parameters based on real data</td>
<td></td>
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<tr>
<td>- Use the model to replicate the real data</td>
<td></td>
</tr>
<tr>
<td>- Writing part of the paper</td>
<td></td>
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</tbody>
</table>
### Chapter 4

<table>
<thead>
<tr>
<th>Title</th>
<th>Comparative Evaluation of Different Computational Models for Performance of Air Source Heat Pumps Based on Real World Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Publication</td>
<td>Proceedings of the International Conference on Environmental and Climate Technologies - CONECT’15</td>
</tr>
<tr>
<td>Data</td>
<td>Sensory data about the electricity consumption and energy production of heat pumps from 8 houses gathered by <a href="http://www.liveheatpumps.nl">www.liveheatpumps.nl</a>; weather data</td>
</tr>
<tr>
<td>Brief explanation</td>
<td>In this paper, the seasonal performance factor of heat pumps in real world situation is studied. Different mathematical models, are fitted to the data and compared to each other.</td>
</tr>
</tbody>
</table>
| Own contribution | - Exploring the data  
- Exploring the relevant literature  
- Tuning the parameters of models  
- Comparing the results of different models  
- Writing a substantial part of the paper |

### Chapter 5

<table>
<thead>
<tr>
<th>Title</th>
<th>Comparative analysis of the efficiency of air source heat pumps in different climatic areas of Iran</th>
</tr>
</thead>
<tbody>
<tr>
<td>Publication</td>
<td>Proceedings of the International Conference on Improving Sustainability Concept in Developing Countries - ISCDC’15</td>
</tr>
<tr>
<td>Brief explanation</td>
<td>In the paper, the economical aspects of heating are analyzed for different regions of Iran, as a developing country which economy is based on oil. And it is investigated that why heat pumps are not used in this country.</td>
</tr>
</tbody>
</table>
| Own contribution | - Exploring the relevant literature  
- Getting economical data about the energy pricing strategies in Iran  
- Getting weather data of different regions of Iran  
- Implementing the simulation models  
- Defining the simulation setup  
- Writing a substantial part of the article |

### 1.6.2 Part II: Addressing research question 2

Evaluating the performance of photovoltaic solar panels (PV systems) based on their production data of 1 year may be inaccurate because the weather circumstances in that year may not be representative for other years. Therefore, a prior analysis can be helpful. The performance of PV solar systems can be analyzed prior to their installation based on a computational model, and this information can be used to select the best place(s) and orientation(s) to install them. This part focused on maximizing the output/production of PV systems in houses, by choosing the best positioning for them. On the other hand, the degradation rate of some domestic PV systems is studied. This part contains two published papers, described in Table 1.3:
Table 1.3: Table of Content, Part II

<table>
<thead>
<tr>
<th>Chapter 6</th>
<th>Analysis of the Performance a PV System Based on Empirical Data in a Real World Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title</td>
<td>Introduction</td>
</tr>
<tr>
<td>Publication</td>
<td>proceedings of the 2nd International Congress on Energy Efficiency and Energy Related Materials – ENEFM’14</td>
</tr>
<tr>
<td>Brief explanation</td>
<td>In this work, the generation of solar panels according to their location and orientation is studied. We analyzed the generation of some PV systems based on their location and orientation, using a computational model. And we compared the results to real data collected from a number of PV panels at different locations and with different orientations day-by-day and panel-by-panel for a whole year.</td>
</tr>
</tbody>
</table>
| Own contribution | - Exploring the data  
- Comparing the simulation results and real data  
- Writing part of the paper |

<table>
<thead>
<tr>
<th>Chapter 7</th>
<th>Analysis of Performance Degradation of Domestic, Monocrystalline Photovoltaic Systems for a Real-World Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title</td>
<td>Chapter 7</td>
</tr>
<tr>
<td>Publication</td>
<td>Proceedings of The Conference of Environmental and Climate Technologies - CONECT’17</td>
</tr>
<tr>
<td>Data</td>
<td>Production of PVs of different roofs of a net-zero house &amp; Weather data from the meteorology institute KNMI.</td>
</tr>
<tr>
<td>Brief explanation</td>
<td>In this paper, the degradation rate of some PV systems in a dynamic environment of a house is studied. To do that, we applied Seasonal and Trend decomposition using Loess (STL) technique on the time series of the performance of each PV system.</td>
</tr>
</tbody>
</table>
| Own contribution | - Exploring the relevant literature  
- Exploring the data  
- Extracting the performance time series from row data  
- Coding the programs with a coauthor  
- Applying STL technique  
- Writing a substantial part of the paper |

1.6.3 Part III: Addressing research question 3

A common way to optimize aspects of the thermodynamics of a house is by running simulations and manipulating different variables or parameters. However, thermal characteristics of a house have an important effect on heat energy usage. To run an acceptable simulation, it is necessary to have an approximation of these characteristics. Moreover, being aware of these characteristics, and comparing them with other similar houses (same size, building year, etc.), can help the owners to find out if there is room for decreasing the energy usage by, for example, improving the insulation level.

In this part of this thesis, the focus is on data analysis approaches to estimate the characteristics of a house based on sensory data. We know that measuring these characteristics needs precise thermal experiments. However, we propose a method to automatically estimate
two of the most important thermal characteristics of a house, i.e., the loss rate and the heat capacity, based on data gathered by a simple thermostat. Moreover, it is shown how we can use the proposed techniques to discover the reason of problems in the heating process of a house. This part contains three papers, explained in Table 1.4

Table 1.4: Table of Content, Part III

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Publication</th>
<th>Brief explanation</th>
<th>Own contribution</th>
</tr>
</thead>
</table>
| 8       | Chapter 8: Agent-Based Analysis of Annual Energy Usages for Domestic Heating based on a Heat Pump | Proceedings of The 2nd International Conference on ICT for Sustainability- ICT4S’14 | This paper proposes a simulation based approach to estimate the annual energy usage for heating a case study house using a heat pump. It is possible to use this approach to predict the energy demand of houses with more confidence. Therefore, house owners can decide the specifications for other renewable energy systems to obtain a net zero house. | - Tuning the parameters of the system  
- Fitting a mixture model to the data  
- Writing part of the paper |
| 9       | Chapter 9: An Analysis Method for a Smart Thermostat to Make Humans Aware of their Heating Energy Efficiency | A shorter version is published in the Proceedings of the International Conference on Environmental and Climate Technologies - CONECT'15 | This paper proposes a method to automatically estimate two of the most important thermal characteristics of a house, i.e. thermal capacity and the loss rate. This method is validated based on a dataset of 99 houses. | - Setting the innovative approach with a coauthor,  
- Coding and applying the suggested technique  
- Collecting the weather data based on postal codes  
- Writing a substantial part of the paper |
| 10      | Chapter 10: A Data Analysis Approach for Diagnosing Malfunctioning in Domestic Space Heating | Proceedings of The 4th International Conference on ICT for Sustainability- ICT4S’16 | In the case of a problem in the heating process that leads to wasting energy, it is important to discover it and its reason ASAP. The proposed method can be used to firstly find out that there such a problem exists, and also to identify the cause of the problem. To validate this approach, a simulation environment of the energy system in a house has been used | - Individual work & the single author of the paper |

1.6.4 Part IV: Addressing research question 4

Dynamic pricing is a common approach to achieve a better balance between electricity production and its consumption. This assumes that individual households adopt their usage
patterns based on energy prices, which is not always fully correct. Smart controllers (like smart thermostats) are tools which can help householders to shift their usage to when the energy is cheaper. These controllers can also optimize the costs by temporarily storing energy. However, the knowledge about the behavior of the users plays an important role. The subject of this part is about the impact of the behaviour of people on the energy usage and optimization strategies in households. This part contains two chapters, described in Table 1.5

Table 1.5: Table of Content, Part IV

<table>
<thead>
<tr>
<th>Chapter 11</th>
<th>The Role of Knowledge about User Behaviour in Demand Response Management of Domestic Hot Water Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brief explanation</td>
<td>This paper investigates to what extent knowledge about actual user behaviour can contribute to local optimization of energy usage. We use computational simulations to study whether a smart heating system that applies a pre-heating strategy for domestic water during periods of low prices can benefit from good predictions of the user behaviour, in financial terms or in terms of energy saving. Moreover, simulations are used to investigate the effect of different goal temperatures for the pre-heating strategy</td>
</tr>
</tbody>
</table>
| Own contribution| - Setting up the simulation environment & doing the experiments  
- Reviewing the relevant literature  
- Analyzing the simulation results |

<table>
<thead>
<tr>
<th>Chapter 12</th>
<th>A Computational Model for the Role of Advertisement and Expectation in Lifestyle Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Publication</td>
<td>A shorter version is published in the Proceedings of the International Conference on Brain Informatics - BI’17</td>
</tr>
<tr>
<td>Brief explanation</td>
<td>A computational model is proposed that simulates the dynamics of cognitive states of a human during formation and change of behaviour. Such a model can be used as the basis of a human-aware assistant system. The application domain focuses on sustainable behavior, changing the time of electricity usage. This model shows the role of short-term advertisements to propagate forming long-term behaviours and habits to a more sustainable lifestyle.</td>
</tr>
</tbody>
</table>
| Own contribution| - Setting different hypothesis and scenarios  
- Setting up the temporal causal oriented model  
- Setting the parameters of the model  
- Mathematical analysis to check the model and results  
- Writing a substantial part of the paper |

1.7 Publications

The work presented in this thesis is a collection of following papers:


• Seyed Amin Tabatabaei, Jan Treur, Erik Waumans, Comparative Evaluation of Different Computational Models for Performance of Air Source Heat Pumps Based on Real World Data, In Energy Procedia, Volume 95, 2016, Pages 459-466.

• Seyed Amin Tabatabaei, Jan Treur, Comparative Analysis of the Efficiency of Air Source Heat Pumps in Different Climatic Areas of Iran, In Procedia Environmental Sciences, Volume 34, 2016, Pages 547-558.


In addition to the papers above, the following papers also have been published in the context of this PhD project:


References


