Sustainable residential districts : the residents' role in project success

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Sustainable Residential Districts

The residents' role in project success

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PREFACE

"*And others [seeds] fell into the good ground, and yielded fruit, growing up and increasing; and brought forth, thirtyfold, and sixtyfold, and a hundredfold*" (Mark 4:8).

In the spring of 2001, I moved to the Netherlands; I left my home Syria, I left behind my childhood memories and I left behind my friends. A journey to the Netherlands was begun; a journey to the unknown. At that time, all what I knew about the Netherlands was limited to van Gogh, Rembrandt, Ajax Amsterdam and Ruud Gullit. There were many challenges to overcome; to learn the language, to get to know the culture, to become a member of the Dutch society and last but not least: to feel home again. It was very clear that I had to work very hard but also to had a good luck.

Looking back on the last five years, I can only conclude that this research offered me a sense of self-confidence, satisfaction, pride and pleasure. I also have to conclude that accomplishing this thesis was not possible without support of my promoters, my colleagues and last but not least: my family.

First of all, I would like to express my sincere thankfulness to Ger Maas; my first supervisor, my motivator and my source of inspiration. Since the first meeting in 2003, Ger has been acting as a supervisor, facilitator and colleague. Our cooperation has resulted in my own Master thesis concerning selection of contractors for The Dutch industry, two graduation theses and this doctoral thesis. Ger, you taught me to be broad-minded, to be self-assured and to be myself. Thanks for all the opportunities you have offered me and for the many valuable experiences.

Further, I would like to thank my second supervisor Cees Midden who taught me, within one year, the basics of environmental psychology. He inspired me to learn more about the interaction between people and technologies. Cees, it was great to work with you and I hope we can continue working together in the future.

I am grateful to Annelies van Bronswijk for her support. She taught me that 'research is a travel from pleasure to despair and the other way around'. She also taught me that everything I learnt on the way to the defense ceremony is more important than the defense ceremony itself. I also would like to thank the other members of my PhD committee, Anke van Hal and Michiel Haas for reading my thesis and providing me with good feedback.

Next, I also would like to thank Jules Huyghe for his great contribution to this thesis. Jules, you helped me to gain new insights and to enrich my knowledge of HVAC systems. I also would like to thank Mieke Oostra and Nico Lamerichs for supporting and facilitating this research.

For all those who taught me and supervised me during my study, I would like to express my gratitude using an Arabic proverb pronouncing as '*man allamani harfan serto laho abdan'* which means: my Master is the One who taught me my first letter, and I am forever His slave.

Many thanks go out to my TU/e colleagues (Erik, Francesco, Frans, Liliana, Michiel, Remy, Ruben and Wim) who shared with me those pleasure and despair moments and to my BAM colleagues (Annemarie, Anouk, Arjen, Arno, Gerson, Giel, Harry, Jordy , Maarten, Mathilda, Raymond, Regina, Robert and Yvonne) who supported me during my study period.

I also want to thank my adorable mother Hana, my brothers Dany and Raby, my sister Dima and the rest of my family who all supported me, believed in me and motivated me to take up challenges. Last but not least I would like to thank my lovely wife Rima who perhaps endured the most during my study period. I would like to thank her for standing beside me and for her understanding during all those weekends and nights that I spent on this thesis. Thanks for your great support!

Gaby Abdalla, Enschede, 2012

I would like to dedicate this thesis to my mother and to the memory of my father

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1. Introduction

1.1 Introduction

Sustainable residential districts have been realized worldwide. These districts are promoted to be efficient in the use of natural materials and sustainable energy resources. Realizing such districts is very essential to achieve environmental objectives as imposed by governments and simultaneously to create good living conditions for people. This research focuses on investigating success in sustainable residential districts.

This chapter discusses the choice of this topic and lists the research objective and questions. It also briefly discusses the method used in this research and outlines the structure of the whole thesis.

1.2 Motivation

Currently, climate change is one of the most threatening global challenges and future risks facing our society. Intensified human activities have resulted in more emissions of greenhouse gases in the atmosphere. Greenhouse gases have been speeding up the natural warming up process of our planet, which can result in the extinction of ecological systems, animals, melting down of ice pole caps and changing weather patterns [UNEP, 2011].

Another global challenge and future risk facing our society is depletion of natural resources. Developments in the energy market showed an increasing trend in energy prices. The price of crude oil increased about 285% in the period between 2000 and 2010 (import price in the

Netherlands) [OECD, 2011]. Electricity and natural gas prices for domestic consumptions increased about 72% and 77% respectively in the period between 2001 to 2010 [CBS, 2011]. The built environment is responsible for about 40% of the total primary energy consumption in the EU [EPBD participants, 2011] and USA [Peterson, 2011].

The impact of human activities on the environment and the consumption of natural resources revealed the essence and role that construction industry can play in making our world more sustainable. Since the Kyoto protocol, the majority of governments around the world have imposed stricter environmental policies. Governments introduced incentive programs to support the construction industry making the transition process to more sustainable built environments [ECTP, 2005].

Developments in the human being's welfare revealed that people are consuming more natural resources, which resulted in higher environmental impact [Schipper, 1997]. People's environmental impact is a function of people's population, people's affluence level and intensity of technology use [Ehrlich & Holdren 1971]. The development of these factors is supported by the evolution in the society culture in terms of general values, norms, perception of comfort, attitudes toward environment and some demographical variables [Vlek and Steg, 2007].

Global challenges require people to change their lifestyle and welfare related habits. However, current trends related to lifestyle and welfare can work counterproductive. Demographically, households become smaller which resulted in increasing demand for dwellings and consequently more energy for space heating and lighting [CBS, 2011]. Energy demands for hot water and space cooling have been increasing as a consequence of welfare, hygiene and comfort levels [Williamson et al., 2010]. Domestic electricity consumption has been increasing as a consequence of increasing number of domestic appliances such as computers, flat-screen TV's and electrical cook tops.

The construction industry has responded to these challenges and developments by initiating and realizing of sustainable residential districts. The objective of these districts is reducing the environmental impact of buildings and simultaneously ensuring good living conditions for the residents [EREC, 2006]. To achieve sustainability objectives in these projects, innovative technologies have been implemented and sustainable measures have been taken such as in BedZED-UK and in DeCaaien-NL.

A quick scan of already realized sustainable residential districts revealed that sustainable residential district projects are still not in the mainstream. Moreover, some districts have failed to achieve their sustainability objectives [Sint Nicolaas, 2011]. This makes new built districts very interest study subject. Frequently mentioned problems are related to complexity in use, dysfunction of unproven technologies, having unrealistic objectives and mismatch with residents needs and expectations [Stevenson and Leaman, 2010]. Sustainable residential districts are quite complex construction projects with special focus on the use phase. In these projects, the essence of the use phase and consequently the role of the residents become more important [Lim and Mohamed, 1999]. Achieving a common agreement on project success is required to successfully roll out of these districts [Fortune and White, 2006].

1.3 Research objective and questions

Sustainable residential districts have been realized worldwide. These districts are promoted to be efficient in the use of natural materials and sustainable energy resources by implementing a highly participative approach between political decisions makers and district stakeholders. These districts are also promoted to ensure healthy and comfortable living conditions for the community in the district without depleting natural resource [EREC, 2006].

Actual performance of sustainable residential districts has been evaluated. However, project evaluation mostly included technical aspects and satisfaction of residents and members of project team members. There is a lack of information regarding a comprehensive evaluation of project success from both managerial and psychological perspectives. There is need to investigate this topic extensively from these two perspectives. Moreover, understanding both managerial as well as psychological aspects in addition to existing technical aspects will create a better insight into success of sustainable residential districts [Stevenson & Leaman, 2010].

This research focuses thus on success in sustainable residential district projects from a managerial as well as psychological perspective. This research therefore fills this gap by using published reports about European Best Practices and in-depth interviews with the residents of sustainable residential districts.

Criteria to assess project success have been studied extensively in the literature [Andersen et al., 2006]. However, project success criteria lists are often to general to assess specific building projects [Carlos and Khang, 2009]. Evaluating success in construction projects using a life-cycle approach has emphasized the essence of project success in the operation phase [Lim and Mohamed, 1999] and the role of the end-user [Stevenson & Leaman, 2010]. There is need to investigate success criteria for sustainable residential districts. This leads us to the first research question.

Research question 1: Which project success criteria are relevant to assess success in sustainable residential district projects?

Project factors are those circumstances or facts which contribute to project results. Success factors are project-specific [Westerveld, 2003] and are related to project success criteria [Belassi and Tukel, 1996]. There is need to investigate success factors for sustainable residential districts. This leads us to the second project question.

Research question 2: Which managerial project factors can influence success in sustainable residential district projects?

The most project objectives of sustainable residential districts are related to decrease consumption of natural resources and to increase energy efficiency. For this aim, innovative measures have been taken and sustainable heating, ventilation and air conditioning systems (HVAC) have been implemented [EREC, 2006]. On the one side, the way residents use sustainable HVAC systems can strongly influence their performance in the use phase. On the other side, technical specifications and design considerations of HVAC systems can strongly influence residents' behavior [Midden et al., 2007]. There is need to understand how residents act in their technological environment and what motivate them to behave in a pro-environmental way. There is also need to understand residents' needs, expectations, perceptions and attitudes toward sustainable HVAC systems. This leads us to the third and the forth research questions.

Research question 3: How can technical specifications implemented in dwellings influence residents' behavior in sustainable residential district projects?

Research question 4: How can residents-related factors influence the performance of sustainable residential district projects?

1.4 Thesis outline and methodology

The thesis is organized into five chapters (excluding this first chapter) covering two topics; exploring success in sustainable residential district projects and exploring one of the contributing factors: residents' behavior toward sustainable heating systems.

Chapter 2 'SUSTAINABILITY IN THE CONSTRUCTION INDUSTRY' discusses global challenges and trends facing the society and how they can affect the construction industry. It also discusses the need to redefine the definition of project success which includes criteria that should be used to assess project success, factors that can support project success and the role of residents in succeeding governmental policies and environmental objectives. This is based on both existing scientific as well as professional literature and on five years' participative observation in the construction industry. This resulted in the accumulation of knowledge on the limitation of sustainable residential projects.

Chapter 3 'LITERATURE REVIEW ON PROJECT SUCCESS' discusses success in construction projects. The chapter introduces an extensive literature research on both project success criteria and project success factors which provides better insight into leading researches and mostly used models. The review provided a list of 22 general project success criteria. These criteria have then been ranked according to their relevance and grouped in three groups of criteria related to People, Planet and Profit. The review discusses also models of project success factors and introduced the 'Project-specific Formal System Model' (Fortune and White, 2009) as research model.

In **Chapter 4 'ANALYSIS OF SIX BEST PRACTICES'** a case study method is used to indicate the relevance of project success criteria in relation to sustainable residential district projects. For this aim, six European best-practice district projects have been analyzed. Detailed information about the six cases has been listed in '**APPENDIX 1: DESCRIPTION OF SIX BEST PRACTICES**'.

The analysis of the six cases provided seven criteria to assess project success. The Project-specific Formal System Model (suggested in Chapter 3) has been used, together with the seven criteria, to indicate project factors that can support success in sustainable residential districts. Project performance is analyzed by comparing measures (which are implemented to meet theoretical project objectives) with their actual performances in the use phase. Data were acquired by official published reports. The results are discussed and conclusions are drawn. Chapter 4 revealed that residents have an important role in contributing to project success. The residents' role is then extensively studied in Chapter 5.

Chapter 5 'ANALYSIS OF RESIDENTS' INFLUENCE' discusses the role of the residents in sustainable residential district projects and their influence on the actual performance of the sustainable heating systems. The chapter introduces a literature review of leading environmental behavioral studies focusing on the relation between people and technologies. The theory of planned behavior is then suggested as theoretical framework for this study. The chapter explains further the method used which includes: the questionnaire design, data collection and data analysis.

The design of the research questionnaire is based on a formal questionnaire and practical instructions as suggested by Fishbein and Ajzen (2010). For this aim, a pilot research was performed using interviews with 11 residents of De Caaien, a Dutch sustainable residential district. Project De Caaien and the implemented HVAC system are described in '**APPENDIX 3: DESCRIPTION OF DE CAAIEN'**. The pilot research provided behavioral elements which are relevant for this study. The behavioral elements were then used to design the research questionnaire. The questionnaire is enclosed as **'APPENDIX 5: QUESTIONNAIRE: SUSTAINABLE HEATING SYSTEMS'**. Face-to-face interviews were hold with 135 residents to complete the questionnaire. Results of descriptive statistics, correlation analyses, reliability tests and regression analyses are listed. Finally, the results are discussed and conclusions are drawn.

Chapter 6 'DISCUSSION AND CONCLUSIONS' presents a general discussion of the research and its implications and merits. The chapter also states the contributions to both the study domain of total quality management (project success) as well as to the study domain of environmental behavior (residents' behavior). The chapter states also the research recommendations for the construction industry, sustainability regulations, and environmental assessment tools. Limitations of the research and areas for further research are also discussed. The research methodology is illustrated in Figure 1-1.

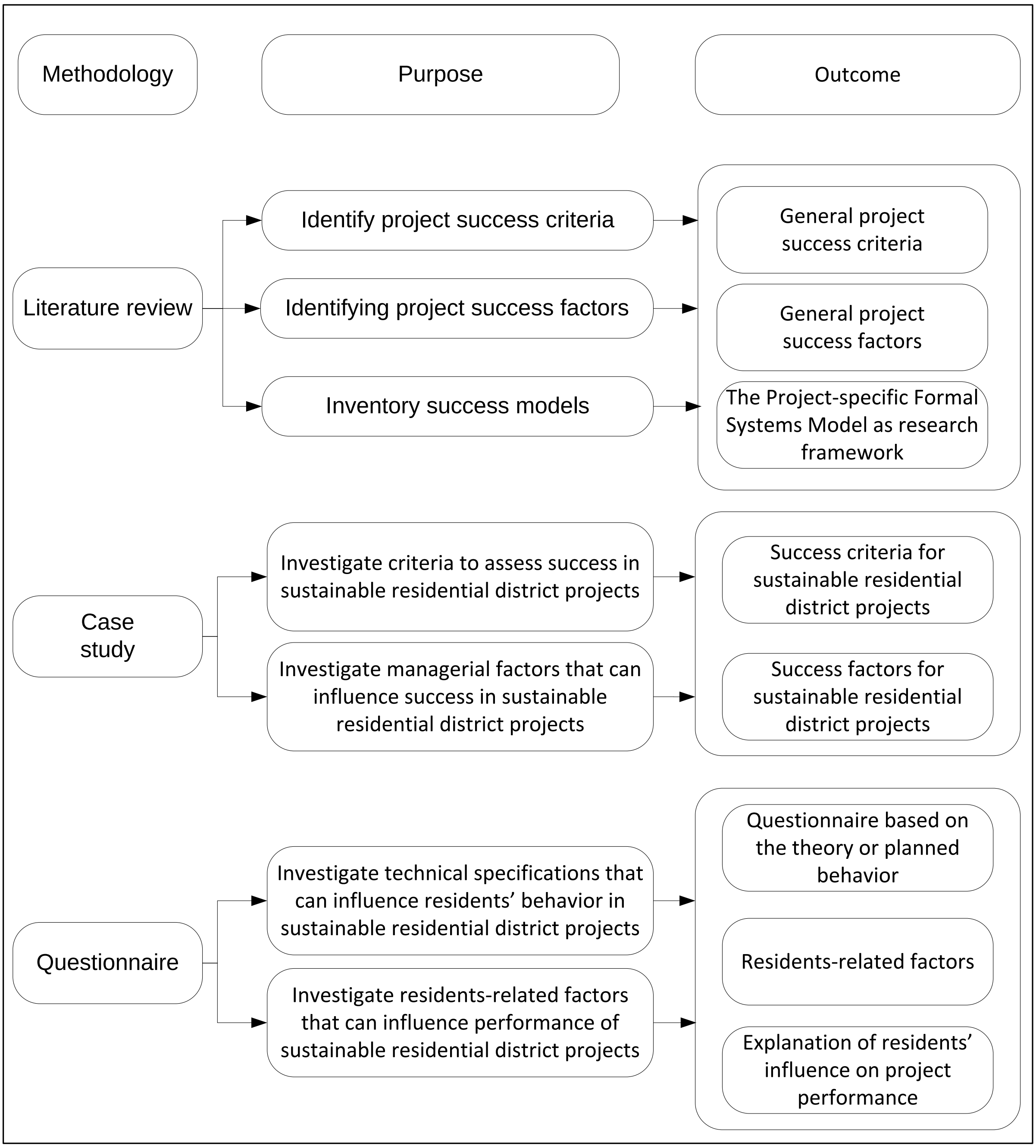


Figure 1-1*:Illustration of the research methodology*

2. Sustainability in the construction industry

2.1 Introduction

The construction sector represents a strategically important sector, providing buildings and infrastructures which form the basis for all sectors of the economy. The construction sector is characterized by many enterprises and high labor intensity; it is also highly dependent on public regulations and public investments. Furthermore, the construction sector is orientated toward domestic markets which results from the nature of the product, and material intensity [EUROFOUND, 2005]. These facts show the role of the construction industry in facing global challenges such as climate change and depletion of natural resources. The construction industry is anticipating environmental friendly policies introduced by governments and to the stricter building regulations. These challenges lead to a transition process by transforming its products to more sustainable products, re-defining roles and responsibilities of project stakeholders, re-integrating the fragmented supply chain, and effective involvement of all stakeholders. In this chapter, these challenges and trends are discussed.

2.2 Challenges and trends

The construction industry will have to adapt to global challenges and future risks. Furthermore, the future competitiveness strategy for the construction sector will need to address global environmental and social challenges. In the report ‘Sustainable Competitiveness of the Construction Sector’ key challenges of the European construction sector have been presented in four groups [Ecorys, 2011]:

1. Internal challenges (value and supply chain)
    1.1. Poor innovation performance in the sector
    1.2. Poor productivity levels
    1.3. Narrow skill sets
2. External challenges (market conditions and demand)
    2.1. General macroeconomic environment
    2.2. Demographic change
    2.3. Labor market conditions
    2.4. Major drivers of structural change
    2.5. Demands for convenience
3. Relative competitive position
    3.1. Weak growth prospects in EU markets
    3.2. Fragmented industry structures
    3.3. Growing international (global) competition
4. Regulatory and other framework conditions
    4.1. Regulatory environment
    4.2. Access to finance

This research focuses on residents' influence on the performance of sustainable residential district. Therefore, challenges related to environmental impact and residents' aspects are discussed. These challenges are: climate change, energy efficiency and prices, environmental regulations, demographic aspects and developments in the construction industry.

2.2.1 Climate change

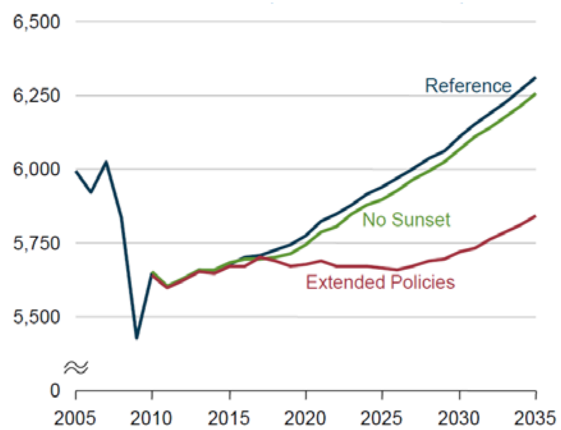


***Figure 2-1**: Energy-related carbon dioxide emissions in three cases[1], (million metric tons) [US EIA, 2011]*

Climate change is one of the greatest challenges facing our planet and society. There is some doubt about the role of human being in climate change [Allen, 2005]. However, there is a common agreement among the public opinion, scientists and governments that human beings have a role in climate change [Downing & Ballantyne, 2007] and [Oreskes, 2004]. Human activities have been increasing in the form of growing industrialization, large construction projects, longer transport distances and intensive products consumption. These energy-consuming activities contribute largely to the increasing emissions of carbon dioxide, methane and other greenhouse gases in the atmosphere (Figure 2-1). Greenhouse gas

[1] In the Reference case, growth in renewable generation accounts for 26 percent of total generation growth from 2009 to 2035. In the No Sunset and Extended Policies cases, growth in renewable generation accounts for 36 to 38 percent of total generation growth [US EIA, 2011].

emissions have been speeding up the natural warming up process of our planet. In the next decades, the greatest challenge is to rapidly cut greenhouse gases emissions. This will limit the extinction of ecological systems, animals, melting down of ice pole caps, rising sea levels and changing weather patterns [UNEP, 2011].

There is an increasing awareness of climate change both in society and in science. Sustainability has almost been emerged in all current developments. Sustainable development is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs [Brundtland and Khalid, 1987]. The definition emphasizes two ideas: 1) the idea of needs which has to be given an overriding priority, and 2) the idea of limitation of environment's ability to meet present and future needs of the increasing world's population.

2.2.2 World population and natural resources

World's population has exceeded seven billion on 31 October 2011. The increasing world's population is a great challenge facing our planet. Natural resources are limited whereas the demands for fossil energy, food and natural raw materials are increasing [US EIA, 2011]. The unbalance between demand and supply is pushing prices of natural resources upwards (Figure 2-2).

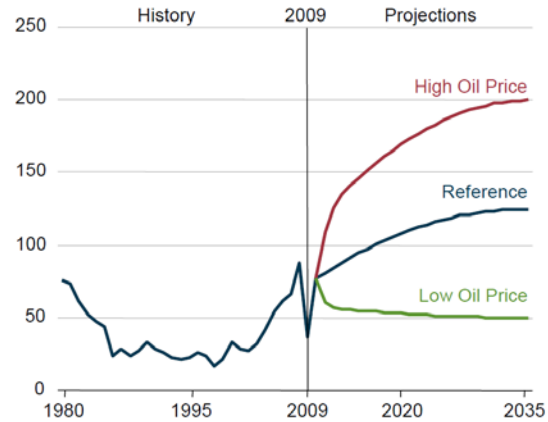


***Figure 2-2**: The assumed Oil price paths in High and Low Oil Price cases, as compared with $125 in the Reference case[2], (dollars per barrel) [US EIA, 2011].*

Developments in the energy market showed an increasing trend in energy prices. The price of crude oil (import price in the Netherlands) increased from $27.59/barrel in 2000 to $78.55/barrel in 2010; an increase of 285% [OECD, 2011]. At the consumers' level, the price of natural gas increased from €0.432/m^3 in 2001 to €0.76/m^3 in 2010; an increase of 77%. The electricity price (in the Netherlands) increased from €0.165/kWh in 2001 to €0.283/kWh in 2010, an increase of 72% [CBS, 2011][3].

2.2.3 Environmental regulations

The construction industry is faced with increasingly stricter regulations in terms of environment protection, energy efficiency, health, and safety regulations. Greenhouse gas

[2] Reference case is based on the assumption that current practices, politics, and levels of access will continue in the near to mid-term. Low Oil Price case is based on relatively low demand for liquids, combined with greater economic access to and production of conventional resources, results in sustained low oil prices. High Oil Price case, high demand for liquids, combined with more constrained supply availability, results in a sharp, continued increase in world oil prices [US EIA, 2011].

[3] These are consumer prices including taxes, network fees and transport fees. Price of natural gas is based on annual consumption of 500m3/year and price for electricity is based on annual consumption of 3000kWh/dwelling/year.

emissions, security of supply and prices of natural resources are the greatest challenges for the society [ECTP, 2005]. The majority of governments around the world has recognized the role of human activities in reducing greenhouse gases and depletion of natural resources [ECTP, 2005]. Since the Kyoto protocol, governments have intensified their search for ways of making large reductions in emissions, efficiently using fossil energy and promoting renewable energy sources.

The construction industry is an important player in making our world more sustainable. The built environment in the USA [Peterson, 2011] as well as in Europe [EPBD participants, 2011] is responsible for about 40% of the energy consumption. Building regulations and codes have been strictly adjusted to encourage reduction of greenhouse gas emissions and efficiently use of natural resources in the built environment [ECTP, 2005].

To stimulate energy-efficiency in the construction industry, governments have imposed stricter buildings regulations and codes. In the Netherlands for example, the energy performance coefficient (EPC) has been introduced since 1995. The EPC value expresses the energy efficiency of a building. The lesser the EPC value, the higher the energy efficiency of a building. The obligated EPC value in building permissions has been reduced several times. The EPC value is reduced to EPC=0.8 in 2006 and by 2012 is reduced to EPC=0.6. According to the latest expectations the EPC value will be reduced up to EPC=0.4 by 2015 [Menkveld et al., 2010]. Currently, the EPC reduction has a side effect: a lowering of the health potential of built environments. This side effect poses an additional challenge for the construction industry [Pernot et al., 2003].

There are also sustainable residential district projects that went beyond the obligated building codes and experimented with innovative technologies to achieve higher environmental goals. These projects have voluntary chosen high ambition in sustainability. Examples are BedZED-UK and De Caaien-NL; these projects indicate what dwellings and HVAC systems may look like in the future. They provided the construction industry with valuable lessons about the future challenges on technical solutions, redefining responsibilities the involved parties, involvement of the users and changing of the construction process.

In the report 'the carbon productivity challenge: curbing climate and sustaining economic growth', McKinsey Global Institute calculated the costs-efficiency of CO_2 abatement for several environmental friendly measures and technologies (Figure 2-3) [Beinhocker et al., 2008]. The figure shows how much greenhouse gas abatement potential lies in some popular strategies/technologies, and simultaneously shows the monetary cost of each strategy. All abatement strategies under the horizontal axis are cost-efficient; they make money. The second point is that the most cost-efficient abatements are related to the building industry: better insulation, efficient HVAC and energy saving lighting. The Figure shows also that some of the cost-efficient measures are strongly related to wealth of users such as 'Lighting systems', 'Air conditioning', 'Water heating' and 'Stand-by losses'.

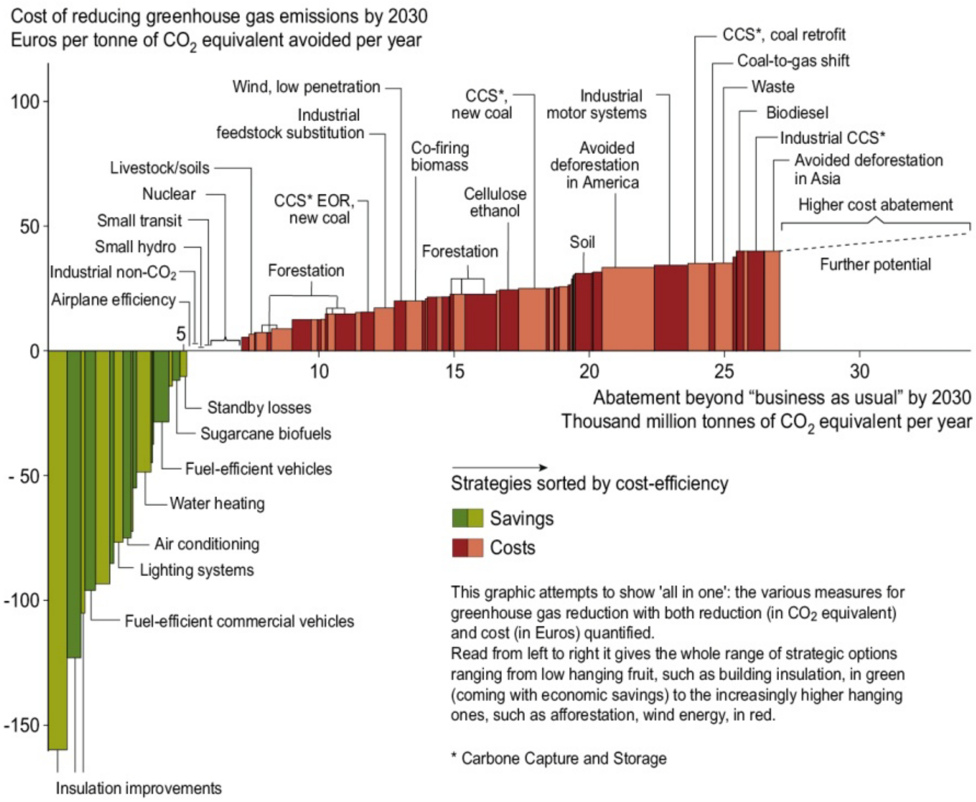


Figure 2-3*: Strategic options for climate change mitigation; global cost curve for greenhouse gas abatement measures [Beinhocker et al., 2008]*

The influence of wealth (affluence) on people's environmental impact was studied by Ehrlich and Holdren (1971). They suggested that the impact (I) is a multiplicative function of Population, Affluence (average consumption per person), and Technology (average resource intensity of the technology used per unit of production); I=P*A*T. Wealth is largely affected by health and comfort conditions during the main activities living, working and transportation in an enclosed space [Hamelin and Hauke, 2005]. The development of these driving forces is supported by evolution of the institutions in which society is organized and in society' culture as expressed in general values, norms, perception of comfort, attitudes toward environment and some demographical variables [Vlek and Steg, 2007].

2.2.4 Demographic change

Global challenges will lead us to more a sustainable economy and lifestyle. However, there are some demographic trends that can work counterproductive. In the Netherlands e.g. the average size of households has decreased from 2.35 in 1995 to 2.2 in 2011 [CBS, 2011]. The percentage of small households (one and two-person household) has increased from 64% in 1995 to 69% in 2011 whereas the number of multi-persons households (more than two-person household) is decreased from 36% in 1995 to 31% in 2011. These trends results in increasing demand on dwellings. Consequently, this results in increase energy demand for space heating and electricity for domestic appliances.

2.2.5 Demands for convenience

Energy demand figures in the built environments also show different trends. Energy demand for space heating has been decreasing in newly built buildings as a consequence of improved thermal insulation and air tightness of the building envelop [Williamson et al., 2010]. However, energy demand for hot water and space cooling in increased as a consequence of welfare, hygiene and comfort levels [Vlek and Steg, 2007]. Domestic electricity consumption is increased as a consequence of increasing number of domestic appliances such as computers, flat-screen TV's, mobile phones, microwaves and electrical cook tops.

2.2.6 Major drivers of structural change

The market has been responding to developments, as mentioned above, by introducing **innovative products** to support the construction industry. These products could be categorized according to their function in the following categories: 1) reducing energy demand such as air-tightened building envelops, thermal insulation materials, insulated glazing, heat recovery ventilation systems and heat recovery from shower water, 2) renewable energy supply such as photovoltaic panels, solar collectors, wind turbines, bio-mass fired heating systems and geothermal heating systems, 3) efficient fossil energy supply such as condensing boilers and district heating systems, and 4) energy saving distribution systems such as floor and wall heating distribution systems.

The construction industry has also responded to **building regulations** and users' demands by realizing sustainable dwellings. Innovative heating, ventilation and air-conditioning systems (HVAC) have been implemented in dwellings to increase buildings' energy efficiency, indoor air quality and thermal comfort. However, HVAC systems at **district-level** give developers scopes to make use of on-site low-energy systems, such as district heating with combined heat and power and heat pump systems.

Additional opportunities arise for more **sustainable energy production** (woodchips, biomass fuel or solar energy production). Using these technical solutions might also result in benefits when project are set up on a larger scale. However, these projects require more integrated approach focusing on all phases of construction process and well organized cooperation among members of the project organization. The new approach requires re-defining stakeholders' roles and responsibilities and involvement of residents in all phases of the construction process.

2.3 Conclusion

The performance of sustainable residential districts, where sustainable HVAC systems are implemented, may be affected by the performance of the HVAC systems and the way residents use their HVAC systems [Stevenson and Leaman, 2010]. Sustainable HVAC systems have to increase energy efficiency and decrease environmental impact but simultaneously to improve indoor air quality and health conditions.

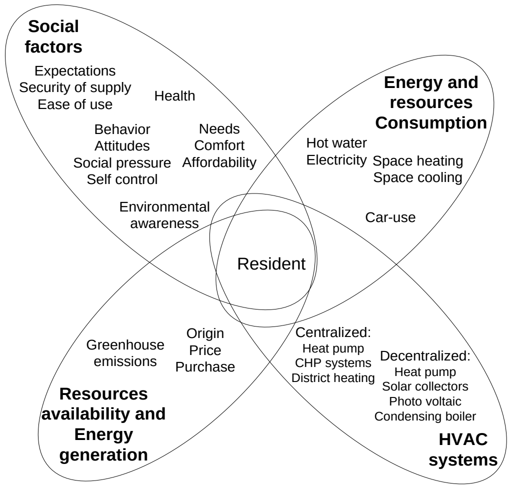


***Figure 2-4**: Positioning of residents in the complex network of natural sources, energy generation, energy consumption, HVAC systems and related social factors.*

Section 2.2 revealed that residents behave and interact in a very complex and dynamic environment where some developments and trends conflict with each other (illustrated in figure 2-4). The section revealed also the essence of residents' role in succeeding governmental policies and reaching environmental objectives. Concluding, issues related to residents' influence on performance of sustainable dwellings needs to be explained extensively. There is a need to re-define project success from residents' point of view. There is a need to find out which factors support project success. And last but not least, there is need to understand how residents' needs, expectations and behaviors can influence actual performance of sustainable dwellings.

3. Literature review on project success

3.1 Introduction

Measuring project success became an essential management tool to lead Construction projects [Tukel & Rom, 1998], [Qureshi et al., 2009] and [PMI, 2010]. There is an increasing number of studies dealing with this topic [Cooke-Davies, 2002], [Chan & Chan, 2004] and [Carlos & Khang, 2009]. Academics and professionals try to investigate it from different perspectives and for different types of projects [Westerveld, 2003]. In this chapter, the topic of project success will be reviewed. Definition of project success, project success criteria and project success factors will be discussed extensively.

3.1.1 Definition of project success

The idea of project success is not new. In the book 'In Search of Excellence in Project management' reported Kerzner that the first ideas about project success and project evaluation were found in the year 1960. A project was considered to be entirely successful if the end product worked or it did not work [Kerzner, 1998]. In the 1980s, new definition of project success was introduced by the researchers in the field of project management. According to project management, a project is successful if it meets three criteria: (i) completed within time, (ii) completed within budget and, (iii) completed at the desired level of quality. These three criteria have been called the Golden Triangle [Kerzner, 1998].

After the introduction of the Total Quality Management, project success took a new dimension; the project performance's dimension from the stakeholders' viewpoint [McGeorge et al., 2002]. In the book 'A Guide to the Project Management Body of Knowledge (PMBOK Guide), a clear link is set up between project success and project stakeholders. The book suggested that measuring project success in terms of budget, schedule and quality is insufficient any more. In the PMBOK Guide, project management is defined as "the application of knowledge, skills, tools and techniques to project activities in order to meet or exceed stakeholders' needs and expectations from a project" [PMI, 2010]. Project success became more related to a wider range of stakeholders' expectations and needs.

Academics and researchers have investigated project success and provided lists and models of project success criteria and factors [Bryde & Robinson, 2005], [Toor & Ogunlana, 2008] and [Papke-Shields et al., 2009]. However, there is some confusion between criteria and factors of project success. A project success criterion is defined as "a principle or standard by which anything is or can be judged" [Lim and Mohamed, 1999]. In the course of time, the relevance of project success criteria is affected by: (i) the changing nature of the construction industry, (ii) increasing complexity of projects, (iii) increasing clients' demand, (iv) changing building codes, and (v) the need to evaluate projects from a lifecycle perspective [Carlos and Khang, 2009].

A project success factor is defined, by Lim and Mohamed, as "any circumstance, fact, or influence which contributes to a result" [Lim and Mohamed, 1999]. Andersen, Birchall, Jessen and Money (2006) have defined project success factors as "those features of projects which have been identified as necessary to be achieved in order to create excellent results". Project success factors are thus needed to achieve beforehand defined project success criteria. Project success factors are, just like success criteria, very depended on project variables [Westerveld, 2005]. In this study we will use Andersen's definition of project success factors.

3.1.2 Criticisms on project success

The definition of project success showed that project success is related to perceptions of the different project stakeholders [Andersen et al., 2006]. Measuring project success can be an ambiguous issue as different project stakeholders can have different project goals [Toor and Ogunlana, 2008]. This is the first criticism. A contractor e.g. can consider a project as successfully realized if no legal actions are taken or if new building method is successfully implemented. A housing corporation can consider a project as successfully realized if residents are satisfied. The ambiguity of project success can negatively affect studies on project success and their outcomes [Pinto and Slevin, 1988-1] and [Shenhar et al., 2002].

The second criticism is that the factor approach tends to view implementation as a static process instead of a dynamic one [Fortune and White, 2006]. The static approach ignores the potential for a factor to have varying levels of importance at different stages of the implementation process [Larsen and Myers, 1999]. Political stability which could be considered as an important success factor in the very first stage of the project (to initiate a project and arrange project permissions) may has less importance in the construction stage.

The third criticism is that the success factor approach does not provide a mechanism for taking account of the inter-relationships between factors [Nandhakumar 1996]. However, these inter-relationships are at least as important as the individual factors. For example, the availability of financial resources for a project could be considered as a success factor. However, this factor is a consequence of many organizational factors affecting the project, and these factors should be identified first.

3.1.3 Project success criteria

The construction industry is dynamic in nature. Building projects become more complex, more innovative and have to meet stricter building codes [Howard & Björk, 2008]. Complex construction projects require effectively involvement of large number of experienced professionals which causes more fragmented construction process [Tijhuis & Maas, 1996] and [Hallowell et al., 2009]. The fragmentation of the construction processes and the number of involved stakeholders explain the difficulty to achieve common agreement about project success during the different phase of the construction process [Andersen et at., 2006]. Researchers do agree about the essence of success criteria as management tool to lead projects [Fortune and White, 2006], but they do not agree about the universality of the criteria [Andersen et al., 2006]. Project success criteria lists are often to general to assess specific building projects [Carlos and Khang, 2009] and [Ojiako et al., 2008]. The idea of success is strongly related to very personal and specific organizational goals and perceptions [Andersen et at., 2006]. It is also strongly related to what persons or organizations intend to achieve [Ahadzie et al., 2008]. Project stakeholders and participants involved with a project may intend to achieve different objectives, which commonly include time, cost, quality, health, safety and learning organization. For those participants, however, expectations on project outcome and the perception of project success may differ and conflict [Lim and Mohamed, 1999] and [Tukel and Rom, 2001]. Evaluating construction projects using a life-cycle approach has emphasized the essence of project success in the operation phase and the role of the end-user.

In the next two sections, four models of success criteria will be discussed and then existing success criteria in the literature will be inventoried.

3.1.3.1 Project success models

Project success during the different construction process phases is investigated by Lim and Mohamed (1999). They classified the perspectives of project success into two categories: the macro and micro viewpoints (Figure 3-1). The macro viewpoint dealt with the question if the original project concept is achieved whereas the micro viewpoint dealt with the question if the project success is achieved in the construction phase. They suggested that only two criteria are sufficient to determine the macro viewpoint of success ‘Completion’ and 'Satisfaction'. 'Completion' criterion alone is enough to determine the micro viewpoint of project success. The micro viewpoint of project success is based on the construction phase where project criteria like time, cost, performance, quality and safety of the contractual parties are determined and tested. Project management success and achievement of project goals will determine the perception of success by individual project team members. The macro viewpoint of project success is based on both the Conceptual as well as Operation phases where the ideas are conceptualized and finally tested. Participants' involvement and satisfaction will determine the perception of success in the operation phase.

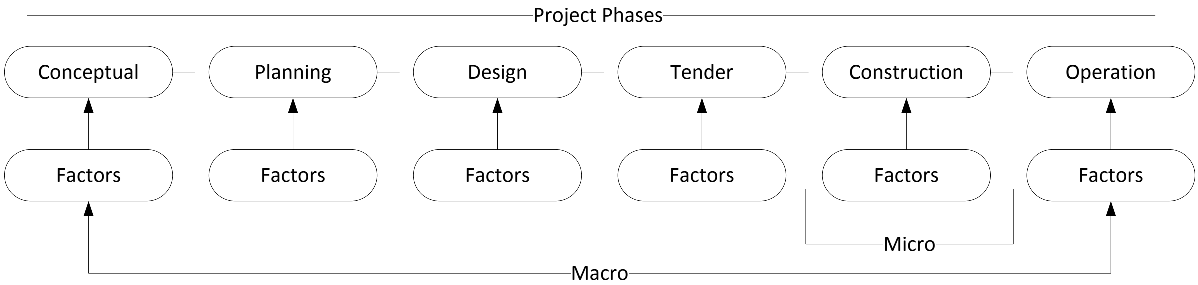


***Figure 3-1**: Building blocks of project life cycle [Lim and Mohamed, 1999]*

Baccarini (1999) has used the logical framework method (LFM) to study the project success perception in the operation phase versus in the other phases of the construction process (Figure 3-2). The LFM is a method developed by the American Aid Agency in the 1970s for International Development to improve project management. Baccarini suggested that successfully realization of a project can only be achieved through achieving success in both the operation phase as well as other construction process phases. However, he suggested that success in the operation phase is superordinate to success in other phases. In other words, product success (related to the operation phase) is superordinate to project success (related to the construction process). Product success explains the impact of the project when a project is executed. Product success criteria include owner's strategic organizational objectives, users' satisfaction, stakeholders' needs and knowledge dissemination. Project success explains how effective and efficient a project is executed from a project management viewpoint. Project success criteria include budget, schedule and quality. These results were later confirmed by a study of [Andersen et al., 2006].

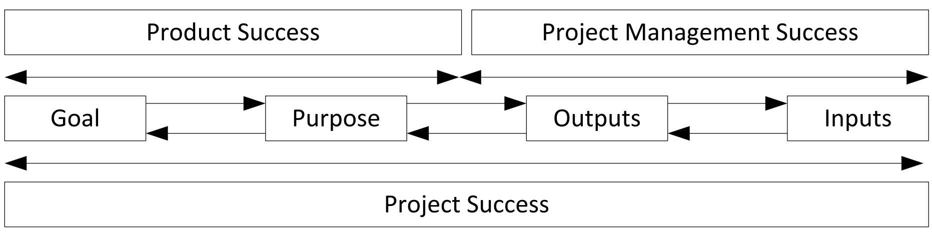


***Figure 3-2**: The logical framework method [Baccarini, 1999]*

Liu and Walker (1998) have studied project success from the fundamental behavior-to-performance-to-outcome (B-P-O) cycle in organizational psychology. They suggested that the complexities of project success are derived from project goals, participants' behavior and the performance of project organizations. They considered the manner by which individuals' perceptions of project outcomes were influenced by the range of factors in each person's perception. They introduced an adapted B-P-O model with two levels of outcome; the first-level outcome and the second-level outcome (Figure 3-3). The model suggested that the first-level outcome (related to project success) is dependent on the instrumentality relating to the second-level outcome (related to participant satisfaction). They concluded that identifying factors of influence, such as self-efficacy, project complexity, commitment, expectancy, rewards, goals and environmental variables, are fundamental in understanding an individual's perception of the advantage of the outcome of a project.

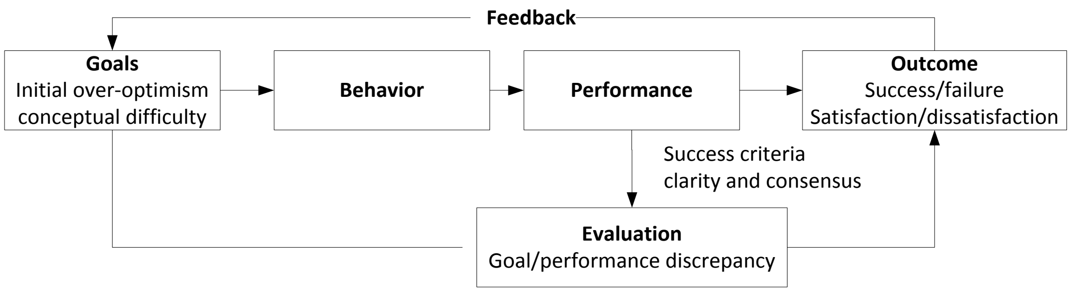


***Figure 3-3**: The behavior-to-performance-to-outcome (B-P-O) model [Liu and Walker, 1998]*

Andersen, Birchall, Jessen and Money (2006) have studied which success factors, within the direct influence of project managers, can make a real difference to the outcome of project endeavors. They suggested project success as a broader concept, which deals with the wider and longer term impact of the project. They suggested also that an overall success should consider both successes before and after the hand-over phase, i.e. project success as well as product success. Project management success can be determined at the end of the project whereas the product success and project performance will be finally decided months or years after the termination of the project. Expanding the project success to a broader concept, thus, will postpone the final judgment on the project.

3.1.3.2 Grouping success criteria

As mentioned earlier, there are many studies dealt with project success criteria and their relevance in construction projects. In this section project success criteria, as mentioned in the literature, are mapped, ranked and grouped.

Raw data about project success criteria were collected using Publish-or-Parish (PoP, 2009) which is based on Google Scholar. The following keywords were used to find relevant published articles in the period between 1980 and 2009: ("Project Success Criteria" or "Success Criteria" or "Project Success") and ("Construction" or "Building").

The search led to a number of publications in various research fields. After filtering out irrelevant and non-academic publications, 59 relevant academic publications in the field of construction remained [***these references are: 2, 5, 6, 7, 9, 10, 12, 14, 16, 23, 25, 26, 27, 34, 36, 37, 38, 39, 49, 55, 57, 61, 66, 89, 104, 107, 127, 128, 129, 131, 133, 135, 137, 138, 140, 141, 151, 152, 155, 157, 158, 160, 168, 169, 173, 174, 175, 178, 182, 194, 198, 200, 202, 212, 213, 227, 228, 229 and 234***]. Success criteria in the 59 articles were collected and their frequencies were calculated by the number of articles in which each criterion is mentioned. The search result led to a list of 22 success criteria for general projects in which the relevance of each criterion is indicated by its frequency. Table 3-1 shows that Schedule, Budget and Quality are the most frequently mentioned project success criteria. Among other frequently mentioned criteria are Client Satisfaction, Project Team Satisfaction, Functionality, End User Satisfaction and Safety.

***Table 3-1**: Frequencies of the project success criteria found in the literature (only criteria having frequencies >5 are mentioned)*

Criterion name	Explanation	Frequency
1- Schedule	Project is completed within time	52
2- Budget	Project is completed within Budget	51
3- Quality	Project output quality met building standards	48
4- Client Satisfaction	Project output satisfied client	33
5- Project Team Satisfaction	Project output satisfied project team members	22
6- Functionality	Project output performs as it should be	20
7- End User Satisfaction	Project output satisfied end-users	18
8- Safety	Safety is guaranteed in all project phases	18
9- Profitability	Stakeholder get profited	13
10- Project Goals	Project met beforehand defined goals	10
11- Learning Organization	Knowledge learning by the company	7
12- Health	Project output strived to create healthy conditions	7
13- Technology Transfer	Knowledge exchange among different stakeholders	6
14- Environmental Friendliness	Project output has less impact on environment	6
15- No Legal Claims	Project realization did not cause legal claims	6
16- Expectations	Project outputs met stakeholders' expectations	6

To investigate if any underlying patterns exist among the found success criteria; the dataset was imported to a statistical analysis computer program (SPSS17) using a two-point nominal scale. If a criterion was mentioned in a particular article the second was Mentioned=1 otherwise it is Not mentioned=0. A Hierarchal Cluster Analysis[4] (HCA) is performed using criteria mentioned more than five times (in total 16 criteria). The Hierarchal Cluster Analysis identified relatively homogeneous groups of success criteria based on their appearance in

[4] The HCA attempts to identify relatively homogeneous groups of cases (or variables) based on selected characteristics, using an algorithm that starts with each case (or variable) in a separate cluster and combines clusters until only one is left. It is possible to analyze raw variables, or to choose from a variety of standardizing transformations. Distance, compactness or similarity measures are generated by the Proximities procedure (PASW 2011).

articles. The HCA is suitable for nominal data. The results of the HCA, groups of project success criteria, are presented in a diagram (Figure 3-4).

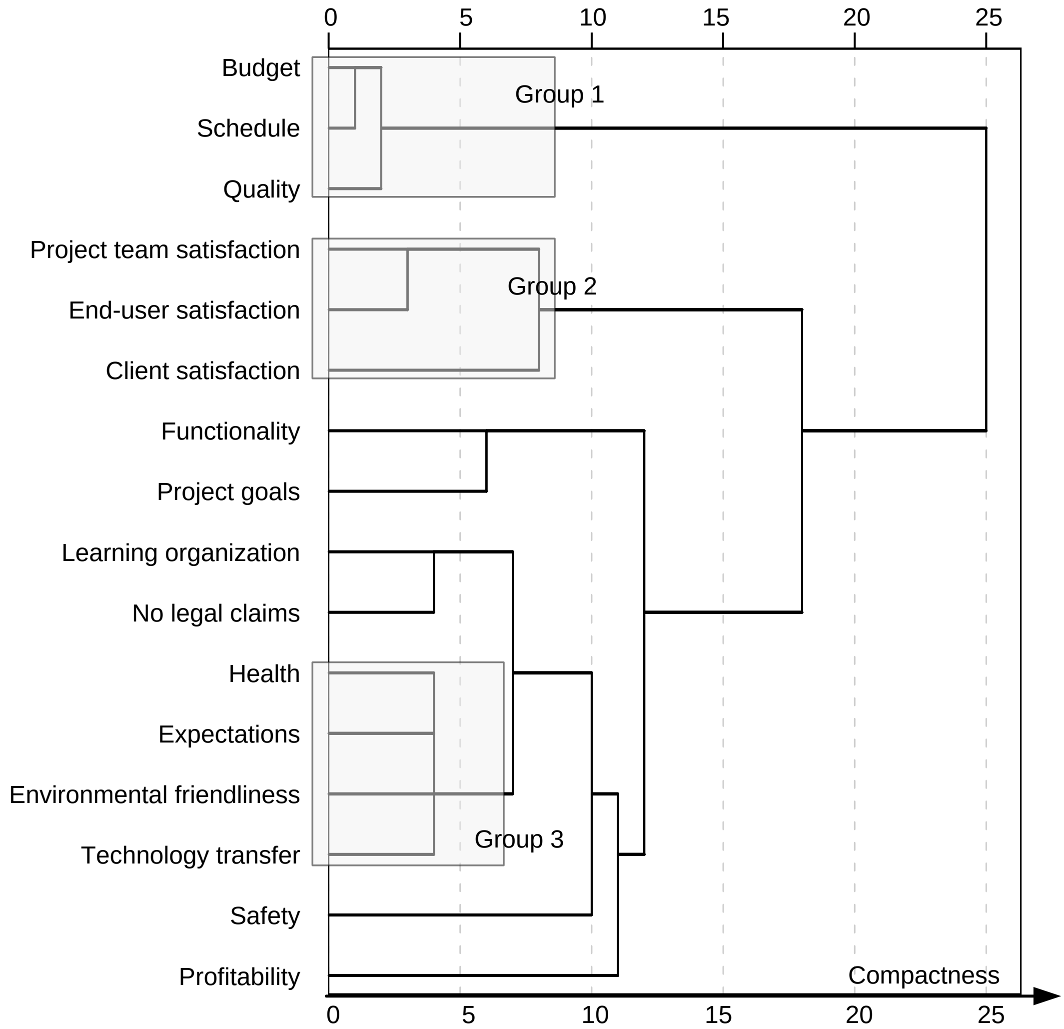


Figure 3-4*: Dendrogram of Hierarchical Cluster Analysis of the 16 project success criteria mentioned in table 2 using Complete Linkage method (n=59)*

Inspecting the dendrogram reveals that three clusters have been indentified indicating three groups of success criteria:

- the first cluster includes Budget, Schedule and Quality
- the second cluster includes Satisfaction of Project team , End user and Client
- the third cluster includes Health, Expectations, Environmental friendliness and Technology Transfer.

The first cluster clearly represents the three criteria of the Golden-Triangle that have the highest relevancy among the criteria. The second cluster represents the cluster satisfaction criteria. The third extracted cluster represents criteria related impact to the environmental impact of the project; this cluster represents thus the 'Environment Cluster'. Looking at these clusters from the Planet-Profit-People perspective we can say that the first cluster represents the Profit success criteria group, the second cluster represents the People success criteria group and the third cluster represents the Planet success criteria group.

3.1.3.3 Conclusion

This literature review on project success criteria revealed that, in addition to the golden triangle criteria, criteria related to people and planet have been used to assess project success. The review revealed also that success assessment has to consider a common agreement among all project's participants regarding project-specific success criteria and to take into account both project success before the handover phase (management success) as well as project success in the operation phase (product success) promoting the interest of Profit, Planet and People.

3.1.4 Project success factors

The first ideas about project success factors were introduced in 1961 by Ronald Daniel in relation to the 'management information crisis' [Daniel, 1961] and later in the years 1960s in more general studies [Rubin and Seeling, 1967] and [Avonts, 1969]. The project success factor, as term, was first used in 1979 by Rockart [*cited in* Jha and Iyer, 2007]. Project success factors are defined as "those features of projects which have been identified as necessary to be achieved in order to create excellent results [Andersen et al., 2006].

Studies on project success factors are affected by developments and findings in studies in the field of project success criteria [Belassi and Tukel, 1996]. Studies on this topic can be categorized in two categories according to their aim: (i) studies that identified project success factors and ranked them on the level of importance [Toor and Ogunlana, 2008] and [Cooke-Davis, 2002], and (ii) studies that identified project success factors and put them in a model to support project managers [Belassi and Tukel, 1996], [Westerveld, 2003], [Fortune and White, 2006] and [White and Fortune, 2009]. In this section, pertinent studies on project success factors will be reviewed.

Belassi and Tukel (1996) have suggested a framework that classifies project success factors and explains the impacts of the factors on project performance (Figure 3-5). They emphasized the grouping of success factors and explaining the interaction between them, rather than the identification of individual factors. In this framework, project success factors are categorized in four groups; (i) factors related to the external environment, (ii) factors related to the project characteristics, (iii) factors related to the project organization, and (iv) factors related to project managers' performance and team members. The framework helps project managers, for example, that the availability of resources is a consequence of many organizational factors affecting the system, and these factors should be identified first.

The framework, however, did not show the relation between success criteria and success factors and how they can influence each other. This relation was investigated later by Eddy Westerveld in his study 'The Project Excellence Model®: Linking success criteria and critical success factors'.

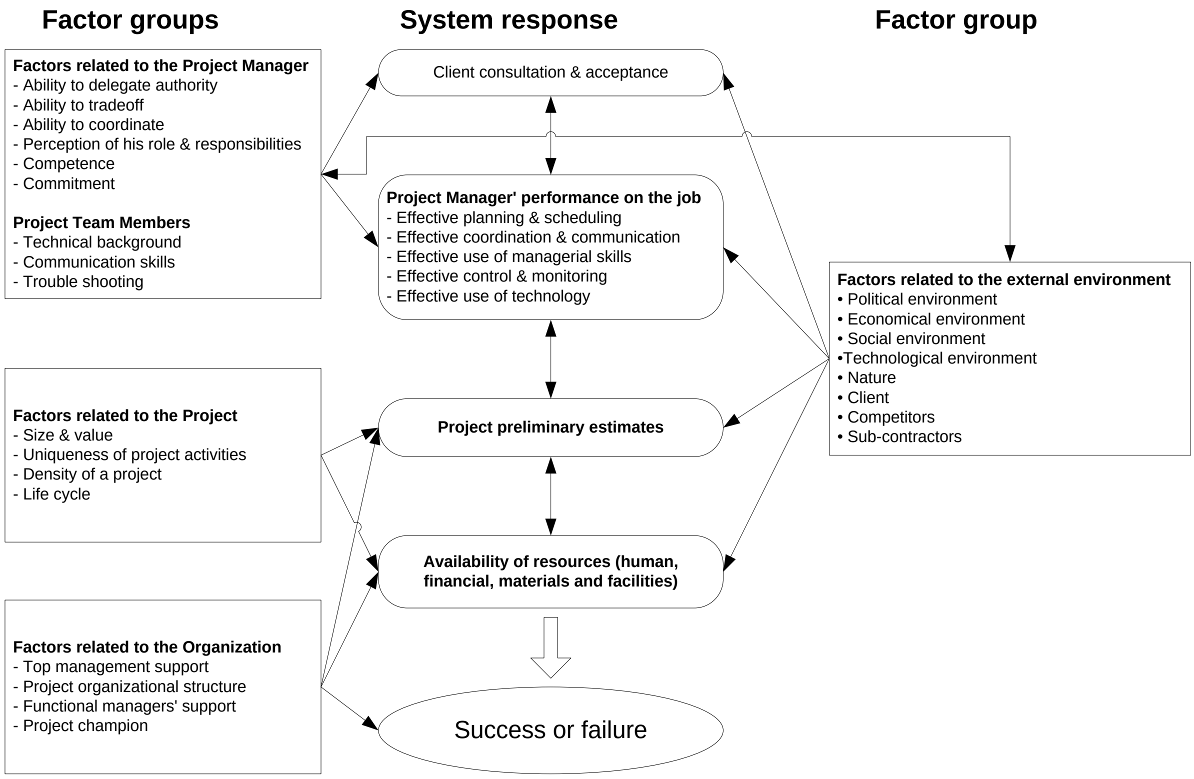


Figure 3-5*: Framework for determining critical success factors in projects [Belassi and Tukel, 1996]*

Westerveld introduced in 2003 the Project Excellence Model®. The model is based on the European Foundation for Quality Management model (EFQM Excellence Model) [EFQM, 2010]. The Project Excellence Model linked project success criteria and project success factors for several types of projects. The Project Excellence Model® consists of six result areas and six organizational areas (Figure 3-6). The six results areas indicate the following project success criteria: Project results, Appreciation client, Appreciation project personnel, Appreciation users, Appreciation contracting partners and Appreciation stakeholders. The six organizational areas indicate the following success factors: Leadership and Team, Policy and Strategy, Stakeholder management, Resources, Contracting and Project management. The model uses five different project types to describe the project organization: namely, Product orientation, Tool orientation, System orientation, Strategy orientation and Total project management.

Based on project goals (decided by the stakeholders) and result areas (provided by the model) project organization choices can be made. Basic choices in the project organization have to be made using the five project types on each of the six organizational areas. The model can then be used to monitor the results and project organization. The model can also be used to analyze and transfer learning experiences to future projects.

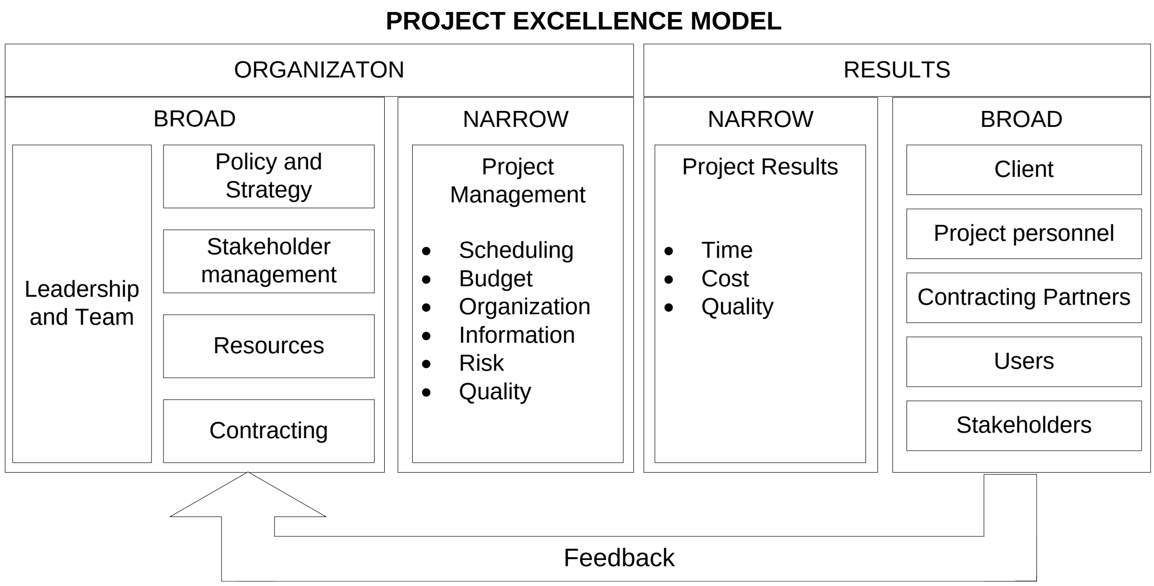


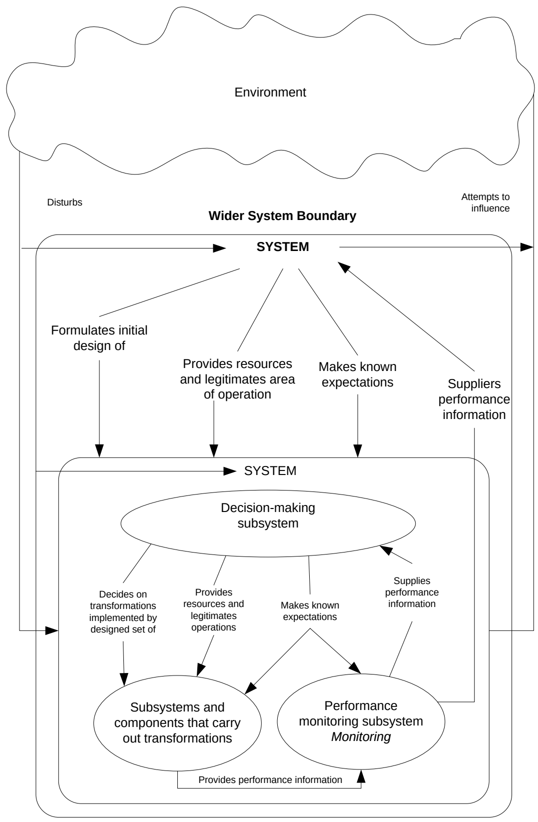
Figure 3-6*: The Project Excellence Model® [Westerveld, 2003]*

An interesting feature is that the model can distinguish both project management success and product success. Especially the fifth project type (Total Project management) emphasized both project results as well as appreciation of all project's stakeholders as success criteria.

The relation between the project success factors in this model is a static one. The model cannot supply information about the interaction between factors. This fact was criticized by Fortune and White (2006) in their paper: 'Framing of project critical success factors by a systems model'. They suggested that the inter-relationships between factors are at least as important as the individual factors but the current success factor approach does not provide a mechanism for taking account of these inter-relationships. They presented in their paper an interactive Formal System Model and explained how factors and factor groups can interact with each other [Fortune and White, 2006].

The Formal System Model (Figure 3-7) is built to obviate criticisms on project success criteria as mentioned in section 3.1.2. The model (i) covers the most important project success factors mentioned in the literature, (ii) it represents individual project success factors as well as related subsystems, and (iii) it can help to distinguish success in projects.

The model consists of nine components/ subsystems, namely: Goals and objectives, Performance monitoring, Decision-maker(s), Transformations, Communication, Environment, Boundaries, Resources and Continuity. Each component in the model represented a factor group including some project success factors. The arrows in the model described how de components influence each other. The model can, thus, be used as a guideline as well as a general evaluation tool in project management. However, the model did not consider specific project success goals or criteria. This makes the model too general to be used for a specific project.



Component of FSM/ project attributes	Critical success factors from literature
Goals and objectives	Clear realistic objectives Strong business case/sound basis for project
Performance monitoring	Effective monitoring/control Planned close down/review/acceptance of possible failure
Decision-maker(s)	Support from senior management Competent project manager Strong/detailed plan kept up to date Realistic schedule Good leadership Correct choice/past experience of project management
Transformations	Skilled/suitably qualified/sufficient staff/team
Communication	Good communication/feedback
Environment	Political stability Environmental influences Past experience (learning from) Organizational adaptation/culture/structure
Boundaries	Project size/level of complexity/number of people involved/duration
Resources	Adequate budget Sufficient/well allocated resources Training provision Proven/familiar technology Good performance by suppliers/ contractors/ consultant
Continuity	Risks addressed/assessed/managed User/client involvement Different viewpoints (appreciating) Project sponsor/champion Effective change management

Figure 3-7*: Critical success factors mapped onto components of the Formal System Model [Fortune and White, 2006]*

Project success factors introduced in the literature are often too general to be used for specific type of projects. Success factor groups can explain project success more accurately than individual project success factors. Moreover, the inter-relationships between the success factor groups can explain how these groups effect each other and how they can contribute to project success.

White and Fortune introduced in 2009 in their paper 'The project-specific Formal System Model' a project-specific version of the Formal System Model. This model can be used by project managers and other professionals to identify actual or potential weaknesses in a project's structure or processes and to look for difficulties in the relationships between the project and the context in which it is or will be taking place [White and Fortune, 2009]. The project-specific formal system model obviates all criticisms on project success factors (Figure 3-8). More information about this model could be found in Appendix 2.

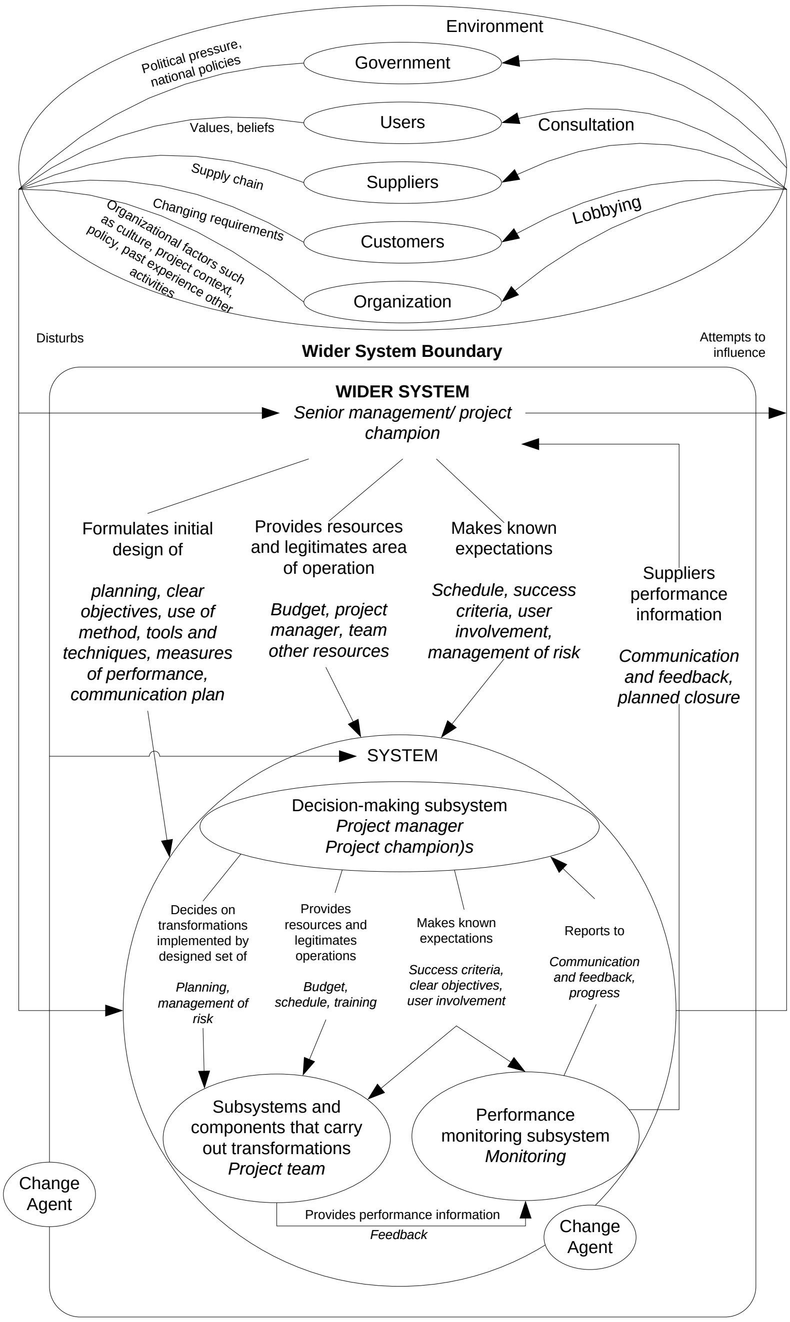


***Figure 3-8**: The project-specific Formal System Model [White and Fortune, 2009]*

3.1.5 Conclusion

The literature revealed that general, individual and static project success factors are insufficient to explain project success. The relevance of project success factors has to be derived from the relevance of project success criteria. Factors groups can explain project success more accurately than individual project success factors. Models of project success factors are often too general to explain specific projects and are often too static to explain project success in a dynamic way.

This literature review revealed also that traditional success criteria (Schedule, Budget and Quality) are insufficient to evaluate success in specific projects. Project success has to be assessed using pre-defined project-specific success criteria. Determination of success criteria has to take into account: 1) the specific project characteristics, 2) building codes and regulations, and 3) creating common agreement among all project stakeholders.

The three mentioned points are clearly considered in the project specific formal system model, intruded by White and Fortune (2009) (Figure 3-8). The model considers project-specific information about the organization of the project, design-related information and building codes as imposed by the government. The arrows in the model consider the ongoing negotiation process between the parties and the input/output of project processes. The model takes into account all criticism on both success criteria and factors and is composed by several parts of the reviewed models. The model can distinguish project success in all phases of the construction process (project management success) and emphasized success in the operation phase (product success) as suggested by [Lim and Mohamed, 1999]. The model assumes that projects of specific characteristics have specific success criteria which consequently influence the relevance of project success factors as suggested by [Westerveld, 2003]. And last but not least, the model does indicate the inter-relationships between project success factors. In Chapter 4, this model will be used to investigate project success in sustainable residential district projects.

4. Analysis of six best practices

4.1 Introduction

In Chapter 3, project success criteria and factors have been reviewed. The chapter introduced a list of 22 general success criteria. It also introduced the project-specific Formal System Model as a framework to investigate success factors in sustainable residential district projects.

In this chapter, success in sustainable residential district project will be investigated by answering research questions 1 and 2.

Research question 1: *Which project success criteria are relevant to assess success in sustainable residential district projects?*

Research question 2*: Which managerial project factors can influence success in sustainable residential district projects?*

4.2 Research methodology

To answer research question 1 and 2, a comparative case study methodology is carried out. The choice of this research methodology was based on recommendations suggested by Piet Verschuren and Hans Doorewaard (2005). The authors mentioned in their book 'Designing a Research Project' that: (i) a case study can create an overall view and obtain much more knowledge by focusing on various aspects that can explain the whole phenomenon of project success, (ii) the flexibility of this strategy as it requires less pre-structuring than other strategies; this can help improving the data collecting process during the study, and

(iii) the fact that results of a case study can be accepted more readily than other strategies [Verschuren & Doorewaard, 2005].

Six European sustainable residential districts have been selected for this research. The selection of the cases was based on the following requirements: (i) all cases are European well-known sustainable residential districts that are listed as best practice in both [Secure Project 2009] and [Energy cities 2009], and (ii) all cases are already realized and post-occupancy evaluation data are available. Summarized description of the six cases has been listed in Table 4.1. Appendix 1 provides detailed information about the cases.

In-depth data were collected from: (i) existing official publications about these cases, (i) non-published data acquired from the project teams, and (iii) supplemented data acquired from members of the building team who were and still are involved in the project. The publications were used to determine the relevance of the 22 project success criteria (found in section 3.1.3.2) for sustainable residential districts. The results were compared to the results from the desk research and conclusions were drawn.

To find out which factors do support success in sustainable residential districts, project objectives and project achievements were mutually compared. The comparison was done with respect to the success criteria as founded in previous paragraph. Implemented project measures have been analyzed for each project success criterion by answering two questions: i) did a project measure successfully achieve its objective? and ii) which factor(s) did support or impede the achievement of that project objective?

Then, project success factors are extracted by comparing the factors in the six cases. The structure of the tables used in the comparison is listed below.

An example table: Evaluation of project measures in relation to a success criterion in the six cases

Case study	Objective	Result	Explanation
Name of the case	An objective in relation to a success criterion	Met or not met	Why was this objective (not) met and which factor did support or impede that

Finally, the project-specific Formal System Model (Figure 3.8) was used to explain project success/failure in the six cases. The results were then discussed and conclusions were drawn.

Table 4-1: *An overview of the seven sustainable residential district project used in this research [Secure Project 2009] and [Energy cities 2009]*

Location (Handover)	Site area	Number of homes	Project aim	Implemented technology	Driving factor	Problems in use
BedZED London, UK (2002)	1.4	95	No use of fossil energy	District biomass plant (heating and electricity); solar roof panels; high thermal insulation; passive solar energy	Environment and project champions	Overheating on top floor; dysfunction of district plant.
Bo-01 Malmö, S (2001)	22	1567	No use of fossil energy and ecology	Underground aquifer for heat storage in winter and use of sea water; biogas from waste; solar roof panels, wind turbines; solar collectors	Best practice example and EXPO2001	Energy consumption calculations failed; actual consumption is higher than project team members aimed.
Eco-Viikki Helsinki, F (2004)	23	787	Ecological design; gathering experience	District plant (heating and electricity); high thermal insulation, solar roof panels (electricity), solar collectors (hot water)	Energy planning contest	Energy consumption Public transport and facilities missing
Eva-Lanxmeer Culemborg, NL (2002)	38	250	A zero-energy balance	Biomass station (electricity and heating), solar roof panels (electricity), solar collectors (hot water), high thermal insulation; surplus electricity is fed in public grid	Sustainability and residents' initiative	Energy consumption is higher that theoretically calculated and feeding the CHP system by biogas has been failed up to now.
Kronsberg Hanover, D (2000)	100	3000	The right mix of functions	Wind & solar energy; 2 district plants (heating & electricity); high thermal insulation; passive solar energy; low energy light bulbs; training for building constructors	Regional policy, housing shortage and EXPO2000	Electricity consumption is higher than what theoretically was estimated as residents purchased more domestic appliances.
Vauban Freiburg, D (2001)	38	2000	Ecological, social and economical requirements	Solar roof panels (electricity), solar collectors (hot water), high thermal insulation passive solar energy	Green image Learning while Planning	Average energy consumption is higher than project objective. Conflicting ownership structures of the facilities

4.3 Results

In this section, results from the case study are presented: (i) results on success criteria for sustainable residential districts, (ii) then results on success factors, and (iii) results on applying the research model.

4.3.1 Success criteria for sustainable residential district projects

Three groups of success criteria were identified in section 3.1.3.2 related to People, Planet and Profit. Official published reports and non-published reports were consulted to identify which of these project success criteria groups were considered in the six European residential district projects. The results are listed in Table 4-2.

***Table 4-2**: The most important project criteria in the six European cases*

Case	Health	Technology Transfer	Expectations	Environmental friendliness				
				Efficient use of energy	Efficient use of water	Efficient mobility	Sourcing policy	Achieve social mix
BedZED	M	M	N.M	M	M	M	M	M
Bo-01	M	M	N.M	M	M	M	M	M
Eco-Viikki	M	M	N.M	M	M	M	M	M
Lanxmeer	M	M	N.M	M	M	M	M	M
Kronsberg	M	M	N.M	M	M	M	M	M
Vauban	M	M	N.M	M	M	M	M	M

Note: N=6, (M=mentioned), (N.M=not mentioned)

Table 4-2 shows that three criteria: Health, Technology transfer and Environmental friendliness from the third group Planet were mentioned as relevant to measure project success in the six cases. Only the criterion 'Expectation' was not mentioned in the cases. Another point is that the second success criterion 'Environmental friendliness' is considered as a broader criterion including five sub-criteria: 1) Efficient use of energy, 2) Efficient use of water, 3) Efficient mobility, 4) Sourcing policy, and 5) Achieving social mix.

In addition to the criteria Health, Technology transfer and Environmental friendliness, other specific success criteria were mentioned in single-cases. For example (soil reclamation in Bo01), (stimulation of food production in EVA-Lanxmeer) and (collecting waste for composting system in BedZED). Apparently, these criteria are project-specific. Therefore, these additional criteria will not be used in the further analysis.

4.3.2 Success factors for sustainable residential district projects

In section 4.3.1 success criteria for sustainable residential districts were presented. There criteria were Environmental friendliness (including Efficient use of energy, 2) Efficient use of water, 3) Efficient mobility, 4) Sourcing policy, and 5) Achieving social mix), Health and Technology transfer. In this section, these criteria and sub criteria are used to find out success factors for sustainable residential district projects.

***Table 4-3**: Evaluating measures and objectives related to efficient use of energy in the six cases*

Case	Objective	Result	Explanation
BedZED	90% energy reduction for space heating and 33% reduction of electricity consumption	Met	The two objectives are met by improving thermal insulation of building envelopes, having good orientation, taking advantage from ventilation heat recovery, efficient use of daylight and passive solar heating. Residents, however, were not used to deal with the new sustainable features in their dwellings such as fully glassed facades and atria and how consequently to use their windows and ventilation system. Residents complained over overheating problems in the summer [Corbey, 2005].
	Achieving fossil energy neutrality at the district level	Not met	A woodchips-fired CHP system was implemented for space heating and hot water supply. During the first period, the system has performed properly. Chosen technology was not proven yet. Due to technical problems and financial difficulties, the system is failed down and is replaced with gas boilers; BedZED is not fossil energy neutral at the moment [Corbey, 2005].
Bo-01	Usage of 100% renewable energy	Met	1,400 m² of solar collectors, placed on top of ten of the buildings complement the heat produced by the heat pump to supply the area. A large wind power station (2MW) placed in Norra Hamnen (the north harbour) and 120m² of solar cells produce electricity for the apartments, district-level heat pump, fans and other pumps within the area [Persson and Tanner, 2005].
	Reduce total energy consumption to 105 kWh/m²/year	Not met	120kWh/m²/year is achieved. Theoretical assumptions and calculations did not prove realistic; this was due to lack of experience and underestimating residents' behavior. However, renewable energy sources have been used in combination with heat pump heating system [Persson and Tanner, 2005].
Eco-Viikki	Usage renewable and passive energy	Met	The large number of glazed balconies and conservatories facing southwards are implemented and formed the most evident feature differing from conventional dwellings. In addition, supplementary features, such as the solar collectors, ventilation cowls on the roofs of the residential blocks were implemented [Hakaste et al., 2005].
	Reduction of space heating up to 115kWh/m2/yr	Not met	Individual cases achieved 87kwh/m2/year but on average the energy consumption is 120kWh/m2/yr indicating that individual cases consumed more than that. Discrepancies between theoretical assumptions and calculations did not prove realistic; this was due to lack of experience and underestimating residents' behavior [Hakaste et al., 2005].
EVA-Lanxmeer	Usage renewable energy	Met	Thermal insulation of building envelopes is improved and passive solar heating and lighting were used [energy-cities, 2009].
	Reduction of energy consumption up to 93kWh/m2/yr	Not met	All dwellings are provided with heat recovery ventilation systems, residents, however, used to ventilate their dwellings naturally by opening the windows (especially the bedrooms when residents were not at home). Therefore, energy consumption objective is not met as 104kWh/m2/year is consumed. Residents' complained that the heating system (low-temperature wall heating system) responded too slowly for space heating [energy-cities, 2009].
	CO_2 Neutral estate and Usage of hot fill appliances	Not met	Up to now, feeding the CHP system by biogas from gasification system on site has been failed due to technical and financial difficulties [Swinkel, 2010]. All dwellings are provided with the needed duct work for hot fill appliances but residents did not use them [Swinkel, 2010].
Kronsberg	Reduce energy consumption for space heating up to 50kWh/m2/yr	Not met	Low energy consumption for heating due to improving thermal insulation of building envelopes, taking advantage from ventilation heat recovery and passive solar heating. Although some passive houses in Kronsberg achieved 13,4kWh/m2/yr, the average energy consumption was 56kWh/m2/year [Czorny and Rumming, 2007].
	30% reduction of electricity consumption	Not met	In Kronsberg 6% of energy consumption is reduced. Theoretical assumptions did not prove realistic as residents' behavior toward purchasing and using electrical appliances was not predicted properly [Czorny and Rumming, 2007].
Vauban	Energy demand of 65 kWh/m2/yr for space heating	Met	Low energy consumption for heating due to improving thermal insulation of building envelopes, taking advantage from ventilation heat recovery and passive solar heating. Passive houses in Vauban achieved 15kWh/m2/year but on average energy consumption was 45kWh/m2/year [Dresel, 2008].

Data in Table 4-3 revealed that in the six cases, measures have been taken to minimize energy demand and to maximize energy efficiency. The measures are related to the ‘Trias Energetica’ approach; a three step approach to increase the energy efficiency. First, the energy demand is reduced by improving thermal insulation of the building envelope, use of heat recovery possibilities and passive energy heating/lighting. Second, the remaining energy demand is met by renewable technologies sources and third, when needed, efficiently use of fossil energy. The cases differ, however, in the extent to which each of these three measures is prioritized.

Due to technical problems and financial difficulties regarding unproven technologies, two cases could not achieve their objectives; BedZED and EVA-Lanxmeer. BedZED is not more fossil energy neutral because the CHP is failed down and the CO_2 neutrality in EVA-lanxmeer is not succeeded as natural gas, instead of biogas, is used for the CHP system.

Heating systems at the district level are applied for space heating and hot water supply. These systems seemed to have high level of efficiency as individual peaks could be leveled off.

In BedZED, Bo-01, Eco-Viikki, EVA-Lanxmeer and Kronsberg, residents’ behavior is mentioned as an essential factor to achieve high energy efficiency. Purchasing of electrical household appliances, use of windows and doors, use of thermostat, use of ventilation systems and consuming hot water seemed to be strongly related to residents’ behaviors. In Vauban, however, energy efficiency objectives were met and no information was specified about the influence of the residents.

Table 4-4*: Evaluating measures and objectives related to efficient use of water in the six cases*

Case	Objective	Result	Explanation
BedZED	Achieving ground water treatment plant (GWTP) in the estate.	Not met	On the scale of BedZED, it was financially infeasible to build and operate a GWTP. Afterwards, it has been replaced by a membrane bioreactor (MBR) for recycling waste water for non-potable domestic use; it is not a good environmental measure as it does not meet the sustainability standards [Corbey, 2005].
	Achieving Sustainable Urban Drainage Schemes		Green roof and rainwater harvesting systems and the porous paving in the car parking areas are realized. However there have been problems with the drainage systems because gaps between the blocks are filled with weeds and material were stored on the gravel filter so there was a risk of flooding and a future maintenance liability [Corbey, 2005].
	Reduction of drink water demand	Met	33% reduction of drink water consumption is achieved due implication of saving appliances (dual flush 2/4 liter flush toilet and reduced flow taps and shower head) and visible meters to make residents more aware of their water consumption [Hodge and Haltrecht, 2009].
Bo01	Reuse rainwater and preventing water run-off	Met	Rainwater is treated locally through surface run-off systems, without any connection to the community infrastructure i.e. green roofs, channels and dams and grey-water is treated in the city's purification post. Residents appreciate these measures but some problems were found, however, by visually handicapped persons stumbled on the rainwater channels [Persson and Tanner, 2005].
	Reduction of drink water demand	Met	Having individual and visible consumption-based water metering and billing has reduced consumption by 22% [Hakaste et al., 2005].
Eco-Viikki	Reduction of drink water demand	Met	Having individual and visible consumption-based water metering and billing has reduced consumption by 33% [Hakaste et al., 2005].
	Preventing water run-off and improve the habitat for the vegetation	Met	Structural and architectural measures were taken to capture water coming from rain, melting snow and roofs to be slowed down and soaked into the ground. These measures were appreciated by the residents [Hakaste et al., 2005].
EVA-Lanxmeer	Reuse rainwater and preventing water run-off.	Not met	Rainwater running off from roofs, road surfaces, kitchen sinks led to retention pools by a drainage system, treated and lead into ditches. Waste water from toilets is collected separately, fluids are treated separately. Due to some health (Legionella) concerns and changing legislations, the 'gray-water installations in houses' have been removed [Swinkels, 2010].
Kronsberg	Preventing water run-off and increasing rainwater infiltration	Met	Water run-off is reduced up to 3% and water infiltration increased up to 50% meeting successfully the project targets. Residents appreciate implemented measures [Czorny and Rumming, 2007].
	Reduction of drink water demand		Consumption of drink water is reduced by: (i) water-saving devices are implemented such as water-air mixers, flow limiters and constant flow regulators, (ii) implementing of individual and visible water meters in all apartments, and (iii) guiding residents how to deal with water efficiency measures helped to reduce [Rumming et al., 2004].
Vauban	Preventing water run-off and increasing rainwater infiltration	Met	Water run-off is reduced and water infiltration increased in about 80% of the area. Rainwater is collected separately and is used in houses or infiltrated into the ground. Residents appreciate those measures [Dresel, 2008].
	Reuse sewage		Sewage is transported via vacuum pipes into a biogas plant where it ferments together with organic household waste, generating biogas which is used for cooking [Sperling, 2010].

Data in Table 4-4 revealed that the most measures for reuse rainwater worked properly. These measures, however, haven't direct interaction with residents unless gray water distribution network is built to reuse rainwater. In EVA-Lanxmeer, gray-water installations have been removed due to health concerns (Legionella) and costs issues. In BedZED, technical problems and financial difficulties regarding the Green Water Treatment Plant caused technology failure. The GWTP was, however, not-proven technologies at this level.

The consumption of drink water, in contrast, seemed to be very dependent on residents' behavior and households' profiles. In the six cases measures were taken to reduce drink water consumption (reduced flow taps and shower head) and residents were guided to adopt new lifestyle. This approach seemed to work properly but it still hard to say to what extent residents' behavior is responsible for drink water consumption.

***Table 4-5**: Evaluating measures and objectives related to technology transfer in the six cases*

Case	Objective	Result	Explanation
BedZED	External knowledge transfer	Met	Intensive media interest and weekly guided tours have benefited from the presence of the BioRegional and Bill Dunster architects in the site. The BedZED principles and lessons learned have been used by designers and planners worldwide [Hodge and Haltrecht, 2009].
	Inter-organizational knowledge transfer	Met	The first ideas behind BedZED were worked out by architect Bill Dunster and Chris Twinn after the realization of Bill's Hope House. When initializing BedZED, experts from BioRegional and Peabody Trust were added to the building team. The knowledge transfer found place within this team and then transferred within the organization of the involved parties [Dunster, 2010].
	Residents' guidance	Met	There was no resident's participation in the design process. A Green-Lifestyle Officer was pointed in the area to meet and greet new residents and guiding them how to live in BedZED [Hodge and Haltrecht, 2009].
Bo01	External knowledge transfer	Met	Thirteen different projects and regular seminars were conducted about information, public education and environment communication as part of Bo-01. The media was used to promote the project and the environmental friendly lifestyle [Persson and Tanner, 2005].
	Inter-organizational knowledge transfer	Met	Project stakeholders have been directly involved in negotiating the quality program of Bo-01. The project was phased in and knowledge in first phases was applied in the later phases [Persson and Tanner, 2005].
	Residents' guidance		The project 'Environmental TV on the web' used communication technologies to communicate with people to encourage them to adopt an environmental friendly lifestyle [Persson and Tanner, 2005].
Eco- Viikki	External knowledge transfer	Met	A forum for ecological debate was organized for developing a large open ideas competition for the detailed plan of Viikki involving a group of experts to discuss the ecological opportunities and model solutions. All project outputs and lessons learned are published in the media. Visits and guided tours are arranged in Viikki [Hakaste et al., 2005].
	Inter-organizational knowledge transfer	Met	Project developers, architects, engineers and contractors were involved in an implementation team that was supported by a wide multi-disciplinary expert group. The project was phased in and knowledge in first phases was applied in the later phases [Hakaste et al., 2005].
	Residents' guidance	Met	Potential residents have been involved in the decision-making process concerning their neighborhood block from the beginning of the project together with the implementation team. Residents from the self-build projects group were also involved during the project phases [Hakaste et al., 2005].
EVA-Lanxmeer	External knowledge transfer		Intensive media interest and regular guided tours are organized by the EVA Foundation. The foundation has benefited from the presence of the first residents (initiators of the project) in the site [Kaptein, 2009].
	Inter-organizational knowledge transfer		The EVA Foundation played a key role in developing Lanxmeer, in cooperation with the Culemborg municipality, the Ministry of Housing, Spatial Planning and the Environment and many private parties. Future residents, architects, consultants, the urban development agency, the municipality, the building contractors etc were involved in design and realization phases. EVA foundation was in charge of coordination, knowledge dissemination and trainings of involved parties [Goed, 2002].
	Residents' guidance	Met	The Lanxmeer concept was developed by a group of scientists having diverse backgrounds (EVA Foundation). The residents participated in several workshops in the first phase of the project resulting in good input for the project including an urban development plan. Later, residents were trained and guided to become familiar with the new environmental friendly lifestyle. Post-occupancy evaluations are conducted. Some of the residents are still actively involved in EVA Foundation [Kaptein, 2009].

Kronsberg	External knowledge transfer	Met	Intensive media interest and guided tours were organized in Kronsberg. The principles of Kronsberg and lessons learned have been published and disseminated through e.g. Concerto (European Union research program to promote sustainable residential districts) [Czorny and Rumming, 2007].
	Inter-organizational knowledge transfer		The Kronsberg Environmental Liaison Agency (KUKA) was set up on site by Hannover City to facilitate coordination with City administration, disseminate information, and provide information and training to all stakeholders. Knowledge in first phases was applied in the later phases [Czorny and Rumming, 2007].
	Residents' guidance		KUKA provided trainings and workshops to get input from potential residents and to guide the new residents into the new environmental friendly lifestyle. Post-occupancy evaluations were conducted and results were used to improve next phases of the project [Czorny and Rumming, 2007].
Vauban	External knowledge transfer	Met	Intensive media interest and guided tours were organized in Vauban. The principles of Vauban and lessons learned have been published and disseminated national as well as internationally [Sperling, 2010].
	Inter-organizational knowledge transfer	Met	The City Council Vauban Committee was set up on site by Freiburg City as main platform for information exchange, discussion, decision preparation and training to all stakeholders. Knowledge in first phases was applied in the later phases [Dresel, 2008].
	Residents' guidance	Met	Residents were effectively participated in the design, realization and use phases of the project through the Vauban Forum. The forum was in charge of residents' trainings and communication between Project Group Vauban and City Council Committee [Dresel, 2008].

Data in Table 4-5 revealed that all cases succeeded in involving project stakeholders and residents in the project planning and realization. Data also revealed two ways of inter-organization knowledge transfer. First, knowledge was transferred between members of project team. And second, knowledge was transferred through the several subprojects; the so called ‘learning by doing’ approach. Data also revealed that residents’ involvement found place in two phases of the project. First, residents’ involvement in the design phase to provide input about their needs and expectations. Second, residents’ involvement in use phase as residents’ feedback was used to improve further projects.

***Table 4-6**: Evaluating measures and objectives related to achieving social mix in the six cases*

Case	Objective	Result	Explanation
BedZED	Social mix housing	Not met	Dwellings in BedZED are about 20% higher in price than the average price of a dwelling in the same area. Although different households' profiles have been moved to BedZED, it failed to achieve social mix housing [Corbey, 2005].
Bo01	Social mix housing	Not met	Dwellings in Bo01 were more expensive then the local average. Bo-01 attracted mainly highly educated and high income people [Persson and Tanner, 2005].
Eco-Viikki	Social mix housing	Met	Eco-Viikki attracted several resident's profiles especially families with children and students who studied in the university. However, single and newly married residents complained that the area was too much designed for children and less attention was paid for other residents' profiles [Hakaste et al., 2005].
EVA-Lanxmeer	Social mix housing	Not met	There is no social housing yet in the estate. Only environmentally oriented, highly educated and high income people have chosen for EVA-Lanxmeer. Initiating social mix housing years after finishing Lanxmeer still facing resistance from the first residents [Swinkel, 2010].
Kronsberg	Social mix housing	Met	Affordable housing and social mix are realized in the estate. However, first residents did not appreciate this aspect especially when the municipality has accommodated low income families of many persons [Kier, 2010].
Vauban	Social mix housing	Not met	It is the group of well educated, ecologically oriented middle class people who introduced the new life style and gave Vauban its specific shape. These people were absolutely crucial for the success of Vauban. Social mix housing needed governmental subsidies, but that was cancelled [Sperling, 2010].

Data in Table 4-6 revealed that social mix were difficult to be achieved in sustainable districts. Differences in education, believes, interests, origin, income and household size have impeded to attract different residents' groups to the district. Social mix was implemented in Kronsberg and Viikki. However, dissatisfaction among the residents was reported.

***Table 4-7**: Evaluating measures and objectives related to achieving efficient mobility in the six cases*

Case	Objective	Result	Explanation
BedZED	Social mix housing	Not met	Dwellings in BedZED are about 20% higher in price than the average price of a dwelling in the same area. Although different households' profiles have been moved to BedZED, it failed to achieve social mix housing [Corbey, 2005].
Bo01	Social mix housing	Not met	Dwellings in Bo01 were more expensive then the local average. Bo-01 attracted mainly highly educated and high income people [Persson and Tanner, 2005].
Eco-Viikki	Social mix housing	Met	Eco-Viikki attracted several resident's profiles especially families with children and students who studied in the university. However, single and newly married residents complained that the area was too much designed for children and less attention was paid for other residents' profiles [Hakaste et al., 2005].
EVA-Lanxmeer	Social mix housing	Not met	There is no social housing yet in the estate. Only environmentally oriented, highly educated and high income people have chosen for EVA-Lanxmeer. Initiating social mix housing years after finishing Lanxmeer still facing resistance from the first residents [Swinkel, 2010].
Kronsberg	Social mix housing	Met	Affordable housing and social mix are realized in the estate. However, first residents did not appreciate this aspect especially when the municipality has accommodated low income families of many persons [Kier, 2010].
Vauban	Social mix housing	Not met	It is the group of well educated, ecologically oriented middle class people who introduced the new life style and gave Vauban its specific shape. These people were absolutely crucial for the success of Vauban. Social mix housing needed governmental subsidies, but that was cancelled [Sperling, 2010].

Data in Table 4-7 revealed that transport impact has been met in the six cases. Sustainable measures included: (i) having daily facilities close to or in the district, (ii) good connections to the public transport, (iii) replacing parking bays to the edges of the district, and (iv) creating car-free zones in the district. Strictly limitation of parking possibilities caused resident's dissatisfaction that resulted in moving that parking problem to the surrounding area.

In some cases (Vauban and EVA-Lanxmeer) residents had to enter into legally binding agreement to regulate parking use in the district. This approach seemed to be difficult in use as policy roles were hard to be controlled, especially for new residents they may refuse to sign it.

Table 4-8: *Evaluating locally sourcing materials related objectives in the six cases*

Case	Objective	Result	Explanation
BedZED	Material sourcing policy within 35 miles area	Not met	This restriction has affected the quality delivered by contractors and locally material sourcing could not be guaranteed. Especially low-environmental impact products were hardly to be found in this restricted area [McDonald, 2010].
Bo01	Using local environmental friendly materials	Met	There was no distance limitation for sourcing material or contractors. Materials had, however, to meet requirements as suggested by the National Chemicals Inspectorate [Persson and Tanner, 2005].
Eco-Viikki	Using local environmental friendly materials	Met	The usage of low environmental impact materials was suggested in the quality program in the first phases of the project. The implementation of this criterion was left outside the actual criteria because of its complexity [Hakaste et al., 2005].
EVA-Lanxmeer	Using local environmental friendly materials	Not met	Sustainable Building (DuBo) standards were required to source materials and contractors including distance and certificates to be provided by the contractors. However, difficulties were mentioned regarding maintaining the DuBo requirements and many contractors have evaded it [Kaptein, 2009].
Kronsberg	Using environmental friendly materials	Met	Project stakeholders were taught and stimulated to uses environmentally compatible building materials, and when possible locally materials were sourced. The sourcing area was not limited. The Kronsberg experience exposed the difficulties of making such standards binding on others through clauses in land sale contracts [Czorny and Rumming, 2007].
Vauban	Using environmental friendly materials	Met	Vauban reported some difficulties in implementing restricting of sourcing area for materials and contractors. Project stakeholders were, however, stimulated and taught to use environmental friendly materials. There was no distance limitation for materials sourcing [Sperling, 2010].

Data in Table 4-8 revealed two measures for sustainable material sourcing: (i) using environmental friendly materials and (ii) restricting the sourcing area for used materials and involved contractors. In the time these projects were realized, it was hard to have good control on used materials due to lack of product-certifications. Also suppliers were not used to deal with such requirements. This measure forced some contractors to obviate the roles and use materials that not meet the requirements.

Restricting the sourcing area, to reduce CO_2 emissions by transport, had negative influence on the possibility to find good materials and well qualified (sub) contractors. Reduction of CO_2 emissions could be to the detriment of quality.

Table 4-9: *Evaluating measures and objectives related to health in the six cases*

Case study	Objective	Result	Explanation
All cases	Common measures	Met	Attention was paid to ensure good indoor air quality and thermal comfort by improving building air tightness, the ventilation system, use of passive lighting, use of passive heating and space heating system.
BedZED	Ensuring optimal indoor air quality	Not met	A post-occupancy evaluation showed some problems regarding the thermal comfort (in the winter only 44% said that the indoor temperature was just right, in the summer only 10% said the temperature to be just right) and regarding air quality (52% found air in the summer stuffy). The overheating problems were because the large percentage glass in the facades as no shading measures were taken [Hodge and Haltrecht, 2009].
Bo-01	Ensuring optimal indoor air quality	Not met	A post-occupancy evaluation showed that residents were satisfied with air quality. There response was dispersed indicating some problems regarding overheating in the summer, cold in the winter, draughts, uneven temperature. The overheating problems were because the large percentage glass in the facades as no shading measures were taken [Persson and Tanner, 2005].
Eco-Viikki	Ensuring optimal indoor air quality	Not met	A post-occupancy evaluation showed that seven out of every ten households were reasonably satisfied with the ventilation in their home. There was dissatisfaction with the mechanical ventilation (noise problem) and some overheating problems (in the summer). The overheating problems were because the large percentage glass in the facades as no shading measures were taken [Hakaste et al., 2005].
EVA-Lanxmeer	Ensuring optimal indoor air quality	Not met	A post-occupancy evaluation showed some noise problems (37%), moisture problems (12%), and space heating problems (19%). The overheating problems were because the large percentage glass in the facades as no shading measures were taken [de Vries, 2003].
Kronsberg	Ensuring optimal indoor air quality	Not met	A post-occupancy evaluation showed some problems regarding ventilation systems (noise and draught). The overheating problems were caused by the large percentage glass in the facades as no shading measures were taken [Czorny and Rumming, 2007]. However, passive houses in Kronsberg showed better results as shading measures were taken [Feist et al., 2005].
Vauban	Ensuring optimal indoor air quality	Not met	A post-occupancy evaluation showed some problems regarding ventilation systems (noise and draught) [Sperling, 2010].

Data in Table 4-9 revealed that health related objectives are mainly linked to thermal comfort, acoustic and air quality. All six cases have improved health conditions by improving building air tightness, the ventilation system, use of passive lighting, use of passive heating and space heating system.

Post-occupancy evaluations revealed that the six cases failed to fully meet their health-objectives. Problems were experienced in extreme weather conditions in the winter and in the summer. The main mentioned problems are related to thermal conform (overheating in the summer and cold in the winter), to the perception of air quality (draught and dry air from the ventilation), and to noise produced by the ventilation system. There is, however, no efforts done to evaluate the real air quality including microbial contaminations and CO_2 concentrations.

The main cause of thermal discomfort was the large percentage glass that was used to gain passive solar energy. The cases suggested also that shading devices should be implemented as standard in such dwellings. However, this measure has not been taken in these cases.

4.3.3 Explaining project success/failure

The project-specific Formal System Model was used, as explained by White and Fortune (2009), to explain project success/failure in the six cases. First failing modes were identified by means of the model and then the model was used to explain project success or failure.

In this section the results of model implementation are presented. In the tables, headed as Mapping of failings associated with projects, some rows are left empty. This means that no failing were found in relation to model component in that project.

***Table 4-10**: Mapping of failings associated with BedZED onto the components of the Formal System Model in BedZED*

Formal System Model	Failure modes
Environment disturbs	Failure to: manage uncertainty in predicting residents' behavior in relation to using the heating system and purchasing electric cars that would benefit from the solar energy. Learn from past experience as it is the first in this context.
Wider system boundary	Failure to: consider effect/views of end-users as residents were not involved in the project design.
Wider system	
Formulates initial design	Failure to: The goals (i) to achieve fossil energy neutrality, (ii) to implement photovoltaic panels to feed electric cars, and (iii) to implement a GWTP were not realistic using technologies available at that time;
Provides resources and legitimates area of operation	Failure to: some technologies were not proven and some contractors were not qualified enough as sourcing area was restricted
Legitimates area of operation	Failure to: some contractors were not used to adapt new ways of working. The CHP and GWTP technologies were not fully understood
Makes known expectations	Failure to: control budget, some technical issues were overvalued human issues.
Communication channels	Failure to: acknowledge project complexity
System boundary	Failure to: viewpoints from the residents were not considered in the design phase
Decision-making subsystem	Failure to: assign teams that cooperated properly as some problems were mentioned about the local sub-contractors
Decides on transformations	
Provides resources and legitimates operations	Failure to: define and fully understand underlying technologies.
Makes known expectations	Failure to: control resistance to change as failed technologies had to be replaced (CHP system)
Transformation subsystems	
Provide performance information	
Performance monitoring subsystem	Failure to: identify misleading information about the CHP system and GWTP
Report to	Failure to: report misleading information
Supplies performance information	Failure to: report on performance of supplier of CHP system
Attempts to influence environment	

Data in Table4-10 revealed the failure modes recognized in BedZED. The main problems are related to three points: (i) implementing non-proven technologies to achieve ambitious project goals, (ii) failure to form teams that properly cooperate with each other (as result of the local sourcing policy), and (iii) failure to influence the environment to make the needed changes.

***Table 4-11**: Discrepancies revealed by applying the project-specific Formal System Model in BedZED*

Main component	Discrepancy or comment
Goals and objectives	BedZED was a forerunner with ambitious objectives including: • achieving the fossil energy neutrality at the district level, • promoting usage of electrical cars • achieving a groundwater treatment plant (GWTP) • locally sourcing of building material and (sub)-contractors All these objectives were too ambitious and were not fully met.
Performance monitoring	There was a system of performance monitoring and feedback. Performance and progress delivered by the subcontractors were regularly monitored and discrepancies were timely fed back to the core project team. Budget overrun was also timely fed back to the project team. Also a post-occupancy evaluation was held in among the residents.
Decision-makers	Bill Dunster (from Dunster architects) was the site project manager who took (in consultation with BioRegional) day-to-day decisions and reported to the project team. Bill Dunster made clear most of his expectations; however it was also clear that budget was never firmly established at the start of the project.
Transformations	The construction of BedZED was undertaken by Ellis & Moore Consulting Engineers (as main contractor) and key sub-contractors. The sub-contractors were mainly chosen according to their quality but should also be local. Sub-contractors did not cooperate as expected leading to some conflict in the realization phase.
Communication	There was a clear communication plan maintained by the project manager Bill Dunster between the involved parties. The presence of the office of Bill Dunster architects in the district supported daily communications between the parties.
Environment	The site project manager failed to influence Peabody sufficiently leading to the replacement of the woodchips-fired CHP with natural-gas fired boilers.
Boundaries	Responsibility of the project manager and the project director were clear defined
Resources	BedZED benefited from a deal made with London Borough of Sutton as they sold the land for the project at below market value due to the planned environmental objectives. An adequate budget was provided by Peabody and all essential resources were provided.
Continuity	It was clear that BedZED could not display continuity and the project could not make satisfactory recovery from environmental disturbances; e.g. no funds could be found to replace the woodchips-fired CHP system with a new CHP system.
Project champion	Bill Dunster was greatly benefited the project. He implemented his ideas in his hope house and converted them into a sustainable residential district.
Change agent	The project manager was acting as a change agent for the project. In his role as change agent, he ensured that new membrane bioreactor (MBR) was installed in place of the GWTP
Viewpoints	In BedZED residents' viewpoints were not fully considered; there were some problems with parking spaces and purchasing electric cars.

Data in Table 4-11 revealed that the project had very effective planning, monitoring, control and feedback system and that clear lines of communication were established and there were sufficient resources. The project failed partly, however, to take sufficient account of the used technologies and past experience. The project budget was overrun and it failed to adapt new proven technologies instead of woodchips-fired CHP system.

***Table 4-12**: Mapping of failings associated with Bo-01 onto the components of the Formal System Model*

Formal System Model	Failure modes
Environment disturbs	Failure to: manage uncertainty in predicting residents' behavior in relation to using the heating system.
Wider system boundary	Failure to: consider effect/views of end-users as residents were not involved in the project design.
Wider system	
Formulates initial design	Failure to: The goal to reduce energy consumption to 105 kWh/m2/year seemed not realistic
Provides resources and legitimates area of operation	Failure to: technologies were proven but their impact in the use phase was not clear. Some contractors hadn't the required knowledge/experience to provide the expected results.
Legitimates area of operation	
Makes known expectations	Failure to: some technical issues were overvalued human issues.
Communication channels	Failure to: acknowledge project complexity.
System boundary	Failure to: viewpoints from the residents were not considered in the design phase
Decision-making subsystem	
Decides on transformations	
Provides resources and legitimates operations	Failure to: define and fully understand underlying technologies e.g. passive energy measures and ventilation systems.
Makes known expectations	Failure to: control resistance to change as failed technologies had to be replaced e.g. installing shading devices to overheating problems
Transformation subsystems	
Provide performance information	
Performance monitoring subsystem	
Report to	
Supplies performance information	
Attempts to influence environment	Failure to: persuade end-users to accept and adopt new technologies/measures.

Data in Table 4-12 revealed the failure modes recognized in Bo-01. The main problems are related to two points: (i) theoretical calculations of energy consumptions and the practical results differed in some cases widely due to lack of knowledge, and (ii) failure to adopt new measures to obviate overheating complains in the use phase.

***Table 4-13**: Discrepancies revealed by applying the project-specific Formal System Model in Bo-01*

Main component	Discrepancy or comment
Goals and objectives	Bo-01 was an ambitious project having the following objectives: usage of 100% sustainable energy, reduction of energy consumption up to 105 kWh/m2/year
Performance monitoring	There was a system of performance monitoring and feedback. Performance and progress delivered by the subcontractors were regularly monitored and discrepancies were timely fed back to the quality program team. Also a post-occupancy evaluation was held among the residents.
Decision-makers	A team of experts (from the involved companies) was acting as a daily site project manager who took decisions and reported to a larger project team. Members of the project management team made clear most of his expectations.
Transformations	The construction of Bo-01 was undertaken by many main contractors and sub-contractors (forming the construction team). The (sub) contractors were chosen according to their quality and their past experience.
Communication	There was a clear communication plan maintained by the management team between the involved parties. From the start of the project, the City of Malmö initiated and coordinated the communication plan. In the later phases, the communication plan was in charge of the management team.
Environment	The project management team failed to take additional measures to avoid the side-effects of passive house measures leading to thermal discomfort.
Boundaries	No information was available about this point
Resources	Bo-01 benefited from governmental grant of SEK 250 million and financial support from the European Union to cover the extra costs needed to achieve the high environmental goals.
Continuity	It was clear that Bo-01 could not display continuity and the project could not make satisfactory recovery from environmental disturbances; e.g. no funds could be found to take additional measure to obviate overheating problems.
Project champion	There was no individual project champion but a project team as project champion. But an exceptional role was of the City of Malmö who initiated a strong environmental program and provided the needed support.
Change agent	The project management team was acting as a change agent for the project. In its role as change agent, the team ensured that trainings and workshops to promote the project objectives and the new environmental lifestyle.
Viewpoints	In Bo-01 residents' viewpoints were not considered.

Data in Table 4-13 revealed that the project had very effective planning, monitoring, control system, feedback system, clear lines of communication were established and there were sufficient resources. The project failed partly, however, to take sufficient account of the used technologies and past experience. Problems in the use phase were found but no measures were taken to obviate them.

***Table 4-14**: Mapping of failings associated with EVA-Lanxmeer onto the components of the Formal System Model*

Formal System Model	Failure modes
Environment disturbs	Failure to: manage uncertainty in predicting residents' behavior in relation to using the heating system and parking spaces. Manage political influence e.g. removing the gray-water installations from dwellings.
Wider system boundary	
Wider system	
Formulates initial design	Failure to: The goal to reduce energy consumption was failed and to realize CO_2 neutral area was not realistic
Provides resources and legitimates area of operation	
Legitimates area of operation	Failure to: (sub) contractors hardly adapt their way of work and tried override the sustainability roles in relation to materials.
Makes known expectations	
Communication channels	Failure to: acknowledge project complexity.
System boundary	
Decision-making subsystem	
Decides on transformations	
Provides resources and legitimates operations	Failure to: define and fully understand underlying technologies e.g. passive energy measures, low temperature wall heating system, gasification system and ventilation systems.
Makes known expectations	Failure to: control resistance to change as failed technologies had to be replaced e.g. installing shading devices to overheating problems
Transformation subsystems	Failure to: complete the whole plan as the composting system is never implemented
Provide performance information	
Performance monitoring subsystem	Failure to: identify misleading information about the requirements in relation to material certifications
Report to	Failure to: report misleading information
Supplies performance information	
Attempts to influence environment	Failure to: persuade end-users to accept and adopt the new parking policy.

Data in Table 4-14 revealed the failure modes recognized in EVA-Lanxmeer. The main problems are related to two points: (i) theoretical calculations of energy consumptions and the practical results differed in some cases widely due to lack of knowledge and residents' influence, and (ii) failure to adopt new measures to obviate thermal discomfort in the use phase.

***Table 4-15**: Discrepancies revealed by applying the project-specific Formal System Model in EVA-Lanxmeer*

Main component	Discrepancy or comment
Goals and objectives	EVA-Lanxmeer was an ambitious project having the following objectives: involve residents to create their own living environment, promote ecological and car-free lifestyle. These goals were mainly met. Other goals realizing CO_2 neutral district and, reduction of energy consumption up to 93 kWh/m2/year and using DuBo-certified materials were not met.
Performance monitoring	There was a system of performance monitoring and feedback. Performance and progress delivered by the subcontractors were regularly monitored and discrepancies were timely fed back to the EVA-Foundation and the project organization. Also a post-occupancy evaluation was held in among the residents.
Decision-makers	A team of experts (from the involved companies and the EVA-Foundation) was acting as a daily site project manager who took decisions and reported to the project organization. Members of the project management team made clear most of his expectations.
Transformations	The construction of EVA-Lanxmeer was undertaken by several main contractors and sub-contractors. The (sub) contractors were chosen according to their quality and to sustainability requirements (DuBo requirements).
Communication	There was a clear communication plan maintained by the EVA-Foundation between the involved parties. From the start of the project, the City of Culemborg took an active role in the communication plan.
Environment	The project management team failed to take additional measures to avoid the side-effects of sustainable heating systems in dwellings leading to thermal discomfort.
Boundaries	No information was available about this point
Resources	EVA-Lanxmeer benefited from governmental support because the site was a protected drink water extraction area and normally it is not allowed to build around such areas.
Continuity	It was clear that EVA-Lanxmeer could not display continuity and the project could not make satisfactory recovery from environmental disturbances; e.g. the gasification system is not built yet.
Project champion	The EVA-Foundation is the project champion and especially Marleen Kaptein for her role in initiating the plan.
Change agent	The project management team was acting as a change agent for the project. In its role as change agent, the team ensured that trainings and workshops to promote the project objectives and the new environmental lifestyle.
Viewpoints	In EVA-Lanxmeer all viewpoints were fully considered.

Data in Table 4-15 revealed that the project had very effective planning, monitoring, control system, feedback system, clear lines of communication were established and there were sufficient resources. The project failed partly, however, to take sufficient account of the used technologies and residents' behavior. Problems in the use phase were found but no measures were taken to obviate them.

***Table 4-16**: Mapping of failings associated with Eco-Viikki onto the components of the Formal System Model*

Formal System Model	Failure modes
Environment disturbs	Failure to: manage uncertainty in predicting residents' behavior in relation to using the sustainable heating measures.
Wider system boundary	Failure to: consider views of specific groups (young couples)
Wider system	
Formulates initial design	Failure to: reducing the energy consumption and promoting low car-dependency; these two goals are not fully met
Provides resources and legitimates area of operation	
Legitimates area of operation	
Makes known expectations	
Communication channels	
System boundary	
Decision-making subsystem	
Decides on transformations	
Provides resources and legitimates operations	Failure to: define and fully understand underlying technologies e.g. passive energy measures and low temperature wall heating system.
Makes known expectations	Failure to: control resistance to change residents' behavior in relation to use of sustainable heating system
Transformation subsystems	
Provide performance information	
Performance monitoring subsystem	
Report to	
Supplies performance information	
Attempts to influence environment	Failure to: persuade end-users to accept and adopt the new sustainable heating systems.

Data in Table 4-16 revealed the failure modes recognized in Eco-Viikki. The main problems are related to two points: (i) residents' viewpoints were not fully considered in the design phase resulting in improper use of technologies and sustainable measures, and lack of knowledge about actual performance of HVAC system in the use phase.

***Table 4-17**: Discrepancies revealed by applying the project-specific Formal System Model in Eco-Viikki*

Main component	Discrepancy or comment
Goals and objectives	Eco-Viikki is an ambitious project having the following objectives: implementing passive and renewable energy, promoting ecological lifestyle and reducing consumption of drink water. These goals were mainly met. Another goal namely realizing reduction of energy consumption up to 115kWh/m2/year was not met.
Performance monitoring	There was a system of performance monitoring and feedback. Performance and progress delivered by the subcontractors were regularly monitored and discrepancies were timely fed back to the management group that was responsible for the communication and control. Also a post-occupancy evaluation was held in among the residents.
Decision-makers	A team of experts (from the involved companies, NGO's and residents) was acting as a site project manager who took decisions and reported to the project organization. Members of the project management group made clear most of his expectations.
Transformations	The construction of Eco-Viikki several main contractors and sub-contractors. The (sub) contractors were chosen according to their quality and past experience.
Communication	There was a clear communication plan between the special work groups, project management and management group. From the start of the project, the City of Helsinki took an active role in the communication plan.
Environment	The project management group failed to take additional measures to avoid the side-effects of sustainable heating systems in dwellings leading to thermal discomfort.
Boundaries	There was clear definition of responsibilities of the management group and the project groups
Resources	Eco-Viikki benefited from grants from the city of Helsinki, the National Technology Agency (TEKES) and Ministry of Environment (€ 4 million).
Continuity	It was clear that Eco-Viikki could not display continuity and the project could not make satisfactory recovery from environmental disturbances; e.g. thermal discomfort complains are not solved yet.
Project champion	The members of the workgroup who defined the criteria of the quality program are the project champions.
Change agent	The management group was acting as a change agent for the project. In its role as change agent, the team ensured that trainings and workshops to promote the project objectives and the new environmental lifestyle.
Viewpoints	In Eco-Viikki viewpoints were fully considered only young couples were less considered in the design of the project.

Data in Table 4-17 revealed that the project had very effective planning, monitoring, control system, feedback system, clear lines of communication were established and there were sufficient resources. The project failed partly, however, to take sufficient account of the used technologies and residents' behavior. Problems in the use phase were found but no measures were taken to obviate them.

***Table 4-18**: Mapping of failings associated with Kronsberg onto the components of the Formal System Model*

Formal System Model	Failure modes
Environment disturbs	Failure to: manage uncertainty in predicting residents' behavior in relation to using the heating system and purchasing electric domestic appliances.
Wider system boundary	
Wider system	
Formulates initial design	Failure to: The goal to achieve energy reduction up to 50kWh/m2/year was not met.
Provides resources and legitimates area of operation	
Legitimates area of operation	
Makes known expectations	
Communication channels	
System boundary	
Decision-making subsystem	
Decides on transformations	
Provides resources and legitimates operations	
Makes known expectations	
Report to	
Supplies performance information	Failure to:
Attempts to influence environment	Failure to: control resistance to change residents' behavior in relation to use of sustainable heating system and purchasing electrical domestic appliances

Data in Table 4-18 revealed the failure modes recognized in Kronsberg. The main problems are related to: (i) lack of knowledge about residents' behavior resulting devious energy consumption and, and (ii) failure to adopt new measures to obviate thermal discomfort in the use phase.

***Table 4-19**: Discrepancies revealed by applying the project-specific Formal System Model in Kronsberg*

Main component	Discrepancy or comment
Goals and objectives	Kronsberg had ambitious objectives including: preventing water run-off and reuse rainwater, promoting knowledge transfer, promoting social mix housing, minimizing impact from transport, reducing energy consumption up to 50kWh/m2/year, and ensuring healthy indoor air. The latest two objectives were not fully met in the use phase.
Performance monitoring	There was a system of performance monitoring and feedback. Performance and progress delivered by the subcontractors were regularly monitored by the Quality Assurance Workgroup and Quality Assurance Bureau. Discrepancies were timely fed back to the City of Hannover.
Decision-makers	Several project managers took day-to-day decisions and reported to the project team of each subproject. The Kronsberg Environmental Liaison Agency (KUKA) was in charge of communication between City of Hannover, funding agencies and other project members.
Transformations	The construction of Kronsberg was phased in and the subprojects were undertaken by many contractors and sub-contractors. The sub-contractors were mainly chosen according to their quality and part experience.
Communication	There was a clear communication plan between the project managers and the other involved parties through KUKA. The presence of KUKA in the district supported the daily communications between the parties helped to communicate better.
Environment	The project management team failed to take additional measures to avoid the side-effects of sustainable heating systems in dwellings leading to thermal discomfort.
Boundaries	There was clear definition of responsibilities of the management group and the project group
Resources	Kronsberg has benefited from the additional attention that was received due to the close relationship with EXPO 2000. Kronsberg has benefited from financial support from the European Union in association with the European Commission Directorate General for Energy and Transport.
Continuity	It was clear that BedZED could not display continuity and the project could not make satisfactory recovery from environmental disturbances; no funds could be found to replace the woodchips-fired CHP system with a new CHP system.
Project champion	There were no individual project champions but a project team as project champion. But an exceptional role was of the City of Kronsberg who initiated a strong environmental program and provided the needed support.
Change agent	KUKA was acting as a change agent for the project. KUKA ensured trainings and workshops to promote the project objectives and the new environmental lifestyle.
Viewpoints	In Kronsberg different viewpoints were fully considered; including the residents.

Data in Table 4-19 revealed that the project had very effective planning, monitoring, control system, feedback system, clear lines of communication were established and there were sufficient resources. The project succeeded but partly failed to take sufficient account of the used technologies and residents' behavior. Problems in the use phase were found but no measures were taken to obviate them.

***Table 4-20**: Mapping of failings associated with Vauban onto the components of the Formal System Model*

Formal System Model	Failure modes
Environment disturbs	Failure to: manage uncertainty in promoting residents to move to Vauban.
Wider system boundary	
Wider system	
Formulates initial design	
Provides resources and legitimates area of operation	
Legitimates area of operation	
Makes known expectations	
Communication channels	
System boundary	
Decision-making subsystem	
Decides on transformations	
Provides resources and legitimates operations	
Makes known expectations	
Report to	
Supplies performance information	
Attempts to influence environment	Failure to: control resistance to change residents' behavior in relation to use of sustainable heating system.

Data in Table 4-20 revealed the failure modes recognized in Vauban. The main problems are related to two points: (i) failure to understand the underlying HVAC technologies and to perform in the use phase, and (ii) failure to attract different residents' groups to Vauban.

***Table 4-21**: Discrepancies revealed by applying the project-specific Formal System Model in Vauban*

Main component	Discrepancy or comment
Goals and objectives	Vauban had ambitious objectives including: preventing water run-off and reuse rainwater, promoting knowledge transfer, minimizing impact from transport, reducing energy consumption up to 65kWh/m2/year, promoting social mix housing, and ensuring healthy indoor air. The latest two objectives were not fully met in the use phase.
Performance monitoring	There was a system of performance monitoring and feedback. Performance and progress delivered by the subcontractors were regularly monitored by the project management teams. Discrepancies were timely fed back to the Project Group Vauban.
Decision-makers	Several project managers took day-to-day decisions and reported to the management team. The management team was in charge of communication between City Council Freiburg Committee, Forum Vauban and the Project Group Vauban.
Transformations	The construction of Vauban was phased in and the subprojects were undertaken by many contractors and sub-contractors. The sub-contractors were mainly chosen according to their quality and part experience.
Communication	There was a clear communication plan between the project management team and City Council Freiburg Committee, Forum Vauban and the Project Group Vauban.
Environment	The project management team failed to take additional measures to avoid the side-effects of sustainable heating systems in dwellings leading to thermal discomfort.
Boundaries	There was clear definition of responsibilities of the project management team and the Project Group Vauban.
Resources	The City of Freiburg has bought the area for low price and has benefited from grants of the European LIFE program and the Federal Environmental Foundation that supported the project with € 42 million.
Continuity	It was clear that Vauban could not display continuity and the project could not make satisfactory recovery from environmental disturbances; e.g. thermal discomfort complaints are not solved yet.
Project champion	There were no individual project champions but a project team as project champion. But an exceptional role was of the City of Freiburg who initiated a strong environmental program and supplied the needed support.
Change agent	Forum Vauban is an association approved as official coordinator of citizens' participation by the City and was acting as a change agent for the project. The City Council Committee ensured trainings and workshops to promote the project objectives and the new environmental lifestyle.
Viewpoints	In Vauban different viewpoints were fully considered; including the residents.

Data in Table 4-21 revealed that the project had very effective planning, monitoring, control system, feedback system, clear lines of communication were established and there were sufficient resources. The project succeeded but failed partly to take sufficient account of the used technologies and residents' behavior. Problems in the use phase were found but no measures were taken to obviate them.

4.4 Discussion

The approach has been chosen for this phase was a case study. The choice of this research methodology was very useful to: (i) get broader insight into sustainable measures implemented in six European sustainable residential districts, (ii) evaluate how these measures turned out in the occupancy phase, and (iii) understand the interaction between measures and residents.

Suggested project success factors by Fortune and White [Figure 3-7] seemed to be, to a great extent, applicable for sustainable residential district projects. However, these factors were extracted for a general project as no specific project characteristics were required. As we suggested in this chapter, sustainable residential districts are successful when criteria of the Environment friendliness group are met. Therefore, success factors mentioned by Fortune and White are often too general and sometimes insufficient for our specific projects. Additional success factors are needed to explain the success on the Environment Criteria Group. The factors are extracted by comparing each measure implemented to meet a specific criterion and how that measure was turned out in the use phase.

Success factors related to energy efficiency

With exception of Vauban, all case studies have failed to achieve the energy reduction objectives at the district level. The differences between the theoretical objectives and the actually achieved consumptions verify between 10%-20%. There are three explanations for these differences. First, because of lack of knowledge and experience, theoretical calculations of energy consumptions were unrealistic such as in Eco-Viikki, Kronsberg and Bo01. This corresponds to results found be [Jang and Lee, 1998], [Turner, 2004] and [Cooke-Davies, 2003]. Second, resident's behavior regarding purchasing appliances and dealing with HVAC systems and windows still very difficult to be predicted Kronsberg and EVA-Lanxmeer. This corresponds to results found by [Gill et al., 2010]. And third, in some cases energy reduction objectives were very high and unrealistic.

In this study, the passive house approach was the most efficient way to build sustainable residential districts. Implementing not proven and not full-developed HVAC systems have had negative consequences in the use phase in terms of thermal comfort and health (in BedZED and EVA-Lanxmeer).

Success factors related to energy efficiency found here are: '*availability and implementation of past experience*', '*project has clear and realistic objectives*', '*implementation of proven technology*', 'time*ly and effectively involvement of end-user/client*' and '*technology acceptance by the residents*' and '*good matching between used technologies and residents' behavior*'.

Success factors related to water efficiency
Successfully achievement of water efficiency measures depends on the development scale due to high investments and technical complications (Bo01, Kronsberg and Vauban). In all case studies, excluding BedZED, those measures seemed to work properly.

Excluding gray water distribution network, water efficiency measures do not have direct relation with the residents. Based on this fact, these measures can be successfully implemented if only satisfying technical and financial requirements. Gray water distribution network, which has direct contact with residents, can for health and comfort concerns fail in the use phase.

Consumption of drink water is still very difficult to be predicted; it depends very strongly on the residents' behavior. Water saving measures including reduced flow taps and shower heads can strongly contribute to reducing water consumption. Teaching the residents how to deal with these drink water saving measures, however, seemed to have good effect on the reduction of water consumption (such as in Bo01 and BedZED).

Success factors related to water efficiency found here are: '*implementation of proven technology*', '*good matching implemented measures and project scale*', '*good matching between used technologies and residents' behavior*' and '*timely and effectively involvement of end-user/client*'.

Technology transfer
Knowledge transfer in sustainable residential districts is very essential. All investigated cases have succeeded in involving project stakeholders and residents in the project planning and realization. The knowledge transfer approach used in these cases consisted of two steps. First, knowledge transfer in inter-organizational networks. Knowledge was transferred within members of project team as in Kronsberg and Eco-Viikki. Project team members were organized in platforms to discuss the project planning and realization. Knowledge gained in the project by team member has been transferred to the other members. This result corresponds to finding by [Brensen and Marshall, 2000] and [Sexton et al., 2006]. And second, knowledge was transferred through the several subprojects. Large-scale projects were phased in and almost the same project team members were involved in the subprojects. This approach helped creating a positive atmosphere where project team members get to know each other, understand each other, trust each other and cooperate with each other.

Residents' involvement in projects had two forms. First, residents were involved in the design platforms as project participants (in EVA-Lanxmeer and Vauban). Residents could supply information about their needs and expectations, which can be usefully applied in the design phase. Residents who were interested to join the design platforms were mostly well-educated, environmentalists. This residents' profile did not match with the average actual residents in the use phase. Second, residents have been guided to use their new dwelling as in BedZED and to provide feedback on implemented technologies to improve next projects.

The first approach includes specific residents' profile in the design phase without considering its use for the dwellings, and the second approach includes the residents in the use phase without considering their needs and expectations. A better approach is to combine both approaches; residents' involvement in both the early phases (to provide information about what the need) well as in the use phase (to provide information how dwellings and technologies can be improved).

Success factors related to knowledge transfer found here are: '*having long term cooperation relationship among project team members*', '*large-scale projects are phased in*', '*timely and effective involvement of ser/client*' and '*technology acceptance by the residents*', '*good communication/feedback*', '*effective evaluating and monitoring of used technologies and measures*' and '*good matching between used technologies and residents' behavior*'.

Achieving social mix

Sustainable residential districts compose of innovative measures and technological solutions. These specific projects, which are generally more pricy, attract early adopters, well educated and high income residents. Results from the cases show that social mix housing is only possible with governmental subsidies. Governmental subsidies help low income to settle in such districts. However, this governmental mediation can cause some resident's dissatisfaction among residents.

Success factors related to social mix found here are: '*good communication/feedback*' and '*timely and effectively involvement of end-user/client*'. These factors can mitigate the dissatisfaction among the residents.

Efficient mobility

Measures to reduce the impact of transport and car use in sustainable residential districts have positively turned out in the use phase. Realization of daily facilities close to the district and good connection to public transport can considerably reduce car dependence. Replacing parking bays to the edges of the district provides car-free zones where children can play safely. However, strict limitation of parking bays can cause some resident's dissatisfaction. Measures that did not match resident's expectations seemed to allow residents to behave alternatively: (i) break the parking laws in the district, (ii) use parking bays in the surrounding area of the district, or (iii) later moved-in residents did not assign the legally binding agreement and may break the roles.

Success factors related to efficient mobility found here are: '*timely and effective involvement of end-users/client*', '*good matching between implemented measures and residents' expectations*', '*realization paths for pedestrian and cyclists*' and '*realization of car-free zones at the edges of the district*'.

Local sourcing policy

Measures for sustainable material sourcing include sourcing environmental friendly materials and locally sourcing materials and contractors. Our study showed that environmentally sourcing of building material has turned out properly in the use in the most cases. Quality, health and comfort considerations are essential to make the right choice. In that time, however, it was difficult to control the quality of the use materials. On the contrary, limitation of the sourcing area (sourcing of local material and local contractors) seemed to be a needless restriction. This restriction can be to the detriment of material quality and contractors' knowledge and experience.

Success factor related to local sourcing policy found here are: '*considering health and comfort when sourcing environmental friendly materials*' and '*material sourcing area is not restricted*'.

Health

Health objectives are mainly linked to thermal comfort and acoustic; there is unfortunately no direct link to the actual air quality. Measures to ensure healthy living environment include air tightness, use of passive light and improve air ventilation. Our study showed the health related measures were hard to be met in use phase; residents in the six cases complained that their HVAC systems were not performing properly in extreme weather conditions. In the six cases there were overheating problems complains about the indoor air quality. Although all cases suggested that the problems were partly to be solved using additional measures e.g. shading devices, these measures were not implemented. Technologies and measures to improve the performance of HVAC system should perform properly as a whole system as well as individual parts.

One success factor related to health is found: "*resident-related principals are considered in designing HVAC systems*".

BedZED

BedZED had very ambitious sustainability objectives; it was a forerunner. When the project was initiated, environmental friendly objectives to achieve fossil energy neutrality, to attract residents to purchase electric cars and to implement a green water treatment plant at scale of the site were unrealistic. Although BedZED had very effective planning, monitoring, control and feedback system and that clear lines of communication were established and there were sufficient resources. The project failed partly, however, to take sufficient account of the used technologies and past experience. The project budget was overrun and it failed to adapt new proven technologies instead of woodchips-fired CHP system. The main problems are related to three points: (i) implementing non-proven technologies to achieve ambitious project goals, (ii) failure to form teams that properly cooperate with each other (as result of the local sourcing policy), and (iii) failure to influence the project organization and the residents to adopt some needed changes. However, BedZED could achieve other important objectives including reducing energy consumption, reducing water consumption and being one of the best practice projects in Europe.

Bo-01

Bo-01 had realistic sustainability objectives. Bo-01 had very effective planning, monitoring, control system, feedback system, clear lines of communication were established and there were sufficient resources. The project failed partly, however, to take sufficient account of the used technologies and past experience. Problems in the use phase were found but no measures were taken to obviate them. The main problems are related to two points: (i) theoretical calculations of energy consumptions and the practical results differed in some cases widely due to lack of knowledge, and (ii) failure to adopt new measures to obviate overheating complains in the use phase. Bo-01 provided the Swedish and the European construction industry valuable knowledge and experience about realizing sustainable residential districts. Knowledge was used to successfully realizing other projects in Sweden.

EVA-Lanxmeer

EVA-Lanxmeer is a good example of residents' participation. Residents, with environment information background, have initiated the EVA-Foundation and started communicating to initiate the project. EVA-Lanxmeer had very effective planning, monitoring, control system, feedback system, clear lines of communication were established and there were sufficient resources. The project failed partly, however, to take sufficient account of the used technologies and residents' behavior. Problems in the use phase were found but no measures were taken to obviate them. The main problems are related to two points: (i) theoretical calculations of energy consumptions and the practical results differed in some cases widely due to lack of knowledge and residents' influence, and (ii) failure to adopt new measures to obviate thermal discomfort in the use phase.

Eco-Viikki

Eco-Viikki had, just like Bo-01, realistic environmental project objectives. The project had effective planning, monitoring, control system, feedback system, clear lines of communication were established and there were sufficient resources. However, the project failed partly, however, to take sufficient account of the used technologies and residents' behavior. Problems in the use phase were found but no measures were taken to obviate them. The main problems in Eco-Viikki are related to two points: (i) residents' viewpoints were not fully considered in the design phase resulting in improper use of technologies and sustainable measures, and lack of knowledge about actual performance of HVAC system in the use phase. Eco-Viikki was the first Finish project widely dealt with several aspects of the environment. Eco-Viikki became one of the best practice projects in Europe and provided valuable knowledge and experience for the Finish construction industry.

Kronsberg

Kronsberg is a good example of large scale sustainable residential district projects have to be organized. Kronsberg had very effective planning, monitoring, control system, feedback system, clear lines of communication were established and there were sufficient resources. The project succeeded to closely meet the theoretical project objectives. However, Kronsberg was partly failed to take sufficient account of the used technologies and residents' behavior. Problems in the use phase were found but no measures were taken to obviate them. The main problems are related to: (i) lack of knowledge about residents' behavior resulting devious energy consumption, and (ii) failure to adopt new measures to obviate thermal discomfort in the use phase.

Vauban

Vauban could be considered as the best performing case in this study. Problems were mentioned in relation to two points: (i) failure to understand the underlying HVAC technologies and to perform in the use phase, and (ii) failure to attract different residents' groups to Vauban. However, the project results were very close to the theoretical project objectives. Vauban had very effective planning, monitoring, control system, feedback system, clear lines of communication were established and there were sufficient resources. The project succeeded but failed partly to take sufficient account of the used technologies and residents' behavior. Problems in the use phase were found but no measures were taken to obviate them.

Summary

The six cases could, to different extent, meet their theoretical objective. All cases paid good attention to have effective planning, timely monitoring of the results, having control systems, having feedback systems, communicating through clear lines. Sufficient resources were provided for the project. However, knowledge about residents' needs, expectations and behaviors was lack. As result, cases (partly) failed to ensure entirely good performance in relation to energy consumption, thermal conditions and indoor air quality.

4.5 Conclusion

Success criteria

The Golden Triangle criteria are not sufficient to ensure success in sustainable residential district projects. These projects have very special focus on reducing the environmental impact, increase knowledge transfer and improve health conditions. Evaluating project success of these projects requires emphasizing success criteria in the operational phase, namely: Health, Technology Transfer and the Environment friendliness criteria including Efficient use of energy, Efficient use of water, Efficient mobility, Sourcing policy and Achieving social mix.

Success factors related to the project organization

Sustainable residential districts are quite complicated construction projects. Project success could be partly explained by factors suggested by Fortune and White. Additional factors based on sustainability aspects are needed to fully understanding project success in these projects.

Environment-related project objectives should be realistically formulated based on available knowledge and experience among the project team members. Project team members should then be chosen according to their knowledge and skills regarding sustainability issues. Good project leadership and support from local government and project management is essential.

Knowledge transfer is essential for success in sustainable residential districts. Initiating project platforms, where project team members and residents can learn and exchange their knowledge and experience, is a success factor. Large scale projects have to be phased in; project stakeholders have to work in the same team in the several subprojects.

Full-developed and proven sustainable heating and hot water systems at the district level seemed to be reliable and deliver sufficient thermal comfort. Individual energy demands which depend on residents' demographic and household variables could be leveled off in an efficient way. Innovative and test-technologies seemed to turn out negatively in the use phase and caused dissatisfaction among the residents. HVAC systems that do not match residents' behavior and do not meet their expectations and needs allow residents to use the systems in different (and often not sustainable) way.

Sustainable residential districts require high qualitative products and suppliers/contractors who deliver high performance. Any inessential restriction on sourcing policies can turn out negatively in use phase. Quality, health and comfort should be considered when sourcing materials.

Strictly and forcedly parking policy can turn out negatively in the use phase. In general, strict parking policy does not match residents' behavior. This can lead to alternative behaviors such as breaking parking rules.

Residents-related success factors
Timely and effective involvement of residents in the design as well as the realization phase of the project seemed to be the most important factor for project success. In the early phases of the project, residents are essential to ensure good input for project design. Project outputs should meet residents' expectations, needs and behavior. In the use phase, residents are essential to ensure that the project performs as it should do.

Energy related objectives are very dependent on residents' behavior. Understanding residents' behavior and designing HVAC systems according to that will improve performance of HVAC systems.

Concluded, in addition to success factors mentioned by Fortune and White, the following success factors are essential for success for sustainable residential district projects:

- Good matching between used technologies and residents' behavior and needs.
- Technologies are accepted by the residents.
- Implementation of sustainable measures on the district-level to level-off individual peaks.

- Project parties and residents are simulated, instead of forced, to work and behave in a sustainable way.
- Health and comfort are considered for sourcing materials instead of restricting the sourcing area.
- Creating a learning curve by realizing large-scale projects in phases.
- Having long term cooperation relationship among project team members.

The suggested model could explain project success/failure and could confirm the relevance of the extracted factors. However, sustainable residential district projects are multi-goal projects and are too complicated. Projects may successfully meet some projects objectives but may also fail to meet the other objectives. So it is very difficult to concretely say that a project fully succeeded or fully failed. The model, therefore, could be successfully applied to meet success/failure at one success criterion.

Residents of sustainable residential districts are THE KEY FACTOR for project success. Their needs, expectations and behaviors seem to have strong influence on actual project performance. Although many researchers reached the same conclusion, there are little studies that try to understand and explain residents' needs, expectations and behavior. Especially, to understand residents' behavior toward sustainable heating and hot water systems is not studied yet. In the next section, this topic will be reviewed, investigated and discussed.

5. Analysis of residents' influence

5.1 Introduction

In the previous Chapter, we presented project success criteria and factors for sustainable residential district projects. Environment-related criteria (including sources efficiency, mobility efficiency, health and technology transfer) were found as very important to assess success in sustainable residential district projects. It also presented new factors that can support achieving these success criteria. Project factors related to residents were found as very important to achieve project criteria related to energy efficiency, parking, health and technology transfer. These factors are: (i) matching technologies' properties and residents' aspects, (ii) effective evaluating and monitoring of used technologies and measures, and (iii) timely and effectively involving of residents. We found also that residents of sustainable residential districts can strongly affect the performance of sustainable dwellings. However, knowledge on this topic is insufficient [Vale & Vale, 2010].

In this chapter we will discuss the role of residents of sustainable residential districts in achieving energy efficiency goals from a psychological point of view. This chapter will give answers on the third and forth research questions:

Research question 3*: How can technical specifications implemented in dwellings influence residents' behavior in sustainable residential district projects?*

Research question 4*: How can residents-related factors influence the performance of sustainable residential district projects?*

To answer these two questions, residents' role and interaction with technologies will be discussed, a framework will be introduced, hypotheses will be formulated and then a questionnaire will be constructed. Data collection and analysis will be extensively discussed and conclusions will be drawn.

5.2 Residents' role

The construction industry is an important player in the transition process to sustainability [ECTP, 2005]. The construction industry has responded to this process by realizing sustainable dwellings in which sustainable heating, ventilation and air-conditioning systems (HVAC) were implemented. The implementation of sustainable HVAC systems aimed at meeting building regulations in an energy efficient way. However, energy efficiency objectives may not match with the increasing thermal comfort preferences by the residents [Nicol, 2002].

In the transition path to a more sustainable built environment, energy efficiency roadmaps have been introduced. In the Netherlands, an energy efficiency roadmap was introduced by ECN and TNO [Building Future, 2004]. The energy efficiency roadmap presented to what extent energy reduction should be achieved in the years 2010, 2020, 2030 and 2050 (Table 5-1).

Table 5-1*: Energy reduction roadmap in dwellings*

Energy consumption in dwellings	Percentage of energy reduction			
	2010	2020	2030	2050
Energy consumed by HVAC system and for essential lighting	10%	35%	65%	90%
Energy consumed by other domestic appliances	10%	20%	30%	60%

Energy consumption in dwellings (in the Netherlands) is divided in two categories:

1. On average 78% energy consumption by HVAC systems and for essential lighting, including:
    - 55% for space heating and space cooling,
    - 20% for hot water, and
    - 3% for lighting,
2. On average 22% energy consumption for other domestic appliances.

Although a reasonable percentage of this consumption could be reduced by insulating dwellings and using energy efficient HVAC systems, residents may influence the actual performance of sustainable dwelling in the way they interact with the implemented HVAC systems and the way they use lighting and domestic appliances [Stevenson & Leaman, 2010]. A study done by Gill, Tierney, Pegg and Allan (2010) concluded that residents' behavior had a significant impact on heating and electrical energy consumptions in low-energy dwellings. Their results indicated that energy-efficiency behaviors account for 51%, 37%, and 11% of the variance in heat, electricity, and water consumption, respectively.

In sum, the ways residents use their HVAC and other domestic systems are very relevant for determining the actual performance of sustainable HVAC systems and consequently the performance of sustainable dwellings. This indicates the importance of residents in achieving the energy reduction objectives. In the next section, studies are reviewed that explain how residents and technologies interact with respect to the conservation of natural resources.

5.3 Residents' interaction with technology: state of the art

The environmental impact of humans, in this research individual residents as well as households, is roughly dependent on the number of residents, their affluence, and the technology they currently use [Ehrlich & Ehrlich, 1991]. Technology as related to environmental resources use is scarcely mentioned in the field of human behavior and resource conservations. In this section, the interaction between residents and technology in sustainable residential dwellings is discussed.

Midden, Kaiser and McCalley (2007) reviewed studies that dealt with this subject and presented four ways in which humans and technology interact with respect to the conservation of natural resources. In particular, they focused on the roles that technology can play in shaping human behavior and its outcomes. The authors distinguished the following four roles:

- Technology as an intermediary,
- Technology as an amplifier,
- Technology as a determinant, and
- Technology as a promoter.

Technology as an intermediary

Technology, as an intermediary, stands between the behavior carried out by a resident to achieve a certain goal and the use of natural resources on the way to that goal. Residents need technology everywhere and all the time; they are completely dependent on it. In terms of daily life, residents need technology for hot water to take a shower, to keep their house warm, to cook, to have light, to communicate with other people etc. Technology is needed, thus, to fulfill residents' needs.

The choice of technology used to fulfill these needs determines energy use and residents' daily ecological footprint. The technology's role as intermediary has an influence, thus, on the behavior pattern of a person and its ecological outcomes.

Although residents are free in deciding what domestic appliances to purchase, they have, in general, little influence on the decision which HVAC systems (technologies) will be implemented in their dwellings. Usually a project team will decide what sustainable HVAC systems should be implemented to meet energy and environment-related building codes. However, considerations related to these decisions made by the project team may not match with those of the residents [Stevenson & Leaman, 2010].

The second issue is the affluence of residents. Increasing wealth in the last decades did not result in a higher level of general subjective well-being, including life satisfaction, contentment and hedonic experience, but resulted in a significantly rising of consumption levels [Vlek & Steg, 2007]. Wealth changed residents' consumption levels from meeting basic needs into satisfying any luxury fever, for example, luxury kitchen appliances, whirlpool baths, tanning beds, Jacuzzi's, large TV screens, mobile phones, etc.

Residents who prefer a pro-environmental lifestyle are free to set their environmental goals and free to choose the way to achieve those goals. Residents who decided to set pro-environmental goals may achieve their goals not by saving energy but, for example, by having a car-free lifestyle. Similar results were found by an early study done by Gatersleben, Steg and Vlek (2007) about measurement and determinants of environmentally significant consumer behavior. They found that respondents who consider themselves as pro-environmental did not necessarily use less energy. They found also that behavior was more strongly related to attitudinal variables, whereas household energy use was primarily related to variables such as income and household size.

In sum, the intermediary role explains how technologies are used to meet user's basic needs. Residents have beliefs and attitudes about the technologies they use and their outputs. These beliefs may, however, be quite ambiguous. In the case of sustainable HVAC systems, ambiguity may be substantial, because residents do not choose their own HVAC systems and they are mostly not familiar with the implemented innovative systems. HVAC system are implemented to meet residents basic needs of space heating, air conditioning, ventilation and supply hot water. Residents' beliefs about the impact of HVAC systems, however, may be different.

Technology as an amplifier

Technology's role as an amplifier links residents' behavior to the efficiency of the use of natural resources. As the intermediary role, the amplifier's role explains the use of technologies to fulfill primary needs but because of the increasing efficiency of technologies, residents develop, as a side effect, new behaviors, which are more resource-consumptive. This behavior is known as 'the rebound effect.

The rebound effect and its influence on the energy consumption was studied extensively by [Greening et al, 2000] and [Freire-Gonzáleza, 2011]. They suggested two important types of rebound effects; the direct and the indirect rebound effect. The direct rebound occurs when an improvement in energy efficiency for a particular energy technology reduces the effective cost of the technology, which subsequently leads to increased consumption. This can partly or fully offset the expected reduction in energy consumption [Khazzoom, 1980].

For example, residents who expect to have an energy saving boiler may develop new behavior to take a longer shower resulting in more resource consumption.

The indirect rebound effect occurs when the reduction of the effective cost of an energy technology leads to changes in demands of other goods and services that also require energy for their provision [Freire-Gonzáleza, 2011]. For example, residents who expect to save on electricity consumption because they have low-energy light bulbs may develop new behavior to leave their PC on stand-by resulting in more electricity consumption and consequently less cost savings.

The direct rebound effect is more relevant for the present study. In general, the direct rebound effect may offset up to 30% of energy efficiency in household energy use in the industrialized countries and more than 30% for non-industrialized countries [Sorrell et al., 2009].

Another issue is that technology may be improved to increase a specific efficiency-attribute. However, this attribute may not match with residents' needs. Sustainable HVAC systems are improved to increase energy efficiency and to decrease environmental impact. These improvements could, conversely, mismatch with residents preferences for thermal comfort and for having longer showers. Successful sustainable technology should, thus, consider environmental attributes as well as residents' demands [Pitt et al., 2009].

In sum, technology is used to fulfill users' primary needs in an amplified way, which however may also amplify their use of resources. The rebound effect suggests that more efficient technology may primarily serve users' basic needs instead of lowering resource use. However, it is very complicated to define the bounds where the primary needs stops. Technology as an amplifier has a strong influence on users' attitudes. Technologies that do not meet users' needs and expectations may form negative attitudes toward technology's use. In the case of sustainable dwellings, HVAC systems have to effectively meet residents' needs in relation to space heating, air conditioning, ventilation and supply of hot water. Contemporary HVAC systems have also, as residents believe, to amplify their basic output in such a way to ensure an acceptable level of thermal comfort (space heating and hot water). This role of technology foresees that HVAC systems that cannot ensure thermal comfort, to an acceptable level, will fail meeting residents' expectations and form negative attitudes toward use of the systems.

Technology as a determinant

Technology, as a determinant, can directly influence residents' environmental behavior. Technology can affect residents' behavior in two distinct ways. Technology can, first, instantaneously shape behavior by arousing expectations without requiring any recognition or awareness of the opportunities or obstructions on the resident's side. For example, residents will expect, because of the high reliability of the electricity generation system and the distribution grid, to have light whenever they turn the switch on.

Second, the availability of a technology will affect motivationally the residents' readiness to adopt a certain technology and to act in a certain way by offering tempting opportunities or daunting obstacles. The availability of a jet shower in a dwelling, for example, may make its use more likely, while the absence of it will obstruct the use of it. At the same time, the comfort of a modern jet shower that is considered as water and energy consuming device, can tempt residents to have longer showers. Technology can determine the relative likelihood of engagement, regardless of residents' motivation to act.

Some of new technologies are designed to simplify the way in which residents have to use them by introducing full-automatic operating technologies. This improvement was studied by Sarah Darby (2007) on the role of Advanced Metering Infrastructure (AMI) in energy management and reduction. She pointed out that "taking control away from the customer cannot be relied upon to improve the situation: it may actually entrench and legitimize high-demand practices, disengaging customers from any need to consider and question them". She found that there is little evidence to suggest that AMI will automatically achieve a significant reduction in energy demand. She concluded that there has to be a determined focus on overall demand reduction, on designing customer interfaces for ease of understanding, and on guiding occupants towards appropriate action. She concluded also that there is need to develop effective forms of interface, feedback, and support to reach more diverse residents' profiles and to reduce actual consumption.

In sum, technology as determinant can determine how users will interact with their technologies: (i) first by arousing expectations in relation to some technology output, and (ii) second by whether or not a technology is availability and can be used. In the case of sustainable dwellings, the availability of sufficient hot water supply, delivered by HVAC systems can determine the relative likelihood of engagement, regardless of residents' motivation to use the system. When hot water supply is insufficient (i.e. the technology cannot meet residents' expectations), the HVAC system is determining residents' use of the system and may force them to develop new way of use.

Technology as a promoter

Technology, as a promoter, can be used to motivate residents to improve their conservation behaviors by providing them useful information about the energy consumption and by influencing interactions between users and technologies. Feedback on technology use and resources conservations can be given in several forms including written information, computer based-information, and energy monitoring systems.

During the last two decades electronic feedback devices, in this case home energy monitors, have replaced and overcome the traditional ones and the written information media. Energy monitors, which are centrally located in dwellings and have better accessibility for the residents, can provide instantly information about the energy consumption and help residents to take actions immediately. Energy monitors can, in contrast to written information, provide frequent and more detailed information about energy consumption and related-costs and present them graphically. Information could be on the individual as well as on the household level.

The use of technology as promoter can help residents to reduce their energy consumption. This was confirmed by results found by Ueno, Inada, Saeki, Tsuji and Kiichiro (2006). The authors found that the total power-consumption decreased by 18%, the total city-gas consumption decreased by 9% and the energy demand for space heating was decreased by 20% after installing an on-line energy consumption information system. However, these energy savings may be temporary as shown in another study where residents could not sustain the initial savings in electricity consumption of 7.8% after months [van Dam et al., 2010].

The relation between information and effective action was studied by Ajzen, Joyce, Sheikh and Cote (2011). They studied the influence of being well-informed about the environment on the effective action to produce desired pro-environmental outcomes. The study revealed that knowledge about the environment was virtually unrelated to general attitudes regarding the environment. Consequently, it also had no effect on intentions to engage in such behaviors or on reported actions of an environmentally friendly nature.

In sum, technology as a promoter can help users to gain clear understanding of their impact on the conservations natural resources. However, the type of given information, the way information is presented and the frequency in which information is given are very important to have effective feedback that can affect users interaction with technology. In the case of sustainable dwellings, giving timely and effectively designed feedback can persuade residents to reduce their energy consumption.

Users in the case of sustainable dwellings could be individuals as well as households having some common demographic aspects but also some different ones [Gatersleben et al., 2002]. It is, therefore, relevant to investigate the influence of individual users as well as household on technology use and energy saving [van Dam et al., 2010]. A study done by Abrahamse and Steg on the variables that can influence energy saving and energy use revealed that energy use is determined by socio-demographic variables whereas changes in energy use appear to be related to psychological variables as energy saving requires awareness and cognitive effort [Abrahamse & Steg, 2009]. Poortinga, Steg and Vlek (2004) concluded, in their study on values, environmental concern and behavior toward household energy use that a purely attitudinal motivational model to explain environmental behavior might be too limited. They concluded that contextual factors, such as individual opportunities and abilities, can influence environmental behavior.

Improving sustainable HVAC systems is insufficient without the cooperation of residents. Residents' behavior can offset any hypothetical energy savings by wrongly using the system or by installing inefficient lighting. Residents can reject even the most economically viable, simple and well-understood domestic energy-efficiency interventions if they do not match with their lifestyle [Crosbie & Baker, 2009].

Summary
Sustainable HVAC systems are technologies used in dwellings to fulfill user's basic needs in an energy efficient way (an *intermediary* role). Generally speaking, residents will not be familiar with sustainable HVAC systems. This lack of knowledge will make it very complicated to understand the impact of their interaction on the output of these technologies in terms of environmental impact, energy costs or thermal comfort. Sustainable HVAC systems are promoted as being energy efficient and having low environmental impact. Sustainable HVAC systems, however, may play an *amplifier* role in the interaction with residents by increasing residents' expectations on energy savings and thermal comfort. Residents' attitude toward the use of HVAC system will be negatively affected when HVAC systems fail to satisfy residents' expectations, The actual performance of sustainable HVAC systems can *determine* the relative likelihood of residents' engagement in a specific behavior. When hot water supply is insufficient (i.e. the technology cannot meet residents' expectations), the HVAC system is *determining* residents' use of the system and may force them to develop new ways of use. HVAC systems can *promote* residents to use the system in a proper way by giving timely and effective feedback on their interaction with technologies. Three factors can influence this feedback: type of information (e.g. written vs. digital), accessibility of the feedback, the frequency of giving feedback and the information source (e.g. media, HVAC companies or social referents).

This section revealed the essence of understanding how residents act in their technological environment and what motivate them to behave in a pro-environmental way. This section revealed also the need to: (i) understand residents' needs, expectations and attitudes toward sustainable HVAC systems, (ii) understand residents' perceptions of their ability to perform pro-environmental behaviors, (iii) understand which communication and information channels and interventions are effective to motivate residents complying pre-environmental behaviors, and (iv) understand which demographical and contextual factors can influence their behavior. In the field of environmental behavior, the theory of planned behavior is a well-known and widely applied theory to explain and measure users' behaviors. The theory and its application are discussed in the following section.

5.4 Theory of Planned Behavior

The theory of planned behavior (TpB) is an extension of the Theory of Reason Action (TRA) that was proposed by Icek Ajzen and Martin Fishbein [Fishbein and Ajzen, 1975]. TpB is a widely applied expectancy-value model of attitude-behavior relationships, which has met with some degree of success in predicting a variety of behaviors (Connor and Armitage, 1998).

The TpB supposed that behavior results from the intention to engage in a specific behavior [Fishbein and Ajzen, 2010]. Behavioral intentions are assumed to "…capture the motivational factors that influence a behavior, they are indicators of how hard people are willing to try, of how much effort they are planning to exert, in order to perform the behavior…" (Figure 5-1).

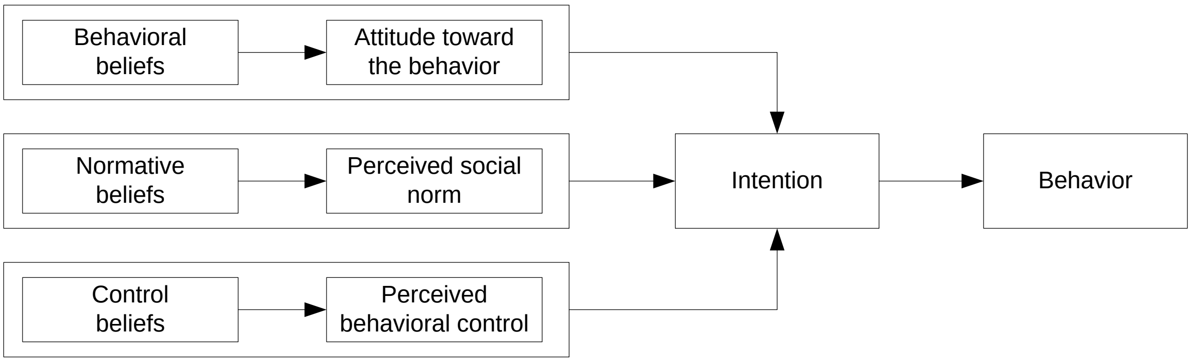


Figure 5-1: *Schematic presentation of the Theory of Planned Behavior [Fishbein and Ajzen, 2010]*

An attitude is defined as "a latent disposition or tendency to respond with some degree of favorableness or unfavorableness t a psychological object". Attitudes reflect the personal overall evaluation of engaging in the behavior, and are based on beliefs about the expected costs and benefits of behavior. Beliefs have two components; these are the strength of the belief and the evaluation of the included consequence of the behavior.

The subjective norm is defined as "an individual's perception that most people who are important to hem/her think he/she should (or not) perform a particular behavior". It indicates the perceived social pressure to engage the behavior and is based on beliefs about the expectations of relevant reference groups concerning the behavior.

Perceived behavioral control is defined as: "the extent to which people believe that they are capable of performing a given behavior that is having control over its performance. Perceived behavioral control is assumed to take into account the availability of information, skills, opportunities, and other resources required to perform the behavior as well as possible barriers or obstacles that may have to be overcome". Perceived behavioral control refers, thus, to the perceived possibility to perform the behavior, which is dependent on control beliefs about the presence of factors that may facilitate or hinder their behavior. Add two components

The TPB is a validated and widely researched behavioral model. It has been used to explain a wide spectrum of behaviors, such as environmentally relevant behaviors [Ajzen et al., 2011], energy consumption [Gill et al., 2010], the use of unbleached paper [Harland et al., 1999[, car use [Bamberg and Schmidt, 2003] and bus use for commuting [Heath & Gifford, 2002].

As we discussed in Section 5.3, sustainable HVAC systems play four roles in the interaction with residents. Sustainable HVAC systems can affect residents' beliefs and attitudes in relation to the outputs of the system (including thermal output and environmental impact). Specification and characteristics of sustainable HVAC systems can also affect how residents will use the system and consequently how they will influence its actual performance. Information about sustainable HVAC systems may promote proper use of technologies if effective communication channels are used forming social influence on residents. Also information about the consequences of residents' interaction is useful if timely and effective communicated with the residents. In the following section, the research statement and the research hypotheses are introduced based on the theory of planned behavior and the technology's roles as discussed in Section 5.3.

5.5 Research statement and hypotheses

The heat pump, as part of a ground-source heat pump system, is widely implemented in the Netherlands for space heating, space cooling and supplying hot water. According to the most recent publications, the number of the implemented systems will increase from 2400 in 2010 to 20.000 systems in 2020 [Sint Nicolaas, 2011]. Theoretically, geothermal heat pump systems can be considered as low environmental impact systems that can help in both CO_2 reduction as well as in energy efficiency [Kleefkens, 2011]. HVAC companies promote heat pump systems as potential solutions in the future. Heat pump systems differ from traditional heating systems in the way they operate and how residents have to use them. Technical companies advise residents to use the heating system automatically to avoid high electricity bills. Operating the heat pump automatically means having consistent set-point temperature and not using the BOOST option. With the boost option, residents can accelerate the system response for space heating or for hot water supply.

The performance of the system depends on a number of factors including the physical conditions of the ground water, design considerations, the size of the system, the size of the household and energy demand for space heating and hot water [Guerra-Santin & Itard, 2011]. Although, heat pump systems are gaining a larger market share, the number of projects that do not perform properly is increasing [Sint Nicolas, 2011].

Hypotheses

Heat pump systems are promoted to ensure optimal thermal indoor conditions in dwellings in a sustainable and energy efficient way. In other words, the heat pump system has to ensure space heating, space cooling, and hot water supply consuming low electricity and producing low CO_2-emissions. Residents can use the heat pump system, just like other technologies, in different ways. The output of the heat pump will have a strong influence on attitude formation and consequently the intention to use the system. The theory of planned behavior suggests, however, that the behavioral intentions are determined by personal attitudes, social norms and perceived behavioral control.

H01. Attitude, social norm and perceived behavioral control predict residents' intention toward operating the heat pump system automatically.

Personal attitudes are based on beliefs about the consequence of system use. With regard to HVAC systems we expect that beliefs about the effects on thermal comfort are a prime motivation for using the system. Beliefs related to the thermal output are strongly related to primary physiological needs that are considered as the literal requirements for human survival [Maslow, 1943]. Secondly we expect other factors to play a role in user's attitudes, such as expected financial costs and environmental impact.

> H02. Behavioral beliefs related to the output of the heat pump system are relevant to form residents' attitudes toward the heat pump system.

Residents could be motivated or daunted in several ways by perceived normative expectations of several actors in their surroundings. Advices, viewpoints and instructions provided by the technical company and pre-environment campaigns in the media will have a strong influence on residents' intention to operate the heat pump properly. We expect also that, based on social interactions, neighbors and family will play an important role in forming the perceived social norm.

> H03. Social referents will influence residents' intention toward operating the heat pump system automatically

The heat pump system can operate full-automatically. Residents can at first regulate the set-point temperature of the living room and choose ECO or COMFORT. The system will, then, ensure space heating, space cooling and for hot water supply. However, the capacity of the system and technological limitations may support or impede residents in operating the system automatically.

> H04. The capacity of the system for hot water supply can support/impede residents' perceived behavioral control toward operating the heat pump system automatically.

Residents differ in their demographical and contextual aspects. These differences result in different residents' profiles having different needs and beliefs in relation to hot water supply [Poortinga, 2004]. Especially household's size can strongly influence residents' intention to use the heat pump system.

> H05. The size of the household will influence residents' behavioral intentions toward operating the heat pump system automatically.

Residents differ in their preferences in relation to thermal comfort as they differ in their physiological conditions and adaptations [Yao et al., 2009]. Residents with different preferences for thermal comfort will, thus, evaluate the performance of the heat pump differently.

> H06. Residents with different thermal preferences will evaluate the performance of the heat pump system differently.

Highly educated, young and socially oriented residents are more accessible to adopt new technologies and are more flexible to accept their limitations. This residents' group is defined by [Rogers, 2003] as early adopters of technologies. We expect that this group will evaluate the heat pump system most positively.

> H07. Highly educated residents will evaluate the performance of the heat pump system more positive than the other residents' profiles.

Installation companies, which provide sustainable HVAC systems, try to stimulate residents to change their lifestyle in a sustainable and energy saving lifestyle. Installation companies provide the residents with information about the heat pump system. Written or oral information intends to shift residents' knowledge-level about the heat pump system and how it can be used in a proper way. However, our model predicts that knowledge about the heat pump system may improve residents' knowledge about the system but will have no direct influence on their behavioral intention [Ajzen et al., 2011].

> H08. Knowledge about the heat pump system will not have any direct influence on the behavioral intention toward operating the heat pump system automatically.

Residents who believe that the heat pump system cannot meet their needs and expectations in relation to thermal comfort may show alternative behaviors. Alternative behaviors however, may decrease the efficiency of the heat pump system.

> H09. Residents will deviate from the automatically operating of the heat pump system if the system doesn't meet their needs resulting in lower energy efficiency.

And finally, the acceptance of the heat pump system among the residents will be influenced by their positive/negative experiences with the system. We expect the residents who negatively experienced the heat pump system will not prefer to use it in the future if they move to other dwelling.

> H10. Positive experience about the heat pump system will positively influence its acceptance among the residents.

5.6 Research method

The theory of planned behavior was applied to explain residents' behavior toward automatically operating of the heat pump system for space heating, space cooling and supply hot water. Data were collected by interviews held with the residents of project 'De Caaien' using closed-ended questionnaire. The choice of the case, the design of the questionnaire and how data were analyzed are described hereafter.

5.6.1 Case description

The study was carried out on households in a Dutch sustainable residential district 'De Caaien' in the area of 'Ypenburg' in the city of The Hague in the Netherlands. The case is extensively described in Appendix 3. The following criteria were considered to select 'De Caaien':

- a heat pump system is implemented for space heating, space cooling and hot water,
- high sustainability ambitions of the project organization,
- residents have used the system for some time, and
- the accessibility to the project data and to the residents.

The HVAC concept used in 'De Caaien' consists of [Dura Vermeer, 2008]:

- a ground source a heat pump in combination with heat exchangers,
- a 150-liter storage tank for hot water in combination with electrical heating element,
- floor low-temperature distribution heating system,
- a CO_2-demand automatic-control ventilation system in combination with pressure sensitive background ventilators, and
- thermostat that enable residents:
    - to regulate the room temperature to a desired set-point,
    - to use the 'BOOST' option to accelerate space heating and water heating,
    - to choose ECO-stand for preparing hot water only off-peak hours or Comfort-stand for preparing hot water all the day.

5.6.2 Pilot research

For the purpose of this study, a questionnaire was constructed. The construction of the questionnaire was based on a formal questionnaire and instruction suggested by the theory of planned behavior [Fishbein & Ajzen, 2010]. The formal questionnaire and the instructions have been listed in Appendix 4. A pilot research was performed using interviews with residents of De Caaien. The aim of the pilot research was to elicit readily accessible residents' behavioral beliefs, normative referents, and control factors for automatically operating of the heat pump. Eleven residents were interviewed in February 2011. Interviews were based on instructions as recommended by Ajzen and Fishbein. Interviews were held individually in a free response format to ensure that residents do not influence each other and to have reliable response. A content analysis of the interviews elicited elements of Attitude, Social Norm and Perceived Behavioral Control.

Residents' attitudes were assessed using six semantic differential evaluative scales in response to the following item: "For me, automatically operating of the heat pump system is" [Osgood et al, 1957]. The six semantic differential scales contained the following six adjective pairs:

1. Bad/ Good,
2. Ineffective/ Effective,
3. Unpractical/ Practical,
4. Useless/ Useful,

5. Unnecessary/ Necessary, and
6. Unpleasant/ Pleasant

Five behavioral beliefs were elicited:

1. Environment Protection,
2. Cost saving in house,
3. Space Heating,
4. Space Cooling, and
5. Having enough Hot Water.

Resident's Social Norms were collected using the following items:

1. People who are important to me want me to operate the Heat pump system automatically,
2. It is expected of me that I operate the heat pump system automatically, and
3. I feel under social pressure to operate the heat pump system automatically.

For practical considerations, the three items of social norm were respectively abbreviated as: (Important Referents), (People's Expectation) and (Society Pressure). Four normative beliefs were elicited:

1. The technical company or the Technical Specialist,
2. Neighbors,
3. Family, and
4. Environmental Groups.

Resident's behavioral perceived control was assessed using the following items:

1. I am confident that I could operate the heat pump system automatically if I wanted,
2. The decision to automatically operating the heat pump system is beyond my control,
3. For me automatically operating the heat pump system is easy,
4. Weather I automatically operating the heat pump system or not is entirely up to me,

For practical considerations the four items of perceived behavioral control were respectively abbreviated as follow: (Want to Use), (Decision to Use), (Ease of Use), (Independence to Use). Six control beliefs were elicited:

1. Capacity of the heat pump system in relation to supply hot water,
2. Capacity of the heat pump system in relation to space heating,
3. Capacity of the heat pump system in relation to space cooling,
4. Adjustment of the flow in the embedded floor heating,
5. Maintenance of the heat pump system,
6. Response of the heat pump system to residents' interventions

Resident's intentions were collected using the following items:

1. I intend to operate the heat pump system automatically ,
2. I expect to operate the heat pump system automatically , and
3. I will operate the heat pump system automatically.

For practical considerations, the three items of intention were respectively abbreviated as: (Intend to Use), (Expect to Use) and (Will to Use).

All residents' responses on intention, attitude, social norm and perceived behavioral control were collected using seven-point scale. In general, it is an ordinal scale as no relative size or degree of difference between the items measured. In the field of psychology studies, the scale is commonly used as interval scale [Fishbein & Ajzen, 2010]. In this study, used scale was indicated using numbers and empirical observations as mentioned in example below:

1-Extremely unlikely	2-Quite unlikely	3-Slightly unlikely	4-Neutral	5-Slightly likely	6-Quite likely	7-Extremely likely

Based on this argument, the scale is considered as interval scale. The choice of 7 point scale was aimed to generate more deviation in the response and to minimize the effect of accidentally response.

Additional questions were included to the questionnaire to enrich the insight about residents' characteristics and their use of the heat pump system. These questions dealt with:

- self-reported past behavior (SR-PB) including:
  - the frequency residents did operate heat pump system automatically,
  - the frequency residents used the boost-option for space heating, and
  - the frequency residents used the boost-option for hot water supply.
- demographic characteristics such as age, gender, size of household, type of ownership, appliances in the dwelling and level of education,
- electricity meter readings at the time of the interview,
- the frequency residents did leave the ventilation openings open,
- residents preferences regarding room temperatures and choice of the dwelling,
- residents' acceptance of the heat pump system, and
- multiple choice questions to evaluate residents' knowledge regarding the heat pump system.

Details of the questionnaire are given in Appendix 5.

5.6.3 Data collection

On the first of March 2011, all households of the 'De Caaien' received an announcement letter explaining the goal of the research and the organization of the interviews. Two weeks later, data collection was started using face-to-face interviews.

The 'De Caaien' consists of 290 dwellings where 194 already delivered, occupied and researchable; the other 96 were not delivered yet. In total, 135 interviews were fully completed. The sample can be described as follow:

- type of property: 80 (59.3%) social rental segment and 55 (40.7%) sale segment
- type of dwelling: 13 (9.6%) flats and 122 (90.4%) terraced houses),
- residents age ranged between 23 and 68 having a mean of 38.5 year,
- residents' sex: 67 (49.6%) women and 68 men (50.4%),
- household' size ranged between 1 and 6 residents having a mean of 2.81 person compared to 2.1 person in the Netherlands.

For each of the four elements of TPB descriptive statistics, Correlations analysis, scale reliability test, Factor Analysis and Regression Analysis were performed. All analyses were performed three times using:

- original scales range from 1 to 7,
- bi-polar scales range from -3 to +3, and
- re-coded scales (if not normally distributed).

Results of these three scales did not reveal significant differences. Therefore only analyses of the original scales are discussed.

5.7 Results

In this section the results of the analysis are described in five subsections: (i) results directly related to the components of the TpB model including Attitude, Social Norm, Perceived behavioral control and intention, (ii) results related to self-reported past behavior with respect to automatically operating of the heat pump system, boosting for hot water and boosting for space heating, (iii) results related to residents' demographic aspects including age, sex, educational level and inhabitation period, (iv) results related to knowledge of the implemented HVAC system, (v) results related to the choice of the dwelling, and (vi) results related to the residents' thermal preferences.

5.7.1 Explaining the model

In this section, results of descriptive analysis, Pearson correlations, reliability tests, factor analysis and regression analysis for each element of the TpB are presented. These elements are:

1. Attitudes (A), behavioral beliefs (BB) and outcome evaluation (OE),
2. Social Norm (SN), Normative Beliefs (NB) and Motivation to comply (MC),
3. Perceived Behavioral Control (PBC), Control Beliefs (CB) and Power of Control Factor (PCF),
4. Intention (I).

Attitudes

In Table 5-2, means, standard deviations, summary of principal component analysis and reliability test of the direct measures of attitude are displayed.

Results of principal component analysis, displayed in the last column of Table 5-2, revealed that the first extracted component explained 74.1% of the total variance in the observed attitude items and had eigenvalues of 4.45. Cronbach's alpha for the attitude items (α=.929) indicated high internal consistency. Based on these results, the six attitude items could be represented by the first extracted component; this component will be used henceforth as Attitude indicator in further analyses.

Table 5-2*: Means (M), standard deviations (SD), frequencies, summary of principal component analysis and reliability test of the Direct Measures of Attitudes (N=135)*

Attitude item	Negative	Neutral	Positive	M	SD	First component
Bad/ Good	29%	9%	62%	4.52	1.74	.917
Ineffective/ Effective	33%	10%	57%	4.27	1.71	.896
Unpractical/ Practical	30%	6%	64%	4.58	1.74	.890
Useless/ Useful	22%	16%	61%	4.67	1.62	.878
Unnecessary/ Necessary	15%	20%	65%	4.89	1.38	.727
Unpleasant/ Pleasant	30%	11%	59%	4.54	1.81	.843
Eigenvalue						4.45
Percentage of explained Variance by the first component						74.1%
Cronbach's Alpha						.929

Mean values of Attitude items showed slightly positive attitudes towards automatically operating of the heat pump system (the neutral point is 4). However, standard deviation values indicated large variance in residents' attitudes and that the performance of the system differed in different households' conditions. Inspection of the data revealed that the necessity and the usefulness of operating the heat pump system automatically are the highest assessed among the attitude items. In contrast, the effectiveness of operating the heat pump system automatically is the lowest assessed. However, the relatively high standard deviation values indicated that residents differed in their Attitudes. Inspecting the frequencies of attitudes confirms that residents, on average, positively evaluated their attitudes. The percentages show, however, that the necessity and practicality of the systems are the most positively assessed attitude items.

Behavioral Beliefs and Evaluation Outcomes

Means and standard deviations of behavioral beliefs, outcome evaluations and the products of behavioral beliefs and outcome evaluations are displayed in Table 5-3.

In general, residents positively evaluated their outcome evaluations. However, beliefs related to thermal comfort (Having Enough Hot Water and Space Heating) and 'Cost saving' are assessed higher than 'Protecting Environment'. It is worth mentioning that the highest evaluated outcome evaluations have the lowest standard deviations indicating some agreement among the residents.

Residents assessed behavioral beliefs related to the impact of the heat pump (Protecting Environment and Cost saving) positively whereas behavioral beliefs related to the thermal output of the heat pump were neutrally (Space hating and Space cooling) or negatively (Having Enough Hot Water) assessed. Residents believed that operating the heat pump system automatically can help protecting the environment and can save costs. However, this advantage was judged to be to the detriment of the thermal output of the heat pump; hot water, space heating and space cooling. However, the relatively high standard deviations in all behavioral beliefs, especially 'Having Enough Hot Water' and 'Space Heating', indicated that residents differed in their assessing of behavioral beliefs.

The products of outcome of evaluation and behavioral beliefs (BB*OE) determine the impact of the beliefs on the overall attitude. Product values revealed that 'Protecting Environment' and 'Cost Saving' beliefs contributed highly to attitudes toward automatically operating of the heat pump system. Beliefs related to the thermal output of the heat pump contributed lower to these attitudes.

Table 5-3*: Means (M) and standard deviations (SD) of Behavioral Beliefs (BB), Outcome Evaluation (OE) and the product of Behavioral Belief-Outcome Evaluation (BB*OE) (N=135)*

Item	BB		OE		BB*OE	
	M	SD	M	SD	M	SD
Protecting Environment	5.30	(1.41)	5.73	(1.01)	30.54	(10.46)
Cost Saving	5.01	(1.68)	6.48	(0.67)	32.49	(11.50)
Space Heating	4.43	(1.93)	6.22	(0.70)	27.33	(12.18)
Space Cooling	4.97	(1.56)	5.76	(0.95)	28.53	(10.21)
Having Enough Hot Water	2.98	(1.99)	6.64	(0.78)	19.47	(13.12)

Pearson correlations between each of the BB*OE products and the first principal component of the six attitude items are listed in Table 5-4. The correlations can explain the relationship between the behavioral beliefs and the extracted attitude. It can be seen that all beliefs are correlated positively to the attitude. The strongest correlations were related to the beliefs regarding the thermal output of the system including: 'Space Heating', 'Having Enough Hot Water', and 'Space Cooling'. Interestingly, the highest contributed beliefs to the attitudes (Protecting Environment and Cost saving) have the lowest correlation to the attitudes.

Apparently, there is a discrepancy between the expressed importance of outcomes and the statistical relationship. This could be explained by the fact that 'Protecting Environment' and 'Cost Saving' are more sensible to social desirability.

***Table 5-4**: Pearson correlation values of the products of Behavioral Belief-Outcome Evaluation and Attitude (N=135)*

Item	Attitude	Protecting Environment	Cost Saving	Space Heating	Space Cooling	Hot water
Attitude						
Protecting Environment	.22*					
Cost Saving	.33**	.66**				
Space Heating	.50**	.31**	.39**			
Space Cooling	.44**	.35**	.34**	.60**		
Having Enough Hot Water	.45**	.29**	.30**	.30**	.28**	

*Note. *p<.05 two-tailed, **p<.01 two-tailed*

A regression analysis was performed to find which beliefs contribute to predicting attitude [Field, 2009]. In the regression analysis the first extracted factor of attitude was used as dependent variable and the BB*OE products were used as independent variables. Table 5-5 shows the standardized coefficient (β), unstandardized regression coefficients (B) and their associated standard errors for each contributing BB*OE using Forward regression analysis. It can be seen that only 'Space Heating' and 'Having Enough Hot Water' carried significant regression weights (B=.033) and (B=.025) respectively and having standardized coefficients of (β=.405) and (β=.323). The regression weight of 'Space Heating' indicates that as behavioral belief 'Space Heating' increases by one unit, attitude will increase by 0.033 units. This interpretation is true only if the effect of 'Having Enough Hot Water' is held constant. We can say, then, that only behavioral beliefs 'Space Heating' and 'Having Enough Hot Water' are good predictors of the attitude towards automatically operating the heat pump system. Behavioral beliefs related to the functionality of the system dominated the attitude.

Interestingly, 'Protecting Environment', 'cost saving' and 'Space Cooling' beliefs which had high BB*OE values did not contribute to predicting attitude toward automatically operating the heat pump system. This can also be explained by the sensitivity of these beliefs to social desirability. Residents have responded in social desirable way on environment and costs issues. However, actually contributed beliefs are related to the thermal output of the heat pump system.

***Table 5-5**: Regression analysis with the first principal component factor of attitude as dependent and products of Behavioral Beliefs with Evaluation Outcomes BB*OE as independents using the Forward method (N=135)*

	B	SE B	β
(Constant)	-1.388	.183	
Space Heating	.033	.006	.405*
Having Enough Hot Water	.025	.006	.323*

*Note: R^2 = .252 for step 1, ΔR^2=0.095 * significant (P<0.05), not significant factors are not mentioned*

In the last row of Table 5-5, the coefficient of determination (R^2) for direct measured attitudes has been displayed. R^2 is a measure of how much of the variance in the outcome is accounted by a predictor [Field, 2009]. $\Delta R^2$is the increase of R^2 as additional predictor is added to the regression analysis. For the first step, including only 'Space Heating' as predictor, R^2=0.252 which means that 'Space Heating' accounted for 25.2% of the variation in attitude toward automatically operating of the heat pump system. However, when the second significant predictor is included in the analysis, R^2 is increased by 9.5%. So, the inclusion of both 'Space Heating' and 'Having Enough Hot Water' has explained 34.7% of the variation in attitudes.

5.7.1.1 Perceived Social Norm

The consistency of the three social norm items was tested using Cronbach's alpha and Principal Component Analysis. Results of the principal component analysis of the direct measures of the social norm, displayed in the last column of Table 5-6, showed that the first extracted component explained 65.17% of the variance in the observed social norm items and had Eigenvalue of 1.96. For the social norm items Cronbach's alpha was 0.732 two decimals is enough indicating reasonable internal consistency. These results showed that the three social norm items formed a one-dimensional social norm construct that could be represented by the first extracted principal component. The extracted component will be used henceforth, as Social Norm, in further analyses.

In Table 5-6, means and standard deviations are displayed. Means of social norm items showed slightly negative responses towards automatically operating of the heat pump system (the neutral point is 4). This indicated a weak social influence toward automatically operating the heat pump system. This could be explained by the fact that this behavior is more related to indoor activities which are invisible for external referents.

Table 5-6*: Means (M), standard deviations (SD), summary of principal component analysis and reliability test of the Direct Measures of Social Norm (SN) (N=135)*

Items of social norm	M	SD	First component
Important Referents	3.89	1.06	.799
People's Expectation	3.72	1.05	.757
Society Pressure	3.71	0.97	.787
Eigenvalue			1.96
Percentage of explained Variance			65.17%
Cronbach's Alpha			.732

In Table 5-7, means and standard deviations of normative beliefs, motivation to comply and the product of normative beliefs with motivation to comply are displayed. Residents frequently mentioned that 'Technical Specialist' and 'Environmental Groups' prefer to operate the heat pump system automatically. This can be explained by the role of the technical specialist who was the information source about the heat pump systems in the delivery phase of the dwellings whereas the environmental groups were general information sources using the media sources. Residents mentioned that 'Neighbors' and 'Family' are neutral (both around 4) toward automatically operating of the heat pump system.

Means of MC's showed that only Technical Specialist seemed to have a slightly positive influence on the motivation to comply the automatically operating of the heat pump system whereas 'Neighbors', 'Family' and 'Environmental Groups' had slightly weak influence. However, resident's assessment of referents' influence was highly dispersed, especially for the Technical Specialist'. This means that residents, in general, disagreed about the influence of these referents.

The products of normative beliefs and motivation to comply NB*MC indicated the perceived social pressure by the important referents. Means of these products are displayed in the sixth and seventh column of Table 5-7. 'Technical Specialist' and 'Environment Groups' have the strongest social pressure on residents whereas 'Neighbors' and 'Family' have relatively low pressure. However, the standard deviations of NB*MC for all social referents are very high indicating high variance of residents' assessments.

Table 5-7*: Means (M) and standard deviations (SD) of Normative Beliefs (NB), Motivation to Comply (MC) and the product of Normative Beliefs with Motivation to Comply (NB*MC), (N=135)*

Social referents	NB		MC		NB*MC	
	M	SD	M	SD	M	SD
Technical Specialist	5.69	1.27	4.75	1.77	27.74	12.74
Neighbors	4.11	1.50	3.41	1.62	14.43	9.73
Family	3.74	1.45	3.41	1.57	13.70	9.78
Environmental Groups	5.54	1.34	3.43	1.50	19.05	10.11

In table 5-8, Pearson correlations between the first extracted principal component of direct measures of social norm items with the NB*MC products are displayed. Inspection of the results showed that the social norm was significantly correlated with all social referents. It is worth mentioning that 'Neighbors' and 'Family', which had low NB*MC means, have higher correlations with social norm than 'Technical Specialist' and 'Environment Groups'.

Table 5-8*: Pearson correlation values of the products of Normative Belief with Outcome Evaluations and the Social Norm (N=135)*

Item	Social Norm	Technical Specialist	Neighbors	Family
Social Norm				
Technical Specialist	.338**			
Neighbors	.714**	.235**		
Family	.613**	.289**	.385**	
Environmental Groups	.230**	.113	.254**	.368**

*Note. **p<.001 two-tailed*

A regression analysis was performed to find which referents contributed to predicting the social norm. In the regression analysis the first extracted factor of the social norm items was used as dependent variable and the NB*MC products as independent variables. Table 5-9 shows the standardized coefficient (β), unstandardized regression coefficients (B) and their associated standard errors for each contributing NB*MC products using forward regression analysis.

It can be seen that only Neighbors and Family contributed to the direct measured perceived social norm carried significant regression weights of B=.006 and B=.041. The regression weight of 'Neighbors' indicated that as Neighbors' influence increases by one unit, social norm will increase by 0.058 units. This interpretation is true only if the effect of 'Having Enough Hot Water' is held constant.

Interestingly, 'Technical Specialist' and 'Environmental Groups', which had the highest NB*MC means, had no contribution to predicting the direct social norm. This can be explained by the fact that using the heat pump system, a behavior that can be performed indoor, is less sensitive to external influence as the behavior happens in dwelling where no extern control is from social referents. The impact of both 'Technical Specialist' as 'Environmental Groups' is relevant in the very first phase of the project as residents need and look for information. However, their impact will probably weaken in the course of time as the installation company is no more engaged in the project. The weak impact of the 'Technical Specialist' could be also explained by the careless service delivered by the installation company as residents complain about that during the interviews. Residents, in the use phase, consulted their neighbors and family for information and support.

***Table 5-9**: Regression analysis with the first aggregated principal component factor of Social Norm as dependent and products of Normative Beliefs with Motivation to Comply as independents using Forward method (N=135)*

	B	SE B	β
(Constant)	-1.39	.104	
Neighbors	.058	.006	.561*
Family	.041	.006	.396*

Note: R^2 = .509 for the first step and ΔR^2=.134 for the second step * significant (P<0.001)

The coefficient of determination for the direct measured perceived social norm (R^2=.509) means that 50.9% of the variability in the perceived social norm could be accounted for by the first predictor Neighbors. Adding Family as second predictor increased R^2 by 13.4%.

For the first step, including only 'Neighbors' as predictor, R^2=0.509, which means that 'Neighbors' accounted for 50.9% of the variance in the social norm toward automatically operating of the heat pump system. However, after the second significant predictor 'Family' was included in the analysis, R^2 increased by 13.4%. So, the inclusion of both 'Neighbors' and 'Family' explained 64.3% of the variance in the social norm.

5.7.1.2 Perceived Behavioral Control

The consistency of the four perceived behavioral control items was tested using Principal Component Analysis and Cronbach's alpha. In the last column of Table 5-10, results of the principal component analysis are displayed. Results showed that two principal components were extracted. In terms of consistency, the third direct item showed some deviation from the other three items. The consistency test showed a low value for Cronbach's alpha (α=.652) while suggesting that alpha would increase to α=.820 when deleting the third item.

Possibly this item was wrongly interpreted by the interviewees. The third item was removed to increase the consistency of the scale of the perceived behavioral control.

In the last column of Table 5-11, results of the principal component analysis for perceived behavioral control, after removing the third item of PBC, are displayed. Results of the principal analysis showed that one principal component was extracted explaining 76.05% of the variability and having an Eigenvalue of 2.28 (α is increased to α=.82). Based on these results we can say that the three items of direct perceived behavioral control could be represented by the first extracted principal component. The extracted component was used, for perceived behavioral control, in further analyses.

Table 5-10: *Summary of exploratory factor analysis and reliability test for the four items Direct Measures of Perceived Behavioral Control (N=135)*

Item of perceived behavioral control	Factor Loading (1)	Factor Loading (2)
Want To Use	.927	-.185
Decision to Use	.898	-.273
Ease of Use	.172	.942
Independence To Use	.772	.329
Eigenvalue	2.3	1.10
Percentage of explained Variance	57.45%	27.61%
Cronbach's Alpha	.688	

In the second and third columns of Table 5-11, means and standard deviations of the three of perceived behavioral control items are displayed. Inspection of these values shows that only Independence of Use was slightly positive assessed whereas 'Want to Use' and 'Ease of Use' are slightly negative assessed (the neutral point is 4).

Table 5-11: *Mean (M) values, standard deviation (SD) values, summary of principal component analysis and reliability test of three items of Direct Measures of Perceived Behavioral Control (N=135)*

Item	M	SD	First component
Direct Measure PBC [Want To Use]	3.32	1.40	.936
Direct Measure PBC [Ease of Use]	3.47	1.06	.912
Direct Measure PBC [Independence To Use]	4.91	1.49	.756
Eigenvalue			2.28
Percentage of explained Variance			76.05%
Cronbach's Alpha			.820

In Table 5-12, means and standard deviations of Control Beliefs (CB), Power of Control Factor (PCF) and the CB*PCF products are displayed. Inspection of the second and third columns showed that control beliefs of 'System Response', 'Capacity for Hot Water' and to somewhat 'Capacity for Space Heating' have positive means. Control beliefs of 'Adjustment', 'Capacity for Space Cooling' and 'Maintenance' have slightly negative means (neutral point is 4). Residents believed, on average, that the capacity of the heat pump for space heating and hot water is insufficient and that the system responds too slowly to resident's demands.

However, all six control beliefs had high standard deviations indicating large difference between the residents.

Inspection of the third and fourth columns shows that all PCF's are positively assessed. However, 'Capacity for Hot Water', 'Capacity for Space Heating' and 'System Response' are perceived to have stronger negative impact on operating the heat pump system automatically. However, all six control factors have high standard deviations indicating large difference between the residents.

Inspection of means of CB*PCF products showed that 'Capacity of Hot Water', 'System Response' and 'Capacity for Space Heating' exerted the greatest impact on perceived behavioral control whereas the other control beliefs exerted less impact. These results indicate that, on average, residents believed that the capacity of their heat pump system for heating and for hot water supply was insufficient and the system responded slowly on their interventions. Because of that, residents were forced to deviate from operating the heat pump system automatically.

Table 5-12*: Means (M) and standard deviations (SD) of Control Beliefs (CB), Power of Control Factor (PCF) and the product of Control Beliefs with Power of Control Factor, (N=135)*

Item	CB		PCF		CB*PCF	
	M	SD	M	SD	M	SD
Capacity for hot Water	5.35	1.91	5.85	1.38	32.27	14.93
Capacity for Space Heating	4.44	2.10	5.53	1.45	25.44	15.12
Capacity for space Cooling	3.56	1.50	4.30	1.46	15.71	9.10
Maintenance	3.54	1.67	4.54	1.47	16.96	11.12
Adjustment	3.87	1.76	4.66	1.43	18.52	11.67
System Response	5.53	1.42	5.06	1.58	28.45	12.00

Pearson correlations of CB*PCF with the direct measures of perceived behavioral control are displayed in Table 5-13. Inspection of the correlations showed that all CB*PCF are negatively correlated with perceived behavioral control. However, 'Capacity for Hot Water' and 'Capacity for space heating' have the strongest negative correlations with extracted perceived behavioral control. This result indicates that the insufficient capacity (according to the residents) of the heat pump systems has impeded the operating of the heat pump system automatically.

Table 5-13*: Pearson correlation values of the products of control beliefs-power of control and the Perceived behavioral control (N=135)*

Item	PBC	Capacity Hot Water	Capacity for Space Heating	Space Cooling	Mainten -ance	Adjust-ment
Capacity for Hot Water	-.660**					
Capacity for Space Heating	-.610**	.525**				
Capacity Space Cooling	-.406**	.262**	.483**			
Maintenance	-.512**	.242**	.328**	.330**		
Adjustment	-.506**	.415**	.403**	.323**	.582**	
System Response	-.375**	.337**	.459**	.259**	.275**	.436**

*Note. **. Correlation is significant at the 0.01 level (2-tailed).*

Inspection of the regression analysis in Table 5-14 showed that only ‘Capacity for Hot Water’, ‘Maintenance’ and ‘Capacity for Space Heating’ significantly contributed to the perceived behavioral control carried regression weights of -.029, -.028 and -.018 respectively.

Using only ‘Capacity for Hot Water’ as predictor is resulted in R^2=0.431 which means that 43.1% of the variability in the perceived behavioral control is accounted by this control belief. Adding ‘Maintenance’ and ‘Capacity for Space Heating’ has increased the variability by 13.2% and 5.2% respectively.

***Table 5-14**: Regression analysis with perceived behavioral controls dependent and products of control beliefs-power of control as independents using the Forward method (N=135)*

Item	B	SE B	β
(Constant)	1.894	,142	
CB*PCF Hot Water	-,029	,004	-,438**
CB*PCF Maintenance	-,028	,005	-,316**
CB*PCF Space Heating	-,018	,004	-,276**

*Note: R^2 = .431 for the first step, ΔR^2=0.132 for the second step, ΔR^2=0.052 for the third step and ΔR^2=0.017 for the forth step. ** significant (P<0.001)*

5.7.1.3 Intention

Results of the principal component analysis of the direct measures of intention are displayed in the last column of Table 5-15. Results showed that only one principal component could be extracted explaining 96.27% of the variance in the observed intention items and having an Eigenvalue of 2.89. Cronbach’s alpha was very high (α=.98) indicating high internal consistency. Based on these results, the three items of intention could be represented by the first extracted principal component. This component was used henceforth, as intention, in further analyses.

***Table 5-15**: Mean (M) values, standard deviation (SD) values, summary of principal component analysis and reliability test of the Direct Measures of Intention, (N=135)*

Items of intention	Negative	Neutral	Positive	M	SD	First component
Intend To Use	12%	13%	75%	5.39	1.53	.980
Expect To Use	16%	13%	71%	5.10	1.54	.974
Will to Use	14%	13%	73%	5.21	1.54	.989
Eigenvalue						2.89
Percentage of explained Variance						96.27%
Cronbach’s Alpha						.981

Intention items had positive means indicating that residents, on average, intended to operate the heat pump system automatically. However, standard deviations were high which indicated high variance in residents’ intention. Inspection of the frequencies and the percentages of the three items of direct measured Intention, in Table 5-16, showed a skewed distribution to the right (high likelihood to intend the behavior). Residents, on average, intended the automatically operating of the heat pump system. These results are confirmed by the percentages of the intention.

***Table 5-16**: Frequencies and percentages of the three items of Intention, N=135*

	Intention [Intend To Use]		Intention [Expect To Use]		Intention [Will Use]	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Extremely unlikely	3	2.2%	5	3.7%	4	3.0%
Very unlikely	7	5.2%	6	4.4%	7	5.2%
Unlikely	6	4.4%	10	7.4%	8	5.9%
Neutral	18	13.3%	18	13.3%	17	12.6%
Likely	17	12.6%	25	18.5%	26	19.3%
Very likely	52	38.5%	53	39.3%	48	35.6%
Extremely likely	32	23.7%	18	13.3%	25	18.5%

Pearson correlations in Table 5-17 showed that the intention to operate the heat pump system automatically was strong-positively correlated with attitude, perceived behavioral control and social norm to a small extent. Attitude and Perceived Behavioral Control were strong-positively intercorrelated whereas both were less positively correlated with the social norm.

***Table 5-17:** Pearson correlation values of Attitude, Social Norm, Perceived Behavioral Control and Intention (N=135)*

Item	Intention	Attitude	Social Norm
Intention			
Attitude	.605**		
Social Norm	.219*	.282*	
Perceived Control	.546**	.618**	.185*

*Note. *p<.05 (two-tailed), **p<.001 (two-tailed)*

Results of the regression analysis, in Table 5-18, show that attitude and perceived behavioral control significantly contributed to predicting the Intention to operate the heat pump system automatically. These predictors carried significant regression weights 0.433 and 0.278 and had significant regression weights of .085 and .085 respectively. Social Norm had no significant contribution in predicting the Intention. Attitude accounted for 36.2% of the variability in the intention. The explained variance of the intention has increased by 4.8% by adding the perceived behavioral control as second predictor.

Table 5-18: *Regression analysis with Intention as dependent and Attitude, Social Norm and Perceived Behavioral Control as independents using Forward method (N=135)*

	B	SE B	β
(Constant)	0	.066	
Attitude	,433	.085	,433*
Perceived Behavioral Control	,278	.085	,278*

*Note: R2 = .362 for the first step and ΔR^2=0.048 for the second step * significant (P<0.05)*

5.7.2 Self-reported behavior

In Table 5-19, frequencies of the self-reported past behavior items are listed. Inspecting the first item showed clear skewness to the left indicating that residents, on average, operated their heat pump system automatically. Inspecting the second and third items revealed more deviation from the automatically operating with respect to boost for space heating and boost for hot water. 18% of the residents reported to, at least frequently, have boosted for space heating and 28% reported to have boosted for hot water.

Table 5-19: *Frequencies and percentages of the residents' responses on the three items of Self-Reported past Behavior, (N=135)*

	Automatically Operating		Boost for Heating		Boost for Hot water	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
1-Never	9	7%	50	37%	34	25%
2-Very rarely	7	5%	50	37%	36	27%
3-Rarely	6	4%	11	8%	25	19%
4-Frequently	24	18%	6	4%	10	7%
5-Very frequently	19	14%	9	7%	15	11%
6-Always	70	52%	9	7%	15	11%

Pearson correlations between items of self-reported past behavior, elements of the model and the actual monthly electricity consumption are presented in Table 5-20. All items of self reported behavior are strongly correlated with intention to automatically operating the heat pump system that indicated that residents will behave, to high extent, in the same way as in the last period. Items of self reported past behavior were, just as the intention, correlated with the elements of the model. The more residents positively evaluated attitude and perceived behavioral control the more they operated the heat pump system automatically and less boosted for hot water and space heating. The monthly electricity consumption, as expected, was negatively correlated with automatically operating of the heat pump system en positively correlated with ‘Boost for space heating’ and ‘Boost for hot water’. The more residents negatively evaluated attitude and perceived behavioral control the more they deviated from the automatically behavior and the more they consume electricity.

***Table 5-20**: Pearson correlations between items of Self Reported Past Behavior and monthly electricity consumption (N=135)*

Item	Automatically operating	Boost for Space heating	Boost for hot water
Attitude	.580**	-.457**	-.519**
Perceived behavioral control	.447**	-.480**	-.547**
Intention	.881**	-.795**	-.740**
Monthly electricity consumption	-.260**	.307**	.219*

*Note. *p<.05 (two-tailed), **p<.001 (two-tailed)*

5.7.3 Demographic variables

Correlations between demographical variables and residents' beliefs are listed in Table 5-21. Inspection the results revealed that the household size has significant correlations with the behavioral beliefs regarding hot water supply. The bigger the household size is, the more residents negatively evaluated the automatically operation of the heat pump system and the more they boosted for hot water supply which resulted in higher electricity consumption. This finding can be explained by the fact that hot water need for large households is more than that for small household size.

Interviewees' age was significant negatively correlated with behavioral belief 'hot water' and negatively with control belief 'capacity for hot water', which means that the older the interviewee was the more he/she believed that automatically operating of the heat pump would supply enough hot water and that the capacity of heat pump for hot water was sufficient. This latter finding was confirmed by the negative correlation with the boosting for hot water.

***Table 5-21**: Pearson correlation values of demographic variables and some Hot water and Space heating related behavior-items (N=135)*

Item	Household size	Age of Interviewee	Education Level	Length of stay
BB [Space Heating]	-.097+	.110+	.094+	-.021+
BB [Hot water]	**-.206***	**.207***	.069+	-.069+
CB [Capacity insufficient for Space Heating]	-.085+	-.091+	-.162+	**.255****
CB [Capacity insufficient for Hot Water]	.140+	**-.313***	-.020+	**.170***
Attitude	**-.176***	.018+	**,325****	-.102+
Social Norm	-.139+	-.53+	.037+	-.077+
Perceived behavioral control	-.131+	**.197***	.114+	**-.256****
Intention	**-.204***	.135+	**.210***	-.140+
SR-PB automatically operating	.101+	-.121+	**-.183***	.083+
SR-PB Boost for hot water	**.213***	**-.190***	**-.180***	.112+
Monthly electricity consumption	**.334****	.022	.057	-.233+

*Note. *significant at p<.05 (two-tailed), **significant at p<.001 (two-tailed) and +not significant.*

There was a correlation between education level and the intention to use the heat pump automatically. The higher interviewees were educated the more they had positive attitudes and intentions toward automatically operating of the heat pump system and the less they would boost for hot water. This result could be explained by the fact that high-educated residents are more open for accepting new technologies and more flexible to deal with their limitations. This residents' profile is comparable to the early adopters as suggested by the theory of innovation diffusion [Rogers, 1943]. According to this theory, early adopters are typically younger in age, have a higher social status and have more financial lucidity.

Interestingly, finding in the last column of Table 5-21, on average, the longer residents had been living in their dwelling the more they believed that the capacity of the system for hot water and space heating was insufficient. This could mean that residents, on average, did not form new habits to deal with the limitations of the system.

Considering that the average household size in De Caaien was 2.81, households were divided into two groups: group 1 represented households of smaller that 3 persons and groups 2 represented households equal or bigger than 3 persons. A Mann-Whitney test was performed to find out if these two groups differed in their evaluation of the system Table 5-22. Results revealed that households of 3 persons or more had negative intention toward the automatically operating of the heat pump system and reported to have boosted for hot water. This finding suggested that the heat pump system was more suitable for households of less than 3 persons.

***Table 5-22**: results of Mann-Whitney test as, 1=household smaller than 3, 2=household equal or greater than 3, N=135*

Behavioral belief	Group	N	Mean Rank	
Attitude	Smaller than 3	63	72.25	Mann-Whitney U=2000.5
	3 or bigger	72	64.28	Sig. (2-tailed)=.238⁺
SN	Smaller than 3	63	68.05	Mann-Whitney U=2265.0
	3 or bigger	72	67.96	Sig. (2-tailed)=.989⁺
Perceived Behavioral Control	Smaller than 3	63	71.98	Mann-Whitney U=2017.5
	3 or bigger	72	64.52	Sig. (2-tailed)=.269⁺
Intention	Smaller than 3	63	79.51	Mann-Whitney U=1543.0
	3 or bigger	72	57.93	Sig. (2-tailed)=**.001***
SR-PB boost for hot water	Smaller than 3	63	60.84	Mann-Whitney U=1817.0
	3 or bigger	72	74.26	Sig. (2-tailed)=**.042***

*Note. *significant at p<.05 (two-tailed) and ⁺not significant.*

Households were also divided into two other groups: group 1 represented households having children and groups 2 represented households without children. A Mann-Whitney test was performed to find out if these two groups differ in their evaluation of the system Table 5-23. Results revealed that households of 3 persons or more had more often negative intentions toward the automatically operating of the heat pump system and reported to have boosted for hot water. This finding suggested that the heat pump system is more suitable for households less than 3 persons.

Inspecting the results revealed that the two groups evaluated the automatically operating of heat pump system differently. Households without children had more positive attitude toward the automatically operating of the heat pump system and reported to have less frequently boosted than households with children.

***Table 5-23**: results of Mann-Whitney test as, 1=household without children, 2=household with children, N=135*

Behavioral belief	Group	N	Mean Rank	
Attitude	Without children	67	76.38	Mann-Whitney U=1716.5
	With children	68	59.74	Sig. (2-tailed)=.**013***
SN	Without children	67	72.45	Mann-Whitney U=1980.0
	With children	68	63.62	Sig. (2-tailed)=.189+
Perceived Behavioral Control	Without children	67	72.99	Mann-Whitney U=1943.5
	With children	68	63.08	Sig. (2-tailed)=.141+
Intention	Without children	67	80.71	Mann-Whitney U=1429.0
	With children	68	55.48	Sig. (2-tailed)=.**000***
SR-PB boost for hot water	Without children	67	56.82	Mann-Whitney U=1529.0
	With children	68	79.01	Sig. (2-tailed)=.**001***

*Note. *significant at p<.05 (two-tailed) and +not significant.*

5.7.4 Knowledge

Residents' knowledge-level regarding the heat pump system was measured by counting correct answers given by the residents on five multiple-choice questions (each question had five possible choices). The number of correctly answered questions was used to determine residents' knowledge level. Table 5-24 shows that 68.1% answered at least three questions correctly and, on average, residents answered 2.93 correctly.

***Table 5-24**: Residents' knowledge-level regarding the heat pump system, Mean=2.93, N=135*

Number of correct answers	Frequency	Percent	Cum. Percent
5	14	10.4%	10.4%
4	19	21.5%	24.4%
3	59	43.7%	68.1%
2	29	14.1%	89.6%
1	14	10.4%	100.0%
0	0	0%	100.0%

Pearson correlations between residents' knowledge and beliefs regarding automatically operating of the heat pump system are listed in Table 5-25. Inspection of the data revealed that knowledge level did not correlate with any behavioral, normative or control beliefs regarding automatically operating of the heat pump system. This finding indicated the knowledge about the system failed to influence residents' behavioral toward automatically operating of the heat pump system. This finding corresponded to [Ajzen et al., 2010].

***Table 5-25**: Pearson correlations between residents' knowledge level and beliefs used in the model*

Beliefs used in the model	Correlation value
Behavioral Belief [Protecting Environment]	-.083
Behavioral Belief [Cost saving]	.009
Behavioral Belief [Space Heating]	-.031
Behavioral Belief [Space Cooling]	-.041
Behavioral Belief [Having Enough Hot Water]	-.152
Normative Beliefs [Company]	-.065
Normative Beliefs [Neighbors]	.005
Normative Beliefs [Family]	-.088
Normative Beliefs [Environment Groups]	.156
Control Beliefs [Hot Water]	.159
Control Beliefs [Space Heating]	.024
Control Beliefs [Space Cooling]	.053
Control Beliefs [Maintenance]	.116
Control Beliefs [Adjustment]	.146
Control Beliefs [Response]	.069

*Note. *significant at p<.05 (two-tailed), **significant at p<.001 (two-tailed) and $^{+}$not significant.*

5.7.5 Choice of the dwelling

Table 5-26 shows which criteria residents of 'De Caaien' considered in choosing their dwelling. Inspection of the results revealed that 'Location of De Caaien' and 'Size of the dwelling' were the most frequently mentioned choice criteria. Although 'De Caaien' has been characterized and promoted by its level of sustainability and energy saving, as the first BREEAM-certificated housing project in the Netherlands, only 18% of the residents considered 'Sustainability' or 'Energy saving' as choice criterion. However, 18% of the residents indicated Sustainability as a choice criterion, which indicating good marketing for this type of dwellings.

***Table 5-26**: Frequencies of choice criteria considered by the residents to choose 'De Caaien'*

Choice criterion	First criterion	Second criterion	Third criterion	Total	Percent
Location of 'De Caaien'	77	13	11	101	75%
Size of the dwelling	23	46	15	84	62%
Plan (lay-out)	4	15	13	32	24%
Price of the dwelling	5	3	19	27	20%
Availability	4	12	11	27	20%
Sustainability	13	7	4	24	18%
Energy Saving	2	13	9	24	18%
Others	5	2	2	9	7%
Architecture	2	2	3	7	5%

Residents were divided into two groups; the first group represented residents who considered 'Sustainability' as criterion for choosing the dwelling and the second group, which represented residents who did not consider this criterion. To find out whether the two groups differed in their beliefs and evaluations regarding the automatically operating of the heat pump system, a Mann-Whitney Test was performed on behavioral beliefs. Results of the Mann-Whitney test are listed in Table 5-27.

Results showed that residents did not differ significantly in their responses on behavioral beliefs. Interestingly, residents who considered the environment for choosing their dwelling did not differ in their behavioral belief regarding protecting the environment.

***Table 5-27**: results of Mann-Whitney test among residents who did vs. did not consider 'Sustainability' as criterion, 1='Sustainability' considered, 0='Sustainability' not considered*

Behavioral belief	Group	N	Mean/Rank	Mean	
Protecting Environment	0	111	65.67	5.23	Mann-Whitney U=1073,5
	1	24	78.77	5.58	Sig. (2-tailed)=.123+
Cost Saving	0	111	66.61	4.96	Mann-Whitney U=1178.0
	1	24	74.42	5.25	Sig. (2-tailed)=.358+
Space heating	0	111	68.00	4.44	Mann-Whitney U=1331.5
	1	24	68.02	4.38	Sig. (2-tailed)=.998+
Space cooling	0	111	67.41	4.95	Mann-Whitney U=1266.0
	1	24	70.75	5.04	Sig. (2-tailed)=.695+
Having enough hot water	0	111	66.92	2.91	Mann-Whitney U=1212.5
	1	24	72.98	3.29	Sig. (2-tailed)=.480+

*Note. *significant at p<.05 (two-tailed) and +not significant.*

Residents were also divided into two other groups: the first group represented residents who considered 'Energy saving' as criterion for choosing the dwelling and the second group represented residents who did not consider that criterion. To find out whether the two groups differed in their beliefs regarding the automatically operating of the heat pump system, a Mann-Whitney Test was performed. Results of the Mann-Whitney test are listed in Table 5-28.

***Table 5-28**: results of Mann-Whitney test among residents how did and did not consider 'Energy saving' as criterion, 1='Energy saving' was considered, 0='Energy saving' was not considered*

Behavioral belief	Group	N	Mean/Rank	Mean	
Protecting Environment	0	111	65.20	5.19	Mann-Whitney U=1021.0
	1	24	80.96	5.79	Sig. (2-tailed)=.063+
Cost Saving	0	111	66.30	4.97	Mann-Whitney U=1143.0
	1	24	75.88	5.21	Sig. (2-tailed)=.260+
Space heating	0	111	67.85	4.42	Mann-Whitney U=1315.0
	1	24	68.71	4.46	Sig. (2-tailed)=.920+
Space cooling	0	111	64.94	4.85	Mann-Whitney U=992.5
	1	24	82.15	5.54	Sig. (2-tailed)=.044*
Having enough hot water	0	111	65.93	2.87	Mann-Whitney U=1102.5
	1	24	77.56	3.46	Sig. (2-tailed)=.175+

*Note. *significant at p<.05 (two-tailed) and +not significant.*

Results showed that behavioral beliefs for 'Space Cooling' differed significantly between the two groups; mean value for the first group was 5.54 and for the second group 4.85. Interestingly, residents who considered 'Energy Saving' as criterion for choosing their dwelling did not differ in their behavioral belief regarding 'Cost saving'. All other beliefs and evaluations did not differ significantly.

5.7.6 Thermal comfort preferences

Residents' thermal comfort preference in the winter was measured using two items: (i) the desired indoor temperature and (i) the set-point temperature in the living room. Means, standard deviations and percentages are listed in Table 5-29. Inspection the data revealed no significant differences between preferred and set-point temperatures. Data revealed also wide variance in residents' thermal preferences having Mean of 21.6C° and Standard deviation of 1.35 for both the desired as well as the set-point temperature. Interestingly, the mean of the desired (or set-point) temperature was higher than recommended by the HVAC Company of 20-21C ° and 56.3% preferred an indoor temperature (living room) higher than 21C°.

***Table 5-29**: Residents' thermal preferences in the winter*

Temperature C°	Preferred temperature		Setpoint temperature	
	Frequency	Percentage	Frequency	Percentage
18.0	1	1%	1	1%
19.0	3	2%	3	2%
19.5	3	2%	2	1%
20.0	17	13%	17	13%
20.5	5	4%	7	5%
21.0	32	24%	29	21%
21.5	7	5%	9	7%
22.0	38	28%	38	28%
22.5	2	1%	1	1%
23.0	19	14%	17	13%
24.0	5	4%	9	7%
25.0	2	1%	1	1%
27.5	0	0%	1	1%
28.0	1	1%	0	0%

In Table 5-30, Pearson correlations between indoor temperature (preferred as well as set-point) and behavioral beliefs, attitude, Social Norm, Perceived Behavioral Control, Intention and Self-Reported Past Behavior are listed. Inspection of the results revealed that both preferred as well as set-pint temperatures showed that the same correlations with the elements of the model. The higher the preferred indoor temperature is the more residents negatively evaluated positive correlations with behavioral beliefs, attitude, perceived behavioral control, intention and boosting for heating. This can be partly explained the limited ability of the system to ensure an indoor temperature of >21C°. Interestingly, desired indoor temperature had no relation with the monthly electricity consumption.

***Table 5-30**: Pearson correlations between residents' preferred indoor temperature and elements of the theory of planned behavior, N=135*

Element	Preferred indoor temperature	Setpoint indoor temperature
Behavioral Belief [Protecting Environment]	**-,174***	**-.238****
Behavioral Belief [Cost saving]	**-,272****	**-.322****
Behavioral Belief [Space Heating]	**-,307****	**-.304****
Behavioral Belief [Space Cooling]	**-,275****	**-.324****
Behavioral Belief [Having Enough Hot Water]	**-,245****	**-.252****
Attitude	**-,271****	**-.291****
Social Norm	-,064	-.134
Perceived Behavioral Control	**-,205***	**-.231****
Intention	**-,190***	**-,299****
Self-Reported Past Behavior-Boost for space heating	**,204***	**.296***
Monthly electricity consumption	,059	.167

*Note. *p<.05 (two-tailed), **p<.001 (two-tailed)*

The influence of the thermal preferences on the use of the ventilation openings was investigated. The correlations between ventilation frequency and the elements of the TpB are displayed in Table 5-31.

Table 5-31: Pearson correlations between the ventilation frequency and the components of the Theory of planned behavior, N=85

Element	Pearson correlations
Behavioral Belief [Protecting Environment]	.039
Behavioral Belief [Cost saving]	.101
Behavioral Belief [Space Heating]	**.424****
Behavioral Belief [Space Cooling]	**.245***
Behavioral Belief [Having Enough Hot Water]	.101
Attitude	.149
Social Norm	.102
Perceived Behavioral Control	.016
Intention	**.229****
Self-Reported Past Behavior-Boost for space heating	**-.237***
Monthly electricity consumption	-.234

*Note. *p<.05 (two-tailed), **p<.001 (two-tailed)*

Inspection of the results revealed that the more residents believed that automatically operating of the heat pump system will meet their needs the frequenter they opened the ventilation openings in the winter. There is also a positive correlation between the intention to operate the heat pump system automatically and using the ventilation openings. Results revealed also that the more residents opened the ventilation openings the more they boosted for space heating. The last finding suggested that the heat pump system did not respond properly on the cold ventilation air coming via the openings. This could be also confirmed by the fact that winter in 2010 was extremely cold.

5.7.7 Acceptance of the system

To find out if residents' experience with the heat pump system could affect their acceptance of this device as heating system, correlation analysis between the elements of the model, self reported behavior and 'the willingness to have the heat pump system' was performed. Pearson correlations are listed in Table 5-30. Results of the correlations showed high correlations between attitude, perceived behavioral control, and intention to use the automatic mode and the intention to have a heat pump system. This result revealed that the more residents positively evaluated the heat pump system the more they would accept it as heating system. Also correlations with the items of the self-reported behavior showed that the more residents operated the heat pump system automatically the more they would accept the system. The last finding suggested that the more the heat pump system met residents' needs the more they would accept it as heating system.

***Table 5-32**: Pearson correlations between 'the intention to have a heat pump system' and elements of the theory of planned behavior and self-reported behavior (N=135)*

Item	Attitude	Social Norm	Perceived behavioral control	Intention	Automatically operating	Boost for space heating	Boost for hot water
The intention to have a heat pump	**.601****	**.176***	**.543****	**,425****	**.375****	**-.416****	**-.371****

5.8 Considerations and limitations

For the purpose of this research, data were collected about the composition of the household e.g. size, number of adults, number of children and age of the interviewee. These data were used to find associations between the different households' profiles and performance of the system on supply of hot water. Interviewees were asked to give the composition of their household; the number of adults and children. No extra information was collected about the age of the children or the other adults. Children and adults may differ in age, sex, time needed to take a shower, the amount hot water needed to take a shower and their lifestyle (sport, school, work, unemployed) resulting in countless profiles. In our study, we did not consider age to distinguish the several profiles of children. The analysis was purely to indicate if households with children may differ from households without children.

5.9 Discussion and conclusions

Results of this research showed that the intention to operate the heat pump system automatically could be explained by the attitude and perceived behavioral control whereas the social norm failed to improve the explanation. Attitude together with perceived behavioral control accounted for 41% of the variability in the intention. Hypothesis 1 [*Attitude, social norm and perceived behavioral control predict residents' intention toward operating the heat pump system automatically*] is thus rejected. Although residents reported that they 'very likely' to operate the heat pump system automatically, the standard deviations were relative high indicating large variations in residents' responses.

These deviations confirm that the heat pump system performed differently in different dwellings or household situations.

Residents had, on average, slightly positive attitudes toward operating the heat pump system automatically. Residents believed, however, that operating the heat pump system is necessary and useful but ineffective. Residents' attitudes were also relatively dispersed indicating that system performed differently in different dwellings and in different household. Behavioral beliefs related to Protecting environment and Cost saving were evaluated, on average, as very favorable. Also the impacts of these two beliefs were positively evaluated. However, these beliefs failed to predict directly measured attitude toward automatically operating of the heat pump system.

Only beliefs related to space heating and supply of hot water were good predictors of the attitude. Behavioral beliefs related to having comfortably indoor temperature and having enough hot water accounted for 34.7% of the variability in the attitude. This finding corresponds to the Maslow's hierarchy of needs as thermal comfort belongs to the basic physiological needs whereas protecting environment and cost saving belongs to the Esteem needs that are less important [Maslow, 1943]. Protecting environment and Cost saving beliefs, however, may be sensitive for social desirability, which was indicated in the difference between results of regression analysis (indirect measurement) and results of Behavioral Beliefs*Outcome Evaluations (direct measurement). Hypothesis H2 [*Behavioral beliefs related to the output of the heat pump system are relevant to form residents' attitudes toward the heat pump system*] is, thus, rejected.

Residents had, on average, neutral perceived behavioral control beliefs toward operating the heat pump system automatically (one item slightly positive and two items slightly negative). Residents believed that the capacity of the system for hot water and the capacity of the system for space heating were insufficient to meet their needs. They believed also that the system responded too slowly on their interventions and changes in outside temperatures. These three control beliefs exerted also the greatest impact on perceived behavioral control whereas the other three control beliefs (Capacity for space cooling, Adjustment and Maintenance) exerted less impact. Residents believed that they have to deviate from the automatically operating of the system if the system is not able to support their needs. Control beliefs 'System response' is failed to predict perceived behavioral control as only 'Capacity for hot water', 'Maintenance' and 'Capacity for space heating' could explain, as predictors, 56.3% of the variability in perceived behavioral control. Hypothesis H04 [*The capacity of the system for hot water supply can support/impede residents' perceived behavioral control toward operating the heat pump system automatically*] is supported.

Behavioral beliefs and control beliefs related to the thermal output of the heat pump system were good predictors of attitude and perceived behavioral control respectively which indicated the essence of the thermal output of the heat pump system in influencing residents' behavior.

The social norm failed to predict residents' intention toward operating the heat pump system automatically. It is worth noticing that the HVAC Company can play an important role before the handover phase (as found from residents' response on normative beliefs). This role, however, is weakened in the use phase as the role of neighbors and family became more important. Especially if residents face problems with the system, they will consult their neighbors and family. Hypothesis H03 [*Social referents will influence residents' intention toward operating the heat pump system automatically*] is rejected.

As mentioned above, residents' responses on intention, attitude and perceived behavioral control were dispersed indicating that the system, according to the residents, performed differently in different dwellings and for different household's conditions. This variation is caused by demographic aspects, thermal comfort preferences or experience residents gained during the period they used the system.

Household' size had a clear influence on how residents experienced and dealt with the heat pump system. Bigger households evaluated the attitude and the intention to operate the heat pump system negatively. They reported also to have boosted for hot water, to meet their needs as the capacity of the heat pump was insufficient. Boosting for hot water resulted more energy consumption and consequently extra payment for electricity bills. Moreover, households of 3 persons or more reported lower intentions to operate the heat pump system automatically and frequently boosting for hot water. Also households with small children suffered from the limited capacity of the system as they reported lower intention to operate the heat pump system automatically and to boost for hot water. Both the size and the composition of households influenced the interactions between the residents and their heat pump system. Hypothesis H05 [*The size of the household will influence residents' behavioral intentions toward operating the heat pump system automatically*] is supported.

Interviewee's education level showed positive associations with the attitude and the perceived behavioral control toward automatically operating of the heat pump system. High-educated interviewees, on average, boosted less frequently for space heating and for hot water. High -educated residents belong, according to Roger's theory of innovation diffusion, to the early adopters. This group could be characterized by openness to adopt new technologies and flexibility to deal with their limitations. Hypothesis H07 [*Highly educated residents will evaluate the performance of the heat pump system more positive than the other residents' profiles*] is supported.

Thermal comfort preferences revealed strong relationships with behavioral beliefs, attitude, perceived behavioral c and intention. Residents who preferred higher indoor temperature evaluated behavioral beliefs, attitude and perceived behavioral control toward the automatically operating the heat pump system negatively. They also boosted for accelerated space heating. Residents were recommended to maintain an indoor temperature of 21℃, which is also the optimum temperature output of the system. Only 43.7% of the residents reported a preferred indoor temperature equal or lower than the recommended temperature which indicates that some discrepancy between residents' preferences and the system output. Hypothesis H06 [*Residents with different thermal preferences will evaluate the performance of the heat pump system differently*] is supported. The frequency residents opened the ventilation openings has also a relationship with residents' evaluation of the system. The more residents positively evaluated the performance of their system, in other words boosted less for space heating, on space heating, the more frequently they opened the ventilation openings (use them properly). This means that residents closed the ventilation openings when the system failed to meet their thermal preferences creating an unhealthy indoor air.

The period residents used their heat pump system had no positive effect on their evaluation of perceived behavioral control. In contrast, the longer residents used the heat pump system the more they negatively evaluated the perceived behavioral control indicating that residents failed to develop new habits or become familiar with the system.

The criteria residents used to choose their dwellings did not relate to their behavior toward automatically operating of the heat pump system. Residents who considered 'sustainability' did not show different behavioral belief. Residents may set environmental goals that are not related to the operating of heat pump automatically, this corresponds to results found by [Gatersleben et al., 2002]. Residents who considered 'energy saving' did not show different behavioral beliefs toward automatically operating of the heat pump system as it may be offset by the rebound effect. Also knowledge about the heat pump system failed to influence residents' beliefs toward operating of the heat pump system automatically. Hypothesis H08 [*Knowledge about the heat pump system will not have any direct influence on the behavioral intention toward operating the heat pump system automatically*] is supported.

Residents self reported past behavior was, just as the intention, strongly correlated to the attitude and perceived behavioral control. Residents who formed a positive attitude toward the automatically operating of the heat pump system and had positive perceived behavioral control operated the heat pump system automatically resulting in lower energy consumption and consequently lower energy bills. Hypothesis H9 [*Residents will deviate from the automatically operating of the heat pump system if the system doesn't meet their needs resulting in lower energy efficiency*] is supported.

The willingness to have the heat pump as heating systems in dwellings is strongly influenced by residents' attitude, perceived behavioral control and intention to operate the heat pump system automatically. Also positive experience (in terms of automatically operating, boosting for space heating and boosting for hot water) seemed to have positive influence on accepting the heat pump as heating system in dwellings. Hypothesis 10 [*Positive experience about the heat pump system will positively influence its acceptance among the residents*] is supported.

Residents of De Caaien differed in their beliefs, demographic aspects, knowledge-level and thermal preferences; they formed different households' profiles. The HVAC Company has implemented a one-size heat pump system for all dwellings and all households' profiles. The system, unfortunately, failed to meet needs and expectations of the different households' profiles. Especially families with children, large households (three persons or more) and residents who preferred higher temperatures (> 21℃) faced difficulties in operating the heat pump system automatically. They were forced to deviate from the automatic mode, the most sustainable and energy saving way, resulting in higher energy consumption and lower satisfaction levels.

Recommendations

Restricting the capacity of the heat pump system for environmental or financial considerations will theoretically reduce the environmental impact and the energy consumption but will, however, not cover the different households' profiles. This will force the residents to operate the heat pump system improperly resulting in higher energy consumption, higher environmental impact, higher energy bills and consequently lower satisfaction-level. Repeat The behavior of the residents, in this case, will offset the gains of energy efficiency and environmental measures. The capacity of the heat pump system for hot water and for space heating should be designed to cover a broader range of households' profiles. The heat pump system should operate automatically but effectively meaning. Residents however, should have the possibility to have more control on their thermal environment. When designing the HVAC system more attention should be paid for choosing the components of the system individually as well as comprehensively. The components should properly perform as individual parts but they have also to complement each other. The floor heating system should be able to compensate the cold air coming from the ventilation system.

6. Discussion and Conclusions

6.1 Introduction

In this thesis we dealt with the success of sustainable residential district projects from both the project management as well as the psychological perspective. We provided new insights into project success criteria for sustainable residential district projects and introduced new project success factors that can support success in these projects. We introduced also new insights into residents' needs, expectations and behavioral aspects that can influence residents' behavior toward sustainable heating systems. And then, we explained how residents interact with their heating systems. In this Chapter, the results of this research are comprehensively discussed. The research limitations, considerations and the generalization of the research results are also discussed. Recommendations for further research are introduced.

6.2 Discussion

In Chapter 2, Figure 2-4 was introduced. The figure illustrated the positioning of residents in the complex network of using natural sources, energy generation, energy consumption, HVAC systems and the related social factors. The figure, as concept, was used as starting point to position this research in the study domain. The figure was also helpful to indicate issues related to the management approach and to the role of residents in sustainable residential district projects.

For the purpose of this research some considerations were taken and some limitations were chosen. In this section we will discuss those considerations and limitations. The generalization of the results will be discussed and some recommendations for future research will suggested.

6.2.1 Considerations and limitation of the research

For the first part of this research a case study method was carried out. One of the criteria used to select the cases was that data from ***post-occupancy evaluations are available and accessible.*** This criterion was essential for the full understanding of the studied cases. The criterion was also essential to make the cases comparable and the whole research executable. However, this criterion has limited the number of visited cases.

The second part of this research dealt with residents' behavior, needs, expectations and perceptions toward sustainable HVAC systems in sustainable residential districts. The research provided better insight into aspects related to residents' expectations, needs and perceptions in relation to sustainable HVAC systems. The research provided also detailed information about how residents interacted with their HVAC systems. As the theory of planned behavior suggests, we used a questionnaire to ***investigate a specific behavior toward specific heating system*** (automatically operating of the heat pump system) in one project (De Caaien). This limitation may restrict the generalization of the results.

The first remark about this limitation is that ***the specific project characteristics, specific technical considerations*** and possible system imperfections might influence residents' behavior toward operating the heat pump system automatically. However, results regarding residents' needs, expectations and perceptions could be generalized. Also results on how residents behave in case of insufficient space heating and hot water supply could be generalized.

The second remark concerns ***some considerations in the questionnaire***. For the purpose of this research, data were collected about the composition of the household e.g. size, number of adults or number of little children. These data were used to find associations between the different households' profiles and the performance of the system on hot water supply. Children (and also adults) differ in age, lifestyle (habits related to taking a shower) and their activities (sport, school, work, unemployed) resulting in countless profiles. The UN defined a child as "a human being below the age of 18 years". Concerning hot water consumption there is, however, great differences between a child of 2 and a child of 18. In the questionnaire, we included a question about the number of adults and children in the family without referring to their age. The interviewees were free to say how much adults or children live the dwelling.

6.2.2 Generalization of the research results

This research composed of two parts; success in sustainable residential district projects and the interaction between residents of sustainable residential districts and their sustainable heating system. The first part of this research was mainly based on a case study approach using six European sustainable residential district projects. Cases differ in size, geographical characteristics, project conditions and project organizations. ***This approach enabled us to provide more readily accepted results than other research approaches*** [Verschuren and Doorewaard, 2005]. We suggest then that success criteria and success factors found in this research could be accepted for other sustainable residential district projects.

For the second part of this research we chose a survey approach. Our case, De Caaien, was selected as an advanced sustainable residential district. De Caaien aimed at achieving an EPC norm between 0.4 and 0.45. This was about 50% less than the legally obliged EPC norm at that time. In the year 2015 an EPC of 0.4 will be obligated for all new residential projects which means that our ***current case a good representative of the projects in 2015***. Our dataset consisted of 135 interviews having a response of 69,7% and covering (59.3% rental housing and 40.7% privately owned), (9.6% flats and 90.4% terraced houses), (residents' age ranged between 23 and 68 having a mean of 38.5 year) and (49.6% women and 50.4% men). The research results could be generalized for Dutch sustainable residential districts where a heat pump system implemented and the EPC= 0.4.

6.2.3 Future research

The first recommendation for future research is to ***expand the behavioral studies with a real-time residents' behavior***. In house-installed energy monitors can supply information about how the heat pump system is actually operated; set-point temperature, demand of hot water, outside temperature, frequency of boost-actions and energy consumption of the heat pump individually. By using this approach insight in residents' behavior could be deepened.

The second recommendation is to ***study similar behavior*** (automatically operating of the heat pump system) ***in other projects with various project specific considerations*** and conditions. So the design of the heat pump as sustainable heating system may be optimized.

The third recommendation is to ***study similar behavior in the same project in a longitudinal research***. Such a study will clearly explain residents' behavior toward automatically operating of the heat pump system and how it changes in the course of time.

In this research we investigate residents' interaction with the heat pump system. The forth recommendation is to study residents' behavior toward other ***parts of sustainable HVAC systems especially ventilation***. This will provide a more completely view of residents' interaction with their HVAC system. And deliver a better link between behavior and HVAC and health.

These recommendations bring another issue up for discussion, namely performing longitudinal post-occupancy evaluation studies. Such studies can elucidate factors that can influence actual performance in the use phase and how factors relevance can change in the course of time.

6.3 Recommendations

In this section three recommendations are made for the construction industry, sustainability regulations, and environmental assessment tools.

Construction industry

There are many construction disciplines involved in the construction process of sustainable residential district projects. Although many construction professionals claim to work cooperatively in building teams, there are many points to be improved.

The concept of sustainable dwellings is usually unknown to new residents moving in. Also to some building professionals energy saving technologies are unknown, especially for brokers and commercial marketing. The extent to which residents are (dis)satisfied partly depends on what they expect from their dwellings or from used technologies. Residents' satisfaction depends also on how dwellings are promoted and sold by brokers and marketing agencies. Residents' expectations regarding project outcomes should be managed well. ***This research recommends proper communication of the strengths and limitations of sustainable measures and technologies in sustainable residential district projects.***

Energy companies may suggest low estimated monthly bills that may not be met in the use phase resulting in high dissatisfaction among the residents. It is, thus, very important to suggest relative high monthly estimated bills to avoid higher energy bills at the end of the year and consequently dissatisfied residents. It is also essential to ***provide home energy monitors as standard measure in sustainable dwellings.*** This makes residents more aware about the consequences of their behavior toward the heat system in terms of energy consumption and energy costs. However, this recommendation is based on our observations during the interviews with the residents and not as direct result of analyzing the data statistically.

Sustainability regulations

To achieve sustainability goals in the construction industry, strict buildings codes have been imposed by governments. In the Netherlands, the energy efficiency of dwellings and buildings is measured by the energy performance coefficient EPC. The current EPC=0.6 will be lowered to EPC=0.4 in 2015, which is a big step. DeCaaien is an innovative project having, theoretically, an EPC=0.4-0.45 which was about 0.4 lower than the obligated EPC at the permission phase. De Caaien could be considered as an example of dwellings that have to meet the EPC requirements in 2015. In De Caaien the capacity of the HVAC system is reduced to meet the EPC=0.4 requirements. This research showed that the HVAC system in De Caaien was, on average, not able to meet the requirements of the occupants in a sustainable way. The research showed also that meeting the EPC requirements was to the detriment of thermal comfort and supply of hot water. ***We recommend introducing an obligated post-occupancy evaluation for all new residential projects during the first five years after the handover phase.*** We also recommend ***delaying the introduction of lower EPC*** norms until the residential projects, according the EPC=0.6, are assessed on actual energy efficiency, residents' satisfaction and cost-efficiency. We also ***recommend unlinking the EPC norm to the capacity of the HVAC system for hot water***; hot water consumption is the most unpredictable factor in dwelling. ***We recommend also implementing adaptable heating systems.*** Such heating systems can suit different household' profiles and can be changed as households change.

Environmental assessment tools

Environmental assessment has recently emerged as an essential component of the construction process toward sustainability. The field of building environmental assessment has developed quickly during the last two decades introducing several building environmental assessment methods world-wide such as (BREEAM, UK and NL), (LEED, US) and (CASBEE, JP). The purpose of sustainability assessment methods is twofold: (i) to assess buildings and assign sustainability-labels and (ii) to be used by building professionals as guidance for sustainable design. This research pointed out that assigning an environmental assessment label to a residential district project cannot ensure sustainable performance in the use phase. This research recommends environmental assessment agencies in two ways; first on aspects related to the residents and second on assigning the certificate. BREEAM-NL Nieuwbouw 2011 consists of nine categories including Health that is weighted by 15% of the total 100% score. The thermal comfort is classified under Health having two credits of the total 6 credits for dwellings. The total weight is accounted for thermal comfort is 5%. A project that doesn't score well on thermal comfort and health may have a good final score on sustainability. This research emphasized the essence of the thermal comfort to achieve better performances on sustainability, satisfaction and energy consumption. ***We recommend assigning more credits to thermal comfort as issue and higher weights to Health as category.***

The second recommendation concerns the current practice that awarding credits is based on theoretical calculations and showed evidences. This research showed that a sustainable design can turn out to be unsustainable in practical use. ***We recommend introducing a complementary BREEAM certificate to be awarded only if dwellings and implemented technologies work properly in the use phase.*** If not, the BREEAM certificate could be withdrawn.

6.4 Conclusions

Success assessment of sustainable residential districts is mainly based on technical aspects and on aspects related to residents' satisfaction. There is a lack of information regarding comprehensive evaluation of project performance from both managerial and psychological perspectives. Moreover, understanding managerial as well as psychological aspects in addition to existing technical aspects will create a better insight into success of sustainable residential districts. This research filled this gap and explained success in sustainable residential districts by answering four research questions:

- **Research question 1:** Which project success criteria are relevant to assess success in sustainable residential district projects?
- **Research question 2:** Which managerial project factors can influence success in sustainable residential district projects?
- **Research question 3:** How can technical specifications implemented in dwellings influence residents' behavior in sustainable residential district projects?
- **Research question 4:** How can residents-related factors influence the performance of sustainable residential district projects?

To answer the first and the second questions a case study research was used. For the case study, the 'Project-specific Formal System Model' is used as research model. Published reports about six European best practice sustainable residential districts have been used to find success criteria and success factors. These districts are (i) BedZED in London, England, (ii) Bo-01 in Malmö, Sweden, (iii) Eco-Viikki in Helsinki, Finland, (iv) EVA-Lanxmeer in Culemborg, (v) Kronsberg in Hannover, Germany and (vi) Vauban in Freiburg, Germany.

To answer the third and the forth questions, 135 face to face interviews were held with residents of DeCaaien; a Dutch sustainable residential district. The theory of planned behavior is used as theoretical framework. The design of the questionnaire is based on a formal questionnaire and practical instructions as suggested by the theory. For this aim, a pilot research was performed to find out which behavioral elements are relevant for this study. The behavioral elements were then used to design the research questionnaire.

Project success criteria

Project success criteria are principles by which a project result can be judged. Project success criteria can be derived from considerations related to People (Residents), Planet (Environment), and Profit (Company); the so called three P's. Project characteristics and conditions influence the balance between these three P's and consequently the relevance of project success criteria. All found success criteria in the literature are related to these three P's. This study shows many agreements with this assertion.

For sustainable residential district projects, the Golden Triangle criteria (Budget, Schedule and Quality) are insufficient to assess project success. This research revealed that health, technology transfer and environmental friendliness including five sub criteria (i) efficient use of energy, (ii) efficient use of water, (iii) efficient mobility, (iv) local sourcing policy, and (v) achieving social mix are needed criteria to assess project success.

Project success factors

Project success factors are any circumstances, facts or influences which contribute to a project result. This study presented new project factors which can support success in sustainable residential district projects.

Timely and effective involvement of the residents in the construction process is an important factor to support project success. In the design-phase of the construction process, (potential) residents are essential to provide the project organization with input in relation to their needs, expectations and preferences. In the use-phase, residents are essential to ensure that the project performs as it should do. ***Guiding of the residents*** to use their sustainable dwellings properly and ***monitoring*** dwellings' performance are essential project success factors in the use phase. These factors were mentioned earlier by other studies as individual success factors. This research suggests considering these factors together as a group.

Knowledge transfer is essential for success in sustainable residential districts. ***Initiating project platforms***, where project team members and (potential) residents can learn and exchange their knowledge, is a success factor. This success factor is also related to ***'Timely and effective involvement of project end-users. Large scale projects should be phased in and realized in sub-projects where the same project team members are involved. This will create knowledge by learning.***

Environment-related project ***objectives should be realistically formulated*** based on available knowledge and experience among the project team members. Ambitious environment-goals that go beyond the building codes may force project members to implement strict efficiency measures such as strict parking policy or strict energy measures. If these measures do not ***match residents' beliefs***, needs and expectations, gains from these measures may be offset by residents' behavior. Too strict measures may force residents to behave in different, often not sustainable, way.

Full-developed and proven sustainable heating and hot water systems at the district level are reliable and deliver sufficient thermal comfort. Individual energy demands which depend on residents' demographic and household variables could be leveled off in an efficient way. Unproven innovations could turn out negatively in the use phase and cause dissatisfaction among the residents.

Sustainable residential districts require high quality products and qualified suppliers/ contractors. Any unnecessary restriction on ***sourcing policies***, products or suppliers, can turn out negatively in the use phase. Quality, health and comfort should be considered when sourcing materials. ***Past performance***, knowledge and skills related to sustainability issues should be considered when selecting suppliers and contractors. ***Good project leadership*** and ***support from local government and project management*** are also essential for project success.

The project-specific Formal System model could explain project success/failure and could confirm the relevance of the extracted factors. Generally speaking, the six cases could be considered as successful projects. However, assessing project success in multi-objectives large-scale projects is often complicated as not all project objectives could be achieved.

Failure of some project objectives partly dependents on residents related factors. Especially objectives related to energy consumption were not fully met in the use-phase due to mismatching with residents' behavior. Residents contribute, thus, strongly to achieving project success in sustainable residential districts. Project factors related to residents are the most relevant factors for supporting or impeding project success.

Residents' behavior

The theory of planned behavior is used as theoretical framework to answer research questions 3 and 4. Face-to-face interviews were hold with 135 residents of De Caaien (a Dutch residential district). The design of the questionnaire is based on a formal questionnaire and practical instructions as suggested by the theory. For this aim, a pilot research was performed using interviews with 11 residents to find out which behavioral elements are relevant for this study. The behavioral elements were then used to design the research questionnaire. In De Caaien, a ground water source heat pump is implemented to for space heating and for hot water supply.

This research revealed that ***behavioral beliefs and control beliefs related to the thermal output of the heat pump system were good predictors of attitude*** and perceived behavioral control respectively. This indicated the essence of the thermal output of the heat pump system in influencing residents' attitude and perceived behavioral control.

Residents' attitude and perceived behavioral control explained the intention and consequently their behavior toward operating the heat pump system automatically. Social norms had no effect on explaining residents' behavior. On average, the intention to automatically use the heat pump system was positive. In spite of that residents quite differed in their responses indicating different residents' perceptions toward the operation of the system and ***that the system performed differently in different household conditions.***

Residents' behavioral beliefs related to space heating and hot water supply are the most important beliefs to explain residents' attitude toward operating the heat pump system automatically. These beliefs are related to residents' ***physiological needs and are overvalued to the environment and cost saving beliefs.*** Residents' attitudes toward automated operation of the heat pump system were evaluated slightly positive.

The capacity of the heat pump system (for space heating and for hot water) and ***technical problems impeded residents' perceived behavioral control*** and consequently the intention to operate the heat pump system automatically. Residents' perceived behavioral control toward automated operation of the heat pump system was, on average, neutrally evaluated. They believed also that the system responded too slowly on their interventions and to changes in outside temperatures. Residents believed that they had to deviate from the automatically operating of the system if the system was not able to support their needs. Control belief 'system response' has been failed to predict perceived behavioral control as only 'capacity for hot water', 'maintenance' and 'capacity for space heating' could explain it.

The social norm failed to predict residents' intention toward operating the heat pump system automatically. It is worth noticing that the installation company may play an important role before the handover phase. This role, however, is weakened in the use phase as the role of neighbors and family became more important. Especially if residents face problems with the system, they will consult their neighbors and family.

Household' size had a clear influence on how residents experienced and dealt with the heat pump system. Households with little children evaluated the attitude and the intention to operate the heat pump system negatively. Also three person's households reported to have boosted for hot water. The results showed that the capacity of the heat pump system was insufficient to meet hot water needs of the two groups. ***Boosting for hot water resulted more energy consumption and consequently extra payment for electricity bills.*** Both the size and the composition of households have influenced the interaction between the residents and their heat pump system.

Interviewee's education level showed positive association with the attitude and the perceived behavioral control toward automatically operating of the heat pump system. High educated interviewees, on average, boosted less frequently for space heating and for hot water. Highly educated residents belong to the early adopters. This group could be characterized by openness to adopt new technologies and flexibility to deal with limitations of new technologies.

Thermal comfort preferences revealed to have strong relationships with behavioral beliefs, attitude, perceived behavioral control and intention. Residents who preferred higher indoor temperature negatively evaluated behavioral beliefs, attitude and perceived behavioral control toward the automatically operating the heat pump system. They also boosted for rapid increase of room temperature. Residents were recommended to maintain an indoor temperature of 21°C, which is also the optimum temperature output of the system. Only 43.7% of the residents reported a preferred indoor temperature equal or lower than the recommended temperature. This indicates some discrepancy between residents' preferences and the system output.

Residents' use of the ventilation openings has also a relationship with residents' evaluation of the system. The more residents positively evaluated the performance of their system and less boosted for space heating and for hot water, the more frequently they will open the ventilation openings (use them properly). This means that residents closed the ventilation openings when the system failed to meet their thermal preferences, which creates an unhealthy indoor air.

The duration residents used their heat pump system had no positive effect on their evaluation of perceived behavioral control. In contrast, the longer residents used the heat pump system the more they negatively evaluated the perceived behavioral control indicating that residents failed to develop new habits or to become familiar with the system.

The criteria residents used to choose their dwellings had no effect on their behavior toward automatically operating of the heat pump system. Residents who considered 'sustainability' did not show different behavioral beliefs because residents can set environmental goals that are not related to the operating of heat pump automatically. Residents who considered 'energy saving' did not show different behavioral beliefs toward automatically operating of the heat pump system. This could be explained by the fact that residents may consider energy saving, on the one side, and operating the heat pump system, on the other side, as two different and unrelated environmental goals.

Also knowledge about the heat pump system failed to influence residents' beliefs toward operating of the heat pump system automatically.

Residents self-reported past behavior was, just as the intention, strongly correlated to the attitude and perceived behavioral control. Residents who formed a positive attitude and a positive perceived behavioral toward the automatically operating of the heat pump system, operated the heat pump system automatically. This behavior resulted in lower energy consumption and lower energy bills. ***Residents who operated the heat pump system automatically have mentioned to accept the heat pump*** as heating system whereas residents who boosted for hot water have mentioned not to accept the heat pump.

Previous paragraphs showed several aspects that can influence residents' behavior. Residents of De Caaien differed in their beliefs, demographic characteristics, knowledge-level and thermal preferences, and can therefore be considered as different households' profiles. The installation company has implemented a one-size heat pump system for all dwellings and all households' profiles. ***The system, unfortunately, failed to meet needs and expectations of the different households' profiles.*** Especially families with children, large households (more than two persons) and residents who prefer higher temperature (then 21℃) faced difficulties in operating the heat pump system automatically. They were forced to deviate from the automatic operation, the most sustainable and energy saving way, resulting in higher energy consumption and lower satisfaction levels.

Restricting the capacity of the heat pump system for environmental or financial considerations can theoretically reduce the environmental impact and the energy consumption but cannot cover the different households' profiles. This will force the residents to operate the heat pump system improperly resulting in higher energy consumption, higher environmental impact, higher energy bills and consequently lower satisfaction-level. The behavior of the residents, in this case, will offset the gains of energy efficiency and environmental measures. The capacity of the heat pump system for hot water and for space heating should be designed to cover a broader range of households' profiles. The heat pump system should operate automatically but also effectively. Residents however, should have the possibility to have more control on their thermal environment. When designing the HVAC system more attention should be paid to choose the components of the system as separate parts well as one whole system. The components should perform properly as individual parts but they have also to complement each other. The floor heating system should be able to compensate for the cold air coming from the ventilation system.

6.5 Research contribution

This research has been done in two knowledge domains; total quality management covering project success and environmental psychology covering residents' interaction with sustainable HVAC systems in sustainable residential districts. The research contributed to the current state of the art of these two domains in five ways. In this section, the research contributions will be highlighted.

In total quality management literature 'project success' is often used in a general manner. This research provided new insights into the project success criteria and their relevance for sustainable residential district projects. ***This research regrouped the existing success criteria in the literature and provided three essential groups of criteria.*** These groups are: the Golden-Triangle group, the Environment group and the Satisfaction group. This is the first contribution.

There are many project success factors in the literature. However, these factors are often, just like success criteria, too general to be valid for specific project. ***This research provided, based on a comparison of six European projects, a list of new project success factors and indicated its relevance for sustainable residential district projects.*** By adding these factors to the Formal system model, an adapted model is generated that explains success in sustainable residential district projects. This was the second contribution.

The second part of the research was based on knowledge from the environmental psychology domain in general and the theory of planned behavior in particular. Residents' behavior toward automatically operating of the heat pump system was investigated. Based on a formal questionnaire ***a new questionnaire was developed and validated.*** The new questionnaire was the third contribution of this research.

The results of this research provide ***new insights into residents' behavioral beliefs related to the interaction between them and their sustainable heat pump system.*** These beliefs enable us to explain how residents interact with sustainable HVAC systems and consequently influencing their performance on sustainability and energy consumption. This was the fourth contribution.

Finally, this research has ***confirmed the applicability of the theory*** for this specific behavior, and the predictability of the theory for this behavior. This was the fifth contribution.

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Appendix 1: Description of six best practices

BedZED

The **Bed**dington **Z**ero fossil **E**nergy **D**evelopment (BedZED) is the UK's largest sustainable mixed-use district; residential as well as work use (Figure A-1-1). BedZED is situated on a brownfield site in the Hackbridge, south London. BedZED was completed in 2002 and comprises 92 homes, community facilities and 1,405m^2 of commercial workspace. The total area is 1.4 hectare and about 220 residents live in BedZED. BedZED was initiated by BioRegional and ZEDfactory and developed by the Peabody Trust.

Main project objectives
The main objective of BedZED was to develop a fossil energy neutral district. BedZED was designed to prove that high quality of life is possible while living within sustainable lifestyles. Sustainable measures for reducing environmental impact have been taken. These measures included use of 100% renewable energy, reduction of energy for heating homes up to 90%, use of passive solar heating, use of photovoltaic panels for feeding of 40 electric vehicles, reduction of potable water up to 50%, on-site ecological water treatment, wind-powered ventilation systems, low embodied energy materials, recycled timber, reused structural steel, bike facilities and recycling facilities.

Figure A-1-1*: BedZED, London, UK*

Implemented technologies
The original technical concept of BedZED consisted of the following elements:

- Improved thermal building envelope and passive solar energy gains,
- Heat recovery wind cowls and night cooling,
- Woodchips-fired combined heating plant (CHP) for space heating, hot water and electricity,

- Gray Water Treatment Plant,
- Photovoltaic panels for feeding electrical cars,

Figure A-1-2 shows how naturally ventilation and passive solar energy measures are implemented in BedZED. Figure A-1-3 shows the Woodchips-fuelled combined heat and power plant implemented in BedZED.

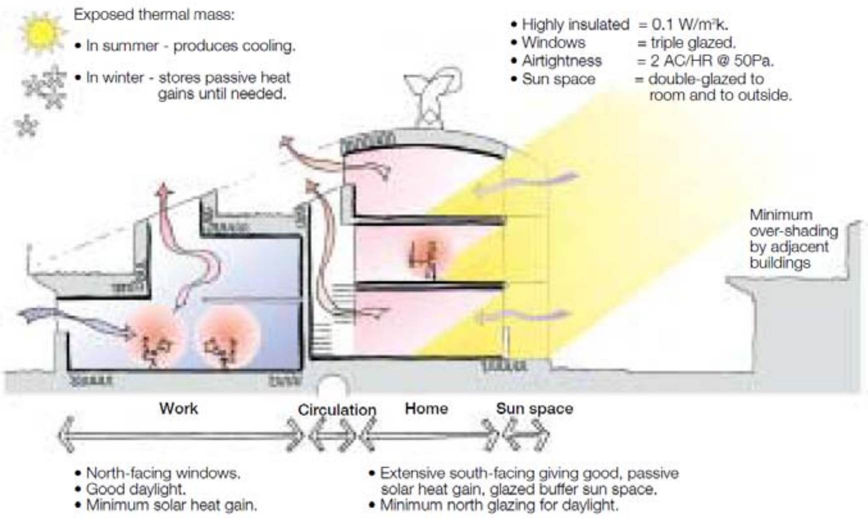

***Figure A-1-2**: Building physics in BedZED [Twin, 2003]*

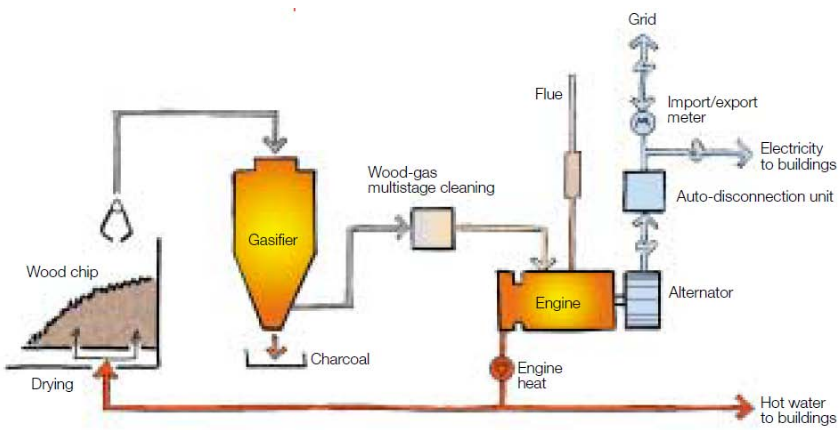

***Figure A-1-3**: Woodchips-fired combined heat and power [Twin, 2003]*

Partners and driving factors

In 1995, before starting BedZED, Bill Dunster Architects (now ZEDfactory) has developed his own Hope House. The Hope House is a low energy live/work unit in which Bill Dunster and his family live. In 2000, Bill Dunster Architects has developed BedZED in partnership with the Peabody Trust, ARUP and BioRegional Development Group. London Borough of Sutton had a crucial role in the project as they awarded the land to BedZED according to the sustainability content of the project. This was the first time that sustainability higher priority got than price. BedZED’s residents are responsible for the district’s activities as well as the management of the common facilities. The main driving factor of BedZED was environment.

Problems in use

The CHP system is failed down due to technical and financial problems. Residents mentioned overheating problems in the summer. The GWTP is replaced due to high operational costs.

Bo-01

Bo-01 represented the first stage of the development of Västra Hamnen (translated: The Western Harbor) in the city of Malmö in Sweden (Figure A-1-4). Bo-01 is pronounced "bo-noll-ett" means "to dwell" and 01 indicates the year the district was opened. The Bo-01 area covers 22 hectares and provides ca 1567 dwellings for around 2350 inhabitants.

Bo-01 shows a large number of architectural solutions, forming a sustainable urban environment. Sustainable measures were taken including energy efficiency, renewable energy supply, ecology, resources and water management. The project has become one of the best large-scale sustainable residential districts in Europe and has got international attention and recognition. The Bo-01 site, a brownfield site, was contaminated by the heavy industrial activities in the harbor area. However, the site location close to the sea and next to the city center was considered as a positive aspect of this development.

***Figure A-1-4**: Bo-01 Malmö, Sweden [Persson and Tanner, 2005]*

Main project objectives

The main project objectives were: (i) soil reclamation as Bo-01 was built on a brownfield area, (ii) using 100% renewable energy resources, (iii) minimizing the environmental impact of transport and realizing attractive green cycle way network and footpaths, and (iv) promoting ecological construction and biodiversity.

Implemented technologies

The energy demand for heating was covered though an underground aquifer which serves heat storage for the winter months as well as use of sea water, complemented with solar collectors. Energy demand for electricity is partly supplied by a wind power plant, photovoltaic panels, and bio-gas fired combined heat and power from the wastes. Figure A-1-5 shows the district energy concept in Bo-01.

Transport needs and car dependency were minimized by creation of pedestrian paths, cycle way network, good connecting to the public transport and all daily facilities were centrally located in the district. All materials were selected according to their reusability and had to meet requirements of the Swedish Chemicals Inspectorate for hazardous materials. Ecology was considered by creation of green walls and roofs and places for different plants and animals.

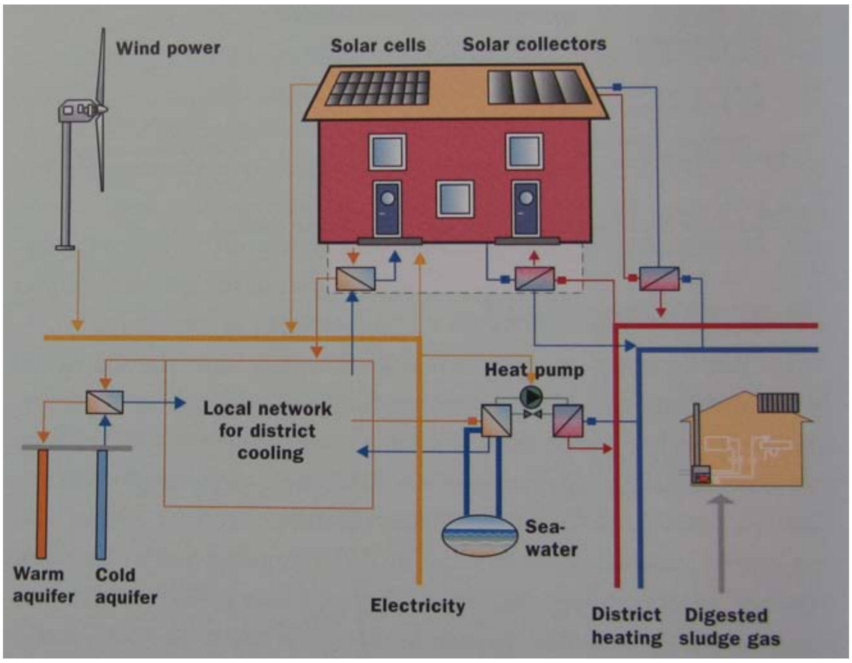

Figure A-1-5*: the district energy concept of Bo-01 [Persson and Tanner, 2005]*

Partners and driving factors

Bo-01 was initiated by the City of Malmö through its environmental policy; the City of Malmö has won the first European price for the development of renewable energy in 2000 "Campaign for Take-off Award". Bo-01 was financially supported by the Swedish Energy Agency. Sydkraft (now E-on) was in charge of the electricity, heating and biogas production and distribution in Bo01. The Quality Program of the project was developed by Bo-01AB in cooperation with construction companies. Bo-01AB was an organizing committee for the Bo01 City of Tomorrow trade fair. Concepts of highly energy efficient houses were developed by Lund University.

The housing exhibition was the driving factor for Bo-01. The exhibition was an opportunity to develop the ecological commitments of the City of Malmö.

Problems in use

Theoretical calculations of energy consumptions and practical results differed widely due to lack of past experience. Residents complained about the quality of the indoor air.

Eco-Viikki

Eco-Viikki was built in the period between 1999 and 2004 at 8 Km to the north east of Helsinki in Finland (Figure A-1-6). The site is situated close to the Viikki Science Park and Helsinki University's Bio-center. Eco-Viikki consisted of about 787 houses for about 1900 inhabitants. The site has also the following facilities: two daycare centers, health center, clubhouse, school and local shop. About 50% of the houses are owner-occupied, 15% are rented, and the remaining 35% houses are right-of-occupancy homes. For this environmentally sound project, a strict ecological plan was created mostly related to the following issues: reduction of pollutants, use of natural resources, healthiness, biodiversity and nutrition.

Figure A-1-6*: Eco-Viikki, Helsinki, Finland [Hakaste et al., 2005]*

Main project objectives

The main objectives of Eco-Viikki were: (i) to gain experience for future ecological projects and to support the National Program of Ecologically sustainable buildings, (ii) to reduce the CO_2 emissions by 20% compared to a conventional building, (iii) to reduce consumption of drinking water, and (iv) to create healthy dwellings.

Implemented technologies

Photovoltaic panels were implemented for electricity production, 2 local solar heating schemes cover a total of 10 properties; low energy housing design; co-generation-based district heating network. A total of 1400m2 of solar heat-collecting panels were implemented to making it the largest such project in Finland.

Partners and driving factors

This project was initiated in 1993 by the Finnish Ministry of the Environment, the Association of Architects and the Municipality of Helsinki. A design competition for the creation of Eco-Viikki was launched where 91 applications were received. Other main partners were City of Helsinki, Technology Agency Tekes and the European Commission. A project platform was launched involving the implementation team (developer, architects, engineers, contractors) and users who were involved in the project.

The driving factors were the government ecological program and the planning competition that was organized by the City of Helsinki.

Problems in use

The main problems in the use phase are related to residents' complaints about the quality of indoor air and thermal comfort condition.

EVA-Lanxmeer

EVA-Lanxmeer is situated near the train station of Culemborg in the Netherlands. EVA-Lanxmeer is situated in a protected water extraction area of about 38 hectares. Special permission was needed to use this site as construction site. The municipality has made an exception and given the needed permissions because of its sustainability context. EVA-Lanxmeer consists of 250 dwellings accommodating 250 residents.

The first ideas of EVA-Lanxmeer originated to the year 1995 in the form of the EVA foundation. The EVA Foundation was cooperation between the municipality of Culemborg and a group of scientists having diverse environmental knowledge backgrounds (Figure A-1-7). The aim of this cooperation was to realize a sustainable mixed-use district where residents have a central role in the design and planning.

Figure A-1-7: *EVA-Lanxmeer, Culemborg, the Netherlands [photo: Marleen Kaptein]*

Main project objectives

EVA-Lanxmeer was intended to gain knowledge and experience on sustainable mixed-use districts. For EVA-Lanxmeer an eight-track sustainability program was formulated. This program included: urban development, land-use, transport, natural sources, water and sewage, energy efficiency, stakeholders involvement and knowledge transfer.

The main idea behind EVA-Lanxmeer was to promote sustainable development using a bottom up approach and integration of software (environment and behavior) and hardware (technologies). The main eight sustainability-tracks formed the reference for this project.

Implemented technologies

Dwellings in EVA-Lanxmeer are thermally well insulated and benefited from passive energy gains. The original HVAC concept consisted of: (i) a heat pump system, (ii) a bio-gas fired combined heat and power plant heat pump system for space heating and hot water supply,

(iii) photovoltaic panels for electricity generation, (iv) solar collecting panels and (v) two small-size wind turbines, Figure A-1-8.

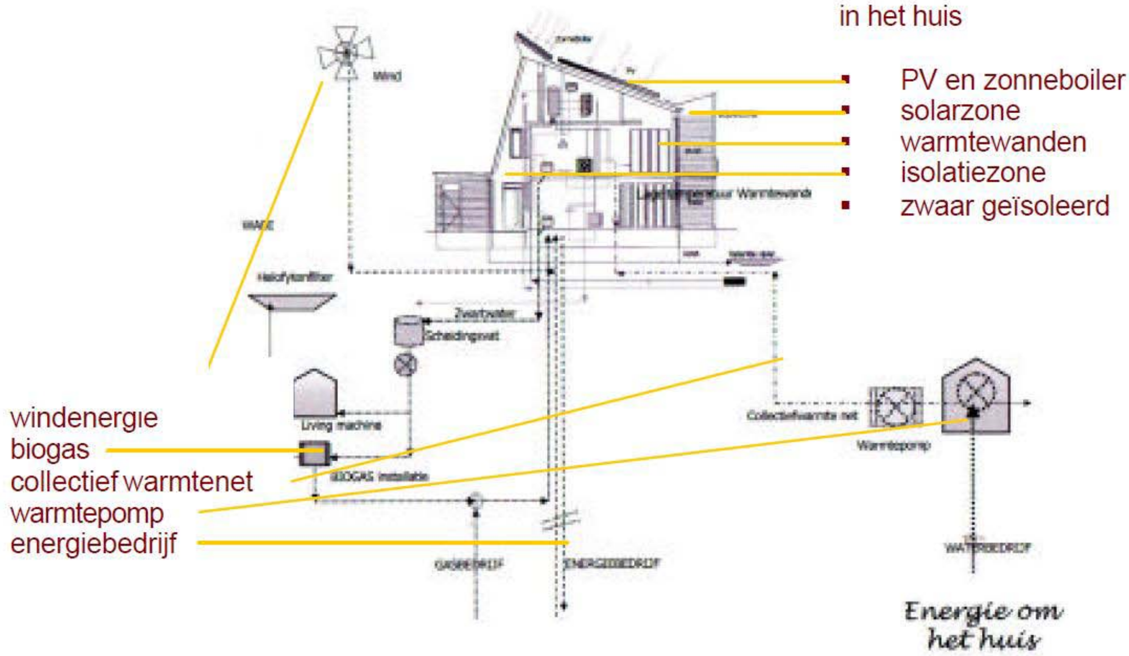

***Figure A-1-8**: HVAC concept in EVA-Lanxmeer [Goed, 2002]*

Partners and driving factors

Residents of EVA-Lanxmeer were the most important factor of this project; really project champions. They initiated the original idea and designed the plan along with the involved construction professionals. The Municipality of Culemborg and the Ministry of housing, Spatial Planning and the Environment have played an important role in facilitating the plan and granting the needed permissions.

Problems in use

Energy consumption results are higher than theoretically calculated and feeding the CHP system by biogas and installing two small-size wind turbines have been failed.

Kronsberg

Kronsberg is situated in the South-East of the City of Hannover. This site was the last remaining area in Hannover that met the conditions for a large-scale building project (Figure A-1-9). The site benefited of the close and well arranged public transport. Two planning competitions were held and the first concept was presented in 1994 for the entire area. Kronsberg aimed at proving that utopias are reality and sustainability is possible. Sustainability aspects considered in Kronsberg included: energy efficiency, water management, social, economy, transport, natural sources and ecology.

Figure A-1-9: *Project Kronsberg, Hannover, Germany*

Main project objectives

The main objective was to build a district with a good mix of functions (residences, leisure and cultural facilities, commerce and agriculture) by taking into account environment protection. Energy efficiency objectives included minimizing of energy demand up to the passive house level (15kWh/m2/year), minimizing domestic electricity consumption by 30% and using renewable energy resources. An extended water efficiency concept based on a semi-natural rainwater management system for the entire area including a combination of infiltration, retention and controlled releases. Landscape planning included a large public green space on the edge of the settlement and a border boulevard between the site and the adjoining countryside, parks and inner courts.

Implemented technologies

Dwellings in Kronsberg are thermally well insulated and benefited from passive energy gains. Some dwellings have been built according to the passive house concept having energy consumption for heating of 15kWh/m2/year. The HVAC concept consisted of two CHP systems are used to for space heating and hot water supply. Electricity efficient appliances were used including 77 washing machines, 106 dish washers, 122 refrigerators and 5615 low energy light bulbs. Figure A-1-10 shows the CHP system implemented in Kronsberg.

Figure A-1-10*: CHP plant in Kronsberg, Hannover*

Partners and driving factors

Both the Municipality of Hannover and the Department of Lower Saxony (Neder Saksen) played an important role in initiating and funding this project. The Kronsberg Consulting Committee, consisted of teachers, researchers, environment protection agencies representatives, was in charge of providing the needed knowledge for this project. The Kronsberg Environmental Liaison Agency (KUKA) was in charge of environmental communication between the project stakeholders and the education and training programs.

There were three driving factors: (i) the World Exposition EXPO2000 that was planned in Hannover and has given a boost for this project, (ii) the environmental policy of the City of Hannover and (iii) the considerable housing shortage in Hannover in the early 1990s.

Problems in use

Residents have complained about the indoor air quality and have mentioned overheating problems.

Vauban

Vauban is built on a former area of a French military site about 3 km in the South of Freiburg (Figure A-1-11). Although the implementation phase was started in 1997, the first ideas of Vauban originated to the year 1993. Raising public environmental awareness was regarded as key component for the design and planning of Vauban. All issues of sustainability, including energy, social housing, ecology, water efficiency, car-use, parking and landscape.

Main project objectives

The most important objective of Vauban was to realize an environmentally sound district using a co-operative and a participatory approach to meet ecological, social, economical and cultural conditions. Other objectives were: (i) promoting social sustainability by ensuring the balance of social groups and realizing social housing mix (rent and sell), (ii) promoting car dependency by promoting walk and cycle paths, good connection to the public transport, creation of car free zones and common paid parking facilities, (iii) promoting energy efficiency by realizing low and energy passive dwelling, and (iv) improving water efficiency by collecting and reusing rainwater.

Figure A-1-11*: Project Vauban, Freiburg, Germany*

Partners and driving factors

The following acting bodies were active in Vauban. Project Group Vauban represented the local authorities and was in charge of the administrative coordination with the Vauban project. The City Council Committee was the main platform for information exchange, discussion and decision making processes. The Committee was consisted of representatives from municipal political parties, the administration and further consultative members such as Forum Vauban. Forum Vauban was an association approved as official coordinator of citizens' participation by the City in early 1995. Besides to these partners, a large number of construction and manufacture companies and semi-governmental agencies were involved in the project.

There were two driving factors for this project: the need to provide accommodation to the growing number of inhabitants and the adoption of the ‘learning while planning’ principle by the project organization and the city of Freiburg.

Problems in use

Vauban has failed on achieving the social mix as it failed to attract different residents’ profiles. Residents have complained about the indoor air quality and have mentioned overheating problems.

Appendix 2: The project specific Formal System Model

This text is cited from [White and Fortune, 2009].

The project-specific Formal System Model

The paper argues that many of the best-known project management methods and techniques are inadequate because they fail to take sufficient account of complexity and uncertainty and do not consider “soft” risks, in particular those arising from a project’s environment. The Formal System Model has only reached a specialized audience because it has required fluency in the language of systems thinking and familiarity with its concepts. This paper also has shown that the Formal System Model has strengths that are missing in many of these methods and techniques. For example, it has shown that it is capable of identifying potential weaknesses in a project’s structure, allowing the environment in which a project is based to be evaluated and allowing the viewpoints of those direct and indirectly affected by a project to be taken into account.

This paper has presented a version of the model that can be used by Project Managers and other practitioners to identify actual or potential weaknesses in a project’s structure or processes and to look for difficulties in the relationships between the project and the context in which it is or will be taking place. In so doing it has provided a robust means of helping them to avoid failure.

Model comparison

There are three steps to use the model:

1. Use the model component and their failure modes (as presented in Table A-4-1) should be investigated for the specific project.
2. Use the information obtained by the step 1 to adjust Figure A-4-1.
3. Compare the Project-specific version of the Formal System Model with the model in the second step. The discrepancies and omissions exist will be used to explain project success/failure.

Table A-4-1: Mapping of the failings associated with projects onto the components of the Formal System Model

Formal System Model	Failure modes
Environment disturbs	Failure to: manage uncertainty; learn from past experience; recognize political influence; take account of the effect of inflation; consider national interests
Wider system boundary	Failure to: consider effect/views of end-users
Wider system	Failure to: consider context; consider values, beliefs, culture which "surrounds" project; appreciate motives of organization in which project is placed; consider effect of resistance to change; consider effect of established communication paths; consider effect of company structure, policy, culture and incentives
Formulates initial design	Failure to: identify requirements/develop unambiguous objectives; produce business plan; produce realistic schedule; establish tracking systems; formulate clear measures of performance; develop communication plan
Provides resources and legitimates area of operation	Failure to: supply satisfactory resources; provide adequate/sophisticated technology; provide reliable technology; provide adequate budget; employ/use properly qualified/experienced staff
Legitimates area of operation	Failure to: adapt new systems to old ways of working; understand underlying technology
Makes known expectations	Failure to: control project; gain commitment of those involved; make clear that consensus is impossible to achieve; ensure human issues considered before technical issues; communicate benefits of project to staff
Communication channels	Failure to: provide effective channels of communication; acknowledge projects do not follow liner route to completion; acknowledge project characterized by complexity
System boundary	Failure to: consider project from different viewpoints – at least from organization, project team, and end-users; trust opinions provided by wider system
Decision-making subsystem	Failure to: assign teams; decide on training needs
Decides on transformations	Failure to: direct teams
Provides resources and legitimates operations	Failure to: provide adequate training; define underlying technology
Makes known expectations	Failure to: control resistance to change
Report to	Failure to: inform on state of components; report misleading information; report on progress
Supplies performance information	Failure to: report on progress; inform organization that project should be abandoned if problems insurmountable without fear of admitting defeat
Attempts to influence environment	Failure to: influence end-users; persuade end-users to accept change

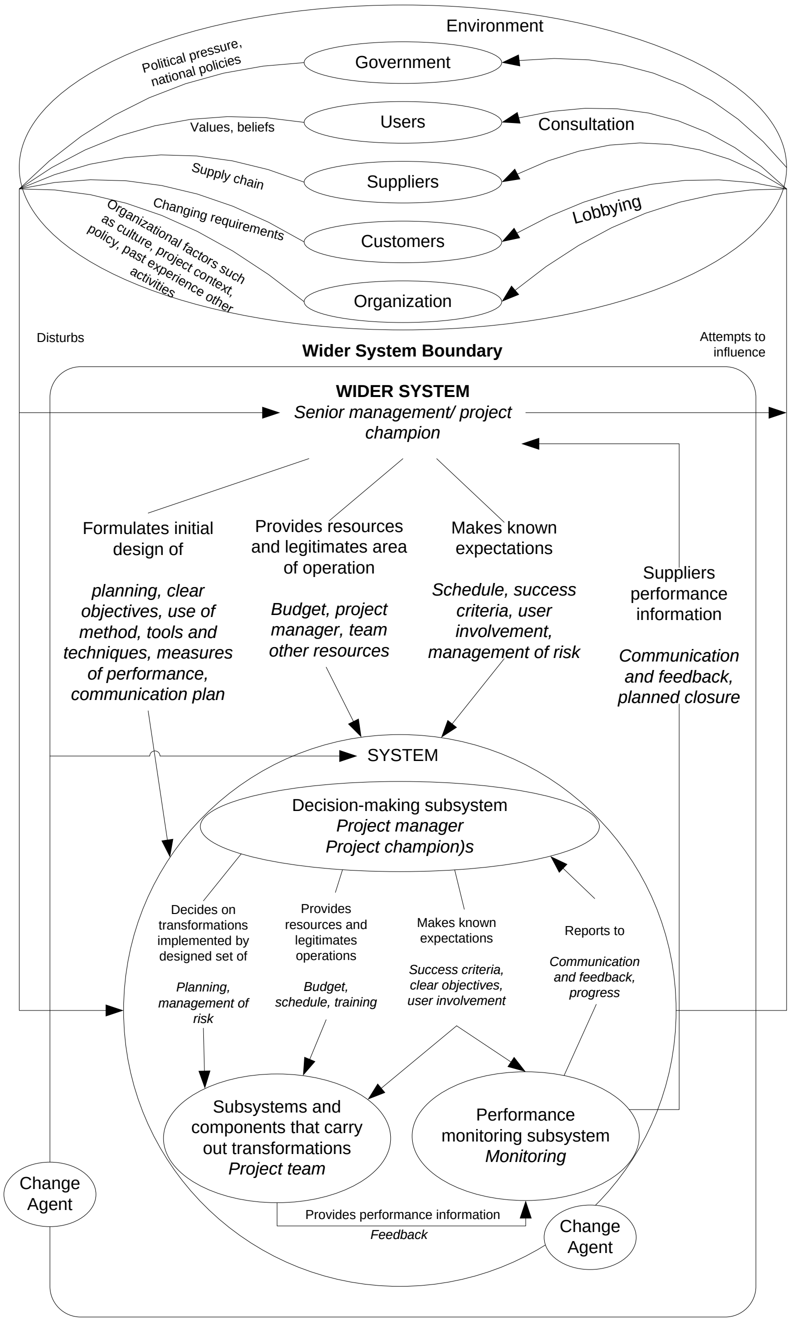

Figure A-4-1: *Project-specific version of the Formal System Model*

Appendix 3: DESCRIPTION OF THE HVAC SYSTEM IN DE CAAIEN

De Caaien

De Caaien is a sustainable residential district situated to the south east of The Hague in the Netherlands. De Caaien comprises of 290 dwellings covering both rental housing and privately owned dwelling. De Caaien is built on the former airfield of the Fokker factory, Figure A-3-1.

Figure A-3-1: *De Caaien, the Hague, the Netherlands [www.decaaien.nl]*

Main project objectives

The PCS-hybrid home is designed to have low energy consumption and low CO_2 emissions; about 40% lower than a reference dwelling. In terms of energy performance coefficient (EPC), dwellings in De Caaien have, theoretically, an average EPC=0.42 which was lower than the obligated EPC=0.8 in 2008.

Partners and driving factors

Dwellings in de Caaien are built by Dura Vermeer according to the principles of the PCS-hybrid concept. The PCS-hybrid concept is developed in cooperation with Itho b.v. and 'Giesbers & van der Graaf'. Two social housing corporations have been involved in De Caaien, Amvest and Ceres. Ceres represented the 'Stichting Woonformatie Ypenburg'; a local foundation that was in charge of sustainable buildings in the district of Ypenburg. The driving factor was to be the first BREEAM-Certificated housing project in the Netherlands.

Implemented technologies
The HVAC concept used in 'De Caaien' consists of [Dura Vermeer, 2008] (Figure A-3-2):

- a ground source heat pump in combination with heat exchangers
- a 150liter storage tank for hot water in combination with electrical heating element,
- thermostat for controlling heat pump
- floor low-temperature distribution heating system, and
- a CO_2-demand automatic-control ventilation system in combination with pressure sensitive background ventilators.

A ground-source heat pump is a device that uses ground water as heat storage and provides dwellings with space heating, space cooling and hot water. In the winter, the heat pump in 'De Caaien' extracts heat from ground water at a depth of 120m, using plastic pipes heat exchangers. The average temperature of ground water at that depth is about 12 °C. The heat pump raises the temperature of extracted water up to 25-40 °C (depends on outdoor temperature). Heated water is then used to supply space heating through a floor heating system and to supply domestic hot water. In the summer, the system pumps 12 °C water in the distribution system to cool dwellings.

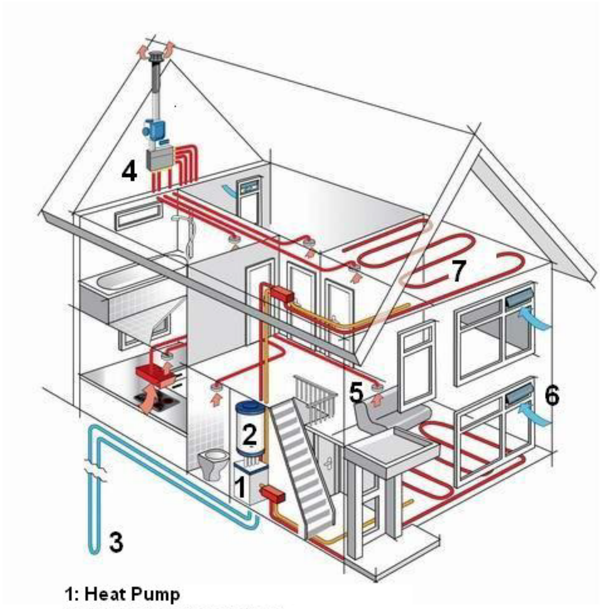

Figure A-3-2:: *The HVAC system in 'De Caaien'*

Theoretically, heat pumps have high coefficient of performance (COP>5) that means that heat pump uses 80% energy from the surroundings and 20% from electricity to deliver 100% heat. Heat pumps can thus reduce CO_2 emissions produced by dwelling. During the night the heat pump warms the domestic hot water storage tank.

All dwellings in 'De Caaien' are provided by a 150liter hot water storage tank. The tank is hanged above the heat pump in a special room in the ground floor. The heat pump raised daily the water temperature up to 62 °C to avoid Legionella problems. According to the installation company, a 150 liter hot water tank is sufficient for an average daily use of a household.

Residents can control both space heating and hot water generation by means of a thermostat. The thermostat enables the residents to:

- regulate the room temperature to a desired set-point,
- use ‘BOOST’ option to accelerate space heating and water heating,
- choose ECO-stand for preparing hot water only in the night or Comfort-stand for preparing hot water all the day,

Residents were advised to use the heating system automatically at the ECO-stand to avoid high electricity bills. Automatically using of the heat pump means having consistent set-point and not using the BOOST option for heating or for hot water.

The floor heating system in ‘De Caaien’ consists of plastic pipes embedded in the floor to provide space heating or cooling. The combination of heat pump and floor heating is a slow-responding system. Approximately, the heat pump needs one day to heat up the living room one °C.

CO2 demandFlow installed in ‘De Caaien’ is fully automatic, demand-controlled ventilation system. However, residents can control the amount of ventilated air by means of a control panel. The ventilation system ventilates the dwellings individually according to the CO2 level in each room. The system ventilates the bathroom according to both the CO2 as well as the humidity levels. Fresh air is provided by the opening above the windows.

Problems in use
Residents complained about the thermal comfort conditions in dwellings and high electricity bills.

Appendix 4: The formal questionnaire

This sample questionnaire is for illustrative purposes only. Also, most published articles contain information about the questionnaire used, but the items shown in this sample questionnaire or employed in prior research may not be appropriate for your behavior, population, or time period. Formative research is therefore required to construct a questionnaire suitable for the behavior and population of interest. If beliefs are to be assessed, they must be elicited anew from a representative sample of the research population. Similarly, items designed to directly assess the theory's constructs must be validated prior to construction of the final questionnaire.

The following description of questionnaire construction is based on the appendix in Fishbein, M., & Ajzen, I. (2010). Predicting and changing behavior: The reasoned action approach.

Formative Research

Defining the Behavior

Before any work can begin, the behavior of interest must be clearly defined in terms of its target, action, context, and time elements.

Example: Physical Activity

We could define exercise behavior as follows: "Exercising for at least 20 min, three times per week for the next three months."

Specifying the Research Population

The population of interest to the investigators also must be clearly defined.

Example: Post-operative patients

In this example, only individuals who have just undergone major heart surgery would be included in the research population.

Formulating Items for Direct Measures

Five to six items are formulated to assess each of the major constructs in our reasoned action model: Attitude, perceived norm, perceived behavioral control, and intention. Seven-point bipolar adjective scales are typically employed. Sample items assessing intention and each aspect of attitude, perceived norm and perceived control are shown below; additional items and instructions to the participants are shown in the sample questionnaire (Part II). Participants are asked to circle the number that best describes their personal opinions. Note that the items are formulated to be exactly compatible with the behavioral criterion and to be self-directed.

Attitude: Instrumental and experiential aspects

My exercising for at least 20 minutes, three times per week for the next three months would be:

bad :__1__:__2__:__3__:__4__:__5__:__6__:__7___: good

pleasant :__1__:__2__:__3__:__4__:__5__:__6__:__7___: unpleasant

Perceived norm: Injunctive and descriptive aspects

Most people who are important to me approve of my exercising for at least 20 minutes, three times per week for the next three months.

agree :__1__:__2__:__3__:__4__:__5__:__6__:__7___: disagree

Most people like me exercised for at least 20 minutes, three times per week in the three months following their major heart surgery

unlikely :__1__:__2__:__3__:__4__:__5__:__6__:__7___: likely

Perceived behavioral control: Capacity and autonomy aspects

I am confident that I can exercise for at least 20 minutes, three times per week for the next three months.

true :__1__:__2__:__3__:__4__:__5__:__6__:__7___: false

My exercising for at least 20 minutes, three times per week for the next three months is up to me

disagree:__1__:__2__:__3__:__4__:__5__:__6__:__7___: agree

Intention

I intend to exercise for at least 20 minutes, three times per week for the next three months.

likely :__1__:__2__:__3__:__4__:__5__:__6__:__7___: unlikely

Past Behavior

In the past three months, I have exercised for at least 20 minutes, three times per week.

false :__1__:__2__:__3__:__4__:__5__:__6__:__7___: true

Administering a Pilot Questionnaire

Eliciting Salient Beliefs

A small sample of individuals representative of the research population (post-operative patients) is used to elicit readily accessible behavioral outcomes, normative referents, and control factors. Although the participants can be assembled in groups, the elicitation is done individually in a free response format.

Instructions: Please take a few minutes to tell us what you think about the possibility of exercising for at least 20 min, three times per week for the next three months. There are no right or wrong responses; we are merely interested in your personal opinions. In response to the questions below, please list the thoughts that come immediately to mind. Write each thought on a separate line. (Five or six lines are provided for each question.)

Behavioral outcomes

- What do you see as the advantages of your exercising for at least 20 minutes, three times per week for the next three months?
- What do you see as the disadvantages of your exercising for at least 20 minutes, three times per week for the next three months?
- What else comes to mind when you think about exercising for at least 20 minutes, three times per week for the next three months?

Normative referents

When it comes to your exercising for at least 20 minutes, three times per week for the next three months, there might be individuals or groups who would think you should or should not perform this behavior:

- Please list the individuals or groups who would approve or think you should exercise for at least 20 minutes, three times per week for the next three months.
- Please list the individuals or groups who would disapprove or think you should not exercise for at least 20 minutes, three times per week for the next three months.
- Sometimes, when we are not sure what to do, we look to see what others are doing. Please list the individuals or groups who, after major heart surgery, are most likely to exercise for at least 20 min, three times per week for the three months following surgery.
- Please list the individuals or groups who, after major heart surgery, are least likely to exercise for at least 20 min, three times per week for the three months following surgery.

Control factors

- Please list any factors or circumstances that would make it easy or enable you to exercise for at least 20 min, three times per week for the next three months.
- Please list any factors or circumstances that would make it difficult or prevent you from exercising for at least 20 min, three times per week for the next three months.

Constructing Sets of Modal Salient Beliefs

A content analysis of the responses to the above questions results in lists of modal salient outcomes, referents, and control factors. These lists are used to construct items to be included in the final questionnaire, as described below.

Formulating Direct Measures

The pilot questionnaire, in addition to eliciting salient outcomes, normative referents, and control factors also includes the items that were formulated to obtain direct measures of attitude toward the behavior, perceived norm, and perceived behavioral control. The data obtained are used to select reliable and valid items for use in the final questionnaire. Each set of items designed to directly assess a given construct should have a high degree of internal consistency (e.g., a high alpha coefficient), and the measures of the different constructs should exhibit discriminant validity. To achieve these aims, one or two items may have to be dropped for each construct. Confirmatory factory analysis is one means of evaluating the quality of the scales to be included.

Finally, the pilot questionnaire also includes measures of any background factors or other variables the investigator believes may be interest for the behavior under investigation. These could be demographic characteristics (age, gender, ethnicity, level of education, income), personality characteristics (e.g., conscientiousness) or other individual difference variables (e.g., self-esteem, sensation seeking), social structure variables (e.g., rural vs. urban residence), and so forth. The results of the pilot study also allow us to evaluate the utility of these background measures: Do the personality and other individual difference measures have high internal consistency? If not, can internal consistency be improved by deleting some of the items? Do any of the background variables correlate with intentions or past behavior? If not, should they be retained in the final questionnaire?

Preparing a Standard Questionnaire

We are now ready to put together the standard questionnaire to be used in the main study. This questionnaire includes the following elements.

(1) Behavioral Beliefs and Outcome Evaluations

With respect to each salient behavioral outcome, items are formulated to assess the strength of the behavioral beliefs and the evaluation of the outcome.

Sample Outcome: Faster recovery from my surgery

Behavioral belief strength

My exercising for at least 20 min, three times per week for the next three months will result in my having a faster recovery from my surgery.

likely :__1__:__2__:__3__:__4__:__5__:__6__:__7___: unlikely

Outcome evaluation

My having a faster recovery from my surgery is

good :__1__:__2__:__3__:__4__:__5__:__6__:__7___: bad

(2a) Injunctive Normative Beliefs and Motivation to Comply With respect to each salient normative referent, items are formulated to assess the strength of the injunctive normative belief and the motivation to comply with the referent individual or group.

Sample injunctive normative referent: My doctor

Injunctive normative belief strength

My doctor thinks that

I should :__1__:__2__:__3__:__4__:__5__:__6__:__7___: I should not exercise for at least 20 min, three times per week for the next three months.

Motivation to comply

When it comes to matters of health, I want to do what my doctor thinks I should do.

agree :__1__:__2__:__3__:__4__:__5__:__6__:__7___: disagree

(2b) Descriptive Normative Beliefs and Identification with the Referent

With respect to each relevant salient referent, items are formulated to assess the strength of the descriptive normative belief and the identification with the referent individual or group.

Sample descriptive normative referent: My friends

Descriptive normative belief strength

Most of my friends who have undergone major heart surgery have exercised for at least 20 min, three times per week for the three months following surgery.

false :__1__:__2__:__3__:__4__:__5__:__6__:__7___: true

Identification with the referent

When it comes to matters of health, how much do you want to be like your friends?

very much :__1__:__2__:__3__:__4__:__5__:__6__:__7___: not at all

(3) Control Beliefs and Power of Control Factors

With respect to each salient control factor, items are formulated to assess the likelihood that the factor will be present and the factor's power to facilitate or impede performance of the behavior.

Sample control factor: Physical strength

Control belief strength

I expect that I will have physical strength in the next three months.

likely :__1__:__2__:__3__:__4__:__5__:__6__:__7___: unlikely

Power of control factor

Having physical strength would enable me to exercise for at least 20 min, three times per week for the next three months.

disagree :__1__:__2__:__3__:__4__:__5__:__6__:__7___: agree

(4) Direct Measures

Another element of the final questionnaire are the direct measures developed on the basis of the pilot data to assess attitudes, perceived norm, perceived behavioral control, and intentions. In addition, the questionnaire will usually also include a measure of past behavior, as described earlier.

(5) Other Measures

The final questionnaire also includes measures of all demographic characteristics, personality variables, and other background factors the investigator decided to retain.

(5) Behavior

Three months following administration of the questionnaire (or another period as defined by the behavioral criterion), the participants are re-contacted and asked to report whether they had exercised for at least 20 min, three times per week for the past three months.

Appendix 5: Questionnaire: 'Sustainable Heating Systems'

Questionnaire: Sustainable Heating Systems

Eindhoven University of Technology

a study about residents' behavior toward sustainable heating systems

Technische Universiteit Eindhoven University of Technology

General questions about the heat pump ***(only one option is possible)***

TQ.1 **Which of the following heating devices is comparable to the heat pump system?**	☐ 1- Electrical heating radiator ☐ 2- District heating ☐ 3- Condensing boiler ☐ 4- Refrigerator ☐ 5- I don't know

TQ.2 **Which of the following issues describes the output of the heat pump system?**	☐ 1- Only space heating. ☐ 2- Only hot water supply. ☐ 3- Space heating and hot water supply. ☐ 4- Space heating and cooling. ☐ 5- Space heating, cooling and hot water supply. ☐ 6- Space heating, cooling, hot water supply and ventilation

TQ.3 **Which of the following statements is true?**	☐ 1- My heat pump system generates electricity ☐ 2- My heat pump system uses ground water to heat or cool my dwelling ☐ 3- The heat pump system could be compared to a refrigerator. ☐ 4- Al statements above are true ☐ 5- Al statements above are false

TQ.4 **Which of the following statements is true?**	☐ 1- The heat pump should operate continuously. ☐ 2- Having a consistent set-point will decrease electricity consumption of the heat pump. ☐ 3- The heat pump is comparable to a refrigerator. ☐ 4- All statements above are true. ☐ 5- All statements above are false.

TQ.5 **Which energy resource is mainly needed to operate the heat pump system?**	☐ 1- Electricity ☐ 2- Natural gas ☐ 3- Air ☐ 4- Oil ☐ 5- Water ☐ 6- I don't know

TQ.6 **How much did you think to save (to pay extra) when using the heat pump system in comparison to you previous dwelling?**	☐ 1- > €300 extra ☐ 2- Between €151 and €300 extra ☐ 3- Between €1 and €150 extra ☐ 4- No saving, no paying extra ☐ 5- Between €1 and €150 saving ☐ 6- Between €151 and €300 saving ☐ 7- > €300 saving

Residents' preferences

WS.1 **What are the most important criteria you used when choosing your dwelling?** *(you may choose maximal **<u>Three</u>** criteria)*	☐ 1- Location of De Caaien ☐ 2- Sustainability ☐ 3- Energy saving ☐ 4- Architecture ☐ 5- Ground plan ☐ 6- Size of the dwelling ☐ 7- Price ☐ 8- Others

WS.2 **What is the preferred temperature in the living room in the winter when you are in home?**	— — , — C°

WS.3 **What is the set-point temperature of the thermostat in the winter when you are in home?**	— — , — C°

WS.4 **What is the preferred temperature in the living room in the summer when you are in home?**	— — , — C°

WS.5 **What is the set-point temperature of the thermostat in the summer when you are in home?**	— — , — C°

Outcome Evaluations

How desirable or undesirable are the following issues?
(only one option is possible)

Outcome Evaluation.1 **For me to protect the environment is**	☐ 1- Extremely undesirable ☐ 2- Undesirable ☐ 3- Slightly undesirable ☐ 4- Neither undesirable nor desirable ☐ 5- Slightly desirable ☐ 6- Desirable ☐ 7- Extremely desirable

Outcome Evaluation.2 **For me to save costs is**	☐ 1- Extremely undesirable ☐ 2- Undesirable ☐ 3- Slightly undesirable ☐ 4- Neither undesirable nor desirable ☐ 5- Slightly desirable ☐ 6- Desirable ☐ 7- Extremely desirable

Outcome Evaluation.3 **For me to have a perfect indoor air temperature in the winter is**	☐ 1- Extremely undesirable ☐ 2- Undesirable ☐ 3- Slightly undesirable ☐ 4- Neither undesirable nor desirable ☐ 5- Slightly desirable ☐ 6- Desirable ☐ 7- Extremely desirable

Outcome Evaluation.4 **For me to have a perfect indoor air temperature in the summer is**	☐ 1- Extremely undesirable ☐ 2- Undesirable ☐ 3- Slightly undesirable ☐ 4- Neither undesirable nor desirable ☐ 5- Slightly desirable ☐ 6- Desirable ☐ 7- Extremely desirable

Outcome Evaluation.5 **For me to have sufficient hot water at every moment is**	☐ 1- Extremely undesirable ☐ 2- Undesirable ☐ 3- Slightly undesirable ☐ 4- Neither undesirable nor desirable ☐ 5- Slightly desirable ☐ 6- Desirable ☐ 7- Extremely desirable

Behavioral beliefs

How likely are the following statements?
(only one option is possible)

Behavioral Belief.1 **Operating the heat pump system automatically will help me to protect the environment.**	☐ 1- Very unlikely ☐ 2- Unlikely ☐ 3- Somewhat unlikely ☐ 4- Neither likely nor unlikely ☐ 5- Somewhat likely ☐ 6- Likely ☐ 7- Very likely

Behavioral Belief.2 **Operating the heat pump system automatically will help me to save cost.**	☐ 1- Very unlikely ☐ 2- Unlikely ☐ 3- Somewhat unlikely ☐ 4- Neither likely nor unlikely ☐ 5- Somewhat likely ☐ 6- Likely ☐ 7- Very likely

Behavioral Belief.3 **Operating the heat pump system automatically will help me to ensure perfect indoor temperature in the winter.**	☐ 1- Very unlikely ☐ 2- Unlikely ☐ 3- Somewhat unlikely ☐ 4- Neither likely nor unlikely ☐ 5- Somewhat likely ☐ 6- Likely ☐ 7- Very likely

Behavioral Belief.4 **Operating the heat pump system automatically will help me to ensure perfect indoor temperature in the summer.**	☐ 1- Very unlikely ☐ 2- Unlikely ☐ 3- Somewhat unlikely ☐ 4- Neither likely nor unlikely ☐ 5- Somewhat likely ☐ 6- Likely ☐ 7- Very likely

Behavioral Belief.5 **Operating the heat pump system automatically will help me to ensure sufficient hot water.**	☐ 1- Very unlikely ☐ 2- Unlikely ☐ 3- Somewhat unlikely ☐ 4- Neither likely nor unlikely ☐ 5- Somewhat likely ☐ 6- Likely ☐ 7- Very likely

Normative beliefs

How likely are the following statements?
(only one option is possible)

Normative Beliefs.1 **The HVAC company thinks that I should operate the heat pump system automatically**	☐ 1- Very unlikely ☐ 2- Unlikely ☐ 3- Somewhat unlikely ☐ 4- Neither likely nor unlikely ☐ 5- Somewhat likely ☐ 6- Likely ☐ 7- Very likely

Normative Beliefs.2 **My neighbors think that I should operate the heat pump system automatically**	☐ 1- Very unlikely ☐ 2- Unlikely ☐ 3- Somewhat unlikely ☐ 4- Neither likely nor unlikely ☐ 5- Somewhat likely ☐ 6- Likely ☐ 7- Very likely

Normative Beliefs.3 **My family thinks that I should operate the heat pump system automatically**	☐ 1- Very unlikely ☐ 2- Unlikely ☐ 3- Somewhat unlikely ☐ 4- Neither likely nor unlikely ☐ 5- Somewhat likely ☐ 6- Likely ☐ 7- Very likely

Normative Beliefs.4 **Environmental groups think that I should operate the heat pump system automatically**	☐ 1- Very unlikely ☐ 2- Unlikely ☐ 3- Somewhat unlikely ☐ 4- Neither likely nor unlikely ☐ 5- Somewhat likely ☐ 6- Likely ☐ 7- Very likely

Motivation to Comply

How strong is the influence of the following references?
(only one option is possible)

Motivation to Comply.1 **Generally speaking, how much do you care what the <u>HVAC company</u> thinks you should do?**	☐ 1- Very few ☐ 2- Few ☐ 3- Slightly few ☐ 4- Neutral ☐ 5- Slightly much ☐ 6- Much ☐ 7- Very much

Motivation to Comply.2 **Generally speaking, how much do you care what your <u>neighbors</u> think you should do?**	☐ 1- Very few ☐ 2- Few ☐ 3- Slightly few ☐ 4- Neutral ☐ 5- Slightly much ☐ 6- Much ☐ 7- Very much

Motivation to Comply.3 **Generally speaking, how much do you care what your <u>family</u> thinks you should do?**	☐ 1- Very few ☐ 2- Few ☐ 3- Slightly few ☐ 4- Neutral ☐ 5- Slightly much ☐ 6- Much ☐ 7- Very much

Motivation to Comply.4 **Generally speaking, how much do you care what <u>environmental groups</u> think you should do?**	☐ 1- Very few ☐ 2- Few ☐ 3- Slightly few ☐ 4- Neutral ☐ 5- Slightly much ☐ 6- Much ☐ 7- Very much

Control Beliefs
How likely are the following statements?
(only one option is possible)

Control Belief.1 **The capacity of the heat pump for <u>hot water</u> supply is insufficient.**	☐ 1- Very unlikely ☐ 2- Unlikely ☐ 3- Somewhat unlikely ☐ 4- Neither likely nor unlikely ☐ 5- Somewhat likely ☐ 6- Likely ☐ 7- Very likely

Control Belief.2 **The capacity of the heat pump for space <u>heating</u> is insufficient.**	☐ 1- Very unlikely ☐ 2- Unlikely ☐ 3- Somewhat unlikely ☐ 4- Neither likely nor unlikely ☐ 5- Somewhat likely ☐ 6- Likely ☐ 7- Very likely

Control Belief.3 **The capacity of the heat pump for space <u>cooling</u> is insufficient.**	☐ 1- Very unlikely ☐ 2- Unlikely ☐ 3- Somewhat unlikely ☐ 4- Neither likely nor unlikely ☐ 5- Somewhat likely ☐ 6- Likely ☐ 7- Very likely

Control Belief.4 **The heat pump needs much <u>maintenance</u>.**	☐ 1- Very unlikely ☐ 2- Unlikely ☐ 3- Somewhat unlikely ☐ 4- Neither likely nor unlikely ☐ 5- Somewhat likely ☐ 6- Likely ☐ 7- Very likely

Control Belief.5 **The heat pump needs <u>adjustments</u>.**	☐ 1- Very unlikely ☐ 2- Unlikely ☐ 3- Somewhat unlikely ☐ 4- Neither likely nor unlikely ☐ 5- Somewhat likely ☐ 6- Likely ☐ 7- Very likely

Control Belief.6 **The heat pump <u>responses</u> slow.**	☐ 1- Very unlikely ☐ 2- Unlikely ☐ 3- Somewhat unlikely ☐ 4- Neither likely nor unlikely ☐ 5- Somewhat likely ☐ 6- Likely ☐ 7- Very likely

Power of Control Factors

To what extent do you agree with the following statements?

(only one option is possible)

Power of Control Factors.1 **If the capacity of the heat pump system for hot water supply is insufficient, it would make it more difficult for me to operate the heat pump system automatically**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Power of Control Factors.2 **If the capacity of the heat pump system for space heating is insufficient, it would make it more difficult for me to operate the heat pump system automatically**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Power of Control Factors.3 **If the capacity of the heat pump system for space cooling is insufficient, it would make it more difficult for me to operate the heat pump system automatically**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Power of Control Factors.4 **If the heat pump system needs much maintenance, it would make it more difficult for me to operate the heat pump system automatically.**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Power of Control Factors.5 **If the heat pump system needs much adjustment, it would make it more difficult for me to operate the heat pump system automatically.**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Power of Control Factors.6 **If the heat pump system responses slow, it would make it more difficult for me to operate the heat pump system automatically**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Direct measures of Attitude, Social Norm, Perceived behavioral control, Intention and Self-reported Past Behavior.
(only one option is possible)

Attitude.1 **Operating of the heat pump system automatically is …**	☐ 1- Very bad ☐ 2- Bad ☐ 3- Slightly bad ☐ 4- Neutral ☐ 5- Slightly good ☐ 6- Good ☐ 7- Very good

Attitude.2 **Operating of the heat pump system automatically is …**	☐ 1- Very ineffective ☐ 2- Ineffective ☐ 3- Slightly ineffective ☐ 4- Neutral ☐ 5- Slightly effective ☐ 6- Effective ☐ 7- Very effective

Attitude.3 **Operating of the heat pump system automatically is …**	☐ 1- Very unpractical ☐ 2- Unpractical ☐ 3- Slightly unpractical ☐ 4- Neutral ☐ 5- Slightly practical ☐ 6- Practical ☐ 7- Very practical

Attitude.4 **Operating of the heat pump system automatically is …**	☐ 1- Very useless ☐ 2- Useless ☐ 3- Slightly useless ☐ 4- Neutral ☐ 5- Slightly useful ☐ 6- Useful ☐ 7- Very useful

Attitude.5 **Operating of the heat pump system automatically is …**	☐ 1- Very unnecessary ☐ 2- Unnecessary ☐ 3- Slightly unnecessary ☐ 4- Neutral ☐ 5- Slightly necessary ☐ 6- Necessary ☐ 7- Very necessary

Attitude.6 **Operating of the heat pump system automatically is …**	☐ 1- Very unpleasant ☐ 2- Unpleasant ☐ 3- Slightly unpleasant ☐ 4- Neutral ☐ 5- Slightly pleasant ☐ 6- Pleasant ☐ 7- Very pleasant

Social Norm.1 **People who are important to me want me to operate the Heat pump system automatically**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Social Norm.2 **It is expected of me that I operate the heat pump system automatically**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Social Norm.3 **I feel under social pressure to operate the heat pump system automatically**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Perceived Behavioral Control.1 **I am confident that I could operate the heat pump system automatically if I wanted,**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Perceived Behavioral Control.2 **The decision to automatically operating the heat pump system is beyond my control,**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Perceived Behavioral Control.3 **For me automatically operating the heat pump system is easy**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Perceived Behavioral Control.4 **Weather I automatically operating the heat pump system or not is entirely up to me**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Intention.1 **I intend to operate the heat pump system automatically**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Intention.2 **I expect to operate the heat pump system automatically**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Intention.3 **I want to operate the heat pump system automatically**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Acceptance.1 **I would like to have a heat pump system in home**	☐ 1- Strongly disagree ☐ 2- Disagree ☐ 3- Slightly disagree ☐ 4- Neutral ☐ 5- Slightly agree ☐ 6- Agree ☐ 7- Strongly agree

Self Reported Past Behavior

(only one option is possible)

Self Reported Past Behavior.1 **How often did the heat pump system operate automatically in your dwelling?**	☐ 1- Never ☐ 2- Very rarely ☐ 3- Rarely ☐ 4- Frequently ☐ 5- Very frequently ☐ 6- Always

Self Reported Past Behavior.2 **How often did you use the 'BOOST' option for quickly space heating?**	☐ 1- Never ☐ 2- Very rarely ☐ 3- Rarely ☐ 4- Frequently ☐ 5- Very frequently ☐ 6- Always

Self Reported Past Behavior.3 **How often did you use the 'BOOST' option for quickly hot water supply?**	☐ 1- Never ☐ 2- Very rarely ☐ 3- Rarely ☐ 4- Frequently ☐ 5- Very frequently ☐ 6- Always

Self Reported Past Behavior.4 **How often did you use additional heating devices for space heating?**	☐ 1- Never ☐ 2- Very rarely ☐ 3- Rarely ☐ 4- Frequently ☐ 5- Very frequently ☐ 6- Always

Self Reported Past Behavior.5 **How often did you operate the heat pump system on the ECO-stand?**	☐ 1- Never ☐ 2- Very rarely ☐ 3- Rarely ☐ 4- Frequently ☐ 5- Very frequently ☐ 6- Always

Self Reported Past Behavior.6 **How often did you operate the heat pump system on the Comfort-stand?**	☐ 1- Never ☐ 2- Very rarely ☐ 3- Rarely ☐ 4- Frequently ☐ 5- Very frequently ☐ 6- Always

Self Reported Past Behavior.7 **How often did you leave the ventilation openings open in winter period?**	☐ 1- Never ☐ 2- Very rarely ☐ 3- Rarely ☐ 4- Frequently ☐ 5- Very frequently ☐ 6- Always

General Questions

PS.1 **The electricity meter readings are**	Low tariff ____kWh Normal tariff ___ kWh

PS.2 **How long do you live in this dwelling?**	…………..year …………..month

PS.3 **Are you female or male?**	☐ 1- Female ☐ 2- Male

PS.4 **How old are you?**	………………year

PS.5 **Type of ownership?**	☐ 1- Rental housing ☐ 2- Privately owned

PS.6 **Household's composition**	…………..Number of adults …………..Number of children

PS.7 **Education?** **(in Dutch and according to the Dutch education system)**	☐ 1- Lager Onderwijs ☐ 2- Lager Beroepsonderwijs ☐ 3- Middelbaar Algemeen Voortgezet Onderwijs ☐ 4- Middelbaar Beroepsonderwijs ☐ 5- Hoger Algemeen Voortgezet Onderwijs ☐ 6- Voorbereidend Wetenschappelijk Onderwijs ☐ 7- Hoger Beroepsonderwijs ☐ 8- Wetenschappelijk Onderwijs ☐ 9- Nooit naar school geweest

THANK YOU FOR YOUR PARTICIPATION.

SUMMARY

Sustainable residential districts: the residents' role in project success

Sustainable residential districts have been realized worldwide. These districts are promoted to be efficient in the use of natural materials and sustainable energy resources. Realization of sustainable residential districts can strongly contribute to achieve environmental objectives as imposed by governmental policies as well as to create good living conditions for people. Sustainable residential districts are quite complex construction projects with special focus on reduction of environmental impact in the use phase. These projects emphasize the essence of the residents' role in achieving project objectives.

A quick scan of already realized sustainable residential districts in Europe revealed that these projects are still not in the mainstream. Moreover, some districts have failed to achieve their sustainability objectives. Frequently mentioned problems are related to complexity in use, dysfunction of unproven technologies, having unrealistic objectives and mismatch with residents needs and expectations.

A literature review on project success revealed that there is a lack of information regarding a comprehensive evaluation of project success from both managerial and psychological perspectives. Moreover, understanding managerial as well as psychological aspects, in addition to existing technical aspects, will create a better insight into success of sustainable residential districts. The review revealed also that there is a need to investigate success criteria for sustainable residential districts. This leads us to the first research question.

Research question 1: Which project success criteria are relevant to assess success in sustainable residential district projects?

Project factors are circumstances or facts which contribute to a project result. They are project specific and are related to project success criteria. The literature review revealed also that there is a need to investigate success factors for sustainable residential districts. This leads us to the second project question.

Research question 2: Which managerial project factors can influence success in sustainable residential district projects?

Most of the objectives of sustainable residential districts are related to decrease consumption of natural resources and to increase energy efficiency. For this aim, sustainable heating, ventilation and air conditioning systems (HVAC) have to be implemented. The way residents use sustainable HVAC systems can strongly influence their performance in the use phase. Technical specifications and design considerations of HVAC systems can strongly influence residents' behavior. Therefore, there is a need to understand how residents act in their technological environment and what motivates them to behave in a pro-environmental way. Hence, there is also a need to understand residents' needs, expectations, perceptions and attitudes toward sustainable HVAC systems. This leads us to the third and forth research questions.

Research question 3: How can technical specifications implemented in dwellings influence residents' behavior in sustainable residential district projects?

Research question 4: How can residents-related factors influence the performance of sustainable residential district projects?

To answer the first and the second questions a literature study and a case study research were used. Chapter 3 introduces an extensive literature review on both project success criteria and project success factors. This review provided better insight into leading researches and mostly used models of success criteria. The review provided a list of 22 general project success criteria. These criteria have then been ranked according to their relevance and grouped in three groups of criteria related to People, Planet and Profit. The review discussed also models of project success factors and introduced the 'Project-specific Formal System Model' as research model for the analysis of the case study.

In Chapter 4 a case study method is used to indicate the relevance of project success criteria in relation to sustainable residential district projects. For this purpose, published reports of Six European best practice sustainable residential districts have been used. These districts are BedZED in London, England, Bo-01 in Malmö, Sweden, Eco-Viikki in Helsinki, Finland, EVA-Lanxmeer in Culemborg, Kronsberg in Hannover, Germany and Vauban in Freiburg, Germany.

The results revealed that the Golden Triangle criteria (Schedule, Quality and Budget) are not sufficient to ensure success in sustainable residential district projects. The results revealed that the following criteria are relevant to assess success in sustainable residential district projects: Health, Technology Transfer, Efficient use of energy, Efficient use of water, Efficient mobility, Sourcing policy and Achieving social mix.

The results revealed also that success in sustainable residential district projects can be explained by the following factors as: Technologies are accepted by the residents, Matching residents' needs and expectations with technical specifications and design considerations, Project parties and residents are simulated, instead of forced, to work and behave in a sustainable way, Health and comfort are considered for sourcing materials instead of restricting the sourcing requirements, Creating a learning curve by realizing large-scale projects in phases, Having long term cooperation relationship among project team members.

The results revealed also that residents of sustainable residential districts strongly contribute to project success. Residents' beliefs, needs and expectations toward the use of HVAC technologies have a strong influence on project performance in the use phase.

The theory of planned behavior (Fishbein & Ajzen, 2012) is used as theoretical framework to answer research questions 3 and 4. The theory of planned behavior assumes that behavior is determined by the intention to perform it. In turn, behavioral intentions are assumed to be determined by attitudes, subjective norms and perceived behavioral control.

Face-to-face interviews were hold with 135 residents of De Caaien; a Dutch residential district where a heat pump system is implemented for space heating and hot water supply. The design of the questionnaire is based on a formal questionnaire and practical instructions as suggested by the theory of planned behavior. A pilot research was performed to provide behavioral elements related to automatically operating of the heating system. Automatically operating of the heating has been advised by the HVAC company as the most energy saving and environmental friendly behavior.

Data analysis revealed that residents' attitude and perceived behavioral control explained the intention toward operating the heating system automatically. Social norms had no effect on explaining residents' behavior. On average, the intention to use the heat pump system automatically was positive. In spite of that residents quite differed in their responses. This result indicates that residents differed in their perceptions toward the operation of the system and that the system performed differently in different household conditions.

Residents' behavioral beliefs related to space heating and hot water supply are the most important beliefs to explain residents' attitude toward operating the heating system automatically. These beliefs are related to residents' physiological needs and are overvalued to beliefs related to environment protection and cost saving. Residents who formed positive attitude and positive perceived behavioral control toward the automatically operating of the heating system operated the heat pump system properly. This behavior resulted in lower energy consumption and lower energy bills.

This research provided new insights into project success criteria and project success factors and their relevance for sustainable residential district projects. This research provided also new insights into residents' behavioral beliefs related to the use of sustainable heating systems. This research explained also how residents interact with their sustainable heating systems and how they can influence the performance their heating system on sustainability and energy consumption. This research provided also a tested and validated questionnaire that can be used for comparable behavior researches.

Curriculum Vitae

Gaby Abdalla was born on 10 January, 1976 in Al-Hasakah, Syria. In 1992 he completed secondary school at ‘Abi Thar Alghefari’ in Al-Hasakah and moved to Aleppo (Syria) to study Structural Design at Aleppo University. He obtained his Master’s degree in 1999. At the end of 2000, he fulfilled a two-year compulsory military service in the range of lieutenant. Along with that he worked part-time as structural engineer with several contractors.

In 2001 he moved to the Netherlands. As soon he arrived, he followed some courses (language, secretarial) and did practical work at the municipality of Hardenberg in the Department Living and Building. In 2003 he started his Master’s degree in Construction Management and Urban Development (currently Construction Management and Engineering) in the department of Architecture, Building and Planning at the Eindhoven University of Technology. Along with his Master study, he obtained his Decision & Process Management certificate (Free Master track with a R&D certificate) as part of the Master track Decision and Design Support Systems (DDSS) in the department of Architecture, Building and Planning at the Eindhoven University of Technology. In his Master’s thesis, he applied the Analytic Hierarchy Process to find criteria for the selection of contractors in the Dutch construction industry.

In 2007 he started his PhD in Performance Engineering for Built Environments, Department Architecture, Building and Planning Department, Eindhoven University of Technology (currently Department of the Built Environment). During his PhD study, he spent two days a week at BAM Techniek-Energy System in Apeldoorn where he gained knowledge about sustainable HVAC solutions for dwellings as well as for offices. Between 2009 and 2012, he was a member of the CIB Working Commission: "W118 – Clients and Users in Construction" at CIB World and the TU/e contact person of the Energy Efficient Buildings European Initiative (E2B EI). During the first two years of his PhD study he supervised graduation projects of Master’s students.

In 2005 Gaby got married with Rita Hanna and moved to live in Enschede. Rita and Gaby have (up to this date) two children; Christian Issa (2007) and Yara Ornina (2009).

Since 2010, he is a member of the church council of the St. Jacob d’Sroug Syrian Orthodox Church in Enschede. He is jointly responsible for the education program and two construction projects of the church (new church building for the parish and new cemetery for the archbishopric).

Stellingen

Behorende bij het proefschrift

Sustainable Residential Districts

The residents' role in project success

Gaby Abdalla

1

In sustainable construction projects stakeholders’ roles and responsibilities should be re-defined in all phases of the construction process (Chapter 4).

2

Energy saving measures should not be at the expense of health and comfort (Chapter 5).

3

Meeting people’s needs and expectations is more efficient then forcing them to change their behavior and habits (Chapter 5).

4

Environmental assessment tools such as BREEAM cannot ensure the achievement of sustainability objectives in the use phase (Chapter 5).

5

Interviewing of residents by the researcher in person is at least as important as the data collected from them.

6

People are concerned about many issues; sustainability and climate change are just two of them.

7

Statistically analyzing data is meaningless without understanding the data itself.

8

The construction industry has to employ psychologists.

9

The war in Iraq has inflicted the reputation and the believability of the Western world in such a way that people in the Arab Spring countries prefer suppression of their dictators to freedom of the Western World.

10

Behind every successful married PhD-student there stands a supportive wife and lovely children.