Energy-flat housing

TOWARDS CONTINUOUS BALANCE IN THE RESIDENTIAL ENERGY SYSTEM

Graduation plan, P2

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MSc Architecture, Urbanism & Building Sciences, track Building Technology

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Graduation Studio

Name: Building Technology, focus on Climate design & Façade design

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Studio choice

Within 10 weeks from the start of my Bachelor in Architecture at the Delft University of Technology, I was completely sure that I made the right choice of study. The combination of design and technique which characterizes architecture fascinated me from the start. As my study continued, I became most interested in the topics of sustainability, climate design and energy. Building Technology interests me because of its objective, scientific based starting points. Knowledge on building technology can improve design by making it simple, to-the-point and logical.

Title of the graduation project: Energy-flat housing, towards continuous balance in the residential energy system.

Graduation project

Problem statement

Project location: The Netherlands

Problem, research questions and design assignment:

The global population and wealth growth result in an increase of energy demand. Whilst renewable and clean energy technologies are rising, the amount of CO2 produced yearly is still increasing. These emissions, combined with other sources of pollution, make the world subject to problems as climate change and global warming. In Europe, buildings are responsible for 37% of the final energy demand (IEA, 2016).

Both residential energy supply and demand are increasing and there is a shift towards electricity as an energy source. Energy consumption in the residential sector in Europe will increase with 18% in the period of 2012-2040 (IEA, 2016). Energy supply rises with the energy demand and the share of renewable
energy supply is increasing, currently being 5.8% in the Netherlands of which 4.3% is solar energy (CBS, 2016).

The intermittent nature of renewable energy supply and energy demand provokes a mismatch that has to be solved, because an energy system always should be in balance. Solutions to the rising mismatch should be researched at all levels of the energy system, including the residential level. Currently, Dutch regulations only focus on reducing demand and increasing renewable supply, neglecting the resulting mismatch. This research focuses on solving the mismatch on the residential level.

In the residential context, currently two solutions are elaborately researched, namely smart grids and batteries. Smart grids, however, only solve the electricity use of home appliances, whilst more than half of the energy used by a building is for space heating (Itard & Meijer, 2008). Batteries can help to shift building energy, but batteries always imply energy losses and environmental impact because of their cycle efficiency and embodied energy.

To solve the energy mismatch on a residential level, dwellings will have to be able to adapt the demand to supply and vice versa. This research focuses on buildings that eliminate the on-site electricity mismatch by architectural design; energy-flat buildings. In energy-flat buildings, the demand and supply of electricity are mutually adapted by design in such a way that they are continuously in balance.

**Research aims, questions and objectives**

This research aims to solve the residential energy mismatch by providing a definition of energy-flatness in the residential context in terms of performance indicators. Moreover, it aims to explore design principles that stimulate energy-flat buildings and to make an example design that is fully focussed on energy-flatness. To fulfil these aims, the main question of this research is:

> How can the residential mismatch of the supply and demand of energy be solved by architectural design?

To find the answer to this question, the following sub-questions are defined:

- What is energy-flatness and what are its key performance indicators?
- How can the supply and demand profiles be adapted?
- How should the energy-flat performance of a design be evaluated?
- What is the mismatch between supply and demand?
- What could an energy-flat design look like?
- How do energy-flat buildings relate to solving the mismatch in the energy system that the building is part of?

The objectives of the research are

- Defining the key performance indicators both graphically and mathematically
- Providing an overview of parameters and design principles that influence residential supply and demand
- Setting up an energy-flatness model that is able to evaluate the energy-flat performance of a design
- Analysing the residential energy supply and demand profiles to determine the current mismatch
- Designing an example design solution for a completely energy-flat house
- Positioning the results in the energy system that a building is part of
Design assignment

The design assignment of this research is included in the objective of ‘Designing an example design solution for a completely energy-flat house’. As will be explained in the methodology section, this objective consists of three designs; one design in which supply fully adapts to demand, one design in which demand fully adapts to supply and one design which takes the best of the two former designs by mutually adapting supply and demand.

Considering the scope and goal of the research, it is expected that the design solutions are extreme and out-of-the-box rather than realistic (i.e. cost-effective). Several studies have shown that energy storage is an essential element in demand-side management and flexible generation. By neglecting the possibility of storage, however, extreme and out-of-the-box solutions will be required to solve the problem. These solutions will explore the boundaries of design as means to reduce the mismatch, they will serve as inspiration for designs and might as well show the potential of new design solutions.
Methodology

The six sub-questions and their related objectives are the basis of the overall methodology. Figure 1 shows how the combination of research questions will lead to answer the main question. The vertical location of the blocks suggests a certain chronology; however, it is considered that a research will have an iterative nature and the flow therefore is not too strict.

All questions and their related objectives are explained in the next section. The last section will show how the answers to the questions relate to each other.

What is energy-flatness and what are its key performance indicators?

To answer this question the following three objectives are achieved:

- Define energy definitions
- Determine the system boundary
- Define key performance indicators

To define the energy definitions, a literature study is done on definitions in the building energy system. Lots of research is done in building energy, so it is important the definitions used in the study relate to the commonly accepted definitions. The system boundary is provided by filling in the framework for Zero-Energy-Buildings as set up by Sartori, Napolitano, and Voss (2012). This framework allows for a logical and complete scoping of the energy system for a building.

The key performance indicators (KPI) are defined by myself, based on meetings with tutors at the Delft University of Technology and inspired by literature. Peer-reviewed papers have been used to explore other performance indicators ((Salom et al., 2011) and (Widén, Wäckelgård, & Lund, 2009)), but it is concluded that the simplicity of the initially designed performance indicators suits the need for to-the-point validation the best. The KPI's are graphically and mathematically defined and are used to evaluate the energy-flatness of a design based on its supply and demand profiles.
The three KPI’s are shown above. KPI 1 is the absolute energy-flatness and is used to determine how energy-flat a design is; the lower the value the better, in which a value of 0 means perfect energy-flatness. In the case that perfect energy-flatness is not reached (which is to be assumed), KPI 2 and 3 can be used to gain more knowledge about the nature of the mismatch. The KPI’s can be used on the supply and demand profiles on different balance periods and time intervals (e.g. daily, monthly, yearly) to provide different insights of the mismatch (e.g. hourly, weekly, seasonally).

How can the supply and demand profiles be adapted?

An overview of parameters and design principles is set-up to show how a building design can be adapted to achieve certain changes in the demand and supply profiles. To determine how the supply and demand profiles can be adapted, research is done to supply and demand solving in:

- other disciplines; by researching basic principles of economics, biology and studying the theory of the Tragedy of the Commons by Hardin (1968).
- other levels; by researching solutions to supply and demand mismatch on the regional, national and international levels.
- other buildings; by researching precedents of sustainable buildings and characteristic elements. Moreover, a literature review on design tools is done that were not found in the precedents.

This research will result in an overview of parameters that have a certain influence on the considered energy flows. The parameters are categorized to design principles using the six profile adaptions as defined by Gellings and Smith (1989). Below, a suggestion of the parameter overview is shown, in which on the right the principles by Gellings and Smith are located:
As has become clear in the system-boundary section, as part of sub-question 1, the focus will be on the parameters in the category of ‘Building’. Climate and user parameters are assumed to be unchangeable. However, changes in user parameters might be suggested if they are easy compared to changing the building parameters. This will become clear in sub-question six: “How do energy-flat buildings relate to solving the mismatch in the energy system that the building is part of?”

How should the energy-flat performance of a design be evaluated?
The energy-flatness of a design is determined by the values of the KPI’s resulting from its demand and supply profiles. These profiles are generated by a dynamic energy-model, using the software package TRNSYS. TRNSYS is a software environment that can be used to simulate transient systems, including the dynamic energy modelling of a building. The software has been commercially available for 35 years and is commonly used in professional practice. The software package consists of a kernel which translates the input to the output and a library of components that can be used to be part of the simulation.
The input and output of the TRNSYS model can be highly customized. The input will be provided by the designs that are made, as well as the user-profile consumption data as discussed in “What is the mismatch between supply and demand?”. The initial output will be the energy demand and supply profiles, which will be translated into the key performance indicators. Figure 3 shows the role of the TRNSYS model.

What is the mismatch between supply and demand?
The mismatch will be defined by determining the supply profile and the demand profile, and then mutually comparing them using the KPI’s as explained in the first section. Moreover, the mismatch will be analysed on a more qualitative level by analysing exceptions and determining the distribution of the different energy flows in the demand and supply profiles.
The demand and supply profiles will be determined in two ways. All the user-depended energy flows (i.e. plug-loads, lighting, domestic hot water) are set by taking Dutch averages, derived from online databases. The building-depended demand flows (i.e. heating, cooling and ventilation) and all energy supply flows (i.e. solar radiation) are determined using the energy model from the previous section. The user-depended flows are, regardless their fixed nature, integrated in the energy model. This way, there will be one overview of outputs of the energy model that can be used for analysis directly.
The KPI analysis and the qualitative analysis of the mismatch result in an overview of the characteristics and potentials of the mismatch, which is used as a starting point for the designs combined with the parameter overview.

What could an energy-flat design look like?
An energy-flat design has the goal to have a perfect match between supply and demand at all times. The earlier defined design principles will be the inspiration for the designs. Energy-flatness will be reached by adapting the profiles of supply and demand. However, since there are two different profiles (i.e. supply and demand), it is undetermined how they should adapt to each other. Three different designs are made to optimize the mutual adaptation. In the first design, the demand profile will be adapted to the (fixed) supply profile. In the second design, the supply profile will be adapted to the (fixed) demand profile. The third design will combine the knowledge of the former two designs by mutually adapting the profiles in the most efficient way. The set-up is shown in Figure 5.

The designs will be documented in a way that can be properly expected from an architectural design, taken into account the focus of the research. Plans, elevations and sections will be provided in scale 1:100. If appropriate, more detailed drawings of details might be added to explain the cornerstones of the designs.

How do energy-flat buildings relate to solving the mismatch in the energy system that the building is part of?
Solving the mismatch of supply and demand completely on the residential level, might not be the most favourable solution depending on the context. Lund, Marszal, and Heiselberg (2011), for example, conclude that for a national energy system, the mismatch of supply and demand can have both a positive or negative effect on the bigger system. At the end of the research, the question to how the energy-flatness in the residential setting relates to bigger systems is answered. It will provide a critical reflection.
on the results as well as give direction to successive research. The answer to this question will be provided partly by literature research from peer-reviewed papers, my own reflections on the research and discussion with my tutors and other scientists.

**Relation of all the sub questions to answer the final question**
All the research based on the several questions provide results that are used to complement each other. Below the main results of the five research questions are shown, as well as how they relate (N.B. the last research question is not regarded, because it is a reflective question that is not part of the design iteration in this research). The reference is used as the starting point. From this, the design principles are used to come up with a design that is assumed to be better. This design is then evaluated using the TRNSYS energy model, whose results are analysed on energy-flatness using the Key Performance Indicators. This will show to what extent the design suffices and where it lacks performance. Then the design principles are used again to improve the design, etcetera. The iteration will be followed until a sufficient design has been reached.

![Diagram](image)

Figure 6: the results of the sub questions are used to set up the iterative design process

**Literature and general practical preference**
The literature used in this research mostly consists of peer-reviewed, recent (i.e. <10 years) papers. Besides, (inter)national databases are used for general data on energy. Moreover, Dutch governmental websites and data is used for the typical Dutch energy consumption and an overview of the regulations.

Regarding images, the aim is to adapt all images to the visual style of the Master thesis and simultaneously filter merely the relevant information. Where possible, own illustrations are used.

Finally, knowledge and experience of researchers and professionals is used by having both informal and formal meetings. These meetings will provide indirect feedback and input.

The complete list of literature used is shown below. All literature is provided in APA6th format, as is required by the Delft University of Technology for a Master Thesis. The list below might expand as the research continues:


Reflection

Relevance

Societal

The Netherlands have the aim to have a completely energy neutral built environment in 2050. Whilst regulations are a useful means to implement sustainability measures to reach this goal, social engagement is an essential factor as well.

This research provides new insights in sustainable dwelling design. It will explore possibilities to make local renewable energy production more cost-effective and simultaneously improve the national energy system. The theoretical extreme designs explored in this research, might inspire society and stimulate them to rethink sustainable buildings. Moreover, the introduction of the term energy-flatness will make the importance of self-consumption clearer and could eventually be used in marketing-terms as well to stimulate society to change towards a sustainable energy balance.

Scientific

This research fills the scientific gap of energy-balancing on the building level. Regionally and nationally, research is done to balance out energy supply and demand by storage, demand-side management, flexible generation, and interconnection. Within the household, smart grids and domotica are introduced to adjust the on/off times of appliances to the availability of electricity. By mutually adjusting on-site energy supply and demand, the research provides new insights in energy balance potentials on the residential level. Making dwellings completely energy-flat, purely focusing on the local supply and demand, is probably not the easiest and best solution. It is thus made clear that this research has the aim to explore (extreme) possibilities to contribute to general knowledge on this topic, from which eventually an optimal design can be derived.

Personal

With every piece of literature concerning climate change and the role of humans in this, I am more surprised on how we (i.e. the human population) got behind on compensating our environmental faults.

In a world that has the big challenge to transform the complete built environment into a sustainable, self-sufficient system, I am eager to dedicate my time and effort to contributing to this process. By doing this research, I gain more knowledge on energy flows in a household and how they can be changed. My overall knowledge on climate change and sustainable buildings will be improved. Moreover, this research also provides a good base to determine whether a successive study in the form of a Ph.D. might suit me.

Finally, I strongly prize the format of a Master thesis as a final project of the studies. Having nine months to extensively research a topic of a students’ own interest, is in my opinion a very motivating and stimulating way to effectively broaden knowledge and gain academic experience.
Time planning

The planning is set-up in line with the methodology and the sub questions, combined with a set of general activities and preparations for official assessments. The formal assessments P1-P5 are fixed in time by the Board of Examiners, the rest of the planning is constructed around these dates.

The period until now (P2) has mostly focussed on the first exploration of the field and the literature review concerning energy flatness and solutions to that. A first report set-up has been made, which allows for a clear structure of the research.

After P2, first the focus will be on finalizing the parameter overview and evaluating the mismatch in the reference case. Parallel to this, the TRNSYS energy model is set up. The reason for these parallel tracks is the assumption that these activities might improve each other’s quality by mutual reflection; the model is needed to evaluate the mismatch whilst the functionality of the model is checked by the evaluation.

Hereafter, a quick review on the earlier finished literature study will be done, because the model set-up and evaluation of the mismatch will provide new information on the relevance of certain input and output information.

Then, the final design phase starts. First, the two designs in which only one of the profiles adapts to the other will be made by the iterative process of design and modelling. Hereafter, a short review is done to the parameter overview which might be improved by the results of the first two designs. Finally, the final design is made based on all the previous knowledge.

The last weeks of the process will focus on improving and critically reflecting the documentation of the research.
Appendix 1: time planning

<table>
<thead>
<tr>
<th>Subquestions</th>
<th>Task</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presentations and products</td>
<td>Prepare presentation (P1 - P5)</td>
<td>Preparation</td>
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<td></td>
<td>Graduation plan</td>
<td>Preparation</td>
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<td></td>
<td>Thesis report to desired level</td>
<td>Preparation</td>
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<tr>
<td>General</td>
<td>Exploration of the field</td>
<td>Exploration</td>
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<td></td>
<td>Background research</td>
<td>Literature review</td>
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<td></td>
<td>Framework set-up</td>
<td>Creation</td>
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<tr>
<td>What is energy-flatness?</td>
<td>Energy definitions</td>
<td>Literature review</td>
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<tr>
<td></td>
<td>Determine the system boundary</td>
<td>Literature review</td>
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<tr>
<td></td>
<td>Define key performance indicators</td>
<td>Creation</td>
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<tr>
<td>How can the supply and demand profiles be adopted</td>
<td>Solutions in other levels/scopes</td>
<td>Literature review</td>
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<tr>
<td></td>
<td>Solutions in other disciplines</td>
<td>Literature review</td>
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<td></td>
<td>Solutions in other buildings (precedent study)</td>
<td>Precedent study</td>
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<td>How should the energy-flat performance of a design be evaluated</td>
<td>Download/install learn basics TRNSYS</td>
<td>Exploration</td>
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<td></td>
<td>Define (additional) input for model</td>
<td>Literature review</td>
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<tr>
<td></td>
<td>Define (additional) output for model</td>
<td>Literature review</td>
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<tr>
<td></td>
<td>Create energy-flatness model in TRNSYS</td>
<td>Creation</td>
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<tr>
<td>What is the mismatch between supply and demand?</td>
<td>Average user-consumption data collection</td>
<td>Literature review</td>
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<td></td>
<td>Modelling of reference design</td>
<td>Creation</td>
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<td></td>
<td>Evaluation of the mismatch</td>
<td>Creation</td>
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<td>What could an energy-flat design look like?</td>
<td>Design variant 1</td>
<td>Creation</td>
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<tr>
<td></td>
<td>Modelling of variant 1</td>
<td>Creation</td>
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<tr>
<td></td>
<td>Upgrade of variant 1</td>
<td>Creation</td>
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<tr>
<td></td>
<td>Design variant 2</td>
<td>Creation</td>
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<tr>
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<td>Modelling of variant 2</td>
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<tr>
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<td>Upgrade of variant 2</td>
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<td>Design variant 3</td>
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<tr>
<td></td>
<td>Upgrade of variant 3</td>
<td>Creation</td>
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<tr>
<td>How do energy-flat buildings relate the mismatch in the bigger energy system?</td>
<td>Literature study based on results</td>
<td>Literature review</td>
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