BACHELOR THESIS REPORT

Energy as a student's priority

ANALYZING ENERGY USE OF UNIVERSITY STUDENTS

M.J. WESTERHUIS

STUDENT NUMBER: 1460668

CIVIL ENGINEERING, FACULTY OF ENGINEERING TECHNOLOGY

UNIVERSITY OF TWENTE, ENSCHEDE

1 JULY 2016

jouw woningcorporatie DE VESTE

UNIVERSITY OF TWENTE.

Colofon

Report of bachelor thesis project

Study program: Civil Engineering (Bachelor stage)

Module: 12

Academic year: 2015/2016

Project conducted between 18 April 2016 – 1 July 2016

Report submitted on 1 July 2016

Author

Mark Jacob Westerhuis
Civil Engineering (Bachelor stage), cohort 2013
University of Twente, Enschede
Student number: 1460668

Principal

Woonstichting De Veste
Eskampweg 1
7731 TA Ommen

Supervision

M. Colenbrander
Woonstichting De Veste (location Enschede)
Housing counselor

dr. ir. A.G. Entrop
University of Twente, Enschede
Faculty of Engineering Technology
Department Construction Management & Engineering

Foreword

As part of the study program Civil Engineering at the University of Twente, a scientific research project is to be undertaken by the participating students during the fourth and final module of the third year. This research project needs to be carried out in commission of a commercial company or a research institute. The duration of the project amounts to a minimum of ten weeks, during which the students are meant to be adopted by the external organization as regular employees. The goals of this module are to let students get acquainted with scientific research practices and also introduce them to their future working field within civil engineering.

This document contains the results of a research project that was conducted for housing corporation De Veste. Research took place at the campus of the University of Twente, with the goal being to develop a model that describes the use of energy of students. The reason to initiate this project was the first ever occurrence of the Sustainabattle, a competition in which student communities compete against each other by lowering their energy use levels as far as possible over the course of a month. This event was perceived as a full scale experiment with which the outcomes of the project could be validated.

The author would like to thank a number of people who were supportive throughout the project and helped in fulfilling the research goals. First, Martin Colenbrander, Richard Ditzel and Annette Weenink of De Veste are gratefully mentioned for their practical support and their willingness to help obtaining the information that was needed to do the research. Tim Reuvekamp for critically looking at the draft report and suggesting improvements. Student communities *Crib Soleil, Beverburcht, Huize Bosøl and Pimpelpatio* for their cooperation for conducting interviews. Rinke, Jannie, Esther and Agnes Westerhuis, for being patient family members during the project and for their moral support throughout the past months.

Mark Westerhuis

Gronau (Westfalen), Germany

1 July 2016

Summary

Housing corporation De Veste owns and administers rental houses in the Netherlands. Part of the housing stock of De Veste includes dormitories for university students, which are located at the campus of the University of Twente in Enschede. In these dormitories, circa 2100 students live together in groups of circa ten individuals. Every student has his/her own room, which is rented by De Veste. Because De Veste aspires to turn all of its properties into energy neutral dwellings (houses using the same amount of energy as is being produced on site, thus creating a zero net energy consumption), this also applies to the student housing at the campus. To reach this objective, it is recognized that the students in their role as lessees should be made to contribute to reaching this goal by lowering their average energy use levels. Yet, despite available studies on energy usage by households in a general sense, it is unknown how students exactly make use of energy and what the defining influences are. Knowledge about this topic is required to be able to make the right decisions with respect to future measures for making the dormitories more sustainable. It is also in the interest of sustainability science in general to get a better view on the energy use by different groups in society.

For these reasons, a research project has been initiated. The overarching goal is as follows:

"The aim is to develop a model that describes the energy use behavior of students by conducting a case study research on dormitories at the campus of the University of Twente."

By making use of the model, the model's user can make predictions about the way in which measures in reality will unfold before they are implemented. Moreover, the findings of the project throw a light upon a thus far underexposed topic within sustainability science. By filling the knowledge gap that exists with regard to the energy use of students as a specific societal group, a more nuanced view on energy use by different household types is established.

For the thesis project, a number of research methods were made use of: both literature and case studies were conducted, as well as data analyses. This way, the different variables of the energy use model and the relations between them could be developed and underpinned.

The validation of the model took place through using the results from interviews with students and evaluating energy use data that was generated during the Sustainabattle. This is a competition in which groups of students compete against each other by lowering their energy use as much as possible over the course of a month. One such competition was organized by De Veste, the University of Twente, sustainability foundation *Generatin'* and sustainability consultancy firm *Zienergie B.V.* at the campus of the University of Twente. For the project, the Sustainabattle was effectively used as a full scale experiment to see whether the functioning of the model coincides with reality.

The literature and case studies returned a list of energy use characteristics, that was brought down to a number of model variables, which are listed in Table 1 and also depicted in Figure 1. These model variables were put into four categories: *Building, Systems, Appliances and Inhabitants*. Between these variables, 17 relations were established in which one variable influences another positively or negatively, depending on what state it is currently in and how that state changes in time to come. After the validation had taken place, one more variable ("Intensity of use appliances") was added, together with its associated relations to other variables. The resulting model is presented in Figure 1.

Table 1: Variables of energy use model

Building	Systems	Appliances	Inhabitants
Transmission surface	Heating concept	Presence of energy sue appliances	Environmental awareness
Degree of infiltration	Heated tap water concept	Presence of lighting	Group motivation
	Ventilation concept	Presence of construction-related energy equipment	Prospect
	Cooling concept	Quality of appliances	Effort
		Use of technology	
		Intensity of use appliances	

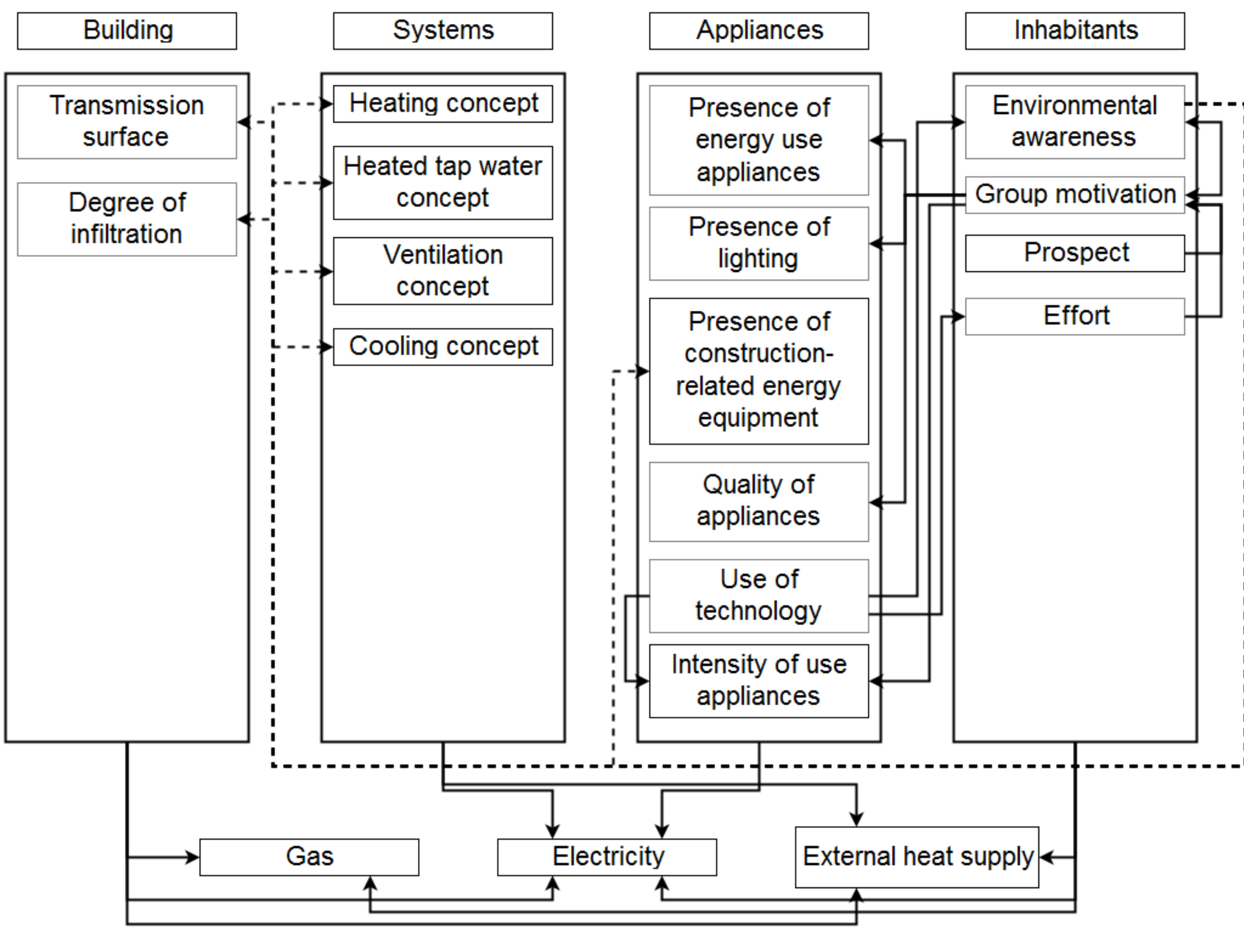

Figure 1: Energy use model

The resulting energy use model indicates that there are both similarities and differences between students and other types of households. Both students and other groups in society share that they have an economical way of thinking when it comes to making efforts for sustainability: as long as a measure does not deliver substantial results, it will not be executed. On the other hand, students differ from other societal groups in that they live in communities and that their dwellings, at least in the case of the University of Twente, do not always comply with today's standards concerning insulation. In practice, the success of motivating students to lower their personal and collective energy use level is significantly dependent on the motivation of a complete student community and not only on individuals.

With this model, De Veste now owns a useful tool that can be used as a guide to evaluate measures and actions for a more sustainable campus, whereas the scientific community receives a clearer view on students and their way of living.

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1. Introduction

This chapter provides an introduction to the background and the specifics of the project. After an explanation about the cause for carrying out the project and the provision of additional background information, the associated research aim, questions and methods will be addressed subsequently. Finally, a reading guide gives an overview of the rest of the report.

1.1 Background and nature of the thesis project

In 1990, the Intergovernmental Panel on Climate Change reported in its first official assessment that humanity is responsible for the current deterioration of the global climate (Intergovernmental Panel on Climate Change, 1990). In the following years, agreements at the international level were signed to implement sustainability in policy, such as the *United Nations Framework Convention on Climate Change* (UNFCCC) in 1992, which forms the foundation for the *Kyoto Protocol* (1997) and the *Paris Agreement* (2015).

At smaller scales, too, the call for governments and companies to approach the management of natural resources and ecosystems in a more sustainable way has steadily increased. Movies such as "An Inconvenient Truth" by Al Gore have become well-known outcries against the current human influence on the world's climate. Furthermore, Non-Governmental Organizations (NGO's) are keeping a close eye on the implementation of signed agreements by national governments. A recent example is the lawsuit that sustainability foundation *Urgenda* filed against the Dutch state in 2015, demanding more effort from the responsible minister to reach previously formulated targets concerning sustainability (Urgenda, 2015). To everyone's surprise, Urgenda came out as the victor of the trial, which indicates that NGO's are indispensable in reaching sustainability goals and do have substantive knowledge on the matter.

One of the fields to pay attention to when pursuing sustainability at a large scale is housing. Globally, 20 to 40% of all energy used is spent on the employment of commercial and residential buildings (GhaffarianHoseini, Dahlan, Berardi, GhaffarianHoseini, Makaremi, & GhaffarianHoseini, 2013). This number includes 23% of the global air pollution and 50% of greenhouse gas production (Yilmaz & Bakis, 2015). To lower this percentage, it has been "internationally recognized to promote innovative approaches for mitigation of carbon dioxide (CO2) emissions […]" (GhaffarianHoseini, et al., 2013). For instance, the industry for solar energy is expected to reach a value of $18 billion in 2019 (SolarPower Europe, n.d.) whereas sustainability has now become a central topic already during the design of a building (Yilmaz & Bakis, 2015). Parallel to this development, assessment methods for a building's performance in sustainability, such as BREEAM and LEED, are gaining importance (Yilmaz & Bakis, 2015).

Although considerable research has been devoted to studying the effects of the measures mentioned above and analyzing energy use in dwellings, the different types of households are not clearly discerned from each other. To date, little is known about the energy use of students, who constitute a distinct group in society regarding their lifestyle and habits (Stanes, Klocker, & Gibson, 2015). The purpose of this thesis project is, therefore, to fill up this knowledge gap by discovering how students use energy in daily life. The results of this undertaking are presented in this report.

1.2 Principal: Housing corporation “De Veste”

The principal of the thesis project is housing corporation De Veste. With a current size of circa 40 employees and its principal seat in Ommen, De Veste is a Dutch company that is active on the real estate market in the eastern and northern parts of the Netherlands. It was originally founded as Stichting Woningbouw Avereest in 1961 and owned a total of 6200 dwellings as of the year 2012. These properties are located in Enschede, Ommen and on the island of Terschelling. The properties in Enschede are 40 dormitories located at the campus of the University of Twente (see Appendix A: Map of campus of the University of Twente). They are solely meant for the accommodation of circa 2100 students (Woonstichting De Veste, 2014).

Furthermore, a number of daughter companies is related to De Veste, *including Salland Vastgoed Participaties BV*, *De Veste Projectontwikkeling BV*, *De Veste Planontwikkeling BV* and *WOM Atolwijk BV*.

Ever since De Veste welcomed a new managing director in 2014, a new strategy for conducting business has been adopted, too (Woonstichting De Veste, 2014). The relationship between the tenants of the properties and De Veste is receiving more priority and attention than before, which is expected to lead to a better cooperation from both sides in all circumstances. De Veste aims to be an active participant in societal developments, in order to be able to provide affordable housing of good quality to individuals and families.

1.3 The Sustainabattle

As part of its efforts to promote and stimulate a sustainable lifestyle among students, De Veste entered a joint venture with sustainability foundation *Generatin’,* sustainability consultancy agency *Zienergie BV* and the University of Twente. Together, these parties initiated a competition called “Sustainabattle” (Sustainabattle, 2016). The Sustainabattle is of great importance to this project, as this event will be used as a tool for the validation of the projects’ result.

During the Sustainabattle, groups of students living in the same dormitory or sharing the same dormitory floor at the campus of the University of Twente compete against each other in order to lower their electric energy use as much as possible. The time span of the competition is one month, with the edition of 2016 taking place from the second week of April until the second week of May. At the end of this month, the group with the lowest energy use level and the best presentation held during a special event for all participating groups is awarded the title of most sustainable student group, along with additional prizes. Further information on the Sustainabattle can be found in Appendix B: The Sustainabattle.

In a broader context, the Sustainabattle is part of a strategy initiated by the University of Twente, called “Smart Living Campus”, which is meant to contribute to the development of the campus towards being a place of sustainable living, learning and working. The goals set by the different projects within Living Smart Campus are to be reached by the year 2020, as formulated by the University of Twente in its development strategy “Vision 2020” (University of Twente, n.d.).

1.4 Problem definition and research aim

De Veste is committed to turning all its properties into energy neutral buildings, also referred to as Nearly Zero-Energy Buildings (European Commission, n.d.; Marszal, Heiselberg, Bourrelle, Musall, Voss, Sartori, & Napolitano, 2011). To date, however, no deadline(s) have been formulated as to when this goal needs to be achieved. Among the supporters for energy neutral buildings is the European Commission, which in 2010 adopted a new directive that defines rules that the EU member states need to adhere to. This document is officially named the Energy Performance of Buildings Directive, abbreviated as EPBD (European Commission, 2010). Against this background, De Veste is thus not only acting on behalf of its own objectives, but also answering to the obligations formulated by the EPBD.

Eventually, the residential buildings at the campus of the University of Twente will also have to meet the energy use standards of the EPBD. To reach this objective, the cooperation of the students living in the dormitories is needed, which in practice means that they should bring down their energy use level. It is, however, unknown what characterizes students in their habits of energy use and what their views on sustainability are. This knowledge is mandatory to be able to make the right decisions for future projects and investments. The problem definition is thus:

"It is unclear how students living in dormitories at the campus make use of energy in their daily lives, which leads to De Veste not knowing how students can be motivated to live more sustainably."

This problem will be solved by making an analysis of the way students use energy in their daily lives. For one, the knowledge generated through this undertaking will contribute to the body of knowledge concerning energy use by a certain societal group. Moreover, the analysis will also provide De Veste with insights into possibilities to reach their sustainability targets.

In order to describe the energy usage of students, it is necessary to develop a model. This project will, therefore, be concerned with finding the constituents of the model (variables) and the relationships between these constituents. Both literature and students living at the campus will be treated as sources of information for the model. Consequently, the definition of the research aim is as follows:

"The aim is to develop a model that describes the energy use behavior of students living in dormitories at the campus of the University of Twente by conducting a literature and case study research."

All activities to reach the aim of the research were completed within quartile 4 of the academic year 2015/2016, which amounts to eleven weeks. The final date to finish the work was set on 1 July 2016.

1.5 Research framework

Based on the research aim given above, the main research questions to be answered is:

"What variables and relationships belong to a model that describes the energy use of students, given the architecture and installed systems of dormitories at the campus of the University of Twente?"

By breaking down the main question into four research questions, the project becomes better manageable. The research is related to three different phases of the model, as presented in Figure 2.

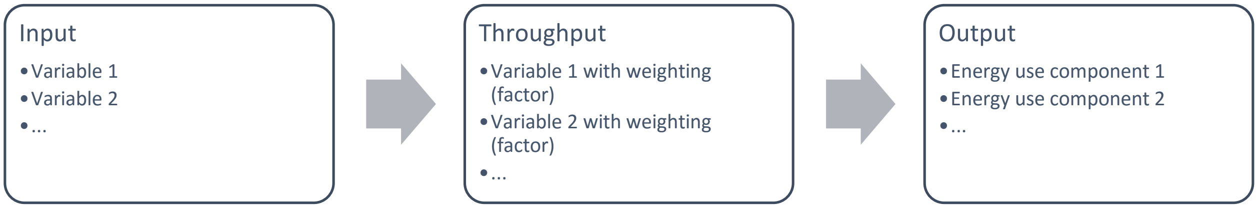

Figure 2: Schematic overview model

The first research question is related to finding the model's variables, which are connected to the input phase of the model. Next, the second research question takes the form of an attempt to apply these variables to students and see what makes them different from other types of households concerning energy use in everyday life. It does not relate to any phase of the model. The following step (research question 3) involves the search for possible interactions between the variables, which is connected to the throughput phase of the model. The output of the model contains the factual energy use levels, which are influenced by the model's variables. For the output phase, no research question has been formulated, because the necessary time, skills and resources for determining the effect of the variables on the output were not available. However, a qualitative assessment model will be made. To eventually validate the model, a fourth research question has been developed.

The final list of research question is as follows:

1. **Which characteristics have an influence on the energy use of students?**

This research question will be concerned with finding the characteristics that form the basis of the energy use model. It will be addressed by two different research techniques: a literature study and a case study. As to the literature study, the findings of other authors in the field of sustainability will be used for the purpose of finding new energy use characteristics. The case study among students living at the campus of the University of Twente will include interviews in order to obtain additional information for adding or removing energy use characteristics from the list. By selecting student groups taking part in the Sustainabattle, their performance in the competition could be compared to their daily life outside of the Sustainabattle. The groups were chosen on the basis of the Sustainabattle's final ranking regarding energy savings, including both the winning and worst performing groups, as well as two averagely performing communities. More information on the Sustainabattle and the groups can be found in Appendices B and C, respectively.

2. **Which energy use characteristics can be adopted into the energy use model?**

For research question 2, the variables to be used in the energy use model are selected in two steps. First, the energy use characteristics are operationalized, which means that the found characteristics are applied to students to see in which way students differ or have common grounds compared to other societal groups. This knowledge is useful for substantiating the relations between the model's variables, later on in the project. The operationalization also allows to make a first selection of characteristics that cannot be considered for use, any longer. Second, the final selection of variables is made by conducting an assessment of the adjustability of the characteristics. The result is a list of energy use characteristics that incorporate adjustable variables to be used in the model. For the operationalization, a literature study and a case study (interview) are conducted, whereas the adjustability assessment takes place on the basis of available information about the possibilities of De Veste.

It is necessary to make a selection of variables instead of using all energy use characteristics, because there is too little time to establish relations between all energy use characteristics. Furthermore, the decision has been made to make a model for De Veste that allows for every variable to be altered according to De Veste's wishes. As not every characteristic can be adjusted to another state, these have purposefully been left out.

3. **What relations do exist among the variables of the energy use model?**

The third research question concentrates on the relations between the model's variables. As with the two earlier research questions, a literature and case study were carried out to find these relations. The final result is a preliminary version of the energy use model that still needed to be validated.

4. **How does the model's description of energy use among students comply with reality?**

Lastly, the model needs to be validated, for which research question 4 has been formulated. The validation takes place through an evaluation of data and interview results gathered during the Sustainabattle (see Appendix B: The Sustainabattle). Moreover, another look at literature is taken to find additional confirmation for the correctness of the model. In Table 2, an overview is given of the research questions and their related research techniques. More detailed explanations about the individual research techniques can be found in Appendix D: Research methods.

Table 2: Research questions and associated techniques

Research question	Research technique
1a: What energy use characteristics have an influence on the energy use of students, based on literature?	Literature study
1b: What energy use characteristics have an influence on the energy use of students, based on a case study?	Interview, measurements (case study)
2a: What value do the characteristics have, when applied to students, based on literature?	Literature study
2b: What value do the characteristics have, when applied to students, based on a case study?	Interview, measurements (case study)
2c: Which characteristics can be altered by De Veste, based on their abilities?	Assessment
3: What relations do exist among the variables of the energy use model?	Literature, data analysis, interview
4: How does the model's description of energy use among students comply with reality?	Literature, data analysis, interview

1.6 Reading guide

The structure of this document orients itself after the research questions. Chapter 2 is about the search for characteristics that define the energy use of students. Its result is a list of these characteristics. Chapter 3 contains the operationalization of the characteristics by applying them to students and see what value they have. Second, the most useful characteristics for the energy use model will be selected. Chapter 4 is concerned with finding the relations that exist between the model's variables. Finally, Chapter 5 concentrates on the validation of the energy use model through the findings of the Sustainabattle.

2. Characteristics of students' energy use

The results of the search for characteristics that define the energy use of students will be presented in this chapter. The related research question (research question 1) is the following:

"Which characteristics have an influence on the energy use of students?"

The energy use characteristics form the foundation of the energy use model, which is the final objective of this project. These will be searched for by conducting a literature study and a case study. After an explanation about the way in which the presentation of the results is organized, the individual research techniques will be addressed. The chapter's conclusion will be a list of energy use characteristics that is tailored to the habits of students as a specific group.

2.1 Organization of the research

The research for coming to the desired result has been organized along two different paths, which run parallel to each other. To keep track of the report's content in this chapter, an explanation is needed to clarify how these paths are related.

The first path consists of two research methods governing the activities for finding energy use characteristics: a literature study and a case study. The second path is a framework of six abstraction levels that will be applied to the literature and case studies. It narrows down from households in general to individual students living at the campus of the University of Twente (see Figure 3). The energy use characteristics will be obtained according to these levels. This way, it is ensured that all relevant aspects concerning energy use among students at both general and detailed levels are covered.

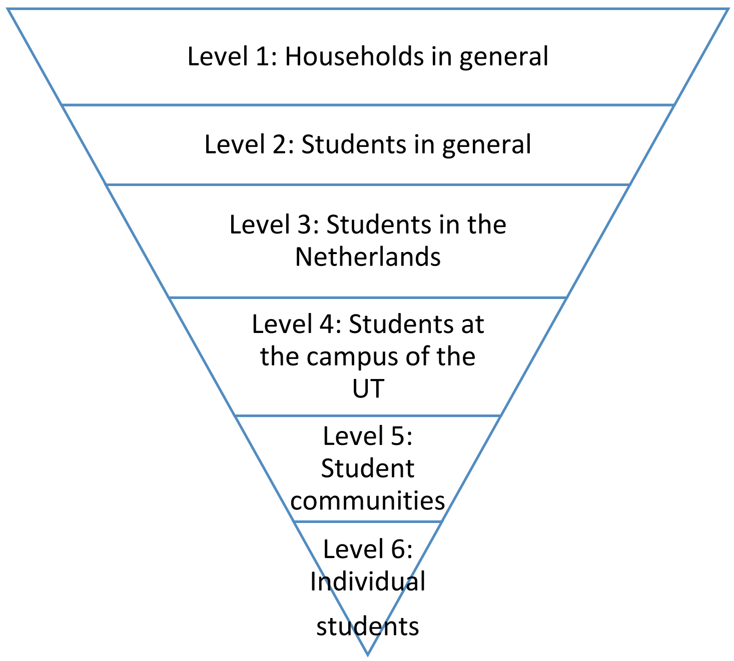

Figure 3: Six abstraction levels

The relation between the two mentioned paths is that the literature study is coupled to abstraction levels 1, 2 and 3, because the required information for these levels mainly comes from literature. The other three levels of abstraction (4, 5 and 6) will be addressed by a case study at the campus of the University of Twente.

To simplify and shorten the search for characteristics that define the energy use of students, an already existing list containing energy use characteristics for households in general will be taken as a starting point (Entrop, 2013). A distinction can be made between five *main characteristics* and thirty *sub characteristics*. The five main characteristics are:

1. Environmental characteristics; variables related to the environment, be it natural or artificial, in which a building is located
2. Occupational characteristics; variables related to the residents of a dwelling whose behavior influences the energy use of a building
3. Building characteristics; variables related to the architectural features of a building which are considered to be influencing the energy use
4. System characteristics; variables related to heating, cooling, ventilation and electric systems in or attached to a building
5. Appliances; variables related to (electric) devices that use energy or reduce energy use, but do not necessarily contribute to healthy and comfortable living environments

The *sub characteristics* are related to these five *main characteristics.* Figure 4 gives a visual representation of the list with the main characteristics at the top and the sub characteristics in boxes underneath the main characteristics.

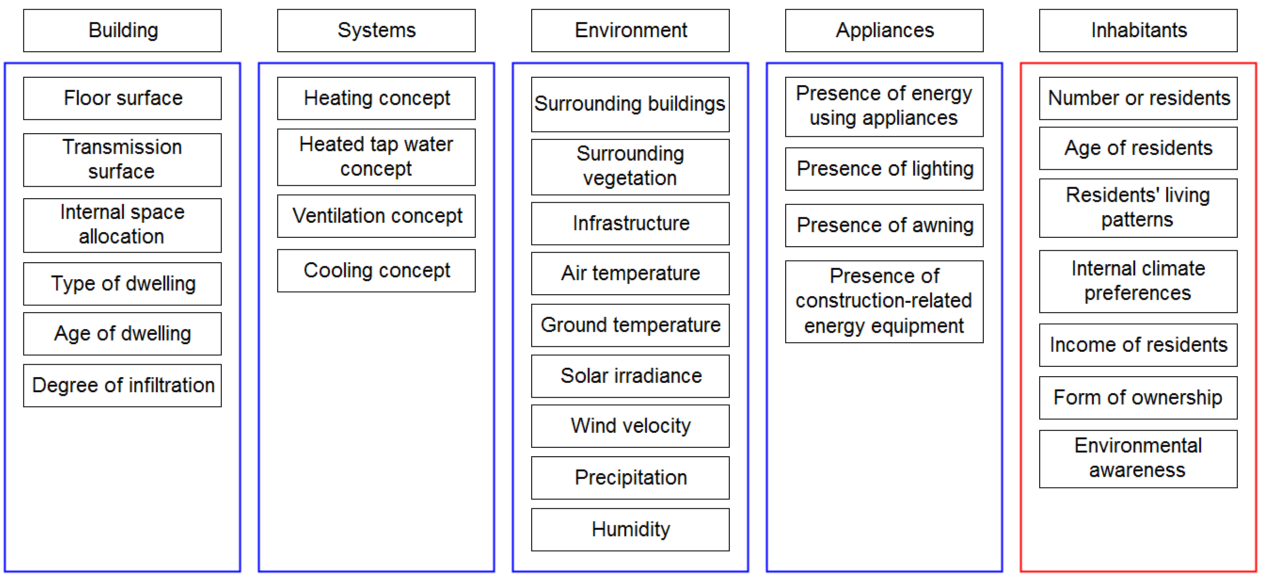

Figure 4: Energy use characteristics according to Entrop (2013). Boxes technically oriented characteristics indicated in blue, box social characteristics indicated in red

The reason for approaching the project using this list, is to save time by building upon available research concerning energy use in general and adding or removing parts if necessary. Due to time restrictions, the correctness of the list will not be disputed. This does pose a threat to the correctness of the project's result, but has to be accepted in order to meet the project's constraints.

For simplicity and comprehensibility, the results for some abstraction levels have been put together: levels 2 and 3, as well as levels 4, 5 and 6 have been combined into separate paragraphs.

2.2 Literature study (levels 1, 2, 3)

During the literature study, level 1 (households in general) will only be concerned with the five main characteristics. Applying level 1 to the sub characteristics, as well, would essentially mean that the whole list of energy use characteristics would be evaluated about its correctness, for which there is no time available. Levels 2 and 3 (students in general and in the Netherlands), however, will look into adding or removing sub characteristics, as these levels focus specifically on students.

The sources from which information was adopted were found through search actions in online databases and search engines. These databases contain scientific research papers covering a wide range of academic fields. For this project, the websites *Sciencedirect* and *Google Scholar* returned the most useful results. Furthermore, additional sources were found through the references of papers they were cited in. Finally, a number of scientific and non-scientific documents were obtained through entering keywords in regular search engines including *Google* and *DuckDuckGo.* In Appendix E: Search actions for scientific sources of information, the utilized keywords and the obtained results are presented.

2.2.1 Level 1

Level 1 is the highest abstraction level, concerned only with households in the most general sense. A number of authors from universities and institutions alike have been found to discuss the influences playing a role in domestic energy use. Some authors approach the topic from the most general point of view possible, by looking at everything in and around a dwelling that could have a share in the overall energy use. Others tend to concentrate on those characteristics that are nearest and most concrete to the inhabitant of a house: the installed systems and appliances.

To start with the general point of view, the five energy use characteristics mentioned by Entrop are frequently found among the accounts of other authors, as well, although every list contains other elements than the others. Majcen et al. define four characteristics including *dwelling, household, occupancy* and *comfort* during their attempt to find an explanation for difference between the theoretical and actual gas use of individual dwellings (Majcen, Itard, & Visscher, 2015). The characteristic of *dwelling* can be coupled to 'building characteristics', whereas the characteristics *household* and *occupancy* fit to 'social characteristics'. However, the environmental, system and appliance characteristics are not mentioned.

The EBC (Energy in Buildings and Communities Programme) uses, yet, another categorization by naming *climate*, *building* and *systems* as major influences of domestic energy use (Energy in Buildings and Communities Programme, 2014). Here, one can see that the equivalents to the environmental characteristics (*climate*), as well as the building and system characteristics are present. However, it is also stated that the influence of the inhabitants of a building's energy use may be just as significant as the technical characteristics. Authors including Guerassimoff and Thomas, Jain et al. and Vicente-Molina et al. explicitly mention the inhabitants of buildings as important influencers of energy use, too (Guerassimoff & Thomas, 2015; Jain, Gulbinas, Taylor, & Culligan, 2013; Vicente-Molina, Fernández-Sáinz, & Izagirre-Olaizola, 2013).

Yu et al. name seven energy use characteristics in domestic environments, which cover most of the five energy use characteristics being assessed (Yu, Fung, Haghighat, Yoshino, & Morofsky, 2011). Apart from *climate, building* and *systems,* the inhabitants' influence is specified in *social and economic factors* and *use-related characteristics, except for social and economic factors*.

The latter can be understood as e.g. *user presence*. Most notably, characteristics such as the influence of (electric) appliances are not mentioned. Instead, *indoor environmental quality* is said to be crucial to energy use, which bears similarities to the characteristic *comfort* mentioned by Majcen et al. (Majcen et al., 2015).

Regarding the influence of the weather or the climate on the energy use of dwellings, Crawley et al. point to the future role the climate will play due to the worldwide climatic change that is taking place (Crawley, 2008). Events caused by the weather are likely to get more extreme and therefore cause an increase in the energy demand of buildings, be it for cooling or for heating. Urge-Vorsatz confirms this view by stressing the future influence of Urban Heat Islands (UHI) (Urge-Vorsatz, Petrichenko, Staniec, & Eom, 2013). These are local urban areas in which the temperature is significantly higher than in the surrounding (rural) region. As temperatures are rising globally, cities should be aware of this development and take action on time.

With view to the directly visible energy use characteristics of appliances and installed systems, several institutions have made calculations as to what kinds of appliances and systems are responsible for what share of the total energy use of an average dwelling (International Energy Agency [IEA], 2014; International Institute for Applied Systems Analysis [IIASA], 2012; United Nations Environment Programme [UNEP], 2009; Energie Onderzoekcentrum Nederland [ECN], 2014). These appliances and systems are referred to as *end-uses*. As well as with the authors looking at general energy use characteristics, the lists of systems and appliances contributing to a dwelling's energy use formulated by the institutions differ from each other. In Table 3, a top five of most consuming systems or appliances drawn up by the mentioned organizations is shown.

Table 3: Top five of most energy using appliances in average households

	IEA	IIASA	UNEP	ECN
1	Heating	Heating	HVAC	Lighting
2	Appliances	Cooling	Heated water	Television
3	Other	Heated water	Lighting	Refrigerator
4	Heated water	Lighting	Computers and other	Dryer
5	Air treatment	Electric devices	Cooking	Heating

Although the rankings may differ, the main finding is that all authors agree that appliances and systems in houses constitute relevant characteristics concerning energy use. They should be reckoned with when the goal is to lower the total energy use of dwellings, as well as the building, climate and inhabitant characteristics.

The findings of the literature study confirm the relevance of the five main energy use characteristics as defined by Entrop. They will be put to use in the energy use model and form the basis of further investigation. From the literature available, no additional overarching energy use characteristics were found. In Table 4, each energy use characteristic is coupled to the relevant authors, who also considered it to be of relevance.

Table 4: Overview sources mentioning main energy use characteristics

Characteristic	Authors or institutions
Building	Majcen et al.; EBC; Guerra Santin et al.; Yu et al.
Systems	EBC; Guerra Santin et al. (under *Building characteristics*); Yu et al.; IEA; IIASA; UNEP; ECN
Appliances	IEA; IIASA; UNEP; ECN
Climate	EBC; Yu et al.; Crawley et al.; Urge-Vorsatz et al.
Inhabitants	EBC; Yu et al.; Guerra Santin et al.

2.2.2 Level 2 and 3

The next two levels of abstraction are the first ones to be concerned with students as a specific group, namely students in general (level 2) and students living in the Netherlands (level 3). Still, these levels are of a general nature, as they mainly concentrate on student households without going into detail about habits of individual. An assessment of available literature was made so as to discover energy use characteristics that are especially relevant for students. A total of two new energy use characteristics have been found to apply to students. These only apply to student households in general. No new characteristics were discovered by focusing on students living in the Netherlands. Additionally, no already given characteristics from the list had to be erased.

Use of technology (level 2): Emeakaroha et al. established a relationship between sustainable living and technology with regard to students (Emeakaroha, Ang, Yan, & Hopthrow, 2014). The availability of real-time information showing the energetic performances of student households appears to have a positive influence on students to take care of lowering their energy use and be more aware of their way of living. It is for this reason, that a new sub characteristic will be added to the existing list to take into account the influence and importance of technology for young people. “Use of technology” will be placed in the category of “Appliances”.

Group motivation (level 2): Peschiera et al., as well as Jain et al. have found that energy use of households contains a social aspect that should not be overlooked (Peschiera & Taylor, 2012; Jain et al., 2013). According to Peschiera, peer pressure does have an influence on the electric energy use of households. Since students often live in communities, be it in dormitories or apartments, the role peer pressure plays in the behavior of an individual student could be significant. Therefore, the sub characteristic of “Group motivation” will be added to the existing list in the category of “Inhabitants”.

2.3 Case study (levels 4, 5, 6)

Through a case study at the campus of the University of Twente, additional energy use characteristics were attempted to be found, apart from the ones obtained through literature. The related research techniques were the execution of interviews with student communities at the campus and making measurements related to the number of electric devices in a dormitory. By doing so, the abstraction levels 4, 5 and 6 are covered, which include students living at the campus in general (level 4), individual student communities (level 5) and individual students (level 6). The participating student communities with additional information, such as their performance during the Sustainabattle, are presented in Table 5.

Table 5: Information selected student groups for case study

Group	Number of group members	Address	Final ranking Sustainabattle (total number of registered participants: 13)	Level energy use at the end of Sustainabattle [kWh/month]
Crib Soleil	14	Campuslaan 57	1	424
Beverburcht	10	Calslaan 1-3	5	429
Huize Bosøl	7	Witbreuksweg 377	10	4565*
Pimpelpatio	7	Matenweg 34	13	672
*** = shared an energy meter with entire dormitory of Witbreuksweg 377**				

The interviews constitute an important source of information for the construction of the energy model and will be referred to multiple times in the following paragraphs and chapters. The format of the interview is included in Appendix F: Interview format. The measurements have been recorded in Appendix C: Selected student communities for case study. Details on the Sustainabattle can be found in Appendix B: The Sustainabattle.

Below, the results of the case study are presented. Four new energy use characteristics were found, which will be added to the list of energy use characteristics. No existing energy use characteristics from the list needed to be removed.

Quality of appliances (level 5): The occasion of visiting the student groups for interviews was made us of by also making an inventory of the appliances present in the building (see Appendix C). Apart from the great number of appliances present in the building, the quality of these appliances was remarkably low for all evaluated groups. Although no (written) information was available about the production year and exact performance of the devices, most of the white goods (such as refrigerators and washing machines) were identified as old and inefficient. Over the years, a significant amount of energy is therefore probably spent on running and maintaining these devices.

The students living at the campus appear to deviate from other types of households not only by the number, but also by the quality of the appliances they use in daily life. This finding is being reckoned with by introducing this characteristic. For this reason, an additional energy use characteristic should be added to the list, named “Quality of appliances”. It will be added to the main characteristics “Inhabitants”.

Effort (level 4, 5, 6): When comparing the answers of the student groups, the effort needed to achieve a more sustainable lifestyle is a great hurdle, no matter which group was asked. One student group stressed to not be willing to make sacrifices, as long as no substantial results are reached. In order for them to be motivated to lower their energy use, it should be made as easy as possible. All student groups suggested independently from each other that they were most willing to change “little things” about their lifestyle, such as turning off the lights when a room is unoccupied or try use less hot water for a given purpose. In short, not much determination to drastically change the group’s acting was visible. Therefore, the energy use characteristic “Effort” will be adopted in the list in the category of “Inhabitants”, because it has a profound influence on the motivation of the whole group.

Prospect (level 4, 5, 6): As mentioned in the previous paragraph, students showed some reluctance when asked whether they were willing to make efforts for a more sustainable household. For them to be motivated to do so, all groups implicitly expressed their need of having a concrete goal to aim for when trying to lower their energy use levels. *Crib Soleil* suggested that a central institution or person should inspire students and set goals for them to work towards, instead of students needing to formulate their own objectives.

Furthermore, the outlook of material or financial benefit is an incentive for students to become and stay motivated, as they then know what they are doing it for. For the worst performing group, *Pimpelpatio*, the prospect of winning a new refrigerator was the very reason to at least take part, although they eventually did nothing to save energy. Thus, the characteristic of "Prospect" will also be adopted into the list of energy use characteristics in the category of "Inhabitants".

Group composition (level 4, 5): Throughout the interviews with the student groups, the enthusiasm of the whole group for sustainability was noticed to play an important role in the decision to even take care of energy use. The effort of a few individuals proved to not be enough to make a difference. This was reflected most prominently in the student group *Huize Bosøl:* although one student signed up for the group to take part in the Sustainabattle, the other group members showed no approval of the initiative. This led to the group not taking part, even though they were registered.

This example shows that sustainability in dormitories can only be reached through a collective effort. "Group composition" as a new energy use characteristic should be added to the list, as the personal opinions of students should finally add up to the group's motivation. It will be added to the category of "Inhabitants".

2.4 Preliminary results

With all levels of abstraction addressed by conducting a literature study and a case study, the list of energy use characteristics that was used as a vantage point has been extended with a number of additional characteristics. Figure 5 gives a visual overview of the achieved results after the work for research questions 1a and 1b was completed.

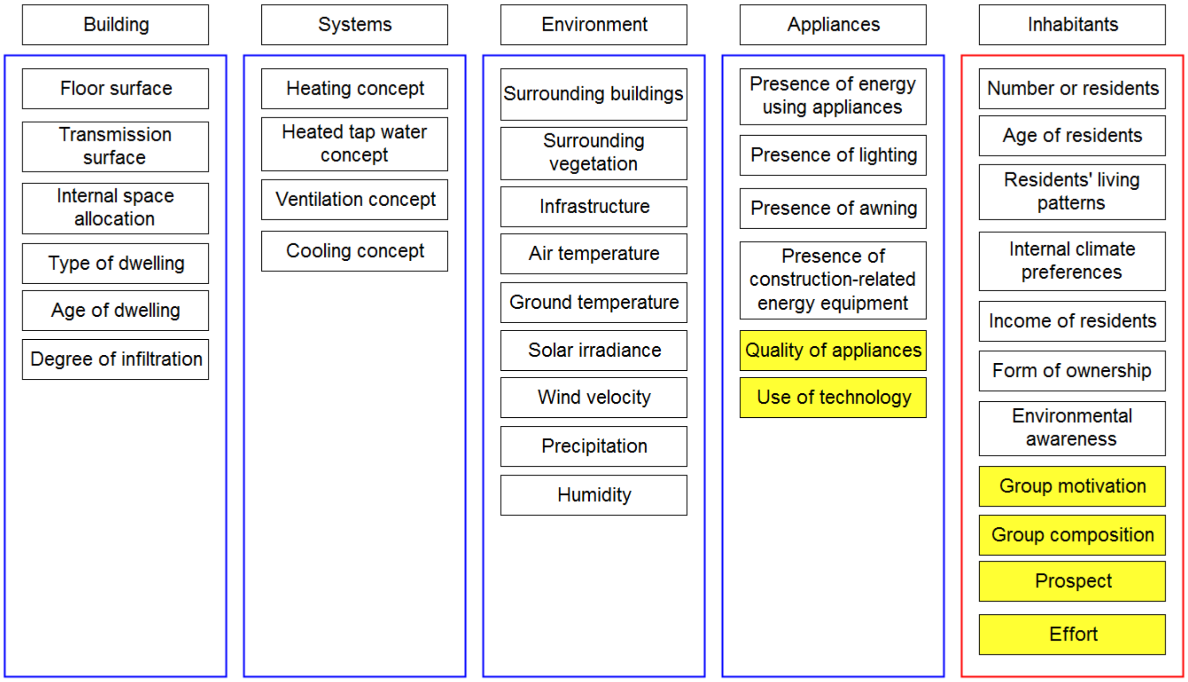

Figure 5: List of energy use characteristics with new characteristics indicated in yellow

3. Operationalization of energy use characteristics

Now that the energy use characteristics of students are known, it is necessary to find out whether of all of them or only a limited number can be used for the energy use model. This will be done in two steps. First, an attempt will be made to operationalize all energy use characteristics. This means that the characteristics will be applied to students in order to see how what the characteristics really mean to this demographic group and thus how they differ from other types of households. When no information about a characteristic can be found, it will not be considered for use in the energy use model. This does not imply that the characteristic does not play a role in the energy use of students, but due to time limits, concrete information is needed to be able to construct a well-functioning model. The second step involves the assessment of the (remaining) characteristics on the basis of adjustability. When De Veste as the model's principal user is not able to change a characteristic to another state, it will also be rejected. The related research question to these activity is as follows:

"Which energy use characteristics can be adopted into the energy use model?"

The approach of finding an answer to this research question is partly the same as for research question 1. For the operationalization, a literature study and a case study will be conducted after the framework of the six abstraction levels mentioned in Chapter 2.1. This time, the case study also includes a data analysis. The nature of the data analysis will be explained in Chapter 3.2. The assessment of the characteristics concerning their adjustability is based on information about De Veste in its function as housing corporation.

3.1 Literature study (levels 2, 3)

By taking a look at available scientific sources, some energy use characteristics from the list belonging to the categories of "Building", "Appliances" and "Inhabitants" will be addressed (see Figure 5). For other characteristics however, no information could be found, which is why they will not be considered for now. Furthermore, level 1 (households in general) will not be considered for this literature study, since it does not have a connection to students and is therefore applicable.

3.1.1 Building

Type of dwelling (level 3): There is a number of housing types which are most common among students in the Netherlands. These include renting a room in a dormitory that is privately-owned, renting a room in a dormitory owned by a corporation or owning a private apartment/house (Poulus, Marchal, & Vijncke, 2014). In case of renting a room, this can either be a room with its own facilities such as a kitchen and a shower, or it can be a room in a dormitory, in which the bathroom, kitchen and living room are shared with other residents. In 2014, more than 60% of all students in the Netherlands studying in Groningen, Enschede, Delft, Leiden, Nijmegen and Eindhoven rented a room in dormitory with shared appliances (Poulus et al., 2014).

3.1.2 Appliances

Presence of energy using appliances (level 2): Steingard et al. have discovered a difference among students and other types of households with respect to (electric) appliances used in daily life (Steingard, 2009). For young adults attending higher education and living independently from their parents, a distinction should be made between two types of appliances. Type 1 appliances require relatively much energy to fulfill their purpose, but are relatively rare given the number of students living in a dormitory. An example would be a coffee machine. On the contrary, there are type 2 devices, which do not need much energy to work, but are found in relatively great numbers in student houses, such as laptops and smartphones. In the case of students, the presence and number of certain types of appliances deviates from the average household and should therefore be observed with care.

3.1.3 Inhabitants

Age of inhabitants (level 3): From research by the OECD, it was estimated that the average age of obtaining the first degree in the Netherlands is around 23 years (OECD, 2014). Given that Bachelor degrees mostly are followed by a study for a Master's degree, this number can be taken as the average age of students in the Netherlands.

Income inhabitants (level 3): According to the Dutch institute *Nibud*, students in the Netherlands generally do not have full time jobs, as they are fully committed to their studies (Nibud, 2015). Therefore, they can only have side jobs, which means that students need financial support from the state and/or their parents.

Form of possession (level 3): Students mostly rent a room or an apartment, due to their limited financial capabilities and the limited period of time students spend in or near the city where they study (Poulus et al., 2014). Although it is possible to buy an own apartment, it is common in the Netherlands to rent a room.

Environmental awareness (level 2): Abdul Aziz et al. show that students in high school and university are positioned in a critical phase when it comes to their habits later on in life (Aziz A., Yusof, Udin, & Yatim, 2013). The knowledge that is acquired by students in their freshman year at university is of a determining nature for his/her opinions and values in the future. Furthermore, Stanes et al. state that young adults of today (*Generation Y*) are more aware of the state of the global and local climate and also acknowledge their role within the current climatic change (Stanes, et al., 2015). This is less so among older generations. As long as the actions for a more sustainable life are not too difficult or costly, younger people are willing to contribute to a more sustainable way of life.

3.2 Case study (levels 4, 5, 6)

For the last three levels of abstraction (4, 5, 6), the answers of students to the interview questions were used to find out how students at the campus of the University of Twente use energy and what their living environment looks like. Additionally, technical data related to the dormitories and measurements were also made use of to make statements about the energy use characteristics.

This data was acquired from several sources. The architectural properties of the dormitories were taken from the inventory system of De Veste and were used to describe the dormitories in which the interviewed student communities live. Second, the number of different types of electric devices used by the different student groups were measured through a stock taking. This enabled a better characterization of the students' lifestyle, which is partly reflected in the way they use certain appliances. The stock taking of appliances can be found in Appendix C: Selected student communities for case study, as well as the architectural properties of the dormitories.

To be able to make founded statements about the influence of the building on the energy use of students, an attempt was made to make energy simulations of the selected dormitories by making use of the computer program *VABI Elements*. Late in the project, it was discovered that

VABI Elements did not return the results that were needed to analyze the influence of the buildings' insulation and construction on the general energy use. *VABI Elements* can only calculate the energy use of buildings, assuming that these are newly built structures, which in case of the dormitories is not the case, as they were built during the 1960's and 1970's. The results of the simulations have been included in Appendix C, anyway, which indicate that currently much energy is probably spent on heating. As to this project, it had to be limited to only providing a description of the architectural state of the buildings.

3.2.1 Building

Floor surface (level 5): From floor plans provided by De Veste, it was concluded that the floor surface of the common living rooms in the examined dormitories amounts to an average value of 26,25 m² (see Appendix G: Calculation dormitories). Related to the total average area of the building (249 m²), these rooms make up roughly 10% of the total area of the dormitory. As these areas are most likely to be heated constantly to guarantee a comfortable indoor temperature, a significant amount of heating energy is probably spent on doing so.

Additionally, the individual private rooms of the students have an average surface of 12,5 m². With an average of 11 rooms in one building, the average amount of floor area covered by the private rooms amounts to 55% of the total surface area. This implies that the individual rooms play a dominant role in the overall energy use, as they take up the most space in the building. Moreover, heat can easily be lost to the less heated dormitory hall, to which the rooms are all connected.

Transmission surface (level 4): There is little information available about the thermal resistance and heat capacity of the walls and floors of dormitories located at the campus. Through conversations with staff members of De Veste, it has become clear that the buildings have undergone renovation operations during the 1990's. Back then, several dormitories were insulated by injecting PUR into the cavity between the inner and outer walls. Most of the insulation material, however, is thought to have rotten away over the years. This leaves the houses in their current state with practically no insulation, leading probably to a constant heat loss.

Internal space allocation (level 5): When looking at the floor plans of the four examined dormitories, one notable property is the presence and location of hall ways in the houses (see Appendix C). Mostly located centrally in the building with all rooms connected to them, the hall ways cover roughly 17% of the total floor area with an average of 42,5 m². As these common areas are not used for dwelling and are thus not or less heated, it is probable that heat losses from the common living room and the individual sleeping rooms of the students not only occur due to interaction with the outside environment, but also because of their connection to the hall ways.

Type of dwelling (level 4): The investigated dormitories on the campus of the University of Twente are freestanding buildings with multiple layers (see Appendix C). Other forms include freestanding dormitories consisting of one layer. Several dormitories are structurally connected to each other, which could lead to heat exchange.

Age of dwelling (level 4, 5): The investigated dormitories situated on the campus were constructed upon or shortly after the founding of the University of Twente in the 1960's (see Appendix C). Concerning the examined student groups, three of the houses are from the 1960's.

The fourth was built in the 1970's. Because the sustainability standards were lower in those years, the age of the buildings tells that today's quality of insulation probably is not reached.

3.2.2 Systems

Heating concept (level 4, 5): There are two possible ways of heating a dwelling at the campus. One is to have a heating concept installed, which burns natural gas (see Appendix C). The other one is to be connected to the heat distribution system provided by the municipality of Enschede. Based on the inventory data of De Veste, most dormitories on the campus either have an HR107 or a less modern VR boiler. A minority is connected to heat provision of a third party, in this case the municipality.

Heated tap water concept (level 4, 5): The way of obtaining heated water in dormitories on the campus is dependent on the general heating concept (see Appendix C). Warmth energy is either acquired through the burning of natural gas via a HR107 or VR boiler or through heat supply by the municipality. Some houses on the campus are fitted with a solar boiler, which includes the examined dormitory at Campuslaan 33.

Ventilation concept (level 4, 5): In the investigated dormitories, either natural ventilation (A1) or natural supply and mechanical discharge (C1) is found (see Appendix C).

Cooling concept (level 4): There are no cooling concepts installed in dwellings on the campus.

3.2.3 Appliances

Presence of energy using appliances (level 5): The occasion of visiting the student groups for interviews was made us of by also making an inventory of the appliances present in the building (see Appendix C). A remarkable property of student communities is the abundance of white goods and consumer electronics such as laptops and smart phones in one house. At an average population of eight people, multiple refrigerators and freezers were found, as well as cooking stoves and washing machines. Moreover, every student owns his/her own laptop and smartphone, which should therefore be taken into consideration for describing the energy use of students in general.

Apart from the great number of appliances present in the building, the quality of these appliances also deserves special attention. Most of the white goods, such refrigerators and washing machines, are old and inefficient. However, at the time that these appliances were (relatively) new, they still would probably not have met today's sustainability standards. Over the years, this has not gotten any better, which is why a great deal of energy is probably spent on running these appliances.

For these reasons, an additional energy use characteristic should be added to the model, named "Quality of appliances". The students living on the campus show to deviate from other types of households not only by the number, but also by the quality of the appliances they use in daily life. This should be reckoned with by introducing this characteristic.

Presence of construction-related energy equipment (level 4): Construction-related energy equipment includes solar panels or wind turbines for energy generation or air conditioning systems that use energy. According to the data provided by De Veste, no construction-related energy equipment is installed in or on the investigated buildings at the campus (see Appendix C).

3.2.4 Inhabitants

Environmental awareness (level 5, 6): Through an interview, the opinions of the student groups and individual students could be recorded. The answers to the questions show that the interviewed students generally do acknowledge their responsibility towards the climate, but are less willing to make sacrifices for it in terms of luxury and personal comfortability. These findings are parallel to the ones of Jain et al. (Jain et al., 2013). Furthermore, all of the groups expressed their own ignorance of their energy use. One of the reasons lies within the system of payment for energy: at the start of the academic year, De Veste collects a relatively high amount of money from every student, so that in case of an exceedingly high energy usage no additional money would have to be claimed. Although this does guarantee De Veste receiving the money they deserve, it diminishes the incentive for students to take care of their energy use.

Another reason for the low level of environmental awareness is the little factual knowledge existent among students. Whereas some students stressed that they had rarely encountered the topic of sustainability much in education or daily life, some also expressed their doubts and skepticism about the truth behind the explanation to climate change as it is generally accepted, nowadays.

3.3 Missing information

As depicted in Figure 6, there are some energy use characteristics that could not be operationalized due to a lack of information. Remarkably, except for “Presence of awning” and “Internal climate preferences”, all unknown characteristics belong to the category of *Environment*. As to students in general, no specific information could be found about the influence of the weather or the climate on their energy use. It is suggested that the influence of the outdoor environment is not much different from the influence it has on other types of households, which could be the reason for this missing information. As to the students living at the campus of the University of Twente, there was no information to be found, either, let alone about the influence of the weather on buildings in Enschede in general.

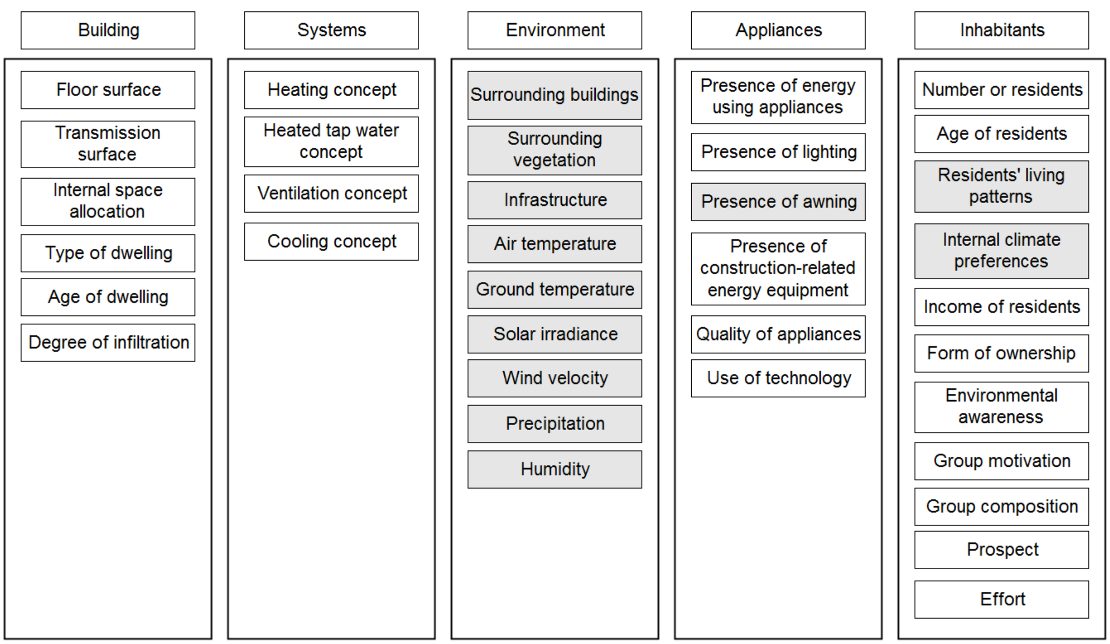

Figure 6: List of energy use characteristics with unknown characteristics indicated in grey

3.4 Selection of variables based on assessment adjustability

Based on literature and findings through the case study, a number of energy use characteristics could be operationalized. On the contrary, a number of other characteristics still do not have a value. This makes it necessary to make a distinction between those characteristics that can be adopted into the energy use model and those that need to be left out, although their role in the energy use of students remains undisputed.

Broadly, a distinction between three classes of characteristics is possible. First, there are the characteristics about which nothing could be found through either literature or data or interviews. Second, there are characteristics about which a statement does exist, but cannot be altered by the model's user, which in this case is De Veste in its role as housing corporation. Third, there are characteristics which do have a value and which are also adjustable in the sense that De Veste does have possibilities within its power to change those characteristics to their wishes.

The characteristics as given in Figure 5 (Chapter 2.1) have been categorized after the three distinctions made in the previous paragraph. In Appendix H: List of energy use characteristics, the reason for deeming a characteristic adjustable or non-adjustable is given for each. Figure 7 presents the outcome this activity.

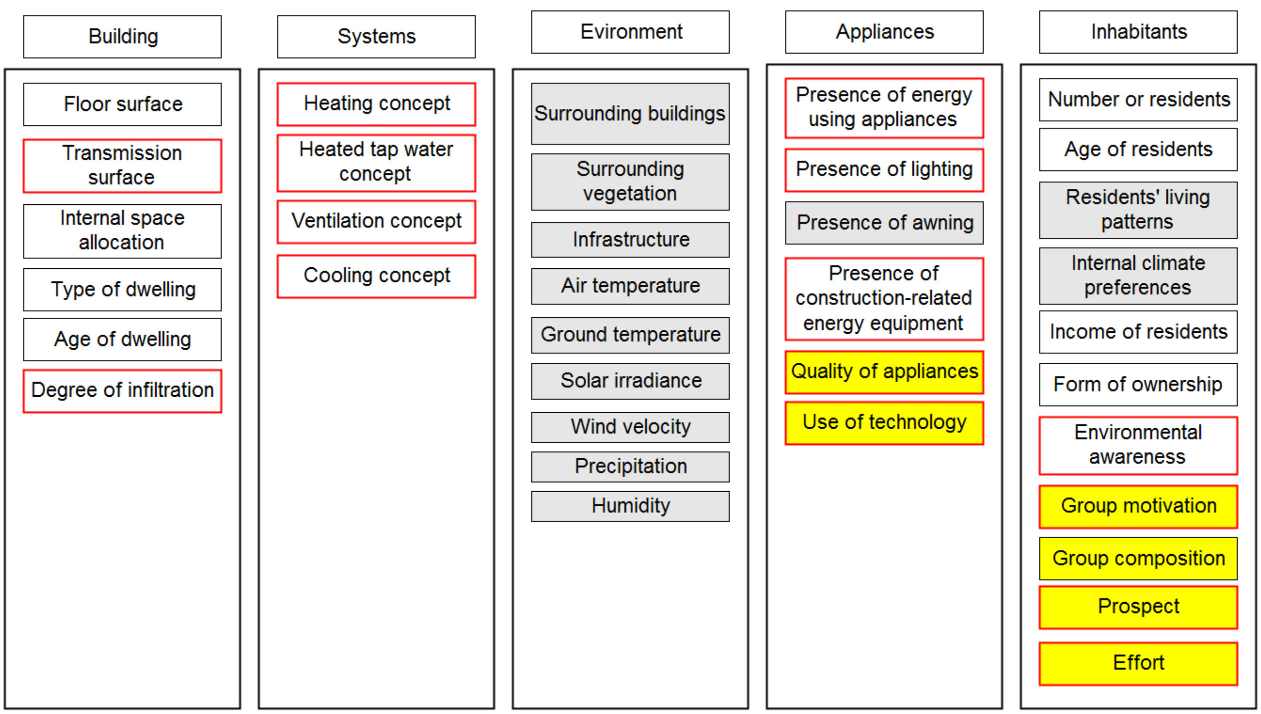

Figure 7: List of energy use characteristics with model variables indicated with red squares, unknown characteristics indicated in grey and new characteristics indicated in yellow

The characteristics without a value are indicated in grey. The characteristics that do have a value are either white or yellow, with the yellow characteristics representing the recently added ones. Those characteristics that have a red lining will be the ones to be included in the model, as these characteristics can be adjusted to the model user's wishes, even the ones that could not be operationalized ("Transmission surface" and "Degree of infiltration"). From this point onwards, the selected energy use characteristics will be referred to as *variables*.

Although it could have been possible to first select the adjustable energy use characteristics and then operationalize them, the opposite has been done. The reason for this is that this way, more information can be provided about the students and the way they currently live, leading the De Veste having more knowledge about what to improve.

3.5 Preliminary results

By leaving out the non-relevant energy use characteristics, the final selection of variables for the construction of the energy use model is presented in Figure 8. In the next chapter, the relations between these variables will be identified and examined.

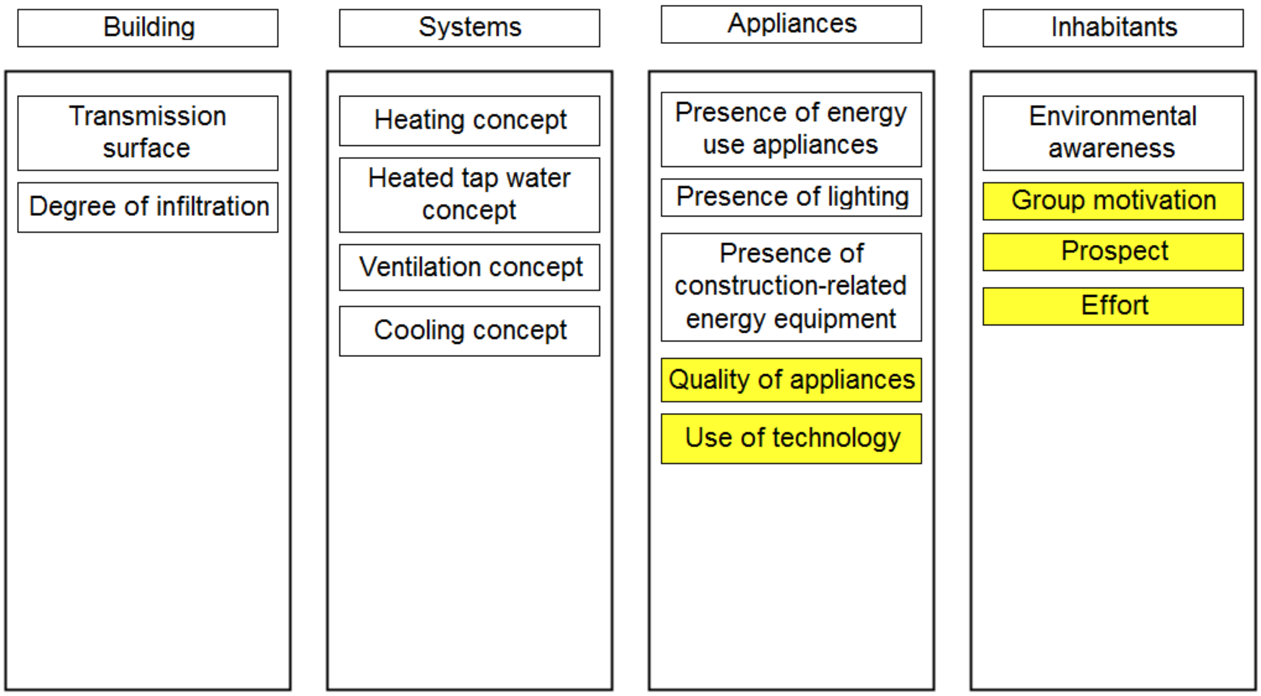

Figure 8: Final selection of model variables

4. Relationships among the model's variables

With all the model's variables selected from the list of energy use characteristics, establishing the relations between the variables is the last step in the model's construction process. The research question that is directly related to this chapter is as follows:

"What relations do exist among the variables of the energy use model?"

The relations have been obtained on the basis of the interview that was conducted with a selection of participating student groups of the Sustainabattle (case study), as well as through literature.

4.1 Literature study

Literature revealed little new information about relations existing between characteristics of a building that define its energy use. Yet, one relatively important relationship was found, which is described below.

Use of technology – Environmental awareness (one-way influence): With regard to the new variable "Use of technology", it can be stated that the supply of information via digital media does have a positive influence on the environmental awareness of students. Emeakaroha et al. point towards a possible energy saving rate of 5-15% of households, based on experiments with students in the United Kingdom (Emeakaroha, Ang, & Yan, 2012). In another article, the same author discusses the positive influence of an "energy delegate" in dormitories, who takes special care about the energy use in the building (Emeakaroha et al., 2014). Combined with Smart Meters, which provide real time information on energy use, a saving rate of 37% was reached. Other authors also write about the incentive to make deliberate, sustainable choices that is created by direct and real time information (Guerassimoff & Thomas, 2015; Jain et al., 2013). The relationship between "Use of technology" and "Environmental awareness" is now such that a better and more intensive use of technology (increase of "Use of technology") is likely to result in a greater environmental awareness (increase of "Environmental awareness").

4.2 Case study

The interview with student groups allowed for the discovering of relations that were otherwise hard to obtain via literature or data. Because the opinions and views of students mainly concentrate on the social aspects of energy use, most relationships were consequently found between the 'social' variables and the variables of the category "Appliances", since these are the most integrated in the daily lives of the residents. In the following, the relationships and their respective functions will be addressed.

Group motivation – Environmental awareness (two-way influence): A section of the interview was specifically meant for acquiring intelligence on the topic of awareness. By comparing the answers of the students, it became clear that there is a wish for more insight and influence on energy use in daily life. It was said that more and better information would result in a greater inclination to act more sustainably. Moreover, environmental awareness in an even broader sense than information supply would foster a 'sustainability culture' at the campus: when sustainability really gets imbedded in the lifestyle of the campus as whole, it would also resonate more with individual students and consequently student communities. It is for these reasons that a link is established between group motivation and environmental awareness. They both influence each other, with greater environmental awareness (increase of "Environmental awareness") resulting in a greater motivation within the group (increase of "Group motivation").

Group motivation – Quality of appliances; Presence of lighting; Presence of energy using appliances (one-way influence): All three variables "Quality of appliances", "Presence of lighting" and "Presence of energy using appliances" are related to the same main energy use characteristic of "Appliances". During the stock taking of appliances in dormitories, it was remarkable to find multiple devices of the same type, which furthermore are mostly old and inefficient (see Appendix B: The Sustainabattle). From the interviews it was concluded that the quality of shared electric devices depends on the amount of money the group as a whole is willing to spend, since refrigerators and other household appliances are bought collectively. These appliances are of type 1, as described by Steingard et al. (see Chapter 3.2.3). On the other hand, type 2 appliances (using little energy but great in number) appear to be bought by individual students. When establishing a link between "Group motivation" and "Quality of appliances", as well as "Presence of energy use appliances", a distinction should be made between collectively and individually bought devices.

The group's motivation to buy a certain device is again influenced by their financial capabilities, which are limited in comparison to other household types (see also Chapter 3.1.3). This is why there is a strong connection between the variables "Group motivation" and those belonging to "Appliances", as the group's motivation for sustainability is determining the quality of electric devices, as well as the actual presence of them and the presence of different forms of lighting. A greater motivation (increase of "Group motivation") will likely lead to a greater quality (increase of "Quality of appliances"). The same is true for "Presence of energy using appliances" and "Presence of lighting".

Prospect – Group motivation (one-way influence): Talking to student groups revealed some new energy use characteristics which will be adopted in the energy use model. One of these is the prospect for students to make efforts for a more sustainable lifestyle. The motivation of individual students for lowering energy use differed depending on whom was being asked about that topic. Still, one of the common grounds for their motivation was the benefit students want to achieve when making choices in favor of sustainability, regardless of which group was asked. There needs to be a goal that students can work towards, preventing the motivation from waning over time (see also Chapter 3.2.4). A greater quality of the prospect (increase of "Prospect"), e.g. by promising prizes or rewards will result in a greater motivation of student groups (increase of "Group motivation").

Effort – Group motivation (one-way influence): A second newly added variable to the energy use model is related to the effort students need to make to achieve a set targets concerning sustainability. When asked what it is that makes living sustainably hard or difficult, the students' opinion is that sacrifices need to be made that inherently influence their living standard in a negative way. These sacrifices constitute themselves both financially and practically. The investment in more sustainable devices is a financial burden students are often not willing to take, even when they can afford it. Waiting for wet laundry to dry naturally and turning off devices instead of leaving them on stand-by takes a bit more patience and effort. Still, the interviewed students admitted to be lazy in some respects and prefer the easier option if it is available to them. When the majority of a student community is made up of students with this mindset, the motivation of the groups as a whole reflects that mindset. Therefore, the less effort students need to make for more sustainability (decrease of "Effort"), the greater the group's motivation (increase of "Group motivation") to collectively stay committed.

Environmental awareness – Building characteristics; System characteristics; Presence of construction-related energy equipment (indirect, one-way influence): There is an indirect influence visible between the 'social' variable of "Environmental awareness" and the 'technical' variables belonging to the categories of "Building" and "Systems". By asking what would be needed to foster a 'sustainability culture' at the campus, the interviewees replied that encouragement given by the university and De Veste would support their efforts. An important element of their answers was their willingness to also financially contribute to the improvement of the houses and systems if the amount of money would not be too high. A greater awareness of the (technical) possibilities for a more sustainable house and a better embedded 'sustainability culture' at the whole campus is likely to increase this willingness, creating a foundation for even greater improvements than only buying more sustainable appliances. This also applies to the "Presence of construction-related equipment", such as solar panels or wind turbines. Based on the findings about the architectural state of the dormitories during the operationalization of the energy use characteristics (Chapter 2.1), investments appear to be needed. The contribution of students could make the funding of such measures better feasible. Although only an indirect relationship, the increase of "Environmental awareness" could possibly lead to a decrease in "Transmission surface" and "Degree of infiltration". On the contrary, the quality of "Heating concept", "Heated tap water concept", Ventilation concept", "Cooling concept" and "Presence of construction-related energy equipment" would increase, as well.

4.3 Preliminary Results

The provisional, non-validated energy use model is presented in Figure 9. It provides adjustable variables which are grouped in four categories: *Building, Systems, Appliances* and *Inhabitants*. Broadly, the categories *Building* and *Systems* can be perceived as the technical categories, incorporating those variables that can only be directly influenced by De Veste. The categories *Appliances* and *Inhabitants* are more socially oriented and are primarily influenced by the students, except for "Presence of construction-related energy equipment". Apart from the solid arrows in Figure 9, there are also seven dashed arrows leading from "Environmental awareness" to all variables of *Building, Systems* and to the variable "Presence of construction-related equipment". These arrows indicate an indirect influence that students have on the state of these variables, as mentioned in the previous subchapter 4.2.

In case of this energy use model, some variables need a lower value to get into a more preferable state, whereas others need a higher value. For example, the effort needed to live sustainably needs to be as low as possible to make for energy savings, which means that the value of "Effort" needs to decrease compared to its current state. On the other hand, the value of "Group motivation" needs to increase to cause further energy savings, since a greater motivation of a student group leads to a more sustainable lifestyle. In Appendix I: Specification model variables, a figure similar to Figure 9 has been included, indicating which variables need to increase or decrease by colors. In addition, Appendix I gives the effect of each relation on the state of the influenced variable, either when one variable is improved or degraded.

To alter the variables in Figure 9, both De Veste and the students share their responsibility. Based on the operationalization of the energy use characteristics in Chapter 2.1, the current state of the variables included in the energy use model was assessed. A visual representation of this assessment is given in Figure 10.

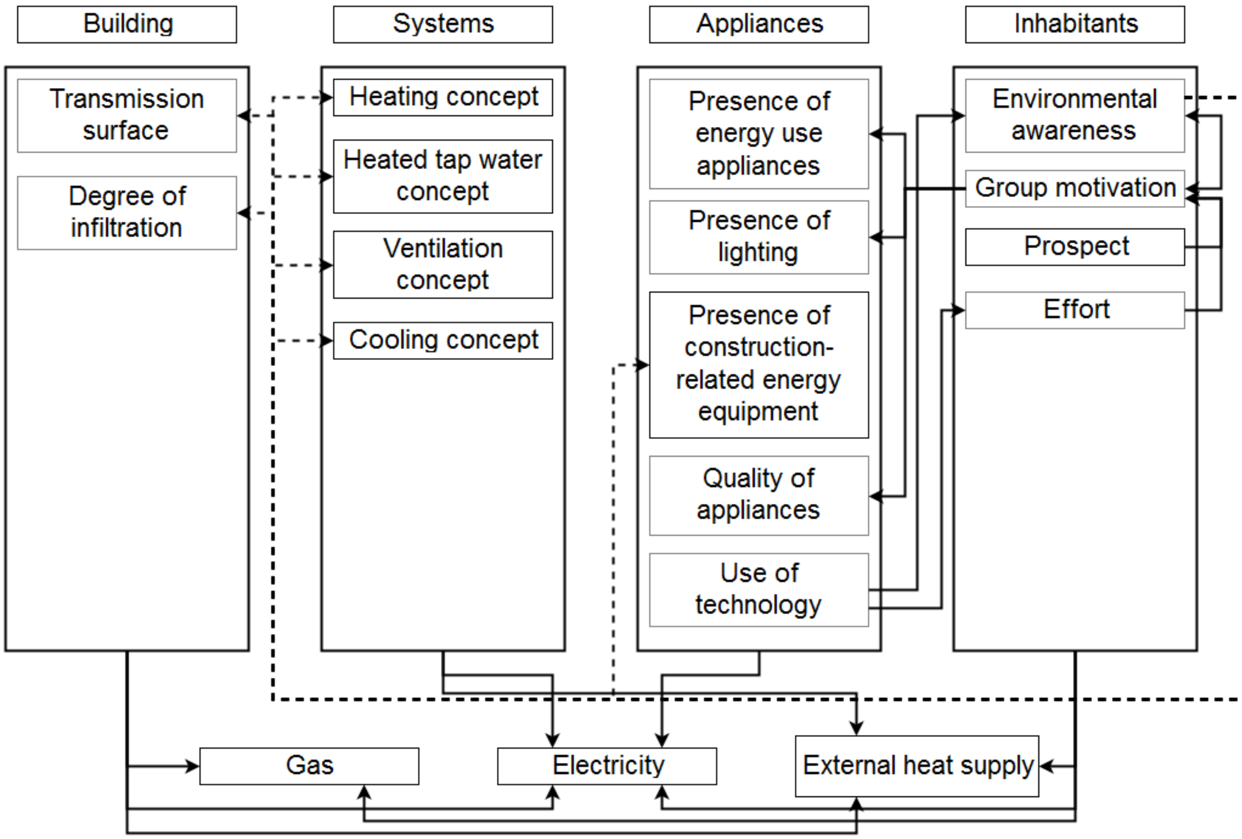

Figure 9: Preliminary, non-validated version of energy use model

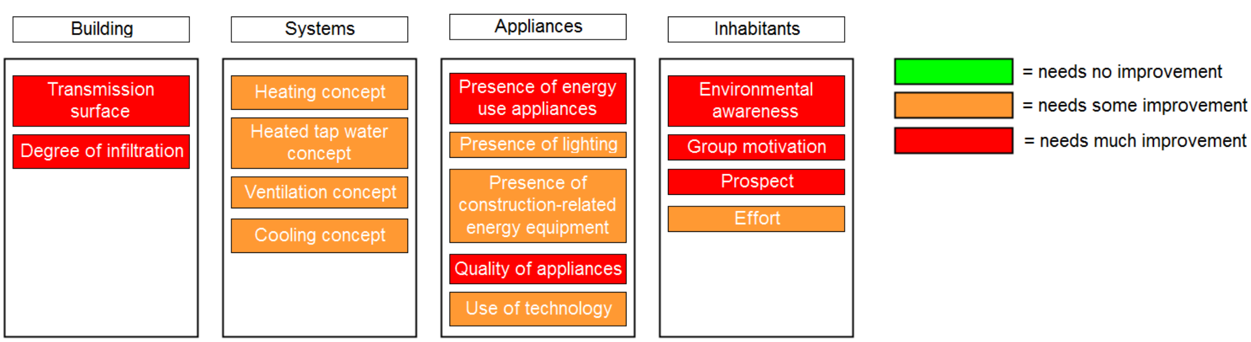

Figure 10: State of model variables (green = no improvement needed, orange = some improvement needed, red = much improvement needed)

The variables have been assigned colors after a relatively simple scheme of three colors, with green indicating no need for improvement, orange representing some need for improvement and red showing a need for much improvement.

5. Model validation

The energy use model in its current form needs to be validated in order to confirm its correctness and proper functioning. To do so, information from the event that sparked the initiation of this project was applied to the model: The Sustainabattle. Research question 4 is directly related to the validation of the model:

"How does the model's description of energy use among students comply with reality?"

The interviews with student communities, their action plans for winning the Sustainabattle and their actual energy use data during the competition are the sources from which the validation will draw its information (see Appendices F, C, B). Both the existence of the model's variables, as well as the relations between the variables will be examined and changes will be applied if necessary.

Although the Sustainabattle was the reason for undertaking the project, it is being used as a tool for the validation of a general system instead of being the research subject. The Sustainabattle in this project is perceived as a deviation from the normal way of life on the campus, thus creating a full scale experiment to validate the structure of the energy use model. The opportunity has thus been taken the maximum advantage of. Further details on the Sustainabattle can be found in Appendix B: The Sustainabattle.

The result of the validation will be the final version of the energy use model. It will be presented at the end of this chapter.

5.1 Interview

A number of questions in the interviews with the selected student communities was aimed at their experiences during the Sustainabattle and how they had performed during the competition. In the paragraphs below, variables and their relationships to others will be addressed and examined concerning their correctness.

5.1.1 Prospect, Effort and Group composition

Upon asking what the students found difficult about living sustainably during the Sustainabattle, it was often said that bringing down the energy use required planning and commitment of all group members. This proved to be a challenge, at times. Because living sustainably is perceived by some as equal to giving up (part of) everyday luxury, some resistance among the interviewees was evident when it came to their own motivation to make efforts for sustainability in general. This was true, even for the winning group of the Sustainabattle. Yet mostly, the competitive nature of the Sustainabattle and the prospect of prizes that could be won led even the worst performing group, *Pimpelpatio*, to sign up. Although they made no substantial contribution to the competition, the value of a concrete prospect can make a decisive difference for students. Both "Prospect" and "Effort" therefore indeed influence the group's motivation.

On the other hand, the two best performing groups (*Crib Soleil* and *Beverburcht*) showed that "Group composition" should also be reckoned with. Although they, too, see sustainable living as a tedious activity, the sentiment within the group was more optimistic and interested, which implies that the 'chemistry' between the residents also plays a critical role in "Group motivation".

5.1.2 Environmental awareness

Parts of the interview were devoted to learning more about the students' awareness regarding energy use in daily life and its development from the moment they left their parental house.

The interviewees in majority admitted to be largely ignorant of their personal or collective energy use. Most of the education they got about sustainability in a household was through their parents, but those lessons are not actively dealt with in daily life. At the end of the day, the students did not have to pay the bills while living at home, which meant that they did not have to deal with it in a profound way.

When asked about other ways the students got informed about sustainability, social media was often said to be the best medium for doing so. Environmental awareness through education appeared to be dependent on the study program of the individual interviewees. Overall, however, sustainability as a topic in any study program seems to be lacking. Because the students did have outspoken opinions about what they knew and how they acted according to it, shows that the variable "Environmental awareness" is indeed relevant to the model.

Another influence of students' awareness is someone's age. From the interview with *Huize Bosøl*, it was learned that the sense of responsibility about one's behavior increases over time. With a number of first-year students living in the dormitory, it was said that these students act relatively more after what they are used to at home than older students do. The variable "Age of residents", albeit unchangeable, therefore influences the "Group motivation" in a way that is less visible than other relationships.

While interviewing *Crib Soleil*, the aspect of a 'sustainable culture' was referred to multiple times. It was mostly talked about in the context of the relationship between "Environmental awareness" and "Group motivation". It was said that a broadly carried sentiment on the campus in favor of sustainability would bring about more groups to act more sustainably. Sustainability, according to the interviewees, had to become something natural. The other way around, the creation of such a sustainable culture also leads to "Group motivation" being influenced "Environmental awareness". When more groups can be enthused about sustainability, the awareness will increase accordingly.

5.1.3 Group motivation

Based on the accounts for "Prospect", "Effort" and "Group composition", the role of "Group motivation" is of major importance for the goal of achieving a lower energy use in dormitories. The influence "Group motivation" has on "Presence of energy using appliances", "Presence of lighting" and "Quality of appliances" is harder to discern, but does exist. From the case of the Sustainabattle winners *Crib Soleil*, it was seen that the group's motivation was defining whether or not to abolish certain types of devices, at least for the duration of the competition. Only with the consensus of the collective it was, for instance, possible to seek alternatives for using the dryer, which did result in energy savings. The same can be said for lighting, as many other groups pledged to do something about their energy use by turning off useless lights.

Concerning the quality of the appliances used by the residents, it was found that devices such as washing machines and televisions are bought by the group as a whole. Therefore, the group needs to make the decision about how much money is to be spent on a device. Although none of the interviewed groups did buy new appliances during the Sustainabattle, it was said that the old, inefficient appliances were mainly a consequence of the decision of the group, which is fueled by the limited financial capabilities.

5.1.4 Use of technology

According to the students, one of the most useful tools for lowering the overall energy use level was the Smart Meter ("Wattcher"). Apart from giving indications about the energy use of certain appliances as soon as they were turned on or off, the Wattcher for the first time gave a significant insight into energy use in general. The two groups who did work with the Wattcher (*Crib Soleil* and *Beverburcht*) were very positive about the device. The existence of the variable "Use of technology" is therefore justified, as is the influence it has on "Environmental awareness", due to the first time encounter students had with their energy use in such a way.

What was not found in literature before, but has been concluded from the interviews, is that the use of technology also influences the amount of effort that is needed to reach a sustainability goal. Because of the specific information the Wattcher gave to the participants of the Sustainabattle, students knew better how to apply changes and achieve a substantial result. This new relationship will be included in the model.

5.2 Action plans

Before the start of the Sustainabattle, all participating groups were instructed to hand in an action plan, in which they should describe their methods for lowering their energy use during the competition. Of the four examined student groups, only *Pimpelpatio* did not hand in an action plan. The groups' ambitions and actual deeds were compared to each other and the actually reached energy use levels so as to find out whether or not the predictions of the energy use model hold true. A summary of the action plans can be found in Appendix C: Selected student communities for case study.

5.2.1 Estimated energy use

By looking at what the three groups with action plans planned to do, it was remarkable to see the difference in their estimations about their monthly energy use compared to their actual energy use in daily life, as can be seen in Table 6. This gives an indication about the ignorance among students about their own energy use behavior, like they already admitted during the interviews (see also Chapter 5.1.2). The state of the variable "Environmental awareness" is therefore indeed inferior.

Table 6: Estimated and actual energy use of student groups, along with performance during Sustainabattle and energy savings

Student community	Number of residents	Estimated energy use [kWh pp/month]	Actual energy use in daily life (level 2015) [kWh pp/month]	Energy use Sustainabattle [kWh pp/month]	Savings during Sustainabattle compared to level 2015 [%]
Crib Soleil	**14**	58	84	42,4	-59,3
Beverburcht	**10**	27	62	42,9	-24,7
Huize Bosøl	**7**	60	116*	99*	-10,8
Pimpelpatio	**7**	-	104	96	-3,5
*** = based on energy use level of entire complex Witbreuksweg 377**					

What is more, is that the number of residents does not seem to influence the group's motivation to take part in the competition. With 14 people, *Crib Soleil* took part in the Sustainabattle, whereas in a group of 7, *Huize Bosøl* could not muster the motivation to join as a collective

(Table 6). This proves that “Group composition” is a relevant variable influencing “Group motivation”, although it is hard to adjust to any desired state.

5.2.2 Applied interventions to the model

Crib Soleil reached an electric energy saving level of 59,3%, which remarkably enough is mainly based on their savings in water use (Table 6). This proves the great role of appliances like washing machines and showers in the energy savings of residents. By forcing these appliances out of availability for a month, the number and quality of appliances once again appear to be of great influence to energy saving among students.

Beverburcht on the other hand focused more on making more efficient use of electric devices, such as the television, the stove or the lights. By doing so, they saved 24,7% of their energy use compared to the level 2015. Both *Beverburcht* and *Crib Soleil* managed to get to almost the same energy use levels, but *Crib Soleil* won on the basis of their 2015 energy use level being much higher than the one of *Beverburcht.* In any case, it is fair to say that both a reduction in water use and less use of electric devices are the two main sources of energy saving for students. On top of that, *Crib Soleil* stressed that they also went beyond energy saving, by also eating vegetarian twice a week and sorting out their waste in different categories. The fact that these students took this initiative all by themselves proves that students do not by definition only take the shortest route to success.

As to the two worst performing groups of the investigated student communities, other events have proven to also contribute to less use of (electric) energy. In *Huize Bosøl* for example, three residents were not present for a week during the time the Sustainabattle took place, which is expected to have contributed a great deal of energy savings for the house. Based on the interviews with *Huize Bosøl* and *Pimpelpatio*, their plans were mainly to use certain appliances a bit less, such as the stove or the microwave.

5.3 Overall functioning of the model

In general, it is safe to say that the model does reflect the events that occurred in reality. All variables of “Appliances” and “Inhabitants” in some way changed their value during the Sustainabattle. On the contrary, the “Building” and “Systems” variables did not change, which can be explained due to the fact that to change these variables, permanent and expensive changes have to be applied. Furthermore, De Veste as the owner of the buildings is responsible for changes in those variables. By applying the events of the Sustainabattle to the model, the following was found.

By providing Smart Meters (“Wattchers”) the environmental awareness indeed increased, whereas the effort needed for sustainability declined. It also led to a decrease in the intensity in which appliances were used. This is why a new variable called “Intensity of use will be added to the model. It is being influenced by “Use of technology”, because the intensity of using appliances decreased due to a greater awareness of energy use. “Group motivation” is also linked to the new variable, because it still is the decision of the group as a whole to decide whether or not to use a device.

These three variables had again impact on other variables. The group motivation was fueled by the growing awareness of what was possible within the possibilities the students had. It was additionally stimulated by the decrease in the effort and through the improvement of the prospect students had, namely winning prizes. The higher motivation of the groups had a positive influence on the presence of energy use appliances (decrease) and presence of lighting (decrease). The quality of the appliances did not get significantly better during the competition due to the relatively short period of time, but the willingness to achieve a better quality however did increase, as expected.

The improvements to the variables were mainly visible in the efforts that were made by *Crib Soleil* and *Beverburcht*, since these two groups were the only ones of the four examined groups to have actively participated during the Sustainabattle. Their energy use indeed decreased through two different strategies, namely less use of water (*Crib Soleil*) and less use of electric appliances (*Beverburcht*).

5.4 Final result

Both the existence of variables and relationships, as well as the functioning of the model under different circumstances have been proven to be correct. The final, validated model is shown in Figure 11. The exact influence of the new variable on other variables and vice versa can be found in Appendix I: Specification model variables.

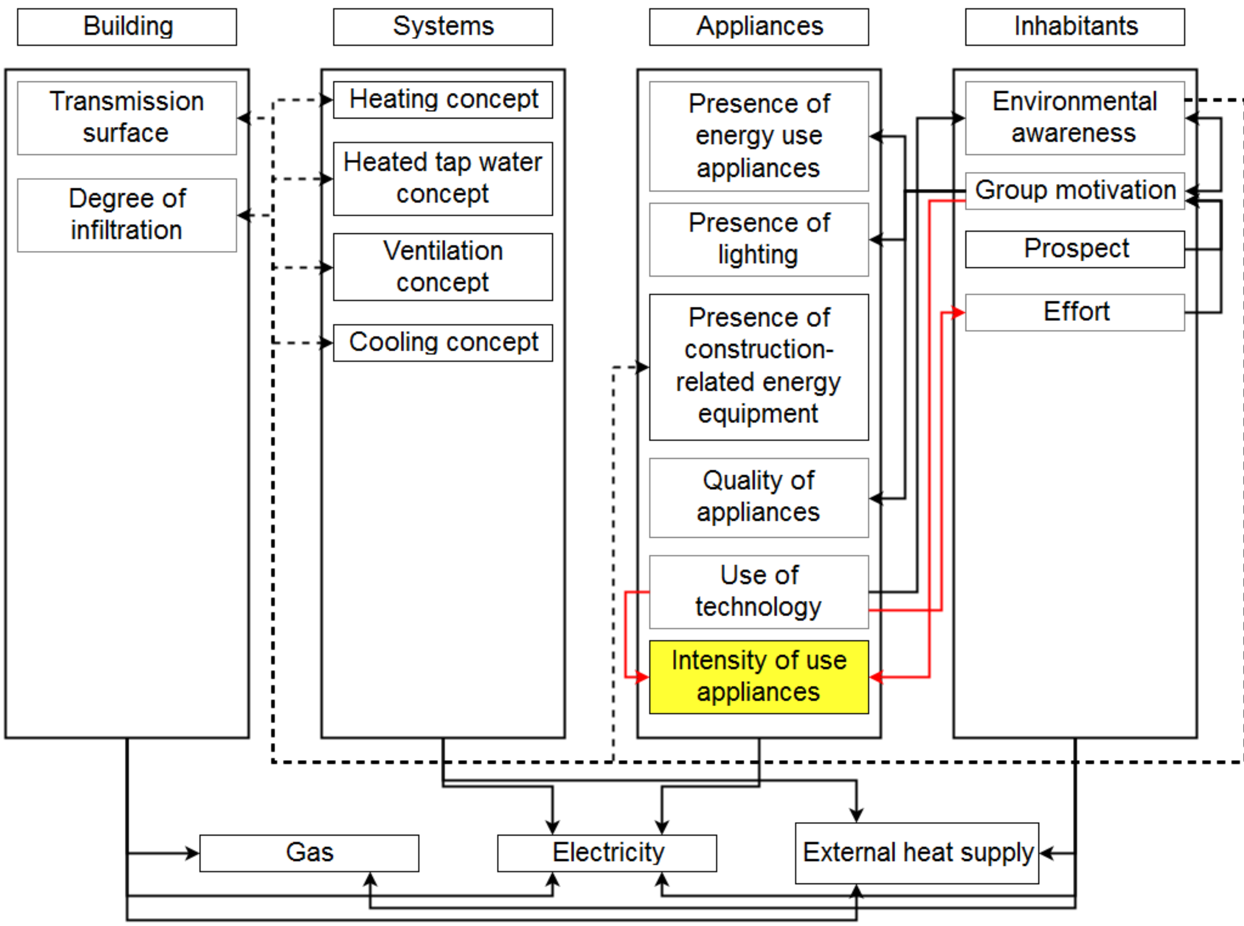

Figure 11: Definitive, validated version of energy use model

6. Discussion

The purpose of this thesis project was to develop a model that describes the influences of students' energy use. The resulting model contains a number of new variables and relations, as well as variables that were taken from the initial list of energy use characteristics provided by Entrop. Still, the process to come to this result deserves a critical view. The outcome of the project, possible explanations and the limitations that came to existence before and during the project will be discussed in this chapter.

As to the *findings* of this project, one of the most prominent ones is that among students, a fair deal of ignorance is observable when it comes to their own energy use behavior. The knowledge and awareness about their own energy use is low, leading to relatively high energy use levels. To enthuse and motivate students to live more sustainably, a joint responsibility has been found between the students as tenants and De Veste as the owner of the dormitories. Whereas the students only have a substantial influence on their own behavior and the way they use (electric) appliances, De Veste is responsible for improving the architectural state of the buildings that the students live in. These improvements include the installation of more efficient systems and new or better insulation materials.

Generally, students and other types of households both share some properties, but also differ from each other in several respects. As to the similarities, it can be said that students are not willing to give up on luxury when prompted to make efforts for a more sustainable lifestyle. Furthermore, the measures to reach a lower energy use level should not cost too much, be in financially or materially. Lastly, some institution or individual should take the lead in making the campus dwellings more sustainable, that is, students need a form of guidance to change their lifestyles into more sustainable ones.

The differences between students and other types of households are that students at the campus live in groups of ten people on average. This adds a new challenge to becoming more sustainable, as not only the individuals should be enthused, but the group's dynamics and consensus also play a crucial role in any initiative for saving energy. On top of that, students appear to not, yet have a great sense of responsibility concerning their own lifestyle. Apart from the fact that they do not know much about sustainable living, they seem to not care that much, either. Lastly, one material difference between students and other demographic groups is the number and quality of the indoor appliances. These appliances are old and inefficient, probably contributing substantially to the current energy use levels.

To make students more aware about their energy use and motivate them to change it for the better, it has been found that digital technology could be of great help in achieving this goal. During the Sustainabattle, smart meters for the first time gave the participants a concrete insight into their own behavior and enabled them to evaluate their measures easily.

Regarding the *possible explanations* of the findings described above, the analogies between students and other types of households could have their cause an economic way of thinking that exists independent of age or education. The main idea is that as long a given measure for more sustainability does not return the desired result, it will not be executed. This kind of reasoning could hold true for both students and adult individuals or groups.

The ignorance among students about their energy use could be explained by the small amount of information and education they receive about living sustainably. Parents, schools and the government are responsible for providing knowledge about the impact of human behavior on the climate and giving concrete tips for mitigating this influence in one's personal life. This appears to be happening too little, at least in the Netherlands.

The bad quality of indoor appliances in dormitories is possibly due to the limited financial capabilities of students. Since they have no fulltime jobs, new refrigerators or freezers are beyond their reach. Because today's generation of students has grown up surrounded by digital technology, however, this could explain why students are very positive about the use of it for the purpose of sustainability. This could contribute significantly to compensate for the bad quality of the electric devices that are owned by students.

When comparing the findings of the project to *other studies*, some similarities are visible. As Stanes et al. already mentioned, today's young adults appear to be more willing to make efforts for a more sustainable life than the older generations (Stanes et al., 2015). They would also recognize their role in influencing the global climate more often than older people do. These findings have been confirmed in this project. Although students do not want to have to make great sacrifices, there is a will to take action for more sustainability, at least to a certain extent.

The success of the smart meters during the Sustainabattle coincides with the findings of Jain et al. Joachain et al. Guerassimoff and Thomas and Emeakaroha et al., who also noticed the benefits of providing people with concrete and easy to understand feedback about their energy use (Joachain & Klopfert, 2014; Guerassimoff & Thomas, 2015; Emeakaroha et al., 2014).

Lastly, the role of the model's variable "Group motivation" is a confirmation of the finding by Jain et al. that peer pressure does make a difference in an individual's willingness to make efforts for more sustainability. Although the interviewed student groups suggested that mutual control did not really exist, this could change when a 'sustainability culture' is created at the campus of the University of Twente.

The *limitations of the research* do give reasons to be cautious about the correctness of the project's results. The energy use model only partly provides information about students' energy use, since the emphasis of this project is rather on the social side of energy use, leaving out the technical influences, due to missing information (influence of the weather, state of insulation dormitories, failed building simulations) and limited time. Second, a total of 21 energy use characteristics were not included in the model because of limited time, which inherently makes the model incomplete. Third, it is still unknown how exactly the model's variables influence the actual energy use. The influences the variables have on each other has been analyzed, but how much the energy use level rises or falls due to a change in one variable would have required more time and resources to investigate. However, the mentioned limitations are solvable by further research. By specifically paying attention to technical issues concerning energy use by students in a future project, the model can be balanced and completed. Incorporating the 21 missing variables in the model would yield the same result. An analysis of the exact influence of the variables on the final energy use level would also only require an extension of this project involving more datasets of energy use.

7. Conclusion

For De Veste to reach its goal of turning all its owned properties into energy neutral buildings, it is necessary to get students living in dormitories at the campus of the University of Twente to collaborate. However, little was known about how students in general and those living at the campus make use of energy. The purpose of the present study was therefore to investigate what defines the energy use of students. By doing so, a contribution could be made to the general body of knowledge regarding sustainability science and De Veste could be provided with concrete information that could be useful for future policy. In the following, the research questions of this project will be shortly revisited and the final energy use model will be presented.

7.1 Summary of findings

As a first step in the construction process of the model, a literature study and a case study were conducted in order to find new energy use characteristics or find evidence that would allow the removal of existing energy use variables from a list provided by Entrop (2013). This resulted in the addition of new energy use characteristics, including *Quality of appliances, Use of technology, Group motivation, Group composition, Prospect* and *Effort*. No existing characteristics were removed from the list.

Second, the found energy use characteristics were attempted to be operationalized by conducting another literature study, using the results from interviews with students and by analyzing data. By operationalizing the characteristics, the differences between students and other types of households became visible. In addition, the acquired information serves as background knowledge when establishing relations between the model's variables. From all characteristics, some received a value, whereas about others, no solid statements could be made because no information could be found. In Table 7 a list is provided with the operationalized and non-operationalized energy use characteristics.

Table 7: Operationalized and non-operationalized characteristics

Operationalized characteristics	Non-operationalized characteristics
Building	***Environment***
Floor surface	Surrounding buildings
Transmission surface	Surrounding vegetation
Internal space allocation	Infrastructure
Type of dwelling	Air temperature
Age of dwelling	Ground temperature
Degree of infiltration	Solar irradiance
Systems	Wind velocity
Heating concept	Precipitation
Heated tap water concept	Humidity
Ventilation concept	***Appliances***
Cooling concept	Presence of awning
Appliances	***Inhabitants***
Presence of energy use appliances	Residents' living patterns
Presence of lighting	Internal climate preferences
Presence of construction-related energy equipment	
Quality of appliances	

Use of technology	
Inhabitants	
Number of residents	
Age of residents	
Income of residents	
Form of ownership	
Environmental awareness	
Group motivation	
Group composition	
Prospect	
Effort	

The next step involved the selection of useful variables for the energy use model from the original list of energy use characteristics. This was done by assessing the characteristics according to their adjustability: if De Veste as the model's primary user could change the state of a characteristic to a desired level, then that characteristic was adopted into the energy use model. All others were not considered any further, although their role in the energy use of students remained undisputed. In Table 8, the selection of variables to be used in the energy use model is given.

Table 8: Adjustable and non-adjustable energy use characteristics

Adjustable characteristics (model variables)	Non-adjustable characteristics
Building	***Building***
Transmission surface	Floor surface
Degree of infiltration	Internal space allocation
Systems	Type of dwelling
Heating concept	Age of dwelling
Heated tap water concept	***Inhabitants***
Ventilation concept	Number of residents
Cooling concept	Age of residents
Appliances	Residents' living patterns
Presence of energy use appliances	Income of residents
Presence of lighting	Form of ownership
Presence of construction-related energy equipment	
Quality of appliances	
Use of technology	
Inhabitants	
Environmental awareness	
Group motivation	
Prospect	
Effort	

Subsequently, the relations between the model's variables were established based on literature, data and interviews with students. Especially the variables related to the behavior of students (all variables belonging to the categories "Appliances" and "Inhabitants", see Table 8) and the appliances they use proved to influence each other. This resulted in a preliminary version of the energy use model, which still needed to be validated (Figure 12).

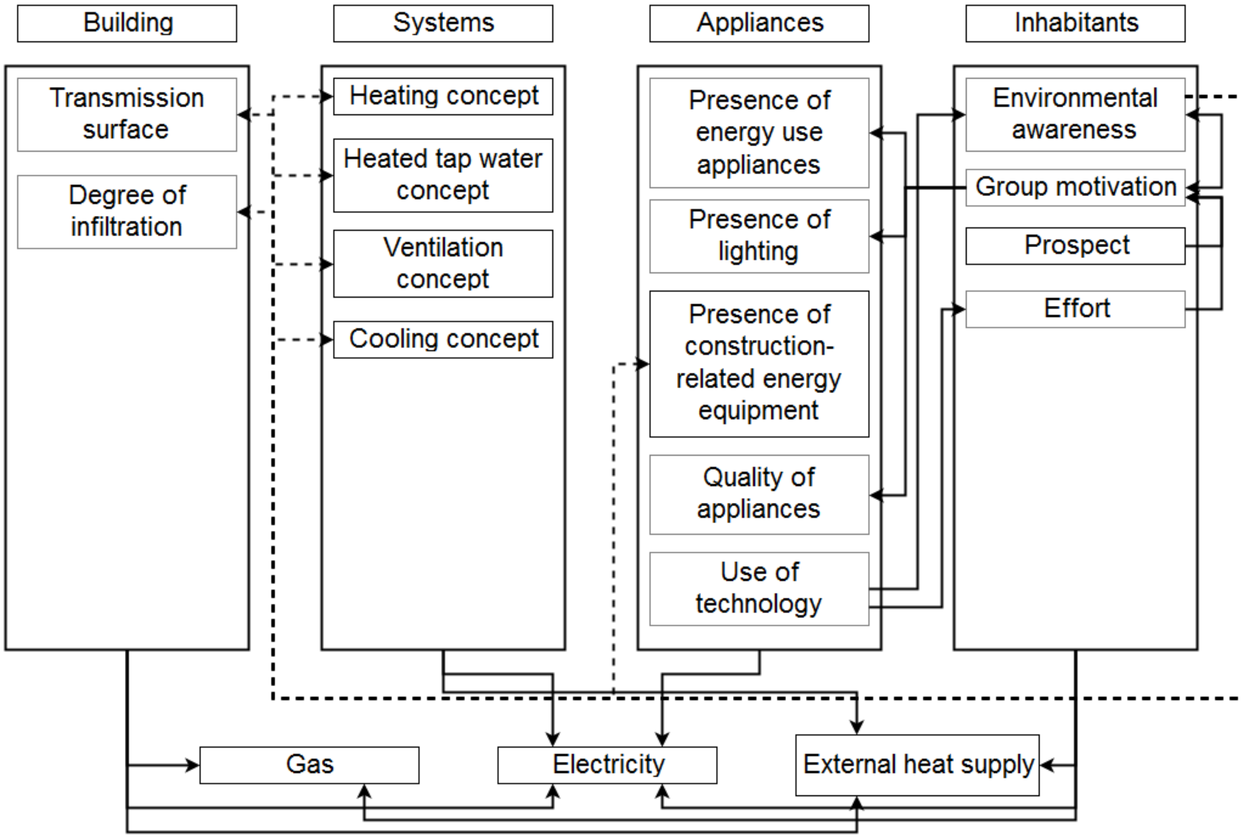

Figure 12: Non-validated energy use model

The Sustainabattle at the campus of the University of Twente was used to validate the model. Because it constitutes an intervention in daily practice, the Sustainabattle in this project was perceived as a full scale experiment to test the correctness of the various energy use model parts, as well as its general functioning. The data that was generated during this event, including action plans of the participating student groups and energy use levels during the competition, was evaluated to see whether the events in reality coincided with the structure and predictions of the model. The relations between the variables and the existence of the variables themselves proved to be correct. One new variable (*Intensity of use appliances*) was added to the model, together with new relations to other variables.

7.2 General result

After the conduction of the validation, during which one variable was added, the energy use model had come to its final form (Figure 13). It consists of 18 variables that can be altered by the user, by which mainly De Veste as owner and administrator is meant. However, the University of Twente itself could also play a role with respect to the variable of "Environmental awareness", which can be altered through education.

Between the variables, 18 relationships have been identified. Of these relationships, 17 are direct. The remaining relationship between the variable "Environmental awareness" and the variables belonging to the categories "Building" and "Systems" is indirect (indicated by a dashed line, see Figure 13, because the improvement of the building and its systems does not take place through the students, but can be made possible through their financial support. The most relationships are found within the 'social' part of the model, as the lion's share of the findings were made through interviews with students. In Figure 13, the final, validated version of the energy use model is presented.

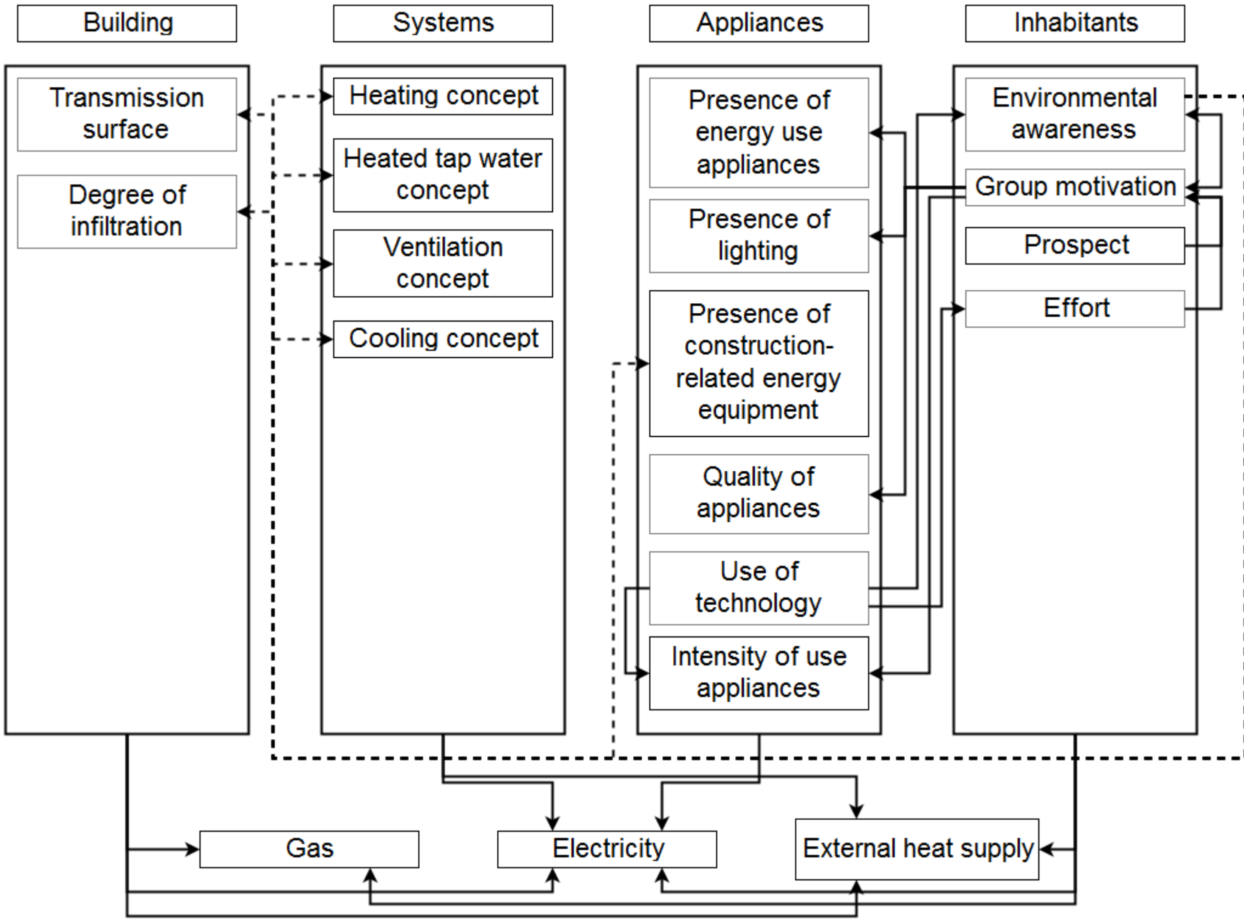

Figure 13: Validated energy use model

8. Recommendations

For the future, a number of suggestions can be made regarding future research and actions that could be undertaken by the several stakeholders within the issue of sustainability at the university's campus. These will be given in the following.

8.1 Students

Since they are the residents of the buildings that are be turned into more sustainable ones, students play a crucial role in reaching this goal. Practically, this means that there are three recommendations which can help students to contribute to a more sustainable environment. These recommendations are based on the findings of this research project.

First, students are called to take the initiative for creating households with lower energy use levels. Although the interviewed student groups admitted that they would like for someone to take the lead in making the dormitories sustainable, they need to step over this hurdle and also think of ideas by themselves. The difficulty of applying these ideas may not be as great as initially thought, provided that De Veste gives its full support.

Second, students are called to start discussions with each other and with the other stakeholders on the campus, such as De Veste and the university. Sharing ideas and opinions could lead to practical and simple measures that appeal to students who would like to make a difference, but do not know how to do so.

Third, it was often noticed during the interviews that students were hesitant to make any effort for sustainability, because others were not taking part, as well. To make students to wait no longer for others to start making decisions for a more sustainable lifestyle, this idea has to be abolished.

8.2 De Veste

As the owner and administrator of the dormitories at the campus of the University of Twente, De Veste is responsible for the technical state of the dwellings and encouraging students to lower their energy use. There are three recommendations for De Veste that could be used as input for future policy, apart from any findings by using the model.

First, it is inevitable to invest into more sustainable buildings by installing more efficient and modern systems, as well as insulating the outer and inner walls. This necessity has been induced from the research on the architectural state of the dormitories at the campus. The investments will eventually save money spent on providing energy. Another suggestion that is based on financial investments comes from students who were interviewed for this project. Upon asking in what way they would like to be helped regarding sustainability, the interviewees responded that they would like to change the devices (primarily the white goods) of their houses. Because of their limited financial capabilities, this could however be done if De Veste were willing to contribute financially through "some sort of initiative that allows to buy new appliances for less money." In case this idea becomes reality, it is suggested to turn this into a reoccurring event, such that the quality of the appliances can be brought up to a sufficient level and stay that way permanently.

On the other hand, De Veste can also make investments in a psychological sense: constant and ongoing encouragement of students to make decisions in favor of sustainability has been found to be important for creating a 'sustainability culture', as one interviewed student called it. Once sustainability and saving energy becomes a norm, rather than an exception, this will yield results in terms of used energy.

From the Sustainabattle and experiences from similar events in other countries, it is known that smart meters contribute greatly to saving energy and enthusing students make efforts for more sustainability. It is recommended to provide all student communities with one smart meter, since this relatively small investment is likely to bring about great savings of energy.

Lastly, De Veste is advised listen to the ideas of students. As communication is claimed to be of major importance to De Veste's business strategy, the discussion with students is to be kept alive and the input of individuals or groups needs to be considered, as it could contribute to the process of achieving energy neutral buildings.

8.3 Policy makers

The University of Twente and the municipality of Enschede are encouraged to also play a role in bringing about a sustainability culture at the campus.

The university is called upon to integrate the topic of sustainability into the curricula even more prominently. From literature it is now known that education plays a key role in making students aware of their responsibility. This implies that the transfer of knowledge regarding sustainability, even only within the borders of the relevant field of study, is likely to add to the overall awareness among students. The need for more awareness was also found during the interviews with students, who attend different kinds of study programs, but do have in common that sustainability is a minor topic within their field of expertise. Working together with De Veste to also promote sustainability outside of the lecture rooms is also suggested, so that sustainability becomes a well-known topic at the campus.

Although the living conditions of students on the campus might from those residing in the city, it is expected that there are enough similarities between the two groups for the municipality to also start campaigns for a more sustainable lifestyle among students. Actions such as the offer to buy new white goods for a reduced price could be also work with students living outside of the campus.

8.4 Future research

The thesis project has left open some aspects of energy use among students that are worth to be investigated in more detail.

First, the research limited itself to investigating students living on the campus of the University of Twente. It could be worthwhile to compare the findings of this project to those students living in the city or in other forms of housing.

Second, the project emphasized the social aspect of energy use, due to limited time, skills and resources. Taking a closer look at the technical side of energy use by students might reveal new details and make the energy use model complete.

Finally, from the research it is expected that the current influence the weather has on the energy use of dwellings will increase in years to come, due to climate change. It is suggested to pay attention to this development, not only for students, but for households in general.

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Appendices

Appendix A: Map of campus of the University of Twente

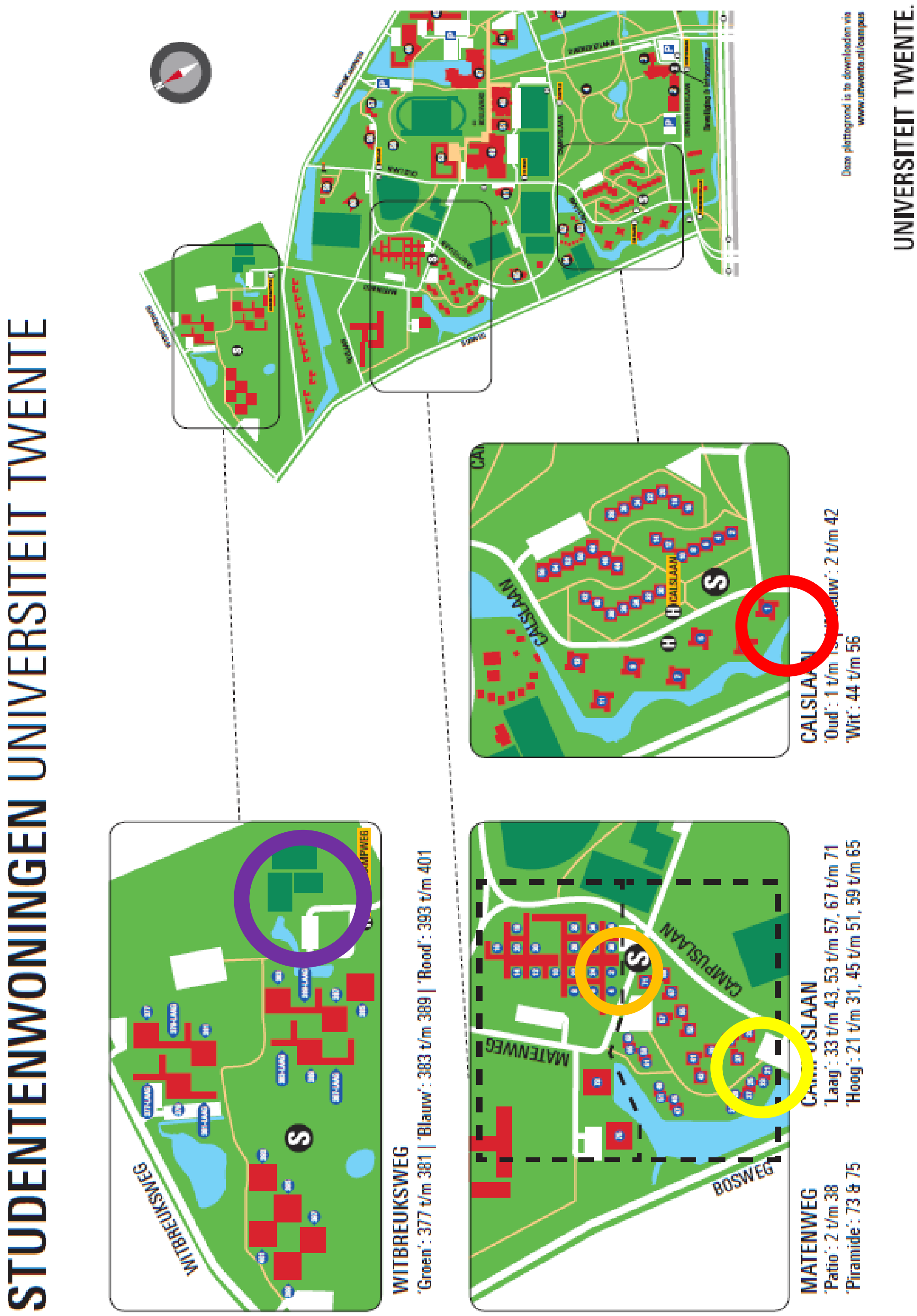

Figure 14: Locations student housing at the campus of the UT (part 1) (Courtesy of University of Twente), with Witbreukswegs 377 indicated by purple circle, Calslaan 1-3 by red circle, Matenweg 34 by orange circle and Campuslaan by yellow circle.

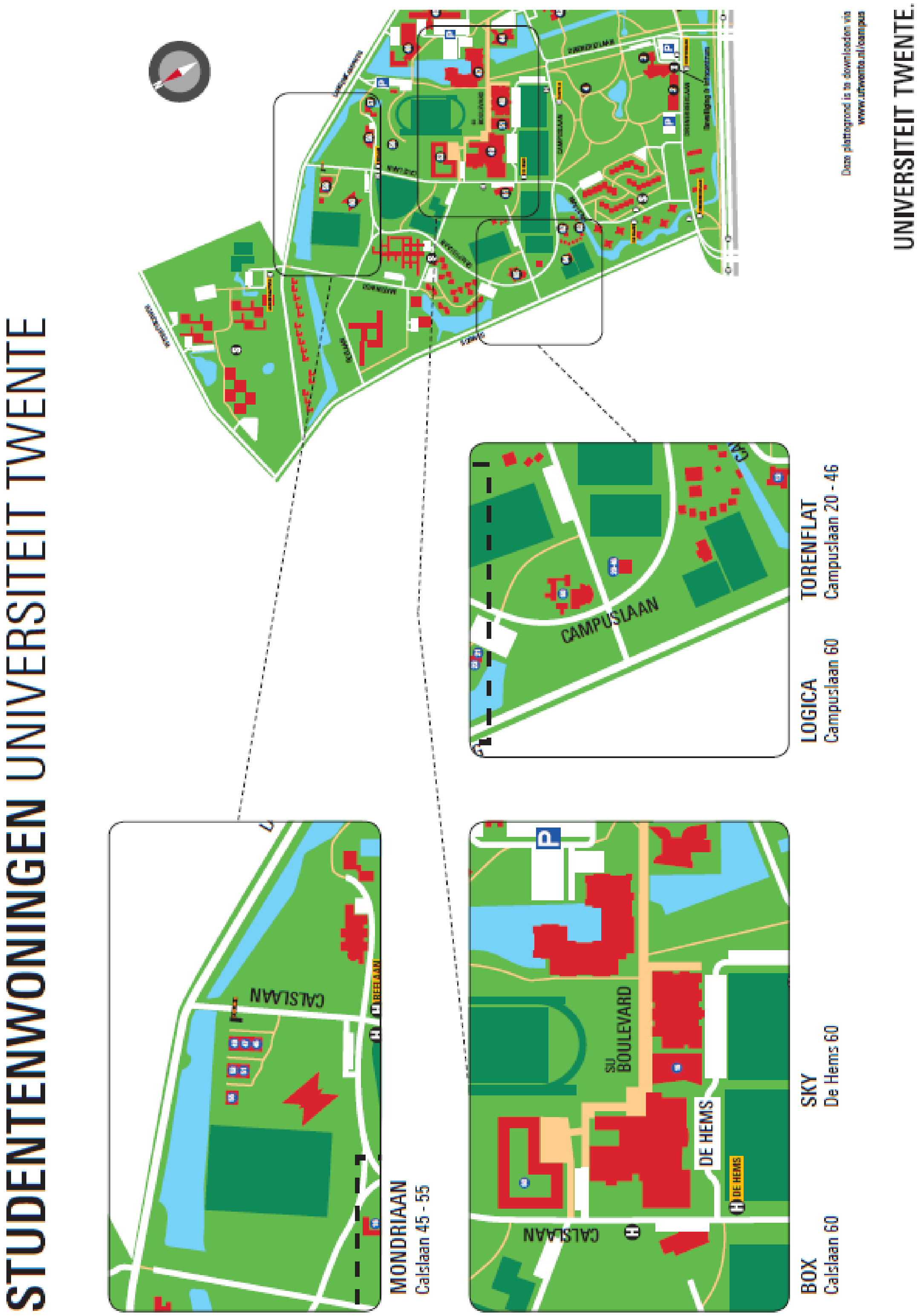

Figure 15: Locations student housing at the campus of the UT (part 2) (Courtesy of University of Twente)

Appendix B: The Sustainabattle

Nature of the competition

The Sustainabattle at the campus of the University of Twente took place between 11 April and 9 May 2016. A total of 24 groups of students had registered to take part (see Table 9). These student groups can live in their own dormitory or live in one part or floor of a dormitory, together with other groups of students living at other floors or in other parts of the building. The goal of the Sustainabattle is to live a sustainably as possible for the duration of one month, thereby staying ahead of the other groups in terms of saved electric energy. The amount of electric energy is compared to the average energy use of the group over the year 2015. The group with the biggest negative difference between average energy use and energy use during the Sustainabattle wins the first part of the competition. In edition 2016, *Crib Soleil* achieved a saving rate of 59,3%, which was enough for the first place in the overall ranking (see Table 10).

Table 9: Groups registered for Sustainabattle

Group	Number of residents	Address	Remarks
Calslaan 1	12	Calslaan 1-1	
Beverburcht	11	Calslaan 1-3	
Calslaan 2a	5	Calslaan 2a	Energy meter together with Calslaan 2b
Batflat	8	Calslaan 4	
Club 9-2	11	Calslaan 9-2	
H.M.C.H. “D.M.V”	11	Calslaan 11-1	
Elf Twee	11	Calslaan 11-2	
Calslaan 12	10	Calslaan 12	Dropped out early in competition
Huize Badeendt	8	Calslaan 22	
Calslaan 34	10	Calslaan 34	Dropped out early in competition
Huize Olifant	5	Calslaan 42A	Energy meter together with Calslaan 42b
2+2 Residence	5	Calslaan 56-1	
Crib Soleil	14	Campuslaan 33	
C35PP	14	Campuslaan 35	
FUNEST	14	Campuslaan 41	
Carpe Noctem	12	Campuslaan 59	
Zeepegel 61	15	Campuslaan 61	
Sjaakvlek	15	Campuslaan 63	
Villa 65	16	Campuslaan 65	
Patio 8	7	Matenweg 8	
Pimpelpatio	7	Matenweg 34	
Matenweg 36	7	Matenweg 36	
Huize Bosøl	7	Witbreuksweg 377 rechtsonder	Shares energy meter together with other groups in building

De Witte Walvis	8	Witbreuksweg 401-108	Dropped out early in competition

The second part of the Sustainabattle is the delivery of a presentation at a symposium held by the organizers of the competition. By giving the public insight into their methods and actions for saving energy and answering questions of a jury, the individual groups can score points, which will be taken into consideration by the jury upon selecting the final winner of the Sustainabattle. This implies that the highest ranking group regarding energy use does not automatically win the competition. Eventually, the group with the best combination of low energy use and presentation wins the Sustainabattle.

Generated data during the Sustainabattle

During the Sustainabattle, the energy use levels of the participating groups was recorded through the use of so-called Smart Meters. These energy meters register and record the current amount of electric energy being used in a household and display the level of energy use on a small screen for the user to be informed. In addition, the recorded energy use levels during the Sustainabattle were sent to a central server via the internet with intervals of five minutes, such that a ranking of the participating groups could be constructed based on the latest energy use levels.

Although 24 groups had registered, 13 of them were included in the final ranking at the end of the Sustainabattle (11 April until 9 May 2016). The ranking is visualized in the Table 10, along with the individual energy use levels and savings compared to average energy use levels over 2015.

Table 10: Ranking energy savings Sustainabattle (student groups of case study indicated in yellow)

Ranking	Group	Number of residents	Energy use during the Sustainabattle [kWh/day]	Energy use 2015 [kWh/day]	Energy saved compared to average 2015 [%]
1	Crib Soleil	14	15,74	38,65	-59,3
2	Elf Twee	11	20,64	44,17	-53,3
3	Batflat	8	18,6	33,71	-44,8
4	Zeepegel 61	15	25,67	34,65	-25,9
5	Beverburcht	11	15,38	20,42	-24,7
6	Patio 8	7	12,62	16,74	-24,6
7	Sjaakvlek	15	19,4	25,49	-23,9
8	Huize Olifant	5	25,82	30,8	-16,2
9	Villa 65	16	53,59	62,34	-14,0
10	Huize Bosøl	7	157,42	176,4	-10,8
11	Calslaan 1	12	21,62	24,15	-10,5
12	Calslaan 2a	5	23,9	26,02	-8,1
13	Pimpelpatio	7	23,15	23,99	-3,5

In total, an electric energy amount of over 3000 kWh was saved by organizing the Sustainabattle, which is about the same amount of energy use by an average household over a year. In currency, 3000 kWh equal more than €1000.

Relation number of residents and saved energy

For the Sustainabattle to be a success for a student group, all group members need to be involved in making efforts for saving energy. By analyzing the data in Table 10, however, it appears that the number of residents in a student community does not make it any more difficult to get the whole group motivated for taking part in the Sustainabattle (see Figure 16).

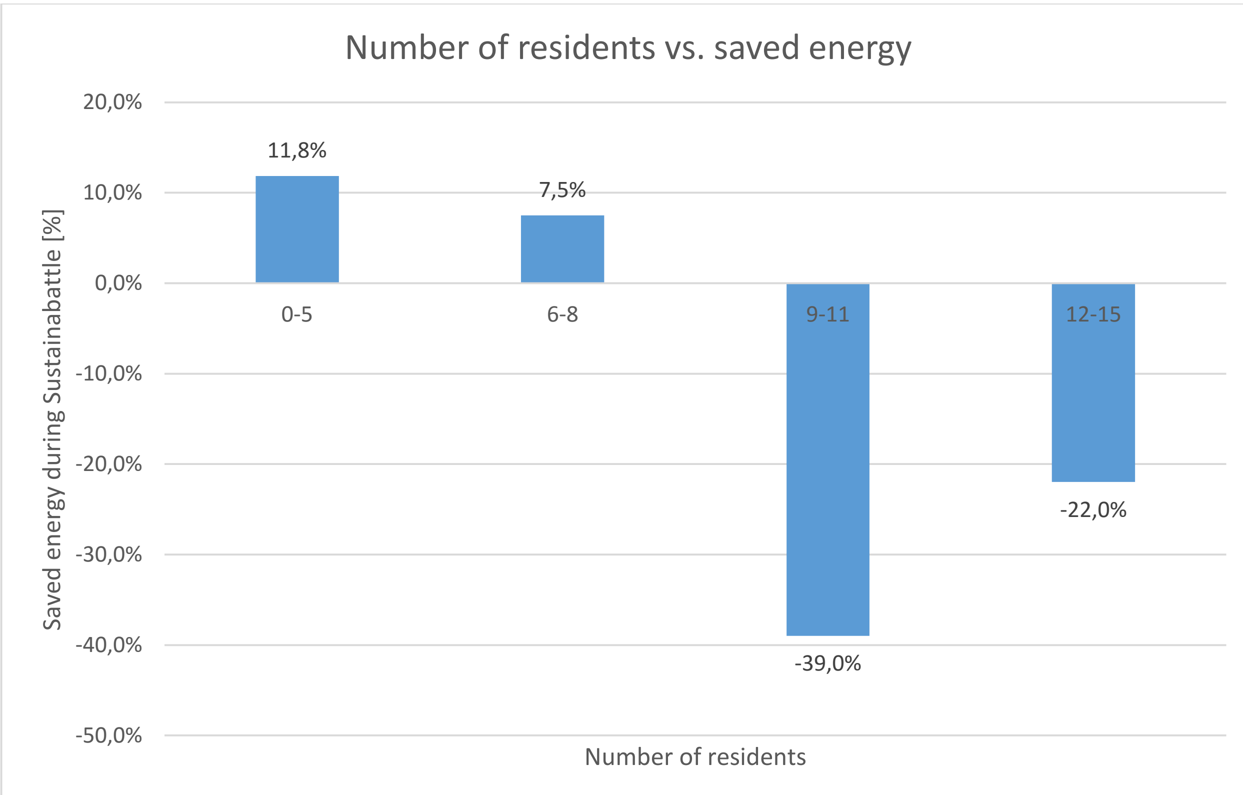

Figure 16: Number of residents compared to savings in energy use

Appendix C: Selected student communities for case study

Calslaan 1-3 – *Beverburcht*

Architecture

Table 11: Architectural properties of Calslaan 1-3

Type of building	**Multi-storey dwelling**
Number of floors	4
Year of construction	1964
Energy Index	2,57
Energy label	C (1,56)

Rooms

Table 12: Rooms Calslaan 1-3

Room	Number
Common living area	1
Bathroom	2
Sleeping rooms	12
Hall	1
Total floor area [m²]	341

Systems

Table 13: Systems of Calslaan 1-3

System	Type
Heating concept	HR107-boiler
Warm tap water concept	Combiboiler (gas)
Cooling concept	None
Ventilation concept	C1 (natural supply, mechanical discharge)

Appliances

Table 14: Appliances in Calslaan 1-3

Appliance	Number	Remarks
Refrigerator	7	5 small, 2 big
Freezer	2	
Stove	2	
Microwave	2	
Washing machine	1	
Dryer	1	Mostly not used
Dish washer	1	
TV	1	
Laptops	11	Incl. 1 laptop common living area
Amplifiers	2	
Smartphone	10	
Coffee machine	1	
Pie iron	1	
Toaster	1	
Electric kettle	1	
Game console	3	

Action plan for Sustainabattle

Table 15: Action plan Sustainabattle Calslaan 1-3

Top five devices using most energy (own estimation)	1. Dryer 2. Refrigerator 3. Deep fryer 4. Laptop 5. Television
Opinion about responsibility for sustainability	Lessees are responsible for use of building; lessor is responsible for the state of the building
Estimated energy use [kWh pp/month] (see also Appendix G)	27
Measures to reduce energy use	- Embrace natural light and study with your curtains half open - Change your bulbs and use CFL or LED bulbs. - Turn off lights if you are not in your room and also turn off the light from your roommates. - Unplug applications which are not in use. - Turn off ceiling lights and use table lamps while studying. - Run full loads of wash. Ask your roommates if they have dirty cloth, too. - Hang dry our laundry. - Set refrigerators to their ideal temperature and do not put hot food in the fridge.
Measures that will actually be carried out	- Not use the dryer - Use less refrigerators - No more instants meals for microwave - Turn off lights if not present

	- Make less use of washing machines

Energetic performance

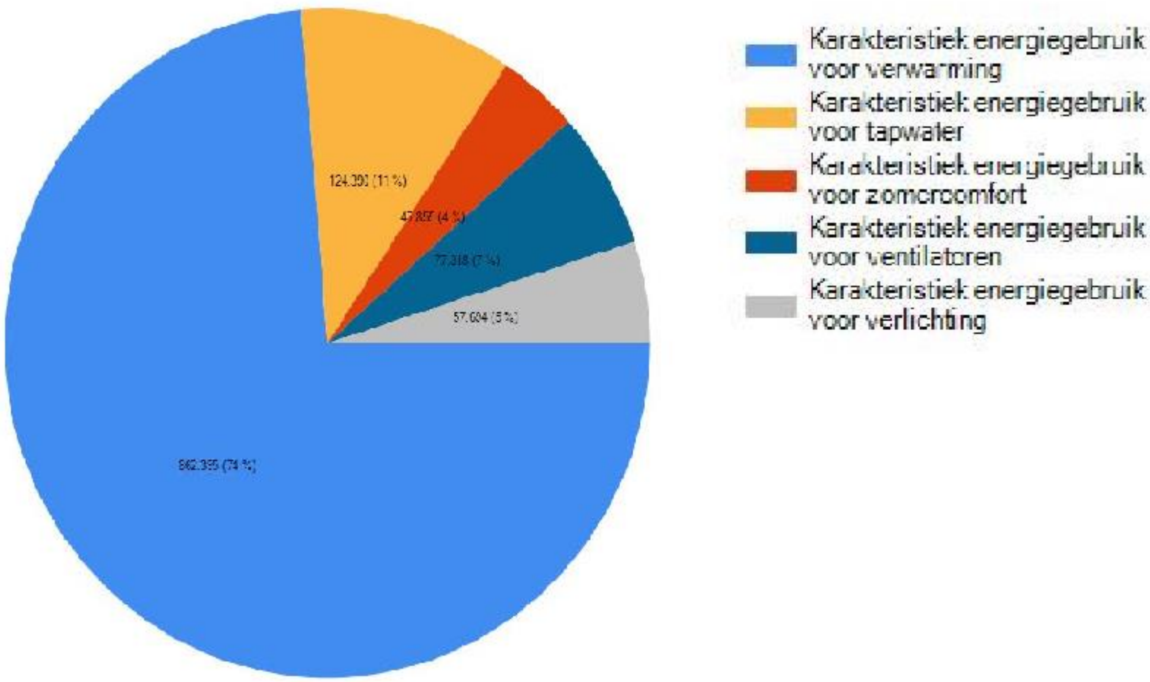

Figure 17: Energy use Calslaan 1-3

No additional information could be collected as was possible for the other dormitories due to software-related issues.

Campuslaan 33 – *Crib Soleil*

Architecture

Table 16:Architectural properties of Campuslaan 33

Type of building	**Multi-storey dwelling**
Number of floors	2
Year of construction	1967
Energy Index	1,38
Energy label	A (0,77)

Rooms

Table 17: Rooms Campuslaan 33

Room	Number
Common living area	1
Bathroom	1
Sleeping room	14
Hall	2
Total floor area [m²]	188

Appliances

Table 18: Appliances in Campuslaan 33

Appliance	Number	Remarks
Fridge	4	
Freezer	2	
Stove	1	
Microwave	3	
Dryer	1	
Laptops	14	
Smartphone	14	
Pie iron	1	
Toaster	1	
Washing machine	2	
Oven	2	Working on gas and electricity, respectively
Hair dryer	1	
Hair straightener	1	
Blacklights	1	
Fog machine	1	
Deep fryer	1	

Systems

Table 19: Systems Campuslaan 33

Systeem	Type
Heating concept	HR107-boiler
Warm tap water concept	Combiboiler (gas) and solar boiler
Cooling concept	None
Ventilation concept	A1 (natural supply and discharge)

Action plan for Sustainabattle

Table 20: Action plan Sustainabattle Campuslaan 33

Top five devices using most energy (own estimation)	1. Freezer/refrigerator 2. Washing machine 3. Microwave 4. Laptop 5. Lights
Opinion about responsibility for sustainability	Joint responsibility between lessor and lessees
Estimated energy use [kWh pp/month] (see also Appendix G)	58,3
Measures to reduce energy use	- Make less use of toasters, microwaves - Make less use of washing machine - Unplug unused devices
Measures that will actually be carried out	- No use of toasters, microwaves - No use of dryer - Eat vegetarian twice a week - Sort out different kinds of waste

Energetic performance

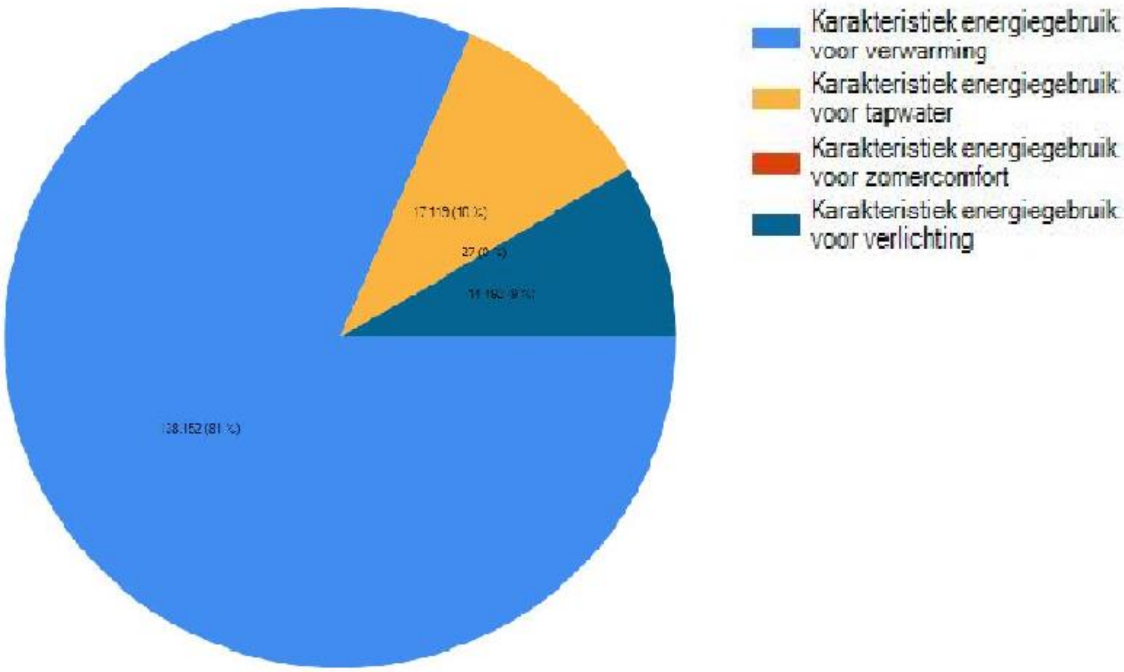

Figure 18: Energy use Campuslaan 33

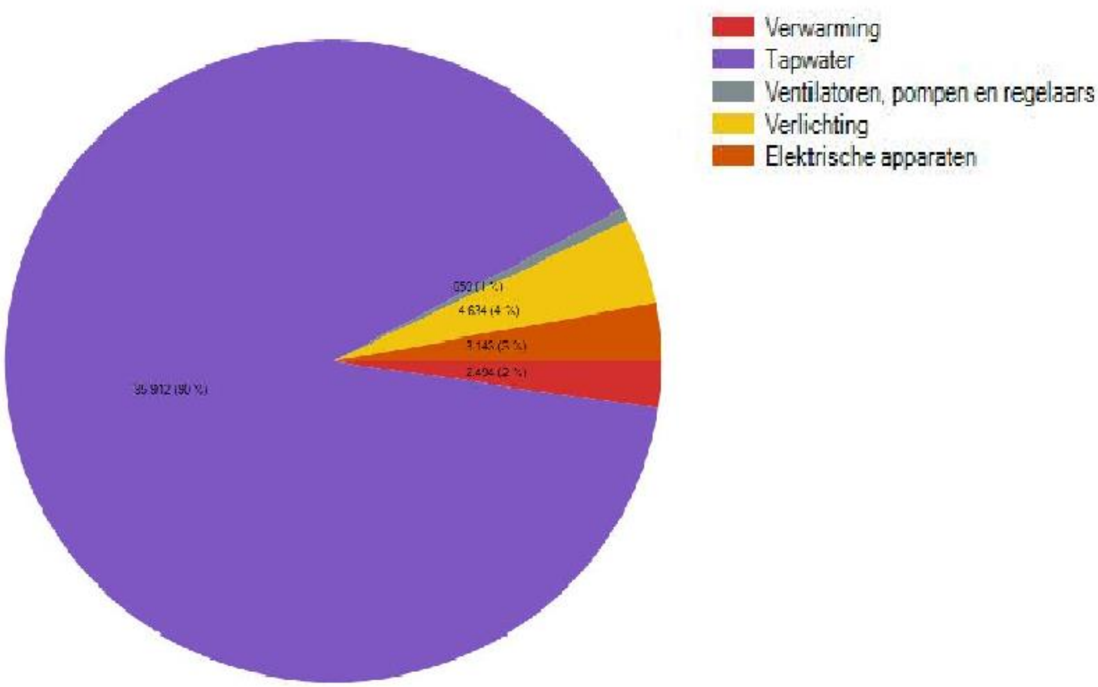

Figure 19: Shares of energy use Campuslaan 33

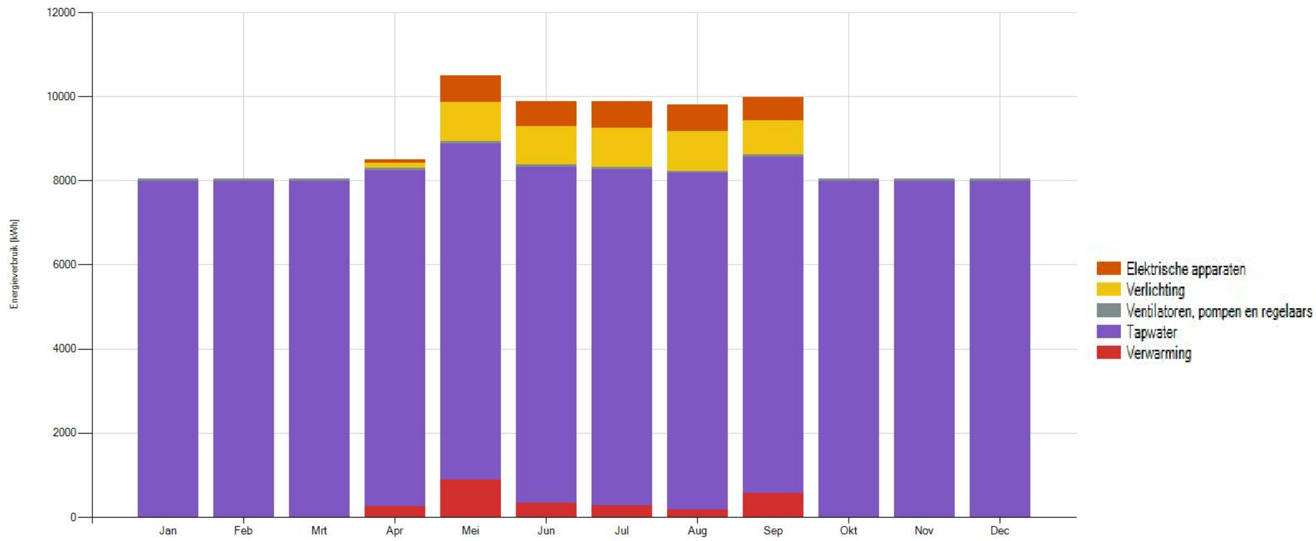

Figure 20: Energy use per month Campuslaan 33

Witbreuksweg 377 (lower right) – *Huize Bosøl*

Architecture

Table 21: Architectural properties of Witbreuksweg 377 (lower right)

Type of building	**Multi-storey dwelling**
Number of floors	4
Year of construction	1972
Energy Index	1,62
Energy label	D (1,9)

Rooms

Table 22: Rooms Witbreuksweg 377 (lower right)

Room	Number
Common living area	1
Bathroom	8
Sleeping rooms	9
Hall	1

Appliances

Table 23: Appliances in Witbreuksweg 377 (lower right)

Appliance	Number	Remarks
Refrigerator	3	
Freezer	1	
Stove	2	
Microwave	1	
Washing machine	1	
Dryer	-	
Dish washer	-	
TV	1	
Laptops	7	
Amplifiers	-	
Smartphone	7	
Coffee machine	-	
Pie iron	1	
Toaster	1	
Electric kettle	-	
Game console	1	

Systems

Table 24: Systems Witbreuksweg 377 (lower right)

System	Type
Heating concept	Heat supply external party (municipality)
Warm tap water concept	Heat supply external party (municipality)
Cooling concept	None
Ventilation concept	A1 (natural supply and discharge)

Action plan for Sustainabattle

Table 25: Action plan Sustainabattle Witbreuksweg 377 (lower right)

Top five devices using most energy (own estimation)	1. Washing machine 2. Freezer/refrigerator 3. Television 4. Electric boiler 5. Laptop
Opinion about responsibility for sustainability	Joint responsibility of lessor and lessees
Estimated energy use [kWh pp/month] (see also Appendix G)	50-80
Measures to reduce energy use	- Turn off lights if not present
Measures that will actually be carried out	- Make less use of heating concept - Be more careful with amount of heated water

Energetic performance

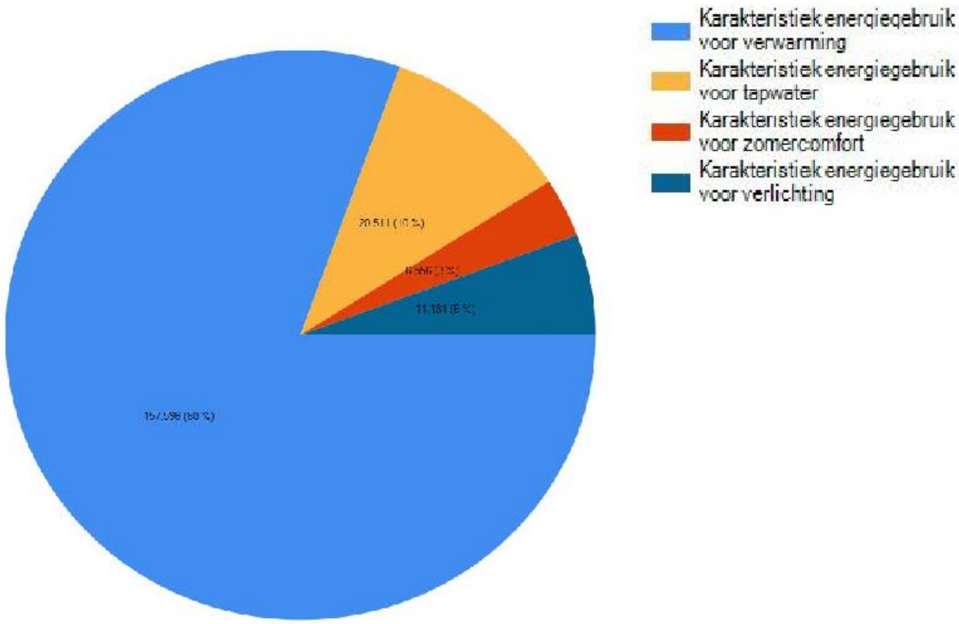

Figure 21: Energy use Witbreuksweg 377 (lower right)

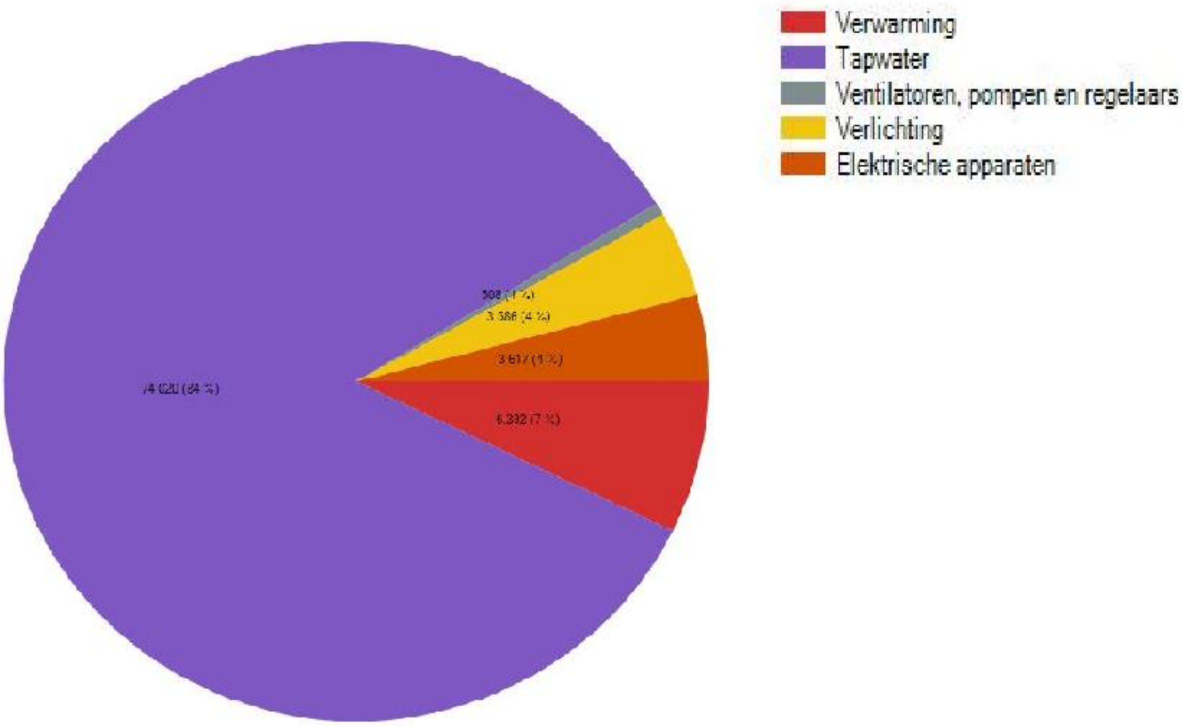

Figure 22: Shares energy use Witbreuksweg 377 (lower right)

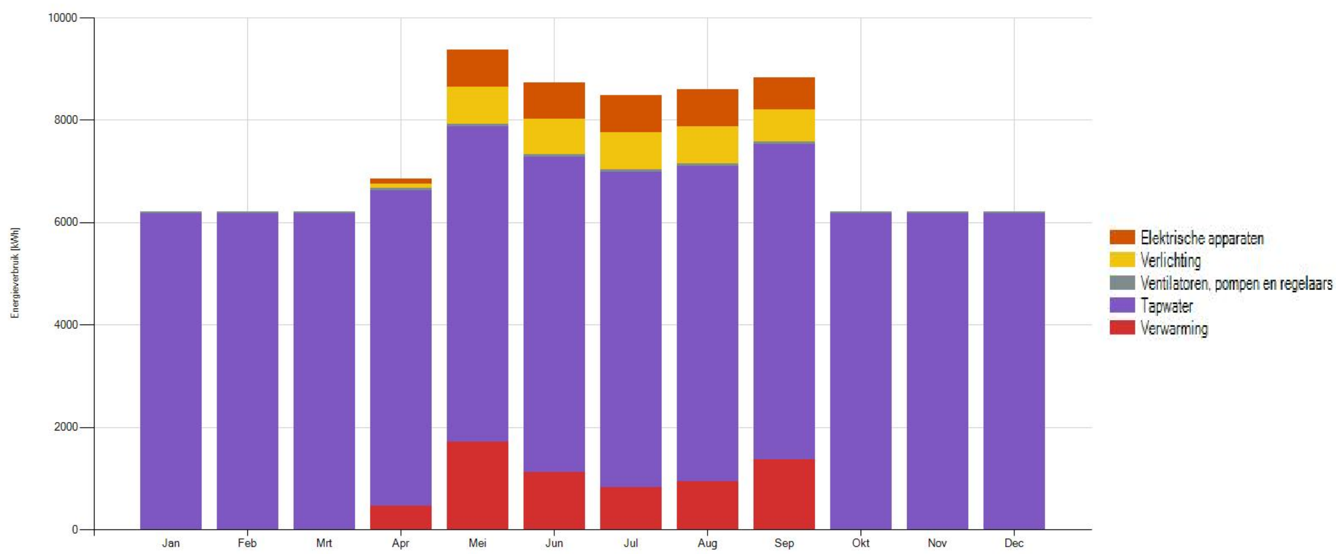

Figure 23: Energy use per month Witbreuksweg 377 (lower right)

Matenweg 34 – *Pimpelpatio*

Architecture

Table 26: Architectural properties Matenweg 34

Type of building	**Terraced house**
Number of floors	1
Year of construction	1965
Energy Index	3,15
Energy label	D (1,9)

Rooms

Table 27: Rooms Matenweg 34

Room	Number
Common living area	1
Bathroom	3
Sleeping rooms	7
Hall	1

Appliances

Table 28: Appliances Matenweg 34

Appliance	Number	Remarks
Refrigerator	6	
Freezer	3	
Stove	2	
Microwave	1	
Washing machine	1	
Dryer	1	
Dish washer	1	
TV	2	
Laptops	7	
Amplifiers	1	
Smartphone	7	
Coffee machine	-	
Pie iron	4	
Toaster	-	
Electric kettle	-	
Game console	1	

Systems

Table 29: Systems Matenweg 34

System	Type
Heating concept	Heat supply external party (municipality)
Warm tap water concept	Electric boiler
Cooling concept	None
Ventilation concept	A1 (natural supply and discharge)

Action plan for Sustainabatle

Pimpelpatio did not hand in an action plan.

Energetic performance

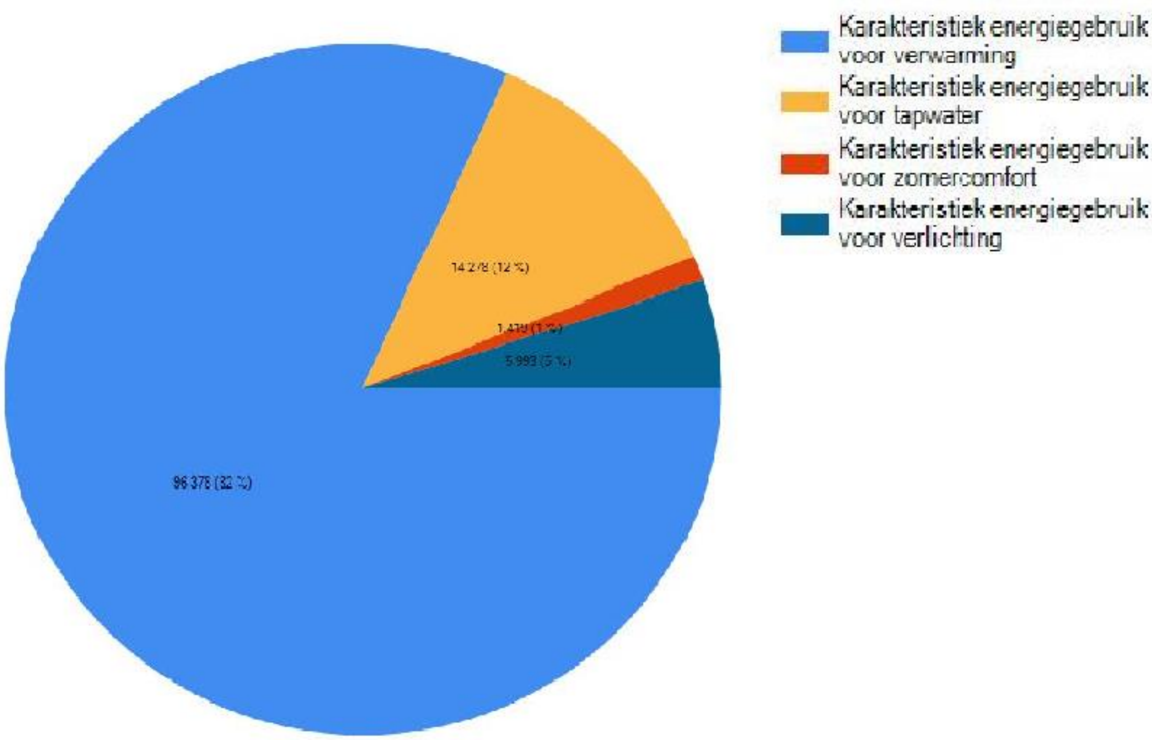

Figure 24: Energy use Matenweg 34

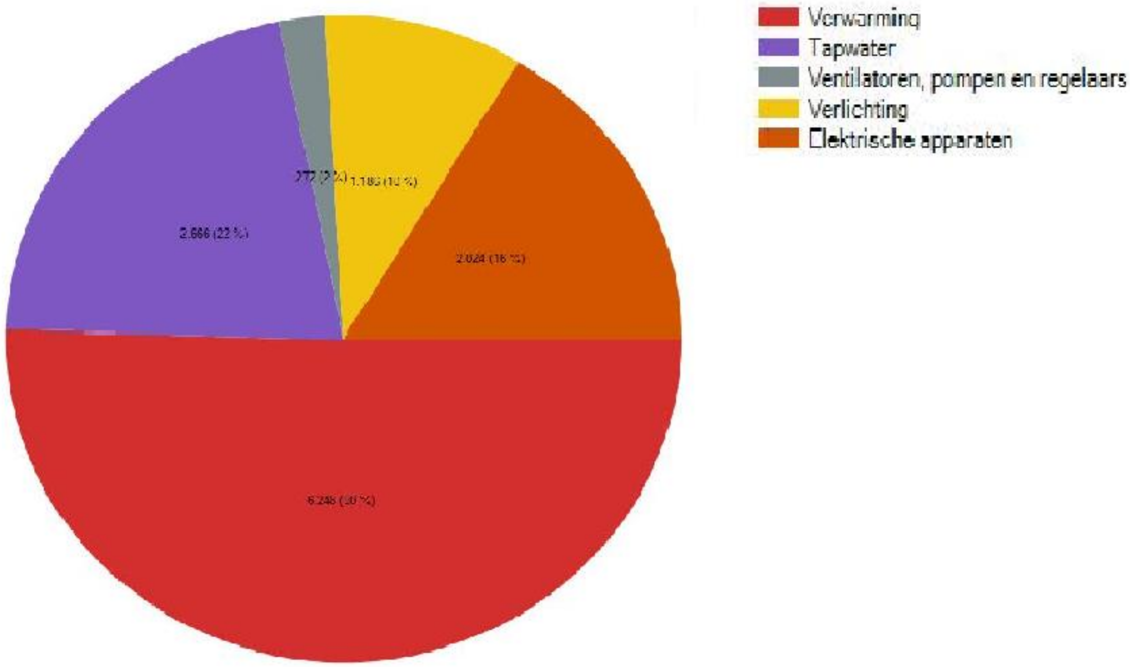

Figure 25: Shares energy use Matenweg 34

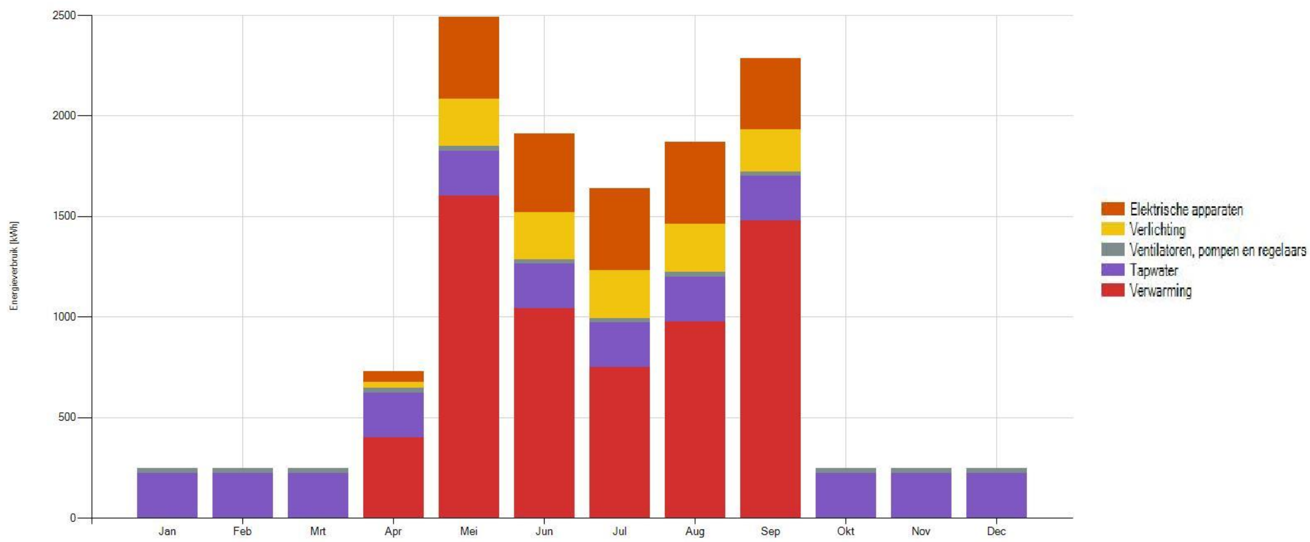

Figure 26: Energy use per month Matenweg 34

Appendix D: Research methods

Desk study

The theoretical part of the project will consist of desk studies. These studies comprise of literature and documents studies, as well as data analysis.

Literature and document study

To back the statements made about different topics and find an academic foundation for the energy use model to be built, literature studies have been incorporated in the project. The findings of other academics provide the foundation for the acquisition of new knowledge. For the purpose of testing the model, the energy plans of the students were also analyzed, which can be considered to be an additional literature study.

The main source of literature was the internet. Digital databases, such as *Sciencedirect* and search engines like *Google Scholar*, to name but a few, were expected to contain relevant papers.

Furthermore, the document study is related to any other desk study that is not related to searching for and evaluating literature. This includes, for example, the evaluation of interview results.

Data analysis

A data analysis was needed for discovering what systems are installed in dormitories, how the variables of the energy use model relate to one another and how well the energy use model matches real life events (such as the Sustainabattle).

The necessary data was obtained from the inventory system of De Veste, as well as from the smart meters which were installed in the dormitories. These sources contained all necessary information concerning building characteristics and installed energy systems, as well as energy use data.

Case study

The activity of conducting interviews was put under the heading of 'case study'. By visiting the student groups and asking them questions about their opinions and their efforts during the Sustainabattle, the questions related to the social aspects of the energy use model could be answered. Along with visiting the dormitories for interviews, the exact number of devices and systems that are being used by students could be counted, as well.

The interviews themselves were semi-structured, which made it easier to ask spontaneous questions or ask questions related to the answer of the previous one. Since 24 groups participated in the Sustainabattle, only a limited number of four groups were visited due to time constraints.

Appendix E: Search actions for scientific sources of information

For finding the scientific articles on which the literature studies are based, multiple search actions on the internet were conducted. These search actions were structured after the instructions given by the University of Twente during the study program of Civil Engineering.

Table 30: Search actions

Search question	"Which technical characteristics play a role in the energy use of students?"
Which aspects should occur in a search result?	- Energy use of students - Technical installations (heating/cooling/electricity/devices) - Influence on lifestyle/energy use
Sources	- Sciencedirect (http://www.sciencedirect.com/) - Google Scholar (http://scholar.google.com/)
Search terms	- Energy use - Students - HVAC - Influence - Behavior - Electricity - Student housing - Cooling system - Heating system - Sustainability - Systems - Technical factors - End use - Components - Lighting - Appliances - Profile
Search queries and results	
Sciencedirect	
Students AND sustainability AND HVAC	- El Asmar 2015 - Aktacir 2007 - Urge-Vorsatz 2013 - Emeakaroha 2014
Students AND energy AND use AND systems	
Students AND influence AND HVAC	
Students AND sustainability AND HVAC	
Students AND heating system AND influence AND energy AND use	- Majcen 2015
Students AND systems AND energy	
Student AND housing AND technical AND factors AND energy	- Konis 2016 - Achtnicht 2014
Student housing AND HVAC	
Students AND energy AND use AND profile	
Google Scholar	

Students AND sustainability AND HVAC	
Students AND energy AND use AND systems	
Students AND influence AND HVAC	
Students AND heating systems AND influence AND energy AND use	
Students AND systems AND energy	
Students AND housing AND technical AND factors AND energy	
Students AND housing AND HVAC	
Students AND housing AND Europe	
Energy AND use AND housing AND technical AND factors	- Crosbie & Baker 2009 - Greening 2000 - Berkhout 2000
Suggestions of Sciencedirect	- Yu 2011
Results of search on 'regular' Google	
Energy AND use AND end AND use AND components	- UNEP 2009 - IIASA 2012
Results via references of found papers	
Majcen 2015	- De Groot 2008
IIASA 2012	- IEA 2006
Emeakaroha 2014	- Delmas 2014 - Emeakaroha 2012 - Froehlich 2009

Appendix F: Interview format

Energy usage

1. What do you estimate to use most energy for?
2. What do students in general use most energy for?
3. How have you changed your perception of energy use since you left your parental home?
4. How are you being influenced by your roommates concerning energy use?
5. What do you consider to be hard about living sustainably?

Familiarity with sustainability

1. How necessary do you think it is that society makes a transition towards a more sustainable use of energy?
2. Do you think that you as (an) individual(s) can make a meaningful contribution to the battle against climate change?
3. How much attention does your study program spend on sustainability in a broad sense?
4. Have you ever encountered information or campaigns about sustainability in any other way and if yes, how helpful was it for your day-to-day life?

Measures for more sustainability

1. What will work better, in your opinion: punishment if you use too much energy or a reward in case you stay below a given threshold value of energy use?
2. What do you think about the use of technology in households for monitoring energy use, such as Smart Meters?
3. How helpful do you think it would be if third parties, such as the university or the (local) government, would give more information about sustainability and sustainable living?

Future of sustainability at the campus

1. What advice would you like to give to policy makers concerning sustainability at the campus?
2. What do you think you yourself could structurally improve about your own lifestyle to make it more sustainable?

Appendix G: Calculation dormitories

Floor surface area common living rooms

Table 31: Floor surface area common living rooms

Dormitory and street	Surface area [m²]
Beverburcht - Calslaan 1-3	31 (including kitchen)
Crib Soleil - Campuslaan 33	31,8 (including kitchen)
Huize Bosøl – Witbreuksweg 377 (lower right)	19,1 (including kitchen)
Pimpelpatio – Matenweg 34	23,1 (including kitchen)
Average	26,25

Floor surface area individual student rooms

Table 32: Floor surface area individual student rooms

Dormitory and street	Surface area [m²]
Beverburcht - Calslaan 1-3	13,25
Crib Soleil - Campuslaan 33	14,1
Huize Bosøl – Witbreuksweg 377 (lower right)	9
Pimpelpatio – Matenweg 34	13,5
Average	12,5

Floor surface area dormitories

Table 33: Floor surface area dormitories

Dormitory and street	Surface area [m²]
Beverburcht - Calslaan 1-3	341
Crib Soleil - Campuslaan 33	188
Huize Bosøl – Witbreuksweg 377 (lower right)	170
Pimpelpatio – Matenweg 34	296
Average	249

Appendix H: List of energy use characteristics

Table 34: List of energy use characteristics and assessment

	Adjustable by De Veste?	**Reason(s)**
Environment		
Surrounding buildings	No	Can only be influenced through construction of new dormitories, which is unlikely to happen
Surrounding vegetation	No	Can only be influenced through planting vegetation (e.g. trees), which is unlikely to happen
Infrastructure	No	Can only be influenced through construction new (subsoil) infrastructure, which is unlikely to happen
Air temperature	No	Part of the (local) climate, which cannot be influenced at all
Ground temperature	No	Part of the (local) climate, which cannot be influenced at all
Solar irradiance	No	Part of the (local) climate, which cannot be influenced at all
Wind velocity	No	Part of the (local) climate, which cannot be influenced at all
Precipitation	No	Part of the (local) climate, which cannot be influenced at all
Humidity	No	Part of the (local) climate, which cannot be influenced at all
Building		
Floor surface	No	Can only be influenced through extending or downsizing dormitories, which is unlikely to happen
Transmission surface	Yes	Can be influenced through improvement insulation of dormitories
Internal space allocation	No	Can only be influenced through reconstruction dormitories, which is unlikely to happen
Type of dwelling	No	Can only be influenced through construction new buildings of different type than multi-storey dwellings, which is unlikely to happen
Age of dwelling	No	Can only be influenced through construction new buildings, which is unlikely to happen
Degree of infiltration	Yes	Can be influenced through improvement insulation of dormitories
Residents		
Number of residents	No	Can only be influenced through adding or removing rooms from dormitories, which is unlikely to happen
Age of residents	No	Average age of students cannot be influenced by De Veste
Residents' living patterns	No	Individual activities of students are based on personal choices and thus cannot be influenced by De Veste
Internal climate preferences	No	Individual preferences are personal and thus cannot be influenced by De Veste
Income of residents	No	Students attend their studies full-time, which cannot be influenced by De Veste
Form of ownership	No	Dormitories are rental homes by definition, which cannot be influenced by De Veste
Environmental awareness	Yes	Environmental awareness can be increased through promotion and initiatives of De Veste

Group motivation	Yes	Group motivation can be increased through promotion and initiatives of De Veste
Group composition	No	Can only be influenced through selecting students before they move into a dormitory, which is unlikely to happen
Prospect	Yes	Can be increased through promising rewards and/or prizes for making decisions in favor of sustainability
Effort	Yes	Can be lowered by taking away as many obstacles for living sustainably as possible
Appliances		
Presence of energy using appliances	Yes	Can be lowered through promotion and initiatives of De Veste
Presence of lighting	Yes	Can be lowered through promotion and initiatives of De Veste
Presence of awning	Yes	Can be installed by De Veste in relatively short time against relatively low costs
Presence of construction-related energy equipment	Yes	Can be installed by De Veste in relatively short time against relatively fair costs
Quality of appliances	Yes	Can be increased through promotion and initiatives of De Veste
Use of technology	Yes	Can be increased through installing smart meters and promotion by De Veste
Systems		
Heating concept (quality)	Yes	Can be increased through installing more efficient heating concepts
Heated tap water concept (quality)	Yes	Can be increased through installing more efficient heated tap water concepts
Ventilation concept (quality)	Yes	Can be increased through installing mechanically driven ventilation systems making for sufficient air exchange rates
Cooling concept (quality)	Yes	Can be increased through installing efficient cooling concept, by the time this is needed (no cooling concepts installed as of the moment of writing)

Appendix I: Specification model variables

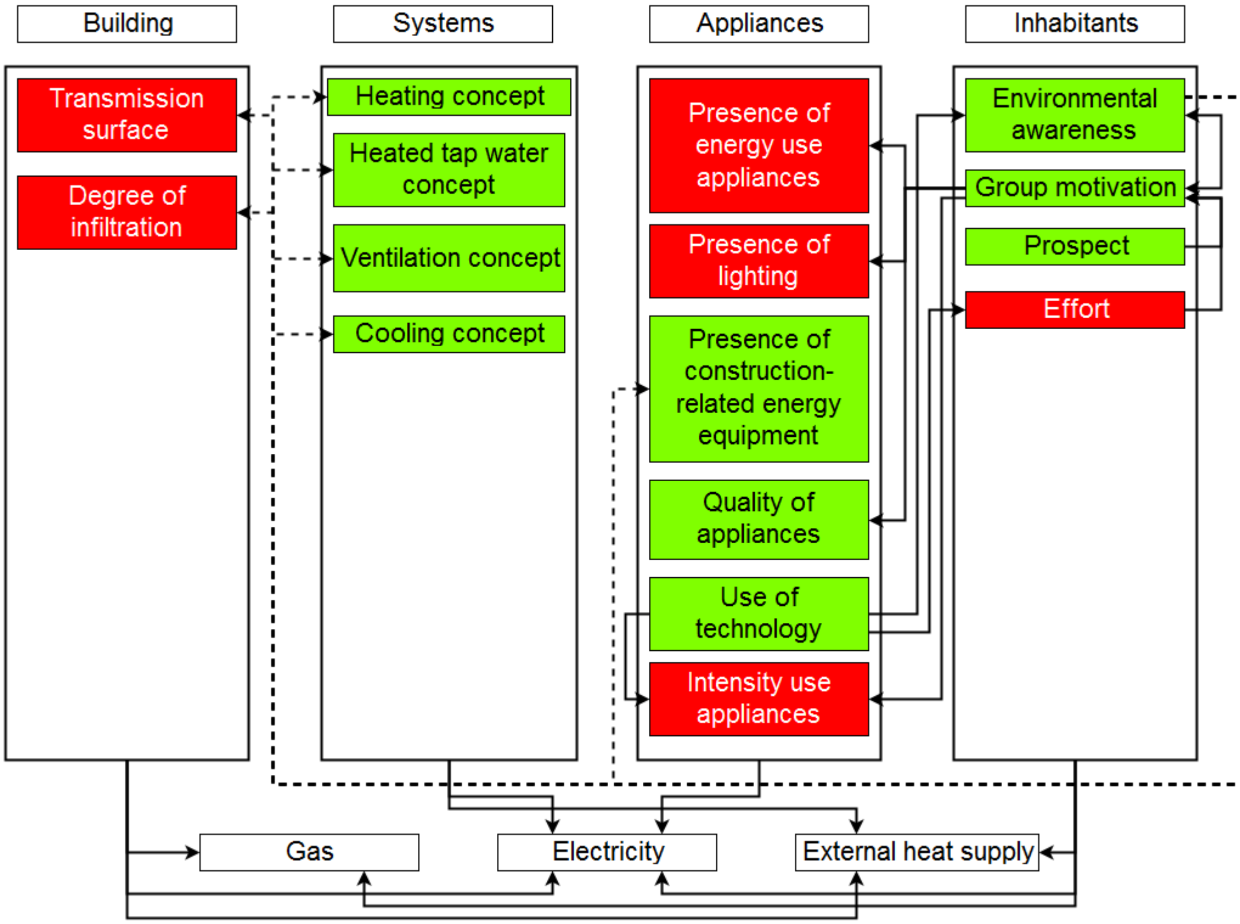

Figure 27: Energy use model with indication of need for increase or decrease of variables (green = increase, red = decrease)

Table 35: Specification of influence model's variables

Variable 1		Variable 2	Improvement variable 1	Improvement variable 2	Influence of increase variable 1	Influence of decrease variable 1
Environmental awareness	→	Group motivation	Increase	Increase	Increase in variable 2	Decrease or static state variable 2
Group motivation	→	Environmental awareness	Increase	Increase	Increase in variable 2	Decrease or static state variable 2
Prospect	→	Group motivation	Increase	Increase	Increase in variable 2	Decrease or static state variable 2
Effort	→	Group motivation	Decrease	Increase	Decrease variable 2	Increase variable 2
Group motivation	→	Quality of appliances	Increase	Increase	Increase in variable 2	Decrease or static state variable 2
Group motivation	→	Presence of lighting	Increase	Decrease	Decrease or static state variable 2	Increase or static state variable 2
Group motivation	→	Presence of energy use appliances	Increase	Decrease	Decrease or static state variable 2	Increase or static state variable 2
Group motivation	→	Intensity of use	Increase	Decrease	Decrease variable 2	Increase or static state variable 2
Use of technology	→	Environmental awareness	Increase	Increase	Increase in variable 2	Increase or static state variable 2
Use of technology	→	Intensity of use	Increase	Decrease	Decrease variable 2	Increase or static state variable 2
Use of technology	→	Effort	Increase	Decrease	Decrease variable 2	Increase or static state variable 2
Environmental awareness	→	Transmission surface	Increase	Decrease	Decrease variable 2	Increase or static state variable 2
Environmental awareness	→	Degree of infiltration	Increase	Decrease	Decrease variable 2	Increase or static state variable 2
Environmental awareness	→	Heating concept (quality)	Increase	Increase	Increase in variable 2	Decrease or static state variable 2
Environmental awareness	→	Heated tap water	Increase	Increase	Increase in variable 2	Decrease or static state variable 2

		concept (quality)				
Environmental awareness	→	Ventilation concept (quality)	Increase	Increase	Increase in variable 2	Decrease or static state variable 2
Environmental awareness	→	Cooling concept (presence)	Increase	Increase	Increase in variable 2	Decrease or static state variable 2