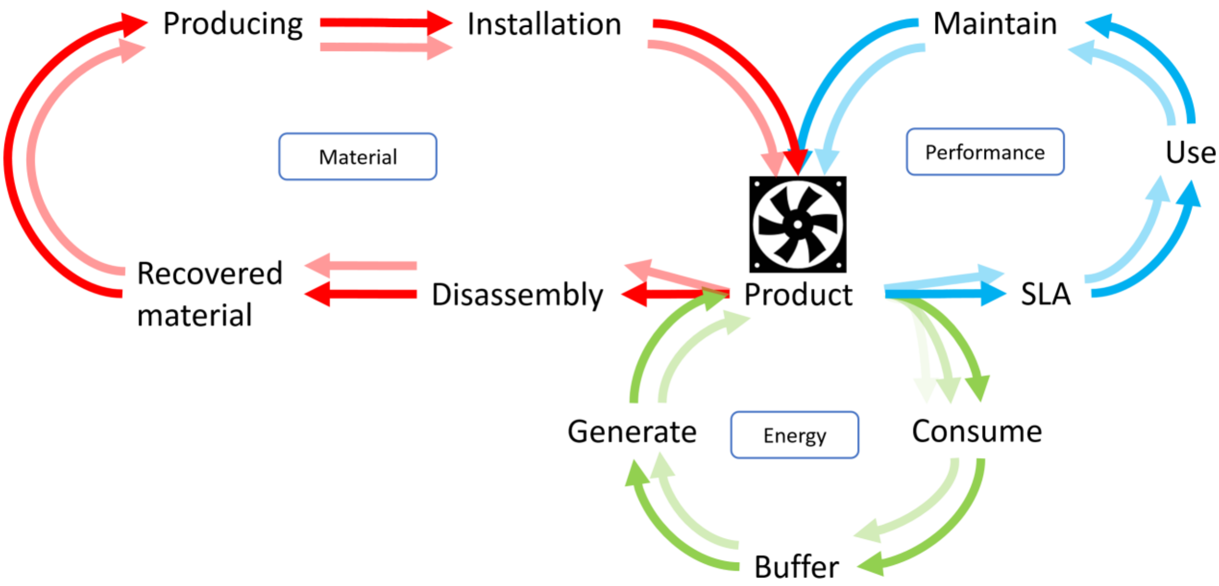
Comfort as a Service with SMART HVAC

A Constructive Technology assessment of the developments in the HVAC industry



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Abstract

The integration of Intelligent hard- and software tends to grow in the construction industry because of the increased connectivity by concepts like the Internet of Things. In the building industry, the HVAC components have a lot potential benefits in the exchange of information with the surrounding. This research identifies the new developments and presents a business model called Comfort as a Service in order to increase the implementation of the communication of (SMART) HVAC components.

In this research, multiple stakeholders explaining their vision on the future technology, challenges and benefits, effects on the society and market strategies of HVAC by a qualitative interview. The results of these interviews are surprising and controversial to the past movement.

The main driver of the developments in HVAC appears to be energy (CO_2) reduction, rather than flexibility or higher comfort as was expected in the literature research. Intelligent HVAC has the ability to reduce energy, by a better selection, timing and distribution of the energy. However, it requires more hard- and software for to coordinate this consumption, internally, but also with the SMART GRID.

SMART HVAC is capable of self-improving, sensing and coordination of the comfort within a building. This characteristic is really a step forward in the development of HVAC. Currently, we are on the edge of implementing this small form of Artificial Intelligence into our buildings.

However, the adoption of these technologies is not happening as quickly as in other industries. Stakeholders identified several challenges for implementing SMART HVAC. The most discussed challenge is the non-feasible business cases. The technology is too expensive for the benefits (mostly energy savings). Secondly, there is a lack of knowledge and poor alignment of main drivers between the real estate owners and the contractors. This gab of knowledge is most probably due to the conservative mind-set in the industry of the past decades. Finally yet importantly, the replacement cycle of an HVAC component is so long (multiple decades), new technologies are very slowly adopted in the market.

In order to face these challenges, this research presents a new fee-based business model: Comfort as a Service (CaaS). This model promises to face most of the challenges identified in this research. In CaaS, the contractor is the owner of the installation and delivers comfort conform a service level agreement (SLA). This will align the main drivers for the contractor and the client, because it transfers the responsibilities of the comfort levels to the contractor. The client does not need to know how he want it, but only what he wants. This requires less knowledge and therefore reduces the barrier to adopt these technologies. The

contractor can invest in the research and development and supply chain of these technologies in order to make the business cases more feasible.

The contractor can and most probably will optimize the costs with SMART components and will re-use the components/materials via the Circular Economy concept (as presented on the cover of this research). The Circular Economy concept in CaaS will increase the feasibility of the replacement of components, and therefore, the replacement cycle will drop. This results in a faster adoption of SMART Technology in HVAC installations.

Comfort as a Service will increase the adoption of SMART HVAC, and thereby increase the comfort for the users as well as stabilizing the energy market and reduce CO_2 emission at the same time.

READING GUIDE

This report is the result of the research to SMART HVAC for the master course Construction Management and Engineering at the University of Twente. The main document describes the global research methodology, results and the conclusion. The appendices providing more information about the topics and the sources of the statements used in this document.

During this research, definitions are used which might not be familiar to all readers of this document. Therefore, the first appendix conducts of a table of definitions to get a proper understanding of the abbreviations and terms used in this document.

The main document is build up in two parts:

- Part 1: The research plan (chapter 1 & 2)
- Part 2: Results and conclusion (Chapter 3 & 4)

The first part contains an introduction (chapter 1) towards the problem definition (part 2). This problem definition describes the environment where HVAC is acting in and the upcoming concepts from the literature study. Chapter 2 describes the methodology and includes a stakeholder mapping. The appendices 2, 3, 4, 5 and 6, support this chapter.

Part 2 of the main document is focussed on the data gathered during the research (included in appendix 9 and summarized in appendix 7) and how this data is used to provide an answer to the problem defined in part 1. This part consists of a result chapter (chapter 3) which is a summary of the analysis provided in appendix 8. The business model Comfort as a Service is described in chapter 4, which is the result of all findings from chapter 3. Based on this analysis a conclusion is drawn and presented in chapter 5. Chapter 6 describes some limitations of this research due to research environment and characteristics. Chapter 6 will define recommendations for the market and recommendations for future research are stated.

Although the main document describes the global information for the research, the appendices providing a more detailed discussion on the topics discussed in this main document.

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1 RESEARCH ENVIRONMENT

1.1 INTRODUCTION

For years, installations in buildings are manual controlled components. However, since the developments in the IT industry, computers are taking over the manual control and therefore, are becoming more and more intelligent themselves. Installations within buildings are being digitally connected to each other and which excellence to SMART Buildings. (Sinopoli, 2009) However, how will new buildings be looking like in 10 years? If buildings are getting smart and are able to determine and control the states of individual parts in the building itself, they are likely to increase the comfort and probably save energy.

This line of thought seems to be very future oriented, but the innovations are going faster than the maturity may think. Installations and software are becoming more important than the building structure itself in the near future. (Sinopoli, 2009) Current construction industry is focussing on the physical building, where a transition will focus more towards installations and building automation.

This research will be focussing on the HVAC components of the installation landscape within a building. HVAC is an abbreviation for Heating Ventilation, and Air conditioning. These air treatment installations are in utility buildings a major part of the expenses and coordination (Sinopoli, 2009). This industry is very conservative and the replacement cycle of components in a building is very long. Both characteristics that results in a slow adoption of new technology.

To increase the adoption and development of these innovations in the HVAC systems for buildings potentially require a policy from the government and/or branch organisations or other market mechanisms who will change the current pace of the industry. This research will both focus on the developments in the HVAC industry and will investigate how to increase the adoption of these new technologies, while looking at the external environment where users and other stakeholders are adopting the innovations with the constructive technology assessment. This research will scratch the boundaries of HVAC systems with SMART GRIDs, sensing and Artificial Intelligence for HVAC systems.

The outcome of this research will suggest a business model, which helps catalysing the adoption of Intelligent HVAC systems (SMART HVAC) in the market. This outcome will align with the issues and concerns multiple stakeholders among the industry currently have. The goal of this business model is to increase the comfort levels and deliver this comfort against a lower price with lower (fossil) energy consumption.

BIM Intelligence has asked to develop an advice on how to provide advice on the future of SMART HVAC contractors and manufacturers. BIM Intelligence requested advice for contractors of buildings and HVAC installation firms and clients. BIM Intelligence is specialised in implementing information management for construction contractors, clients and manufacturers. There is little experience with SMART HVAC. In order to extend the knowledge of the future, and to provide meaningful advice, Jaco Poldervaart of BIM Intelligence has asked to conduct this research.

1.2 Problem Definition

Nowadays the internet of things (Wortmann & Flüchter, 2015) concept is a major element in IT innovations across multiple industries. The Internet of things is a concept that describes the exchange of information in a network of devices. This concept affects most of the industries, and the building industry has a lot of potential benefit to adopt these. (Firner, Moore, Howard, Martin, & Zhang, 2011)

The innovations in the building automation are on the edge of a new era with incremental changes to the intelligence of the system. Plotting the philosophy of the Internet of things on the built environment, there are two major levels: (1) SMART Cities and (2) SMART Buildings.

SMART cities are cities where information is generated and gathered by the city itself to help operating the city (Bach, Wilhelmer, & Palensky, 2010). In example, there is an accident in Amsterdam, and the network recognizes a traffic jam. Based on the routes in the city, the signs in the city can automatically reroute the traffic. This creates the ability that the city can organise the complete traffic in the city and uses the roads in the city optimally. These kinds of interactions are possible because the city can receive information from the sensors within the infrastructure, buildings and other assets within the city. A city with these kinds of functionalities are SMART Cities.

SMART Buildings are (utility) buildings where information is generated and gathered by the building itself to operate the building (Sinopoli, 2009). Individual parts of the buildings like installations, but also windows and doors (Open or closed), temperature and so forth are valuable information to the building in order to optimize the comfort, energy consumption, flexibility and the ability to enlarge the functionalities of the building itself. See all connected systems towards a management console in figure 1.

Besides these two levels, this research will focus one level more in detail. In order to exchange information within buildings, the individual parts of the building have to be exchanging information as well. For HVAC systems (Heating, Ventilation and Air Conditioning), this is one of the larger aspects within a building (Sinopoli, 2009) and is currently not exchanging information with each other.

Nowadays the automated systems in buildings is starting to adopt, where the building security might be the biggest example of building automation. But the predicted innovations in IT Technology are promising, i.e. more calculation power (Mack, 2011) which enables more complex and therefore more intelligent building automation systems.

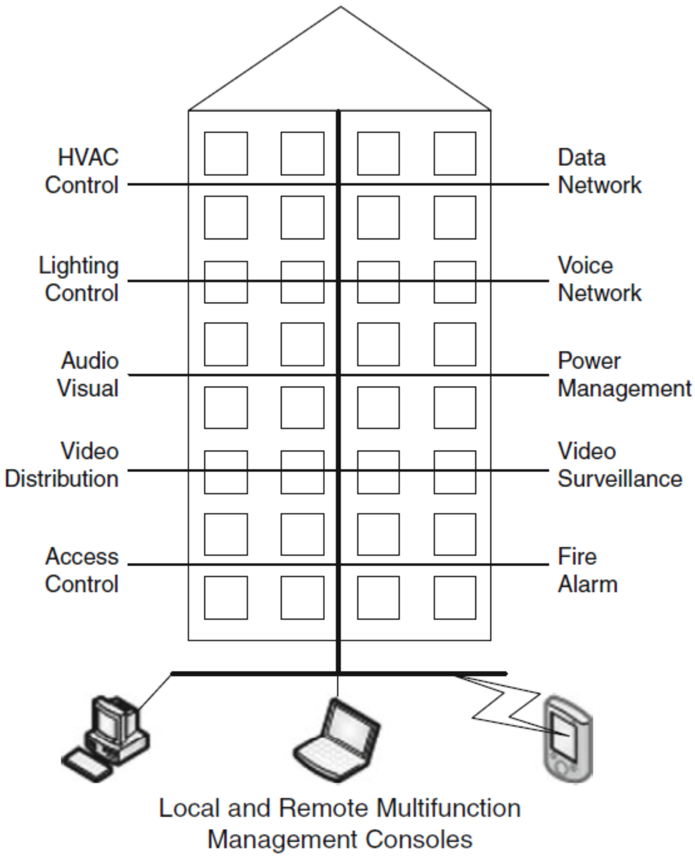

Figure 1 - SMART Building Components (Sinopoli, 2009)

Besides the broad integration of components within a city or a building, there is another movement in the SMART philosophy: SMART GRID (Gungor et al., 2011). SMART GRID is a philosophy that connects all electricity demanding and supplying assets to each other to improve the efficiency of the electricity network as a whole. In the Netherlands, many network managers are investing in the market in order to develop SMART electricity meters for households.

The current energy market is facing a transition from fossil-based energy towards renewable energy. This transformation is creating more problems for the electricity-net owners, since electricity cannot be stored very easily. Currently, when the sun is shining and the wind is blowing, there is too much energy and all power plants have to shut down. But, we do need the power plants to back-up the electricity demands while there is not much renewable energy available (for example during a solar eclipse). Using a SMART GRID will reduce the peaks in the energy-network. In the future, it is likely that installations within buildings (like SMART HVAC systems) are connected to the SMART GRID in order to prevent electricity peeks and in return real-time pricing of the electricity (Brown, 2008). This concept is relevant to the HVAC installations, since the SMART GRID communicates (indirectly) with the SMART GRID.

This research will focus on the innovations of IT in the HVAC systems in the next decade. Concerning the improvements on the Building automation in the Netherlands, there is a lack of knowledge about the future of these systems within the literature.

Figure 2 provides a breakdown of all the presented concepts. The internet of things is the overall concept of connecting devices to each other to create a network of live information. SMART City focusses with this philosophy on the devices in the city, which enables the city to think for itself.

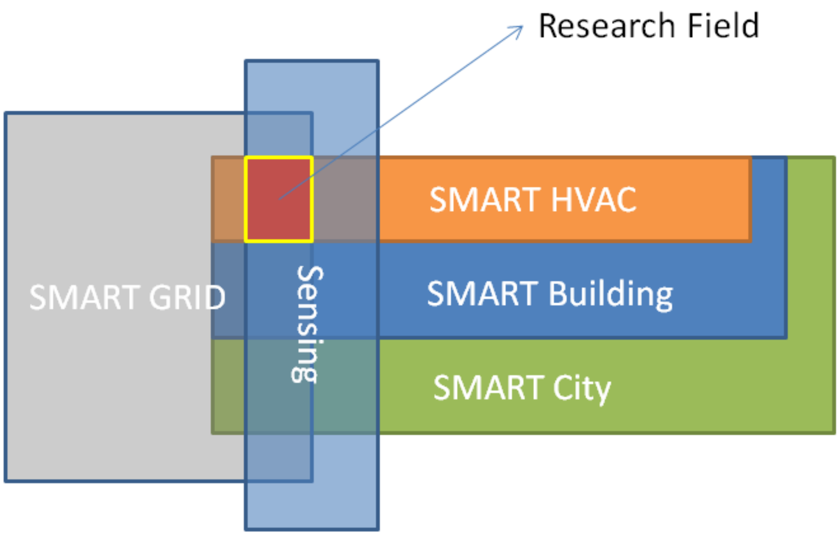

Figure 2 - Concepts Breakdown

Buildings within the city have also sensors, which connects the buildings with the internet of things philosophy. The literature calls these buildings SMART Buildings. For this research, there is one-step more focus, which is called SMART HVAC systems. HVAC are the air treatment units within a building. Connecting these components can create a smart and automated system, which optimize the effectiveness of the system and therefore provides more comfort and saves energy.

The availability of knowledge of the developments and effects of the systems requires is required, in order to govern the innovations within SMART HVAC systems. The existing literature does not describes this concept, since there is a lack of knowledge about the effects of the developments within the SMART HVAC systems over the next decade. The research will investigate this future HVAC in this environment and will seek for a solution to enhance the adoption of the new developments.

2 RESEARCH PLAN

To investigate the described problem, a research plan is required. This research plan consists a methodology and the stakeholders and interviewees that are required to investigate this problem. Appendix 2 describes a more detailed outline of the research plan with a discussion about the literature of the (Constructive) Technology Assessment, appendix 3 for the stakeholder mapping, appendix 4 for the conducted interviews and appendix 5 for the interview protocol.

2.1 LITERATURE METHODOLOGY

For this research, a constructive technology assessment is used. This methodology compares the internal environment of the technology to the external environment of the HVAC stakeholder landscape. The technology assessment is the basis methodology and the constructive technology assessment is a derived methodology of this technology assessment. Appendix 2 is describing a more detailed description of these methodologies. This section will provide a short explanation.

At first, the technology assessment (TA) will explore the impacts of technology on people, social and governmental structures and societies. This method defines an internal environment, which includes stakeholders who have direct influence on the technology. The external environment is including the society and governmental structures.

The constructive technology assessment (CTA) reverses this premise in the investigation. At first, the external environment is investigated and based on this outcome the technology will be adjusted to meet these desires from the external environment.

This research uses multiple strategies of CTA. These are presented in appendix 2.3, these strategies are taken into account while executing the research and defining the conclusion.

2.2 RESEARCH METHODOLOGY

For this research, the constructive technology assessment is used. This methodology is suitable for the problem definition since the external environment has demands and developments where the SMART HVAC can adjust the development route on.

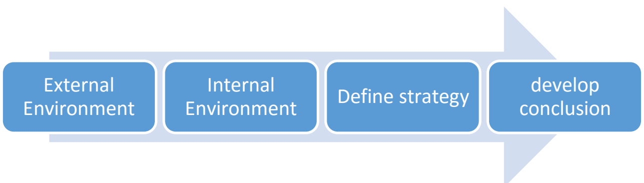

Figure 3 – research steps

This research contains of two sections, the internal environment and the external environment. Both of the environments consists of stakeholders. Figure 3 represents a small roadmap of the research. The first step is to interview the external environment, and thereafter, the internal environment. These interviews forming a strategy, which combined forms the conclusion of this research.

The time path of this investigation is six months and additionally two months of developing a conclusion and reporting the research.

2.3 Questions

The question of BIM Intelligence is to provide insight in the developments of HVAC systems, where the company can advise clients, contractors and manufacturers with business in (SMART) HVAC systems.

To provide valuable advice to BIM Intelligence, the main research question is:

How can the development and implementation of the SMART HVAC technology be optimized to gain maximal effectiveness of the technologies in the future?

There are two sections in this question: the internal and external environment. In the methodology, the constructive technology assessment is explained where the focus is more on the internal effects of an innovation. In the stakeholder analysis, there is a distinction between internal stakeholders and external stakeholders. Since the focus is how the external world effect the internal developments and how they can cooperate on the external environment.

To answer the main question, there are two separated sections. The first section defines the external environment. Interviewing all stakeholders in the external environment, based on the following questions and topics:

- What are the technological needs of the society within the HVAC industry for the next decade?
- What non-technological effects could occur if the SMART HVAC is implemented in the society?

Having these questions answered, the needs and demands of the external environment is set. Projecting the effects of the external environment on the internal environment, will give the ability to investigate the perception differences.

- What possible future technologies are there within the HVAC industry for the next decade?
- What are the effects of the new developments in HVAC systems on the society for the next decade?
- What possible technological challenges are possible facing the developments of SMART HVAC?

- Which strategy seems optimal for enabling the innovations within the HVAC Industry to become SMART?

These last sub questions together answers the main arguments from the first two subsidiary questions about supply and demand at this moment and for the next decade. The second set of questions investigates the implementation of the technologies.

The results dividing in four parts; (1) Future developments, (2) Effects on the society, (3) challenges in the future and, (4) future strategy for HVAC adoption.

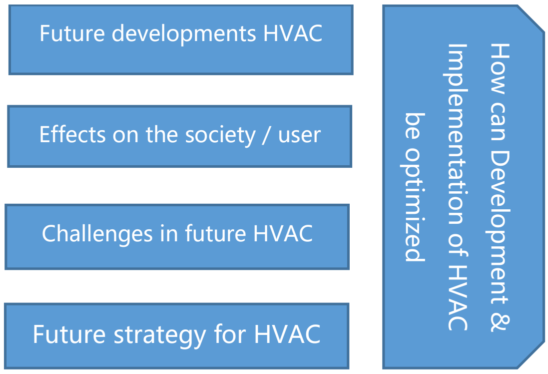

Figure 4 – research pillars

These pillars are the basis for the interview topics and analysis topics. This is a breakdown of the research subsidiary questions into a main research model. Based on this graph, the report is build up. The research conducts of in-depth analysis of the different pillars in qualitative interviews. To make a consistent and valuable outcome of the interviews, appendix 5 presents an interview protocol. The interviews are build based on this protocol.

2.4 STAKEHOLDERS & INTERVIEWEES

In appendix 3, a stakeholder analysis is included. This stakeholder analysis is developing a strategy on which stakeholders are mapped. In the research and in what environment they are placed regarding the CTA methodology.

The following graph (figure 5) describes the position of the stakeholders on the influence and interest for HVAC installations.

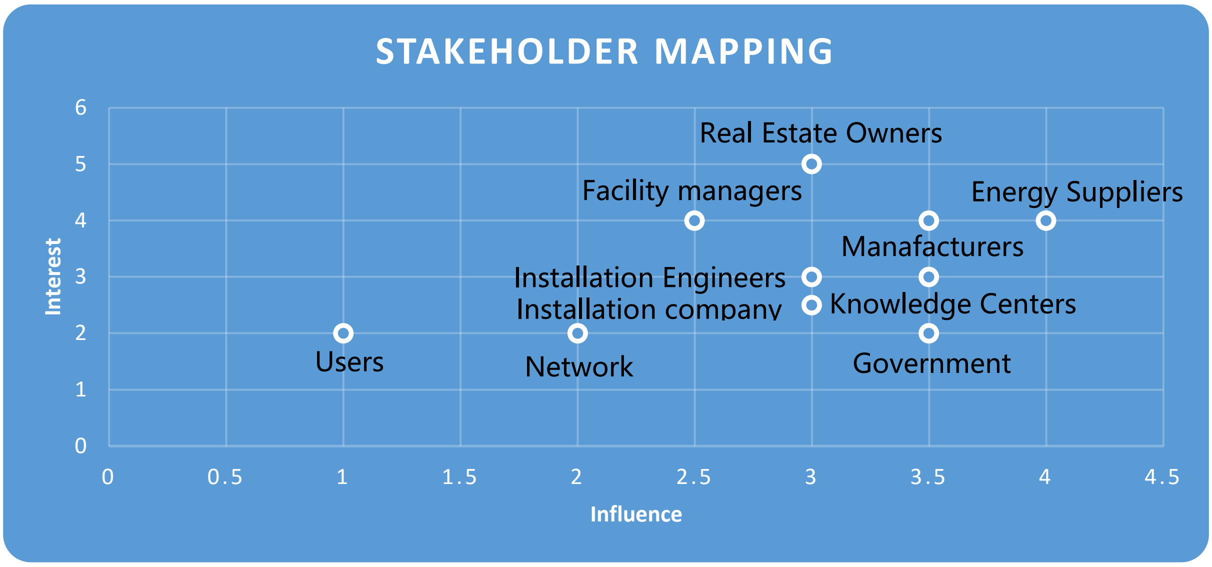

Figure 5 - Stakeholder mapping

Due to limited resources in this research, interviewing all stakeholders in this analysis is not possible. Therefore, this analysis conducts of a selection based on the interest and method of investigation. I.e. to investigate the wishes and visions of the users, a qualitative research is required. This research focusses on qualitative interviews and is therefore not able to investigate all stakeholders.

The following list divides the stakeholders into the internal and external environment. This research is interviewing bold market stakeholders.

Internal Environment	External Environment
Facility managers	Government
Manufacturers	**Real Estate owners**
Energy Suppliers	Users
Network Operators	**Knowledge Centers**
Installation Engineers	
Installation Companies	

Table 1 – Stakeholder group

3 RESULTS

As presented in chapter 2.3, the four research pillars are the foundation of the main research question. Each pillar describes a part of the main conclusion. Appendix 8 describes in depth the results of the interview. Based on the results are analysed (appendix 7). This chapter summarizes the in depth analysis. For more information, please consult the appendices.

3.1 DEVELOPMENTS IN THE TECHNOLOGY AND

The first pillar describes the developments within the HVAC industry. For years, the developments of HVAC based only on increasing the efficiency of the heat-transfer. Currently, the developments are changing towards energy saving systems by buffering energy and the use non-fossil energy resources. These developments are increasing the efficiency of the HVAC installation, but not directly increase of the effectiveness of the HVAC installation. The effectiveness of the installation is hardly mentioned by the interviewees and therefore seems to be no major development focus of the current market.

The identified external developments in this research are mainly a combination between SMART GRID and SMART HVAC. This concept will have a key role in the future of the energy network and since the HVAC installation is one of the major energy consumers in the network, the developments in SMART GRID are influencing the developments in HVAC installations. This connection will have a key role in the developments. Especially, since interviewees are mentioning that energy is the most important problem, which the market need to solve in the next decade.

The energy market and thereby the SMART GRID concept is most likely evolve to a market-based pricing system where supply and demand are compared to each other. This market price is thus the representation of the available energy in the network. It would be interesting if a building can buy and sell energy based on the available energy. The building can store energy, produce energy and uses energy. If the building can anticipate on the market price, and thereby indirectly to the supply/demand status, it can provide stability in the energy network.

Currently, no such system exists and therefore the interviewees were asked what a SMART HVAC could be. The stakeholders define SMART HVAC as: a HVAC installation that is flexible communicates with other devices and is ready for future use where the user of the building is the key-factor. All stakeholders have told their vision on the development of SMART HVAC. All these mentioned innovations are developed in to one analytic model (figure 6). This model is the layout of a self-improving SMART HVAC system, which is able to communicate with the SMART GRID with real-time cost information of energy.

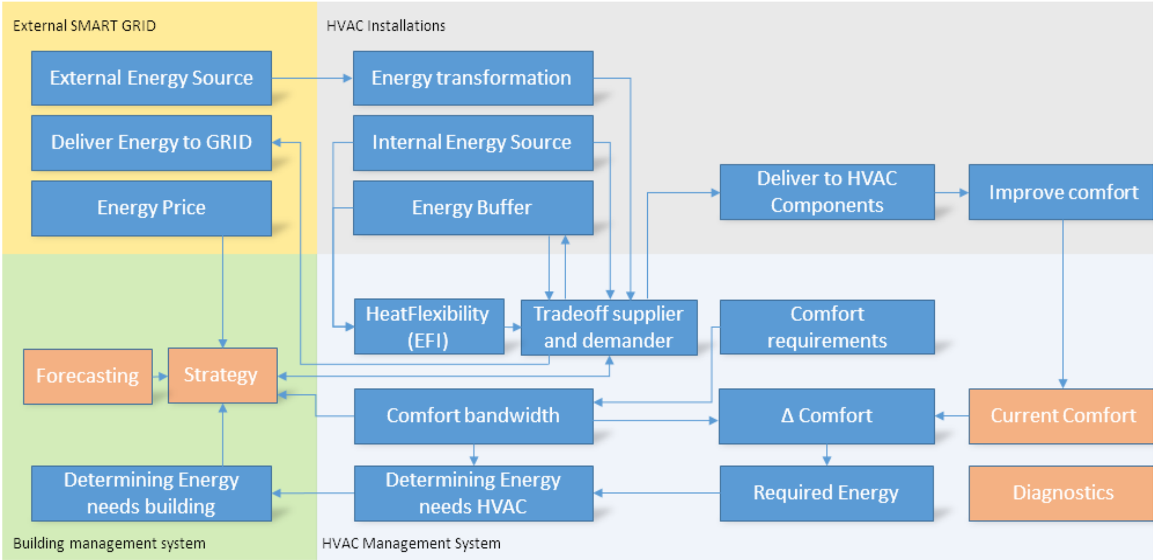

Figure 6 – SMART HVAC

This model contains of four main phases (described by Gartner (2010)): (1) Prescriptive analysis, (2) Descriptive analysis, (3) diagnostic analysis and (4) Predictive analysis. Since in a SMART HVAC the components can exchange information with each other, the state of each component is communicated to the central intelligent hub. Together with the sensor information within the building, this central brain is able to develop strategies on how the building is using which energy source based on the current comfort levels and the current state of the building. This strategy is put into a policy for the installation how to function. Diagnosing the effectiveness of the installation will create the ability to gain more effectiveness of the HVAC installation.

Appendix 5 describes the explanation of this model and more functionalities.

If SMART HVAC systems are configured like the model below, it has many benefits. In the list below, the major benefits for the users, building owners.

- *The performance of the building is more accurate*. Since the building measures the effect of the executed policy, it can adjust the performance while executing in order to optimize the comfort. This is a major improvement compared to the existing installations, where the settings are not changing after the initial installation. That leads to big in-efficiency and lack of performance. Due to the measurements and the feedback loops, the system is able to learn through the lifetime of the asset. A simulation of a building is never 100% matching the actual conditions. Therefore, a self-learning system can improve his own settings, by experimenting and learning from previous decisions and policies.

3.2 Effects on the society

The second pillar in this research is the effect of the developments in the SMART HVAC industry towards the society. Interviewees brought up multiple effects that are be applicable to the society due to the future developments of SMART HVAC. The major effects mentioned by the interviewees are:

- *Increasing effectiveness and flexibility of the installations towards the users.* Since the user experiences more ways to adjust the comfort to his own preferences, he is expecting more functionalities. These effects are challenging for the HVAC market and building owners.

- *Open data* is mentioned the interviewees as one of the major effects since more data is exchanged and stored. Exchanging and gathering the data on a global level, with detailed information. This can reveal a part of the identity of a user (i.e. his activities). If the user is not comfortable by the extent to which the information is shared, the use of SMART HVAC will possibly get into a downfall. The internal market is aware of this situation, but does not understand what these boundaries are.

- *The reduction of CO_2 emissions*. This because the efficiency of HVAC will increase by a better alignment of the components within the system, but also since the system can determine which resource is used. The reduction of CO_2 is also the main goal of the government. With this technology, the goals (and the drivers) of the market and government are aligned.

These challenges affect the developments within the HVAC industry. Most innovations focus on one of these aspects, and again, mostly reducing energy consumption. However, the other two topics will be more hot topics in the next decade.

3.3 Challenges in the HVAC Industry

Although the previous pillars have presented promising developments, there are still some challenges in the market before or during the implementation of SMART HVAC that require a solution.

Based on the literature research, the impression was that most challenges are in the technology part of the industry. During the research, this was not to be the case. The required technology is available, and most challenges are elsewhere in the industry.

The existing major challenges are:

- *The knowledge of the newest developments and the SMART concepts are not available* for most stakeholders. Individuals with personal interests in the matter mostly obtain the knowledge for a company about the innovations in HVAC. These people often work for bigger companies, since they can afford these employees. Modern contracts are minimizing the responsibilities for the owner, so the knowledge disappears from the owner. Users are unaware of the latest developments and therefore not requesting the newest technology.

- *The drivers within the market are currently not aligning*. Everyone in the supply chain is aiming for the highest rate of return, and are therefore often not aligning to the goals of the owner.

- *Low replacement cycle of HVAC Installations*. Forcing technology in a market is the easiest when there is a short replacement cycle. A replacement cycle means the lifetime of an asset from the initial installation towards the point in time where it requires replacement. If this replacement cycle is long, the adoption of the innovation is slow. For HVAC installations, these cycles are very long (multiple decades). Practically, to adopt SMART HVAC, existing installation will not completely be replaced.

- *Low energy prices*. At the moment of investigating, the oil price has reached a new low record resulting in un-feasible business cases. Thereby, innovations should minimize energy consumption are often not feasible or the rate of return is more than a decade. This risk is too high for the owner to invest in radical innovations.

These challenges are clearly available in the market. Although, it is not clear for all stakeholders that these exist. This most probably have something to do with the lack of knowledge, but also experience in the market on the leading-edge technology. Since the market is conservative, these challenges are not really seen as “solvable” challenges. Although this might be the case on short term, during this research, there is a business model that has the potential to solve these challenges. The next chapter will go in to this solution.

4 COMFORT AS A SERVICE

The chapter describes last pillar with presents the strategy how to face the challenges from pillar 3. During the interviews, interviewees provided information about ways to solve these challenges.

The solution to these challenges is a business model, where the contractual form between the owner/client and his contractor is based on delivering a service. Traditionally, the contractor receives this contract per lifecycle stage to different actors within the supply chain. For this business model, all lifecycle stages together combined for one contractor that delivers a service on a fee-based contract.

Appendix 8 defines different contract forms, with the result that the business model "As a Service" is the most suitable for this situation. The goal of an HVAC installation is to deliver comfort to the user and therefore, this business model is called Comfort as a Service (CaaS). This means that the contractor delivers a service towards the owner/client that the comfort is on a proper level. This is a fee-based contract based on the delivered service, in this model; the comfort. A service level agreement (SLA) defines the comfort levels that the owner desires to apply to the building. If the contractor deviates from this SLA, and the performance has not been met, the fee will be restrained from the contractor or even a fine will be imposed if the performance was lacking significantly.

There are four similar existing models in the current market:

- *Software as a service* is the most used contracting type, and defines multiple levels of ownership and responsibility.

- *DBFMO* (Design, Build, Finance, Maintain and Operate) originates from the civil industry and is mainly between public organisations and private companies. DBFMO are complete lifecycle contracts where the contractor is also rewarded and/or punished by the fee-based contract. For this research, these methodologies are used to define the CaaS model and predict which challenges they can solve.

- *Light as a service* is more alike the CaaS model and is introduced by Phillips and others, they deliver light as a service, meaning they are responsible for providing light on the surface according to the Service Level Agreement.

- *Energy Service Companies (ESCo's)*. These companies are delivering energy as a service to the assets. This model is most similar to the CaaS model, only ESCo's are limited to delivering energy. The method of delivering is up to the contractor. The next step is to transfer the responsibility is transport the energy and transform it into comfort for the users.

CaaS complies with the CTA strategy to align both External and internal environment (see page 14, Loci for reflexivity and feedback). The development of SMART HVAC can align both internal and external environment and thereby creates multiple benefits:

- *The CaaS model offers an alignment between client and owner about the output of the HVAC installation.* Since the contractor is responsible and therefore involved in all the lifecycle stages, the contractor needs to have a total-lifecycle mindset. This improves the incentive to place qualitative components and therefore increase the overall quality.

- *The CaaS model will eliminate the investment costs and risks of the owner*, which was another challenge in the previous research pillar. Because the contractor is responsible, the contractor will be earlier adopting innovations, since the owner does not have to be convinced. They have more experiences with the newer (more efficient) technology and have more incentive to implement these, since they also paying the energy bills of the installation.

- The CaaS model requires less knowledge of owners and/or clients. Due to the transferred responsibility, the owner does not need to have the knowledge as currently is required (and is lacking). Therefore, the innovations might speed up, since the passive behaviour will be minimized.

Nevertheless, a service model alone does not solve the last challenge namely, the slow adoption speed due to the slow replacement cycle. Using a circular economy model (CE) solves this challenge. This model defines the re-use and recycling of components, material and energy and used elsewhere. Since the contractor has now many different installations in ownership, this model can re-use components and thereby reduces the price of the installation even more. This model is called the circular economy, introduced in China (Geng, Zhu, Doberstein, & Fujita, 2009). This concept tries to add value to businesses by optimizing the use of resources by collaborating in the supply chain with different parties. Since the contractor is a big actor in the supply chain of the CaaS market, the ability of the contractor to use the circular economy concept is valuable.

Figure 7 explains the circular economy for CaaS:

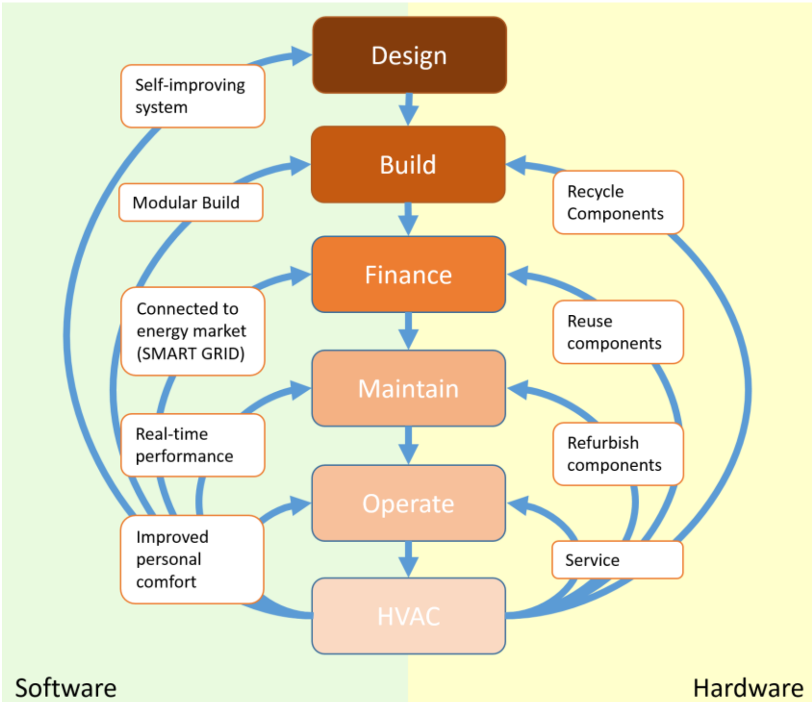

Figure 7 – Circular Economy in a CaaS model with SMART HVAC

This model enables the re-usability of the components on multiple stages in the lifecycle. For this approach, a modular installation is required. This modular installation is easier to adjust using a SMART HVAC, since the software contains of a self-improving system. The contractor can re-locate/refurbish the components and thereby save the costs of complete replacement. In addition, the replacement of components can be more cost-efficient and therefore reducing the replacement cycle, which enables the adoption of innovations.

The use of fewer resources is also available on the software side, where a better alignment, sensing and the exchange of information with other systems will reduce the required resources (mainly energy). Another layout explains of the Circular Economy model in Comfort as a Service even better (see figure 8). This model has the same basic principle as the model above, only is this drawn in in a chain. This model has three cycles: (1) The performance cycle, (2) the material cycle and, (3) the energy cycle. Closing the cycle leads to more efficient use of material/energy. Therefore, the cycles will be smaller and thus more efficient. The product is central in this model and represents any HVAC component.

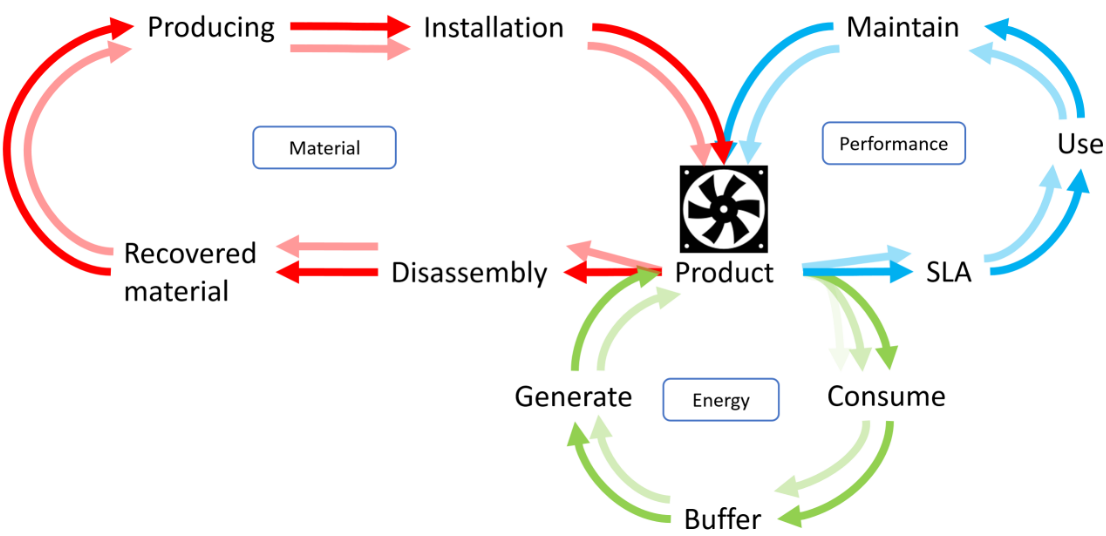

Figure 8 – Improving Circular Economy in a CaaS model with SMART HVAC

Nevertheless, this business model contains of some challenges as well. The challenges still facing are the following challenges:

- *The contracting periods are longer, since these contracts are lifecycle based*. This might not be desirable for the owner, but since they have an SLA, the owner is able to add a clause in the contract to end the contract if the performance is significantly failing over time. This also results in big contracts that eliminates small & medium enterprises (SME's) in this market. These big contractors can hire the smaller enterprises for subsidiary activities. In that case, the general contractor is the coordinator of all activities.

- *Open data*, which is more open than in "standard" contracts. Therefore, the contract CaaS needs to include the use and exchange of data by the service company.

5 CONCLUSION

This research investigated the future developments of HVAC, with the focus on SMART Concepts like SMART GRID and SMART Building. SMART HVAC is part of a SMART Building and is described as: *A Heating, Ventilating and Air Conditioning system with components that exchange information of their status and can anticipate on orders from the central controlling software to optimize the effectiveness and efficiency of the installation within a building*.

For this research, the following research question was stated central: *How can the development and implementation of the SMART HVAC technology be optimized to gain maximal effectiveness of the technologies in the future?*

This question can be divided by four pillars: (1) Future developments in HVAC, (2) Effects on the society, (3) challenges in HVAC and (4) a strategy to face these challenges.

The future developments within the HVAC industry are mainly focussing on increasing the efficiency of the installations rather than increasing the effectiveness. Looking at the developments in the next decade, this will more be focussing on the timing of the energy consumption and reallocation. The HVAC systems will evolve to a SMART HVAC system in the future, which is conducts of feedback-loops to increase the effectiveness and efficiency of the HVAC installations.

Currently, the society is searching for ways to minimize the CO_2 emissions. SMART HVAC systems in combination with SMART GRID concepts are a proper solution for this challenge. These intelligent systems exchange information about the building and its users. The effects of SMART HVAC are also recognizable for the user, since these systems can handle more flexibility for the user together with more effectiveness of the HVAC system.

Multiple challenges turning into opportunities when applying the CaaS model in the next decade. The literature expected that there were challenges on the technological side, but the challenges are more on the combination of the internal and the external environment due to different drivers between client and contractors and the failing business cases for the clients.

The business model Comfort as a Service (CaaS) presents a solution to face these challenges. This model is a fee-based service contract where the contractor delivers the comfort within the building as a service to the client. This business model forces the client to think in comfort levels to define the Service Level Agreement and aligns the drivers of both client and contractor towards lifecycle thinking. Thereby, CaaS transfers the incentive of energy reduction from the client towards the contractor that probably leads to more innovations (as can be found in similar models from other industries). The Circular Economy concept within the CaaS model improves the value towards the client and reduces the resources of the contractor by recycling and reusing products, material and energy,

[SMART]

Therefore, the business model Comfort as a Service catalyses the development and implementation of SMART HVAC technology by the use of a SMART HVAC installation. Thereby, the connection with a market-based SMART GRID is enabling a SMART HVAC to be more cost-efficient.

6 LIMITATIONS

This conclusion is valid in the environment of this research, but might not be valid for all environments. In this section presents the limitations to this conclusion based on the factors in this environment.

6.1 LIMITATIONS TO THE CTA

The limitations are separated in two parts; the first part is describing the limitations of the research methodology CTA. These are according to the literature the limitations of the CTA methodology:

- *The responsibility of managing the technology in the society is not limited to the governmental actors.* Companies and even individuals can be responsible as well for the technology in the society. (Johan Schot & Rip, 1997)

- *The new innovation has been introduced and new platforms are created.* CTA will investigate certain platforms to find the effects of the innovation on among others, the current platforms. When a new platform is raised by the introduction of new innovations, the effects may be different from those that were expected. (Johan Schot & Rip, 1997) "The dynamics of the process are central, and impacts are viewed as being built up, and co-produced, during the process of technical change." (J. W. Schot, 1992)

- *After introducing a new innovation, new "nexuses have been developed between variation and selection*, or supply and demand". So, new investigated innovations may already be evolving to other extends than the calculated effects to serve mostly an even better outcome.

- *Actors are often try to reduce space for negotiating to the direction and nature of technical change* (Johan Schot & Rip, 1997). This can strongly influence the outcome of the assessment.

In the methodology are the actions described to limit the risks and limitations to this assessment in order to increase the value of the research outcome.

6.2 LIMITATIONS TO THE RESEARCH CONDITIONS

Besides the limitations to the research method, the researched environment was not optimal.

- *The interviewee requirements eliminates a certain population and creates a Survivor-bias (Elton, Gruber, & Blake, 1996)*, which results in a biased representation of the industry as a whole. Nevertheless, without this requirement, the interviewees were not able to discuss these concepts, due to the lack of knowledge.

- *This research is only limited to the Dutch market*. Although some interviewees work in multinationals, and the literature is applicable to not only the Dutch market, this research is limited to the Dutch market only. This might also be applicable to similar countries like Germany or Belgium.

7 Recommendations

7.1 Recommendations for Future Research

Since the conclusion is valid in a specific environment, this chapter recommends how this research can expand in order to create more scientific value.

As mentioned in the previous section, the limitations to this research are shaping the conclusion of this research. To enforce this conclusion conducted more on two these fields will increase the scientific value: (1) Internal dynamics of a SMART HVAC system and (2) the CaaS model.

Appendix 8 is suggesting the internal dynamics as described by the interviewees. These internal dynamics requires to be validated by an experiment that include a SMART GRID market price and an anticipating SMART HVAC system where the alignment of the components and their feedback loops are working properly. Pilot projects will retrieve empirical data to adjust and/or confirm the use of this model is working.

In addition, the presented Comfort as a Service requires more investigation. Currently this is a combined business model, and promises to solve many challenges in the industry. However, can this model be used at the first place (concerning the possible legal issues), and thereby, is this model really dealing with the challenges as expected.

These two major future topics complimenting this research and are valuable to the future of HVAC and the energy GRID.

7.2 Recommendations for the market

This research has developed this promising business model Comfort as a Service. To apply this model in the market, recommendations are made for the market.

Contractors have to take bigger steps and take responsibility, by delivering a service instead of a product. This includes the use of CaaS. With the use of CaaS, contractors are able to help many clients with delivering comfort to the building.

Bigger companies, who can afford to spend some R&D, must focus more on IT. Focussing SMART HVAC can help the next step in efficiency and effectivity, which is currently underexposed.

Last recommendation, which is more affecting the benefits of SMART HVAC using a SMART GRID: Government must review the current energy-market. Innovations are developed and adopted faster if there is a correct incentive. Subsidy is currently compensating this adverse incentive. New forms as mentioned in this research like real-time pricing of energy and the use of Co2 tax will increase the value of renewable energy.

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9 APPENDICES

Appendix 1	Table of definitions
Appendix 2	Methodology
Appendix 3	Stakeholder analysis
Appendix 4	Interview Groups
Appendix 5	Interview Protocol
Appendix 6	Interview Questions
Appendix 7	Results
Appendix 8	In-Depth Analysis
Appendix 9	Interview Transcripts

9.1 Appendix 1 - Table of Definitions

BAS	Building Automation Systems – The digital "brain" of the building. This system controls all connected systems.
CaaS	Comfort as a Service – A fee-based contract where the contractor delivers a service to provide comfort to the users. The ownership (and responsibilities) of the installation is transferred from the client to the contractor.
Comfort	Comfort for HVAC are the state when the temperature of the building and its air conditions are in a way that the user of the building feels pleasurable physical ease.
CTA	Constructive Technology Assessment – Research method which is built around the attempt to anticipate effects or impacts of new technologies or new projects with a strong technological component
HVAC	Heating, Ventilation and Air Conditioning installations. Major energy consumer in an utility building.
SMART Buildings	Buildings where information is generated and gathered by the building itself to operate the building (Sinopoli, 2009)
SMART GRID	A philosophy which connects all electricity demanding and supplying assets to each other to improve the efficiency of the electricity network as a whole.
SMART HVAC	A Heating, Ventilating and Air Conditioning system with components that exchange information of their status and can anticipate on orders from the central controlling software to optimize the effectiveness and efficiency of the installation within a building.
TES	Thermal Energy Storage – An energy buffer technique where energy in the form of heat is stored in the ground. This technique can handle long buffer cycles.

9.2 Appendix 2 - Methodology

In this research, the innovations will be analysed by the Constructive Technology Assessment (CTA). This methodology enables the opportunity to define the external environment and align the internal environment towards the external environment. The Technology Assessment is the foundation methodology of many other technology assessments. One of these derived methodologies is the CTA (Constructive Technology Assessment), and is developed at the University of Twente (Johan Schot & Rip, 1997).

9.2.1 Technology Assessment

Technology assessment is the process of exploring the impacts of a new technology on people, social and governmental structures, and societies. Together, a technology assessment and environmental analysis can provide useful inputs into how a company or organization can develop a strong strategy. (JW Schot, Leyten, Roggen, & Smits, 1987)

The Technology assessments are used to "Reduce the human costs of trial and error learning in society's handling of new technologies, and to do so by anticipating potential impacts and feeding these insights back into decision making, and into actors' strategies." (Johan Schot & Rip, 1997).

In the Netherlands, there is an Organisation which executes such assessments: Rathenau Insitute (Former NOTA or Netherlands Organisation of Technology Assessment). This institute provides researchers to conduct Technology assessments.

9.2.1.1 steps in a Technology Assessment

The acronym often used in the literature is: VIMP-SPC (Vaulue, Interests, Motives, and Perspectives – Socioeconomic, Political, and Cultural). This acronym is used to describe 3 steps in the technology assessment: (Rodemeyer, Sarewitz, & Wilsdon, 2005)

The pace and direction of advancing knowledge and application is determined by human choice.

The specific directions in which technoscience is steered, and the pace of its advance, reflect who is making the decisions—their interests, values, motives, and perspectives.

The decisions that are made are determined within a complex social setting that encompasses a range of socioeconomic, cultural, and political components.

This complex social setting interacts with the results of techno scientific advance to create social outcomes. The setting, the science, and the outcomes mutually evolve over time.

These steps are used in TA, but can also be partial used in the CTA. For example in the book of Daey Ouwens, van Hoogstraten, Jelsma, Prakke, and Rip (1987), there are examples with social maps and policy aspects. These can be compared to these 4 steps defined by

Rodemeyer et al. (2005). For this research we use some of these aspects within the Constructive Technology Assessment.

9.2.2 Constructive Technology Assessment

Constructive Technology Assessment (CTA) is based on theories of technology dynamics and attempts to influence technological design and implementation to improve the effectiveness of the technology in clinical practice. (Daey Ouwens et al., 1987)

CTA is built around the attempt to anticipate effects or impacts of new technologies or new projects with a strong technological component. This is a core component of any TA effort. "Whereas traditional TA focuses more on the external effects of a technology and the choice between different technological options, the new field of CTA shifts attention to the steering of the internal development of the technology." (J. W. Schot, 1992)

CTA is based on the idea that during the course of technological development, choices are constantly being made about the form, the function, and the use of that technology and, consequently, that technological development can be steered to a certain extent (J. W. Schot, 1992).

Figure 9 - Process of CTA

Since its first use, CTA has developed from assessing the exact impact of a new technology to a broader approach, including the analysis of design, development, and implementation of that new technology. The literature on technology assessment methods can be divided between diagnostic and intervention methods.

Diagnostic methods of CTA include traditional social sciences techniques and also sociotechnical mapping techniques to identify the past and possible future scenarios of technological dynamics.

Intervention methods are action techniques, including awareness initiatives, controlled experimentation, consensus conferences, and dialogue workshops, to influence technological development and application.

There is also a difference in focus on the CTA. There is a focus on the consumer (cCTA) and a focus on the producer (pCTA) (Johan Schot & Rip, 1997). These two separate focusses are important to understand to consider with the outcome of the research.

Second distinction which can be made is the difference between variation and selection. Variations are by no means tried out purely at random during the search process. Heuristics are guidelines that promise, but do not guarantee, finding solutions to problems. (J. W. Schot, 1992)

Selection between variations occurs in two ways: Ex ante (Obtains when products and processes produced by heuristics are exposed to market-selection pressures, like survival of the fittest) and ex post (Influence is exerted on the generation of variations and thus on the shaping and the choice of the heuristics, more anticipation by a firm for the market).

"The method and design of the exact research activities is determined by the nature of the technology" (Douma, Karsenberg, Hummel, Bueno-De-Mesquita, & van Harten, 2007). The methodology is therefore not explicit described, but will depend and rest on the principles presented above.

9.2.3 CTA Strategies

J. W. Schot (1992) is presenting three CTA strategies for the future. Technology Forcing, Niche Management and Stimulation of Alignment. A short explanation of the strategies down below:

Inverse anticipation and feedback: Technology forcing

With inverse anticipation, the required social goals are taken, and desired technology is forced to head in this direction. Where TA uses the technology and searches for the impacts. (J. W. Schot, 1992)

This inverse anticipation is commonly used for governmental applications to find and force suited technologies for the society.

Graded Learning and feedback: Strategic Niche Management

When forcing a technology, the regulating actors and the technology developers experience a distance. There is time between the introduction of the regulation and the technology developed based on this regulation. This may create problems when modulating and broaden the design process. Sometimes, agencies will develop alternative-technologies themselves to help the industry a step further.

This strategy of CTA will help actors to learn of the taken steps before they make new goals. This will lead to a controlled innovation trajectory. So, a graduated learning process based on the feedback of CTA before making next goals for technology regulations. (Johan Schot & Rip, 1997)

Loci for Reflexivity and feedback: Alignment

When forcing technology, as described before, there is a distance between actor and developer. This distance can be minimalized by own developments (as in Niche Management) but can also be connected by informative platforms to inform the technology developers in order to align the developments towards the desired outcome. (Johan Schot & Rip, 1997)

9.3 Appendix 3 – Stakeholder analysis

To discover the effects on the industry, the stakeholders within the industry are interviewed. Therefore a small stakeholder analysis will be conducted to support the validity of the reseach.

All stakeholders (9) involved in the HVAC industry are determined as: Government, Network operators, Energy companies, facility managers, real-estate owners, Users, facility managers, manufacturers, Installation companies and installation engineers.

These stakeholders are assessed on the goal of the stakeholder and the influence on the HVAC market.

Government, has influence on the regulations for the energy consumption and can stimulate innovations and use of specific technologies by provide funding. The goal of the government is to create a better situation for the society as a whole, therefore is their interest in SMART HVAC moderate.

Facility Managers, are maintaining the building and are responsible for a good functioning HVAC system. Their influence is not large, but their interest in SMART HVAC is large, since it will improve their way of working and makes it more transparent what is happening within the installation.

Network Operators, are interested in a better spread of energy consumption (see SMART GRID). Therefore, SMART HVAC can help the SMART GRID functioning. SMART HVAC is not the core-business of the network operators but have certain interest in these developments. The influence of the network operators is not that big, but are able to adjust the price, by for example using SMART HVAC systems.

Energy suppliers are focussed on delivering enough energy at the correct time with the lowest production price (competitive advantage). The interest of energy suppliers in SMART HVAC systems is large, since the SMART HVAC systems can minimalize the peeks in the energy demands and supplies. The influence of the energy suppliers are also large, since they are determining the price of the energy. If SMART HVAC can be connected to SMART GRID, the energy suppliers will save a lot of energy due to the less peek powers and therefore less required performance of the energy production systems.

Users are not specifically interested in SMART HVAC. When the building has the correct air conditions (humidity, temperature etcetera), users are happy. When users can have reduced energy bills by using SMART HVAC, they can be attracted to SMART HVAC as well. The influence of a user as an individual is very small.

Real estate owners are most of the time in control of large amounts of property. The interest of SMART HVAC of these owners are due to the lower cost on OPEX (operating expenses) due to less energy consumption, possible lower energy price (by SMART GRID method) and lower operate and maintenance costs since the information about errors are more transparent, which reduces time, and thus money.

Manufacturers are focused on selling goods in order to make a profit. Often, innovative products will improve the efficiency and therefore reduce cost for the user. This will make a competitive advantage for the manufacturers. The manufacturers are thus focused on innovation and providing cost saving products for their clients.

Installation Companies are companies which deliver and install the HVAC installations. They have interest in new technology, but have not much influence in the matter, since an engineering company decides what installation specs there are required. The influence they have is the cheaper or better installation brands, which they can gain profit on by cheaper products or faster installation time.

Installation engineers are companies which engineer the ventilation plan and systems for the building. They can decide what technology is the best for the building and which performances the installations are required (effectiveness and efficiency). Therefore is their influence high, and their interest is high if companies demanding state of the art systems.

Putting these descriptions together in one diagram gives: (hereby is the influence and the interest presented on a scale of 1-5.

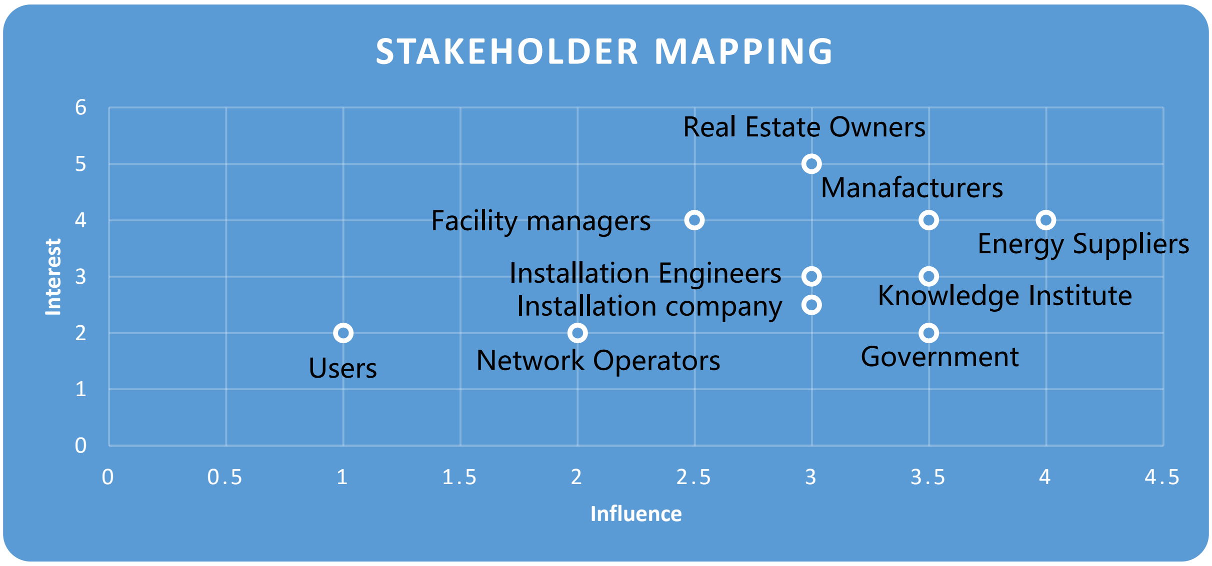


figure 10 - Stakeholdermapping

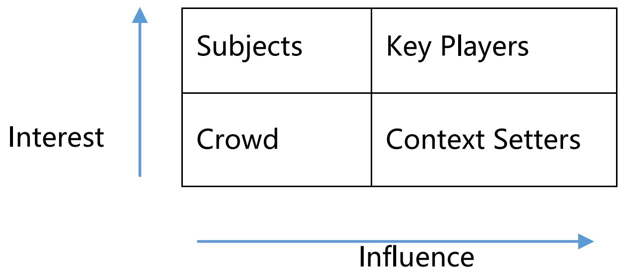


Figure 11 – Stakeholder mapping layout

According to Reed et al. (2009) all stakeholders are useful, but the key players are the ones where really to focus on. Using this chart, and saying the dividing parameter is 2.5, the following stake holders are categorized:

Key Players: Real Estate owners, Network Operators, Manufacturers, Facility managers, Energy Users, installation companies and installation engineers.

Subjects: Network Operators, Government.

Context Setters: -

Crowd: Users

For this research, there will be another distinction between the stakeholders. Because the CTA methodology focusses on the internal developments of the innovation, we first have to know what the external environment demands.

The external environment is determined by the stakeholders: Government, branch organizations & users.

The internal environment is defined by the stakeholders: Facility managers, real estate owners, manufacturers, Energy suppliers, Network operators, installation companies and installation engineers.

Internal Environment	**External Environment**
Facility managers	Government
Manufacturers	Real Estate owners
Energy Suppliers	Users

Network Operators Installation Engineers Installation Companies	Knowledge Centers

Table 1 – Stakeholder groups

9.4 Appendix 4 - Interview groups

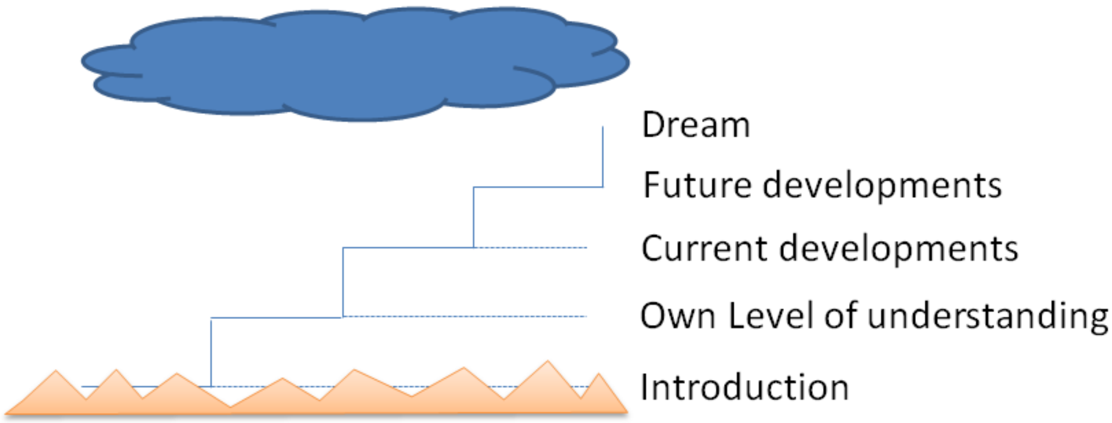
These are annotated by the marks [].

Reference number	Stakeholder group
1	Owner
2	Owner
3	Knowledge Institute
4	Knowledge Institute
5	Knowledge Institute
6	Installation Companies
7	Installation Companies
8	Installation Engineers
9	Facility Manager
10	Facility Manger
11	Manufacturer

9.5 APPENDIX 5 - INTERVIEW PROTOCOL

9.5.1 Bringing the interviewee to proper level of understanding

In order to bring the interviewees on a certain level, an additional strategy is required. This involves a 5 step process.



1. Down to earth, meeting the participant, getting to know their function, and their company.
2. Asking questions about their thoughts on certain concepts like SMART Building, SMART HVAC and/or SMART GRID depending on the stakeholder which is interviewed.
3. Is looking to their own view on current developments, which they use and what the effect is on their environment
4. Slowly introducing missing concepts/technologies. Asking them what implementation problems they foresee etc.
5. Dream stage is where an unlimited future will be drawn to see where the interviewee the optimum will see and barriers for longer terms.

9.5.2 Be unbiased and provide room for the interviewee to tell their story

During the interview, couple of tips and tricks are derived from multiple research articles. The next list is a short list of the key-tips which are taken into account for this research.

- Use open ended questions
- Avoid Leading questions
- Probe issues in depth
- Let the informant lead

9.5.3 Requirements Interviewees

In order to extract valuable information from the interviews, some requirements are set for the interviewees. These requirements are taken into account searching for the interviewees.

- The interviewee must have an understanding of the concepts SMART Building and SMART Grid, and must know the world of HVAC systems.
- The interviewee must know the Dutch HVAC/SMART Building market.
- After the interview, the interviewee must have time to check the outcome of the interview.

Characteristics of the interviewees are important to get answers which are valuable for the research. These characteristics may bias the research, since it is not an average opinion. But for this research, specialists are asked, and these have to have a certain mindset.

Characteristics required for this research are:

- Future minded
- Realistic
- Have a (little) understanding of the SMART Concepts

These characteristics are important to select the interviewees. For this research, not a lot of characteristics will be asked, since this can bias the outcome of the research.

9.5.4 Interview analysis

To analyse the interviews, checklists and matrices are developed to put in consistent data. The matrix is a list of specific topics and leaves can place a summary of the opinion/view of the interviewee on the place.

In the appendix is a concept checklist developed, which answers the topics which are required to cover the questions regarding the specific group.

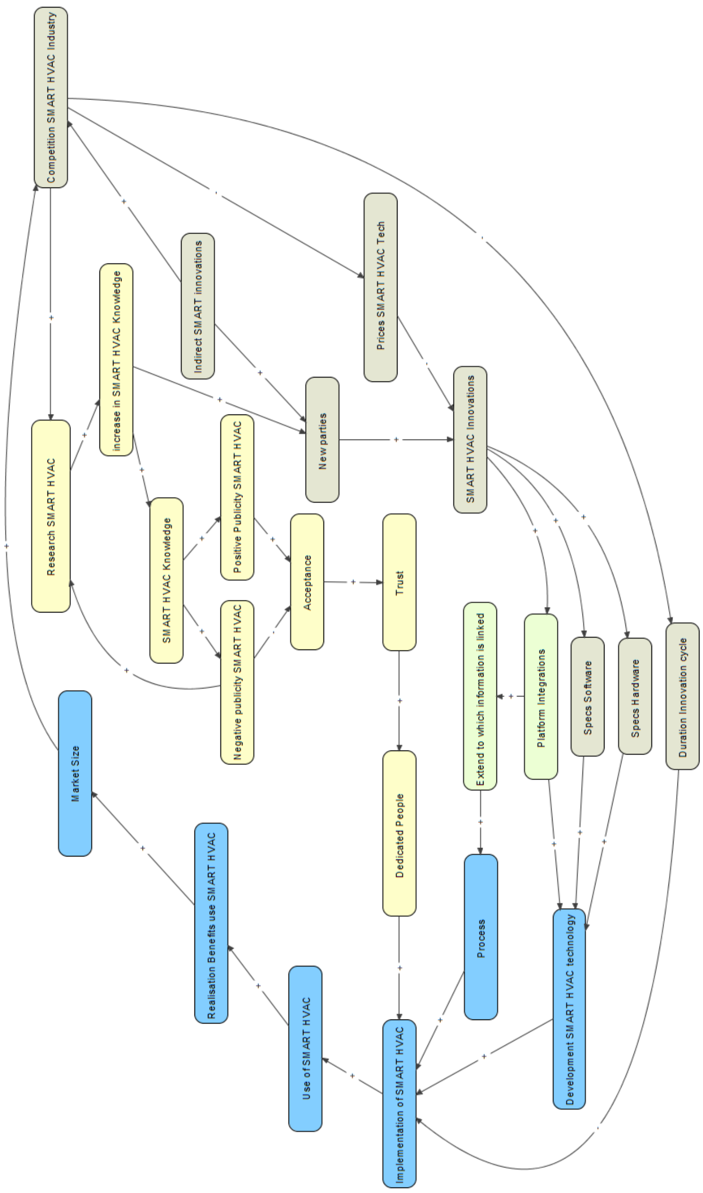
For both interview rounds, different topics and thus checklists are used.

The method of analyzing is more like cross case analysis, but the case is the discipline within the industry. So the Facility Managers, Real Estate owners, etc.

Depending on the output of Round 1, round 2 will be the answer on the questions in round 1.

In appendix []2 figure below is a casual-relation diagram drawn of the situation. This is a concept version of the current understanding of the research field. The interviews will bring a better understanding of the environment and will therefore improve this relation diagram.

At the analysis, this causal relation diagram will be revised based on the qualitative codes of the interviews.


Competition SMART HVAC Industry
Increase in SMART HVAC Knowledge
Indirect SMART innovations
Prices SMART HVAC Tech
Research SMART HVAC
New parties
SMART HVAC Innovations
SMART HVAC Knowledge
Positive Publicity SMART HVAC
Acceptance
Trust
Negative publicity SMART HVAC
Extend to which information is linked
Platform Integrations
Specs Software
Specs Hardware
Duration Innovation cycle
Market Size
Dedicated People
Realisation Benefits use SMART HVAC
Process
Development SMART HVAC technology
Use of SMART HVAC
Implementation of SMART HVAC

9.6 Appendix 6: Interview Questions

1	**General**
1.1	What are SMART Buildings for you?
1.2	What is SMART HVAC?
1.3	What is Building Automation?
1.4	What is BIM?
2	**Technological Needs**
2.1	Which innovations do you see in the next decade?
2.2	Which technology is important for your work within building devices/installations?
2.3	Which software innovations are important for you?
2.4	What do you think is the effect of the proposed innovations for your work?
3	**Building Automation**
3.1	How can Building Automation enhance your work?
3.2	Can you mention examples of Building Automation?
4	**SMART HVAC**
4.1	What can SMART HVAC do for you?
4.2	What do you need in SMART HVAC?
4.3	What benefits can SMART HVAC provide you?
4.4	Which disadvantages can you name for SMART HVAC systems?
4.5	Do you know what SMART GRID is?
4.6	Where do you see a connection between SMART GRID and SMART HVAC?
4.7	How can SMART HVAC helps to manage the asset?
5	**Strategies**
5.1	How do you think, the adoption of SMART HVAC can be catalysed?
5.2	Is governmental action is required (by funding)?
5.3	Is the market too slow with adopting SMART technologies?
5.4	Are consumers aware of SMART Technologies?
5.5	Can SMART GRID help the adoption of SMART HVAC? And how?
5.6	What conditions are there for you to adopt SMART HVAC?
6	**Dream question**
6.1	How will Facility Management looks like in 10 years?

9.7 Appendix 7 - Results

This document represents the findings of the constructive technology assessment. The interviews conducted are transcripted in appendix 9. This transcription is written in Dutch, since the interviewees are Dutch. First of all, the concepts are described in combination of the variety of the different definitions. After the definitions, the different subjects are described to describe the different visions of the stakeholders. In total, 11 stakeholders have conducted an interview. All these interviews have been transcripted and coded (total of 301 different codes). The result of combining codes in combination of the codes itself is the basis of these results.

9.7.1 SMART Buildings

As start of the interview, interviewees were asked what their definition of a SMART Building is. The frequency represents the amount of stakeholders who have mentioned the definition.

Definition	Stakeholder group	Frequency
Flexibility	Owner, Installation Engineers, Facility Manager	3
User Central	Knowledge Institute, Facility Manager, Installation company	3
Optimal control of building	Knowledge Institute	1
Self-learning system	Installation Company	1
Information of function and state of the building	Owner	1
Smart assembling	Installation Company	1
Ready for future use	Manufacturer	1

Observation: Most stakeholders defining the SMART Building concept as flexible and user central. These definitions are closely combined, since users are acting differently and want different options, the building needs to be flexible to adapt these preferences. Furthermore, definitions as Self-learning, optimal control is focussed on the intelligence of the system itself. Dealing with statistics and analysis of the building and act based on these analyses. SMART Assembling is a definition of an installation Company who is also thinking about the building phase of an asset. Although this is more an activity than a functionality, it is an interesting definition of the concept SMART Building.

9.7.2 SMART HVAC

Based on the answer of the SMART Building industry, the interviewees are asked what their definition of SMART HVAC could be, since they have (never) heard of SMART HVAC.

Definition	Stakeholder group	Frequency
Energy saving system	Knowledge Institute, Installation Engineer, Installation Company, Manufacturer	5
Intelligent use of system	Owner, Installation Company, Facility Manager	3
Exchange information of user and environment	Owner, Installation Engineer	2
Working autonomous	Facility Managers	1

Observation: Most stakeholders referring on the definition of SMART HVAC to an energy saving system, by a proper use of the systems. While owners and are more focussed on the intelligence of the system itself, and data exchange. Overall is the goal to save energy by an intelligent system by a more efficient use of the energy. One facility manager used the word "working autonomous", referred to the building management system where most of the people refer to. There is a tendency to make components as independent as possible, while optimisation will be analysed from a Building Management System.

9.7.3 SMART GRID and SMART HVAC

While most definitions are about energy saving systems, they refer to lower the cost of energy. One of the options to potentially lower cost is SMART GRIDS. Where the distribution of energy can be levelled. In this research, interviewees are asked about their vision on SMART GRID and SMART HVAC.

Definition	Stakeholder group	Frequency
Steering on production and demanding side	Knowledge Institute, Installation companies, Facility Manager	4
Exchange energy with environment	Knowledge Institute, Manufacturer	3
[Hardly any knowledge]	Owner, Installation Engineer	2
Internal SMART Heatnetwork	Facility Manager	1
No-Brainer	Owner	1

Observation: Most stakeholders defining SMART GRID as a network including steering on the production side and demanding side. While some are only focussing on the exchange of energy with the environment and do not mention any active steering of the production/demands. Two stakeholders had no proper idea what SMART GRID means. They were aware of the definition, but could not tell what the concept was about. A Facility manager of a big facility was describing a SMART GRID as an internal network of energy distribution, where the others were only referring to the external environment. One owner was involved in SMART GRID projects and said that SMART HVAC and SMART GRID combination was a no-brainer.

9.7.4 Innovations in SMART HVAC

The interviewees are also asked what innovations will change their work in the coming years looking at SMART HVAC concepts.

Remark	Stakeholder
3D Linked information	Knowledge Institute, Installation Engineer
Energy Serving Companies	Knowledge Institute, Facility Manager, Installation Companies
Enlarging comfort	Owner, Installation Company
Improved interfaces and communication	Installation Company
Limit the energy consumption	Owner
Passive energy techniques	Knowledge Institutes, Owner, installation companies, Facility manager
Sensors in buildings	Knowledge Institute
The internet of things	Owner
Ventilation based on over-pressure	Facility Manager

Observation: Interviewees have suggested a variety of innovations. Some product innovations, some process innovations. Most can be funnelled to (1) gathering information for analysis (internet of things, sensor information, interfaces, linked information, (2) Innovations for better comfort (ventilation system, enlarging comfort), (3) less energy consumption like peek-shaving by the use of passive techniques, and (4) change the market dynamics by deliver energy as a service instead of delivering the specified installation by taking the risks.

9.7.5 Barriers to implement "SMART" HVAC

If all innovations are so promising, why isn't everybody implementing the innovations described above? This question is asked to the stakeholders.

Remark	Stakeholder
Afraid to be fully dependent on IT	Knowledge Institute
Afraid to exchange information	Installation Engineer, Installation Company
Business case: Energy is too cheap	Knowledge Institute, Facility managers, Installation Company
Conflicting interests	Owner, Facility manager, installation Company, Manufacturer
Lack of intelligence of Hardware & Software	Knowledge Institute
Lack of knowledge actors	Owner, Facility manager, Installation Engineer
Legislation	Knowledge Institute, Installation Company
Low replacement frequency	Owner, Facility Manager

Observation: These barriers to implement cover multiple fields. First of all, the fear of open information is recognized. By the stakeholders' self or in their supply chain. Thereby, the dependency of IT is also a big topic, which most stakeholders do indirectly agree on.

Looking at the financial side of the barriers, many stakeholders mentioned that the energy is too cheap to implement advanced SMART systems, since the business cases are not feasible enough. If companies are including these technology, it is mostly about their image for corporate social responsibility. Multiple stakeholders are talking about conflicting interest in the innovations, some are supporting them, others are purposely selling conservative materials. This is described in more detail later in this chapter. Lack of knowledge of the actors is also widely recognized by the stakeholders. Much knowledge is gathered by personal interest, and if that is not the focus of the actor, knowledge of the latest concepts and innovations is a barrier to implement it. Legislation is for some parties a barrier, while others see legislation more as catalyst. Low replacement frequency is also a point where the slow implementation is to blame on. Companies have their installations for a very long time in their buildings. Replacement of these installations happens only once in 10-15 years, and happens fragmentally. Implementation of high-end innovations is therefore not often the preferred option.

9.7.6 catalysts for innovation

To validate the barrier question and to investigate if there are more issues about the topic, the question is how to speed up the implementation process.

Remark	Stakeholder
Financial satisfaction	Knowledge Institutes, Installation Companies, Manufacturer
Front-Runners	Knowledge Institutes
Legislation	Knowledge Institutes, Facility Managers
Stimulation from government	Knowledge Institutes, Installation Companies, Facility Manager
To service providing company	Owner, Knowledge institutes, Facility Manager, Installation Companies
More Knowledge	Knowledge Institute, Installation Company, Facility Manager

Observation: Most stakeholders recognize the fact that innovation need and can be catalysed. There are multiple fields where they are focussing on. Much interviewees are explaining that they think that when companies provide a service to deliver the comfort, there will be more incentive to innovate and be more efficient. Secondly, they see that legislation is stimulating the innovation of SMART HVAC. Due to the Energy-neutrality 2020 treaty, companies are more aware of the fact that they have to innovate. The question remains if all companies see this as a hard deadline. Stimulation from the government appears therefore to be a good catalyst, in the form of subsidy, or other stimulation programs for financial satisfaction. Knowledge seems to be a barrier which needs to be solved. No knowledge results in: bad tenders, bad offerings, user is not demanding SMART, etc.

9.7.7 Market dynamics

Market dynamics are often discussed in the interviews. In the next table, an overview of the topics of the market dynamics.

Remark	Stakeholder
Mindset of Installation Company	Installation Engineer, Facility Manager
Knowledge Installation Engineer	Installation Company
Energy Serivice Company	Knowledge Institute, Facility Manager, Installation Companies
Owner experiences Pull on market	Owner
Certainty, no innovation, over dimensioning	Knowledge Institute, Facility Manager
CO2 reduction should be basis of market	Manufacturer

Observation: On the market dynamics, there are different misconceptions about the incentives. Depending on the owner, he feels he has to pull on the market to get the best installations he desires. As discussed before, energy serving companies are mentioned by many stakeholders. Also, companies choose certainty over innovation. And some companies are in a position to advise on older systems where they know the question is fulfilled with more certainty. The mindset of installation companies is rather traditional according to installation engineer and a facility manager. Suggested

9.8 APPENDIX 8 – IN-DEPTH ANALYSIS

The conducted interviews structured by the four sub questions of this research. These four sub questions are transformed towards a 4 pillar based structure in which the results will be presented. Based on the outcome of each pillar, the main question can be answered. This chapter describes the pillars seperately.

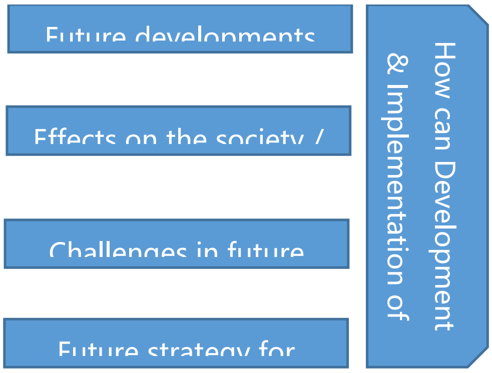


Figure 12 – research pillars

In total, 11 stakeholders have conducted an interview. All these interviews have been transcript and coded (total of 275 different codes). The codes are combined to categories and are the basis of the results. A layout of the codes common codes is described in appendix 3.

Since SMART is a buzzword among many members in the industry, the definition of SMART HVAC is asked to determine the perspective of the interviewee. During the interview, interviewees defined SMART HVAC two separate definitions: (1) an energy-saving system and (2) Intelligent use of the system. For this research, the definition of SMART HVAC is set to: *A Heating, Ventilating and Air Conditioning system with components that exchange information of their status and can anticipate on orders from the central controlling software to optimize the effectiveness and efficiency of the installation within a building*. In this research, these exchanging components are called: *Intelligent components*. The exchange of information is a result of the innovations around the concept "internet of things" where all components can interact with each other.

Besides the intelligent use of the system, the other definition: "an energy-saving system" can be seen as one of the goals of a SMART HVAC, since energy-saving is one of the results of efficiency and effectiveness.

9.8.1 Product developments in the HVAC installation industry

The first pillar to be described is the future developments in the HVAC industry. During the research, interviewees have proposed multiple innovations that are likely to be adopted in the next decade. These innovations are categorized in four categories: (1) Increase efficiency of HVAC installations, (2) increase effectiveness of HVAC installations, (3) the exchange of information through the system and (4) External developments affecting the HVAC industry.

9.8.1.1 *Increase efficiency of the HVAC installations*

This category includes the major developments in the HVAC industry which are focused on the efficiency of a HVAC system. In other words, create the same output, with less resources. Resources of a HVAC system can be expressed in energy. There are mainly three types of energy sources; gas, electricity and heat. Efficiency of HVAC systems can be split into three major parts (1) transformation of energy resources (gas to heat/electricity or electricity to heat) and (3) buffering of energy.

In general, the focus of installations has not always been on efficiency of the system. From the 80's energy consumption was becoming an issue. [10] From this point, many innovations have been adopted by the market, which increased the efficiency of the transformation of energy. Interviewees have suggested that these innovations are coming to an asymptote. I.e. the theoretical efficiency rate from gas to electricity is 110%, and currently the rates are up to 107%. Therefore, the last 3% towards the theoretical maximum will not make a fundamental difference in the efficiency of the HVAC systems. [11]

Energy consumption of building needs to be reduced according to the governments in the EU and others. Main driver behind this movement is the reduction of CO_2 worldwide. New legislation [Rijksoverheid, 2015] demands new buildings to be energy-neutral before 2020. This means that the total energy consumption of a building in a cycle of a year is 0. This legislation is forcing the construction industry to move towards less energy consumption and energy creation within the building (i.e. by solar power). Besides the creation of energy, the energy needs to be buffered, since not all energy is created by the building at the moment of use.

Buffering technology can vary in different types. At first, electricity can be stored in batteries. In the future, a building can consist of a battery which stores energy for a daily to weekly cycle. Saving energy in a battery on year basis (charge in summer and use in winter) requires big batteries, this has to be solved differently according to the interviewees.

Another buffering technique is already used in multiple buildings and becomes a standard for all new buildings: Thermal Energy Storage (TES or in Dutch: Warmte koude opslag). This form of energy buffering creates the ability to store heat and receive heat for longer cycles (i.e. yearly). TES has multiple types, but in the Netherlands, this is mainly used in the ground below the real-estate in the form of heat. In the summer, the buffer will be charged with heat from the building which needs to be extracted (mainly air-conditioning), and in the winter, the heat will be extracted from the source to the building.

A third buffer technology which is experimented with the last years are passive techniques. These are alike the TES, but are integrated in the building itself. The main principle pf passive techniques is to increase the heat capacity of the building, thus the amount of heat added (or removed) to the building to change the temperature. This can be done in two ways:

increase the mass of the building, (i.e. by adding more concrete in the structure) or by adding phase changed materials. Materials which are changing from phase (in this case from a solid to liquid) require a lot of energy. Phase changed materials in buildings are changing phase within the comfort levels (often 20 degrees Celsius) and slow the process down of cooling or heating the building. This last technology is not "new", but will be experimented and included in buildings to solve the energy-neutral challenge.

Last major technology mentioned by interviewees is the natural ventilation. Due to temperature differences and natural flows of air through the building, the energy used to ventilate the building can be reduced. The challenge for product developments is to include all technologies together to create an efficient HVAC system.

9.8.1.2 Increase effectiveness of HVAC installations

Besides efficiency of HVAC systems, the effectiveness of the HVAC installations is also a focus point for the product developments in the HVAC installation industry. Effectiveness of HVAC installations can be defined as: *the extent to which the comfort of the building is matched to the desired comfort of the user*.

Interviewees defined a SMART Building to be user central and flexible. These definitions are also applicable to the effectiveness of HVAC. A SMART HVAC installation requires to be flexible [2,8,9] and user-central as well. The user central means that the user is able to adjust the comfort to his own level.

Comfort in this research is a narrowed definition of which can be commonly known to comfort. Comfort for HVAC are the state when the temperature of the building and its air conditions are in a way that the user of the building feels pleasurable physical ease (partly from Heritage Dictionary). Thus, the air conditions and the thermal radiation of the building to ease the users during their stay in the building.

Since all users have different comfort requirements, interviewees are suggesting that the building needs to be flexible to support these different demands. But, the extent to which the flexibility needs to be implemented is not commonly agreed on. This level of comfort is partly defined by the user, but overall, the owner of the building has to decide to which extend the flexibility and comfort is provided. In general, the more flexibility, the more costs this involved to achieve the desired comfort levels.

The interviewees have not mentioned major effectiveness increasing developments. Many interviewees have the opinion the effectiveness of the HVAC installations is at a proper level. This is a signal that the focus on development is mostly on efficiency rather than effectiveness.

9.8.1.3 Exchange of information

As described before, hard and software are able to exchange information with each other. Interviewees mention issues which occur to bad communication or settings of the installation. By exchanging information of the status of the component with the others, many of these issues can be solved. This section defines how interviewees described the communication with a SMART HVAC system.

Currently, HVAC systems are managed by a building management system (BMS) as described in the literature study, earlier in this document. A BMS has multiple tasks, and HVAC is one of them. A BMS is sensing the building and controlling the HVAC. A SMART HVAC system is referred to the HVAC systems and the HVAC part of the BMS. Most components in the existing buildings are not exchanging information to the BMS, but only accept orders from the BMS (i.e. level 1, level 2, off). Most BMS are rule-based programmed (if-then-else) and to therefore not check the effects on the output, since it is not measurable (due to the lack of information).

The current developments of hardware and software aiming on the exchange of this information. Previously installations are installed on location and are set to the values the engineers have calculated [8]. This might not be the best values, since the calculation can deviate from the real environment and the environment tends to change over time. With intelligent components, the information can be exchanged and thereby feedback loops are created to adjust the settings to the most appropriate settings for the specific situation. This was not able in the rule-based system. Thereby, the rule-based system is not able to cover all scenarios. If the scenario is unknown to the rule-based system, the system falls into wrong decisions.

Besides rule based systems, the alignment within the system can be optimized. In the current buildings it occurs that heating and air conditioning are on at the same time [9]. With communication between components, the alignment of these actions can be judged and properly be solved. Resulting in more efficiency and effectiveness.

The feedback loops in these systems are a part of an overall analysis. In figure 13 an overall-analysis is defined where different types of analysis are combined to define a proper feedback loop for HVAC installations.

This method starts by receiving information from the sensors and components in the system. Based on this information a descriptive analysis is executed, determining what is happened in the building. If the values are not according to the expectations, the values are analysed with the diagnostic analysis, which determines the “why” it did happen, and the system can react on these outcomes by adjusting the settings or warn the facility manager for a failure in performance.

After the "errors" in the system are defined, a prediction can be made what is likely to happen next. For a HVAC installation, this contains of weather predictions, predicted building usage, etcetera. Based on this analysis in combination with the descriptive analysis, the prescriptive analysis can be executed, determining which actions the installation has to take to improve the comfort levels.

Figure 13 – Analysis (Gartner, 2010)

Interviewees mentioned that the current Building management systems are often only use the prescriptive analytics. All Building management systems are focusing on: "what should we do?". Newer installations conduct more sensors and provide feedback towards the central building management and are describing what is happening (Descriptive analytics) [3]. And some companies are using predictive analytics [9,10]. The extent to which the predictive analytics is used, is not determined in this research. The last step in the Gartner analytics methodology, the diagnostic analytics is not mentioned by the interviewees [10] as the future of SMART HVAC.

The combination of all these analyses in one integrated system is the future of SMART HVAC and tends to improve the efficiency and effectiveness of the HVAC installation.

9.8.1.4 Developments affecting the HVAC industry

Besides the development within the HVAC industry, there are adjacent concepts and developments which are likely to affect the HVAC industry. In this research, one major concept is taken into account which is called SMART GRID. This concept is already explained in the literature study, and in this chapter, the link between SMART GRID and SMART HVAC will be described.

As described earlier in this chapter, the interviewees are focusing on reducing energy for the installations. This has two main reasons; (1) saving energy cost and (2) be more responsible for the world. These are both motivations for the owner of the building, which the contractor/engineer has to fulfil. Saving energy cost is a derived incentive to reduce energy to reduce CO_2 emissions.

A SMART GRID connects multiple demanding and supplying instances to each other via multiple resources. A SMART GRID is often referred to as an electric network, but heat networks can also be included in the SMART GRID concept. In a SMART GRID, energy will be distributed among members in the network. But, when the SMART GRID is starting to grow by more buildings which are delivering energy, the power plants are possible there vanishing. If this is the case, who is defining the energy price? At this moment, energy serving companies are defining a price for energy delivery and consume. But in a SMART GRID, a free market concept will be suitable to distribute the energy among the members. [3,4,11]

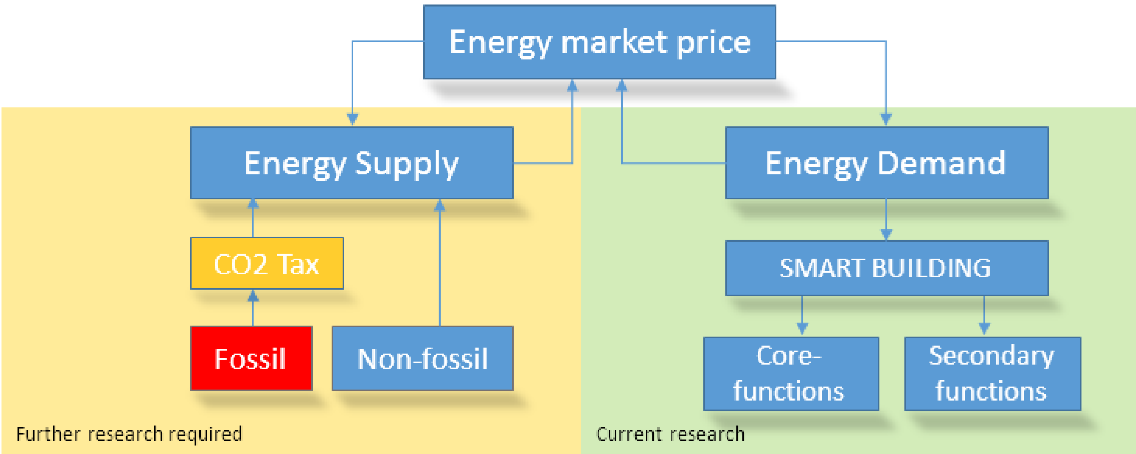


Figure 14 – Flexible Energy-Cost Market

In figure 8, a flexible energy-cost market is drawn with a demanding and supplying side. On the energy supply side, there is a distinction between fossil and non-fossil based energy sources. This distinction is made since the goal of all SMART GRID, Green energy and energy reduction is to reduce CO_2 emissions. Some interviewees mentioned a fossil-based tax which can be laid upon the use of fossil fuels (i.e. gas, coal, oil). If these taxes are implemented, the non-fossil energy is often cheaper than the fossil based fuel and the SMART GRID chooses to use the non-fossil based fuels (if available). TNO developed a software tool to make a distinction between the source, availability and flexibility in an energy source based on a market-based algorithm. This comes close to a SMART GRID described in this research. Although the supplying side of energy is very interesting, this research focusses on the demand side of the energy. With the focus on the HVAC installations, which is often the major energy consumer in the building. The modern building itself contains of both energy supplying as well as energy demanding instances. A SMART HVAC/BMS has to make the trade-off which source is used to serve which need. For this reason, the SMART HVAC has close connections with the SMART GRID, and is a part of this GRID as demanding instance.

The first application of the SMART GRID – SMART HVAC integration is the timing of energy consumption of the external GRID. In the current energy market, a main issue are the peaks in the energy consumption and supply. If the sun is shining in the Netherlands, the wind is blowing and there is very little electricity consumption, most power plants have to stop producing electricity, since there is enough produced by the GRID itself. But, these power plants are required to fill the lack of electricity, for a winter night without any wind and a lot of electricity consumption (i.e. new year's eve). Then, all the power plants and emergency power generators have to scale up to fulfil this electricity demand. [10]

The described scenarios are extreme scenario's, but companies are forced to use a small bandwidth of energy consumption. To reduce the cost of energy by shaving the peaks in the network, not only by adding power sources to the GRID, but also tweaking the demanding side of the network will allow the peaks in the GRID to level out.

This tweaking on the demanding side is part of the BMS and especially the task of a SMART HVAC system. By anticipating on the energy availability from the GRID, the SMART GRID can level out the external energy consumption by using buffers in the building.

There are mainly two types of buffers: (1) Energy buffers and (2) comfort buffers. An energy buffer is a buffer where energy can be stored, but which is not recognized by the user. Mostly in the form of heat or electricity. These innovations are described earlier in this chapter. By charging and consuming this buffer, the energy in the external GRID can be leveled.

The second buffer type is the comfort buffer. This buffer is the bandwidth of the comfort parameters defined by the owner. For example, the temperature of the air must be between 19 and 21 degrees Celsius. The theoretical total energy in the comfort buffer is now 2 degrees' Celsius times the heat capacity of all air in the building. These types of buffers can be included in multiple parameters which are defined for the comfort delivered by the HVAC installation.

Before one single process flow of the information exchange between SMART HVAC can be described, one remaining part needs to be described. This part is developed by TNO and is now formalized towards an ISO standard. The Energy Flexibility Interface (EFI). This interface is describing the flexibility to which extent the energy source is able to deliver energy on any given time. For example, a photo Voltaic panels are not flexible at all. When the sun is shining, electricity is generated, and no sun, no electricity. The availability of the sun is not in our control, and therefore not flexible. A gas heater is very flexible, since it can turn the production on or off whenever is needed. This EFI is required to choose between different energy sources and can be combined with the CO_2 emission values of an energy source.

9.8.1.5 Process flow of a SMART HVAC installation

For this research, one main process flow will be described to get a proper overview of how the HVAC innovations relate to each other. Till this point, the innovations are described separately and mentioned a little cohesion about the goal of the innovation. But now the major fields are explained, one single process model can be drawn which positions all concepts described above in one process flow.

In the basis, this process flow consists of all four analytics described by Gartner (2010) in figure 14. It is a feedback loop in order to improve the system while functioning. And it includes the concepts of SMART GRID and internal energy sources based on an energy availability, in this model presented as an energy price defined in the free energy market of the SMART GRID. The model includes the determination of the energy is used from internal energy sources, external energy sources and/or consume/charge the buffers.

The model is presented in figure 15 where four quadrants are defined: (1) External SMART GRID, (2) HVAC Installations, (3) HVAC Management System and (4) the Building management system. External SMART GRID is the free energy market where energy can be delivered or consumed from. The HVAC Installations represents the physical installations like ventilation units, boilers, buffers, air condition units, etcetera. Both lower quadrants are representing software-based decisions and measurements with the Building management system and the SMART HVAC part including sensors from within the building.

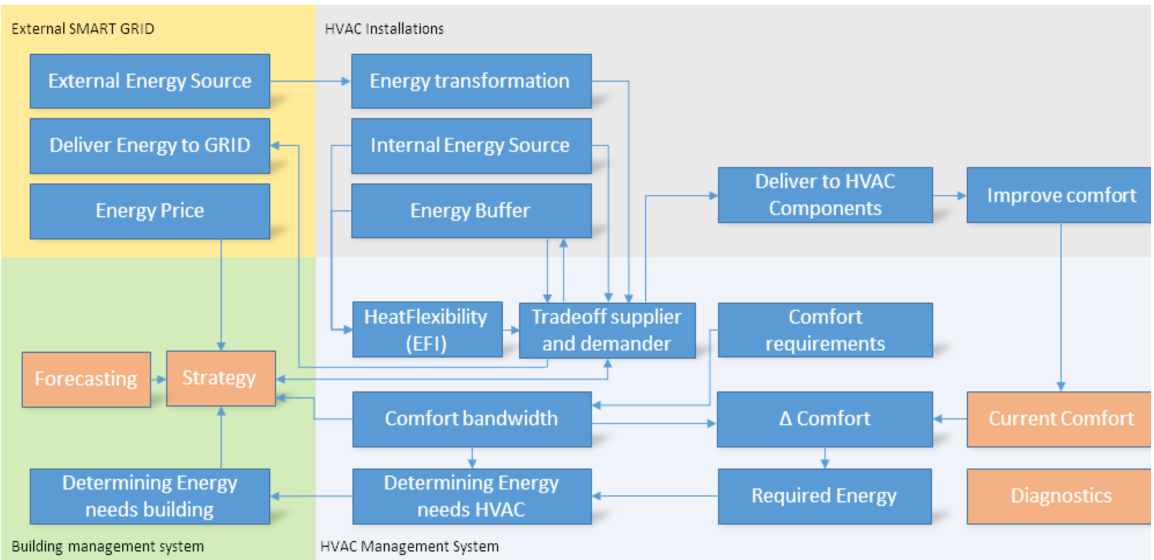


Figure 15 – SMART HVAC

The goal of this process flow is to develop a strategy on which the installation is working, to improve the comfort while minimizing the energy consumption from the external network based on the market price. This strategy is the prescriptive analytics of this process flow. In this strategy, there are all kinds of decisions made which component in the building receives how many energy, the strategy is actually the conductor of the energy within the building. The strategy consists of 5 major inputs: (1) Forecasts, (2) available energy in buffers and the state of the internal energy source, (3) position of the current comfort parameters within the comfort bandwidth, (4) the required energy by the building prioritized by component and (5) the energy availability/price from the SMART GRID.

The first input is the current energy price from the market. This determines the position of the market in the supply and demand state. Based on this price, the installation can choose to postpone the improvement of the comfort towards the lower comfort threshold or already push the comfort to the upper threshold when the energy price is low in combination with the forecasted scenario.

Secondly, forecasts are predictive analytics which consists of the weather and the usage of the building in the coming period. In order to determine the change in comfort by the environment and change by other use of the building, the energy consumption can be forecasted. In this forecasting, the energy availability/price can also be estimated, by the wind conditions and intensity of the sun though the SMART GRID. In combination with historical data, the diagnostic analytics can help improve this estimation.

The third input for the strategy is the existing energy within the building located in the top middle of the diagram. This process is a trade-off between the multiple energy sources: Energy buffer, internal energy sources. The state of these components are determined and compared to their flexibility. This information is pushed to the strategy and compared with the overall energy demand versus the energy price and the forecast of the energy price.

The fourth part of input of the analysis is the comfort bandwidth which can, in combination with the current comfort, be determining what the current comfort buffer is within the building. The current comfort in the building is analyzed by the descriptive analysis.

The last input of this process flow is the energy requirements of the building and thereby the HVAC installation. The current comfort developed by the descriptive analysis is measured with the sensors throughout the building and the installations. The descriptive analysis combines all sensor information and compares the current comfort against the comfort bandwidth which is defined in the comfort requirements. The system "knows" by the initial design calculation and historical data how many energy is required by which components to improve the comfort even more. The required energy is a deviation from the amount of energy required to improve the comfort to which extent. These energy requirements are prioritized and presented together with the overall energy needs of the building towards the strategy.

The frequency to which this strategy is reprocessed can varying from once every second towards once an hour or more. This all depends on whether the comfort bandwidth is tight and the energy demands within the building change a lot.

When the strategy has defined how many energy is consumed and from which source, the system can execute the strategy by actually transport the (external) energy towards the components and transform the energy to other forms to improve the comfort of the building itself. It might also be the case that the building has enough energy and the energy price within the SMART GRID is very high. The system can also deliver energy towards the GRID in order to earn money by selling the energy against a high market price.

To close the feedback loop, the improved comfort will be measured again at the new development of the strategy. The diagnostic analysis will run on the background analysing all data and is searching for why things are happening. If values are not improving while they should, the diagnostic analysis will investigate what could cause the problem by looking at historical data and will adjust the settings within the strategy parameters to improve the effectiveness of the system. This is a very important step, since all installations in the current buildings are nearly optimized after being installed. Because it is not transparent what is happening within the building. If there are made changes in the rule-based program, it is mainly because users/managers have discovered an improvement, not because the system is telling them to.

It might also be that a component is failing on its performance by something the system itself cannot solve. For example, an internal crash or broken parts. The diagnostic analysis needs to report this towards the facility manager combined with the priority of the issue. The system can automatically try to cover the failing components till the component is being repaired.

This process flow described a methodology to combine the existing concepts in one place by combining the SMART HVAC towards the SMART GRID. This methodology tends to save a lot of energy and especially, contributes to a stable and smooth SMART GRID. In the next chapter, the discovered effects of these systems on the user and the society as a whole are described.

9.8.2 Effects of SMART HVAC on the user and the Society as a whole

In this chapter, the results of the second research pillar are described. This pillar focusses on the effects of an integrated SMART HVAC system (as described in the previous chapter) on the user and the society. These predicted effects can be grouped in three groups: (1) improved effectiveness, (2) less emissions (3) open data. These effects are partly determined by the interviewees, and partly by the existing literature. These effects are predicted effects, since a system like this does not exists nowadays.

9.8.2.1 Improved effectiveness of the HVAC installation.

A SMART HVAC has the goal to improve the effectiveness of the installation. The improved effectiveness can be explained in two categories: (1) Feedback loops and (2) increased flexibility.

Currently, many installations are not configured properly [8]. They do not have the ability to improve on its own and are nearly to never adjusted. This lack of adjustment creates automatically an inefficiency and ineffective installation from the start of the lifecycle. Feedback loops as described in the previous chapter are improving the settings of the installation and thereby the effectiveness (and efficiency) of the installation itself.

An example mentioned by the interviewees is the Thermal Energy Storage (TES) systems. For a long time, TES systems were not properly set up [8]. For this reason, the installations were not as efficient as promised and also not as efficient as they could be. This creates a passive behaviour in the market for new innovations for energy generating. Although these negative biases from clients, the newer TES systems are more efficient and profitable. Therefore, almost all new bigger buildings are using a TES system [4,6]. This movement in the industry determines that a certain point is reached where the majority is convinced to use the technology. The TES market is moved from Early-adopters to early majority. (Schilling, 2005) This point is very important to reach. Before this point, the innovation might be rejected, but if the early majority is adopting the technology, the market will adopt the technology to a large extend (towards late majority).

A SMART HVAC also enables more flexibility in the system. The system is more flexible on itself by the algorithm based software instead of the rule-based software. This difference is able to adopt changes in the system occurred by failure as described before, but also to changes from the users of the building. This results in the ability to control the HVAC system as central or decentral as the owner wants. The system is able to level out the different comfort demands in different rooms and even towards different users. Although the interviewees have been doubting to which extent the flexibility has to go, the system can adopt the changes with the current setup.

The effect of this functionality on the user is the fact that the user is more able to change the building towards his comfort level and thereby is feeling happier, is more productive, etcetera.

9.8.2.2 Less Emissions

Another effect of SMART HVAC on the society is less emissions of fossil resources. This effect is a derived effect from two factors: (1) the system reduces energy consumption and (2) the contribution of SMART HVAC to level out the peaks in the SMART GRID.

As described before, SMART HVAC focusses on minimizing the energy consumption of the building. The main reason for the market to produce this is the legislation of the new energy neutral law [6,11] [Rijksoverheid (2015)]. The main driver behind the energy reduction is the reduction of CO_2. In this premise, SMART HVAC reduces CO_2. The reduction of CO_2 is the motivator for most of the presented innovations.

Secondly, the SMART HVAC can make a trade-off about the origin of the energy source. This trade-off can mainly be focussed on energy-cost and availability, but can also be influenced by the amount of produced CO_2. Although the trade-off is mainly focused on energy-cost. This energy-cost is a result of the availability of the energy and the trade-off between fossil and non-fossil sources if the SMART GRID contains of "CO_2 tax".

Thirdly, the SMART HVAC can transform energy at times towards other forms of energy like hydrogen gas. This production will be executed when the SMART GRID is containing of a lot of energy. When the energy-price in the SMART GRID is low, the amount of green energy will be high, and therefore these hydrogen gasses can be produced from a high percentage of green energy.

9.8.2.3 Open Data

The last effect of SMART HVAC on the users and the society is the open data. The data in open data can be defined as the exchange of information through the system which are captured or processed by the system. For the functionalities for SMART HVAC, a certain amount of openness is required. This openness is a challenge according to the interviewees, but are not aware to what extent sharing data is appropriate. Some interviewees recognize the fear of the owners for open data [7,8]. Owners are responsible for the data collected and created by the building about, among other things, the users. On the other hand, suppliers are also afraid for open data considering the performance of their products is open for everybody. [8]

Although the installation companies and engineers seems to link sources without any limits [8], manufacturers are not really happy with the transparency in data. When information about the durability of their products is be compared to others [8], they can lose their business, due to lack of durability, performance or what so ever. For the market as a whole, this information is valuable, since they can make better predictions about the performance of the installations.

The openness of data for companies can be implemented in contracts, if the company knows what kind of information can be exchanged. Besides company information, personal information is much harder to protect as an owner. This personal information is often focused on guiding the user in the choices for their daily lives. The information is clustered by person, and is built especially for the specific user. Looking at HVAC, these choices are not that many. There may be personal preferences for local environment, but this information is hardly personalized and therefore not easily experienced as "out of control".

Interviewees were also explaining the fear of losing control of the technology [7, 8]. This feeling of control is not only on the owner side, but also on the user side [10]. As long as the user has the feeling he is the one in control of the information, it is appropriate to combine the information.

At the same side, the market recognizes this movement and quote "Data is available, so we are obligated to use it" [7]. This refers to the duty of companies to deliver the outmost service and intelligence for their users. This in order to move the excitement factor of the methodology of (Matzler, Bailom, Hinterhuber, Renzl, & Pichler, 2004) as high as possible. Excitement factors are crucial to a good comfort experience. The methodology of (Matzler et al., 2004) describes different factors on which the experience is based: Basic factors, performance factors and excitement factors. The extent to which the user is experiences comfort can be laid out against these factors to determine the priority of each factor.

The user experiences that it is more about him, so users are expecting more". [7] This quote is representing the extra functionality of the building that the users are expecting on a certain level. As for (Matzler et al., 2004), these go from excitement factors towards basic factors. Meaning, in the beginning, users are excited to see these new functionalities, but at a certain level they expect the functionality to be present.

For data exchange with the SMART GIRD, this needs to be in a low frequency. [11] If the frequency is too high, the GRID can recognize the activities within the building and thereby lose some privacy. The smaller the building, the better this information is visible by a high update frequency.

9.8.3 Challenges of (SMART) HVAC in the next decade

In the current market, the HVAC industry faces some challenges. These challenges are investigated among all stakeholders. Also, the challenges of SMART HVAC are investigated. Interviewees were asked what the challenges or barriers are for this approach. In this chapter, these challenges are described in three parts: (1) Technological challenges, (2) Knowledge and (3) challenges in the market dynamics.

9.8.3.1 Technological Challenges

For the upcoming ten years, the challenges in technology is not directly in the technology itself, but more in combining the technology with the sensors and software [3]. The process model described in the first research pillar, is based on technology which already exists. The integration of interfaces onto components and connect them to internet is also a step which is currently implemented. There are minor improvements on these technologies, but real technological challenges are not to mention before creating a SMART HVAC.

9.8.3.2 Knowledge in the industry

More of a challenge is the knowledge in the industry. Since the HVAC industry is a conservative [6,11] and stiff market, the knowledge of most companies is not leading edge. The knowledge of companies is often determined by the personal interest of one or more individuals who are aware of in the new developments. [6,9]

These individuals taking the company towards a higher level and thereby share the knowledge throughout the company. This process is very slow and the installers are one of the last ones who truly understand the newest developments. [9]

Big owners are aware of the newest innovations, since they can afford an actor who is able to keep track of these. Smaller owners are not able to do so (or not willing to) and are therefore not aware of the newest developments in the industry. Since the market is not fully aware of the newest development, the smaller owners are not advised to use newer technology and therefore the adoption of new HVAC innovations are not used. [4]

The users are unaware of the latest developments and are therefore not asking for the latest technology. [4] Although the users are not asking for the latest developments, the owner will implement these, since it is mostly about energy-saving technology, which is focussed to save costs over time.

Knowledge institutes are aware of the lack of knowledge in the industry and are organising events to keep the companies up to date with the latest technology. [4] Nevertheless, the smaller companies are trying to focus more on the current technology, rather than thinking ahead.

The challenge for this industry is to create a market where "old" technology is combined with the newest concepts. Thereby is the challenge to learn the market in general what the vision of the different concepts are in the future.

9.8.3.3 Challenges in market dynamics

The last group of challenges concerns the dynamics in the market. These challenges are described in two categories which are mentioned by the interviewees. The first category deals with the difference drivers for the market and the client. The second category focusses on the failing business cases, since energy is relatively cheap.

9.8.3.4 Clients perspective vs Market perspective

From a client perspective, the comfort for the users is the main-function of a building. Therefore, it is important that the comfort is on a proper level, and that the costs to reach that comfort are as low as possible [1,10]. For larger companies, Corporate Social Responsibility (CSR) is a large factor where durable energy and innovations are stimulated to create a good image to the individuals. [1] This CSR is an extra motivation to put extra money into a good image of the company/brand.

Nevertheless, the focus of the market (from now called the internal environment) is more on earning as much money as is feasible [8,10] while complying to the requirements set by the client. Innovations from the market are likely to be installed under two circumstances: (1) The client asks for possibilities for the innovations [1], and (2) the market is healthy and competitive and tries to be distinctive on knowledge and new/improved products. [7] The last option will only be presented if the client is comfortable with the innovation and experiences low risks.

The first reason is called Market pull (Schilling, 2005), and is mentioned by owners and knowledge institutes [1,4]. The second circumstance is called Technology push. This is also mentioned by knowledge institutes, and installation companies. This is contradicting, but this is probably due to the variety in clients (big and small). Bigger clients that are interviewed are an early majority type of adopter or even early adopters (in pilots), while other (smaller) clients are much more conservative [2] and therefore more towards the late majority adopters (according to the definition of Schilling (2005)).

Although a client may be an early adaptor for many innovations, the replacement cycle of a client is not high (10 years or more) [1,9]. This low replacement frequency is lethal to the speed of innovation. Many installations are having a long durability and are therefore not quickly replaced. Due to this slow cycle, the innovations are not fast implemented by the market. SMART Systems do only function optimal when the complete system is connected to the central software. [3]

Besides the adoption speed, large firms are using incubators to help start-ups to get in the innovation funnel [7], (Schilling, 2005). For large clients and companies (i.e. ABN, Schiphol and Heijmans), the radical changes in systems are tested in pilot projects, often provided by start-ups. However, these start-ups are often lacking resources (capital) to insure the big projects [1] (Schilling, 2005). Some bigger companies are binding these start-ups to them in a joint venture in order to create a win-win situation by sharing risk, profit and knowledge [7]. Due to this behaviour, innovations in the construction industry can easier being made. Big contractors and installation firms have knowledge of the market and the clients, while start-ups are having in-depth knowledge of the product. However, this way of thinking is not widely shared, since only one installation Company is explaining this as their strategy. [7]

If these technologies are really discontinuing innovations cannot be defined based on the current data. The There is clearly an S-curve in the technology, where we are at the bottom of the line. But, these decentral innovations are occurring on multiple fields, it could be characterized as decentral and discontinue. (Schilling, 2005)

The challenges for the market dynamics is to align the drivers behind the innovations at the contractor and client, which are currently contradicting.

9.8.3.5 Business cases are often not feasible

Many stakeholders are referring to it; energy is too cheap. For about 3 to 4 cents per kWh for the commercial market is really cheap [10]. For bigger buildings, this is only a fraction of the cost of their core-businesses, and are therefore not considered as major expenses. [5] For i.e. an accountant, these costs are not transparent, since they do not know how the building can perform [5,10] . They accept the costs and are not making an in-depth review of the energy expenses with the goal to possibly upgrade the system in order to be more efficient.

If a client wants to adopt a newer technology, the business cases are often not feasible, since the return on investment is too long. [7,9] If a new technology cost for example 10.000 euros, and the energy price is 4 cents /kWh, the new technology needs to save at least 250.000 kWh. In this example, a reduction of at least 2.85 kW is required to get a return on investment within 10 years. So, companies are not very willing to invest money with a long return on investments. [5]

Legislation is therefore to stimulate the use of new technologies with the goal to save energy. The European directive energy performance buildings (2010/31/EU) of May 2010 states that all buildings after 31 December 2020 have to be build (almost) energy neutral (AgentschapNL, 2013). The energy neutral definition is when the EPC value is almost 0. Zero on the meter and no-energy bill methods are also mentioned in the directive. Installation companies are aware of the directive, but are sceptical about the execution of the directive. They see that only four years are to go, and there is a long road to go [6].(Ellram, 1995)

Another form of stimulating the market by the government is subsidy. The government does recognize the difficulty in the business cases for new technology, and therefore provides subsidy for extra stimulation. Although subsidy motivates the technology on the short term, some are sceptical about the subsidy when the subsidy is terminated, a big gap for the business cases appears. [4,8]

Some interviewees are suggesting that energy costs should be higher in order to stimulate the innovations. [5,10] At first, this seems to be a reasonable option, since the civilians are paying about 5 times as much for a kWh. [10] But, some companies are relying so much on their energy-expenses, if these costs are multiplied by 5, they will probably be bankrupt. Civilians are paying excise over the energy (± 15 eurocents per kWh). It will be interesting for future research if companies are paying excise as well for their electricity usage.

An example of this challenge was recently in the Dutch market. An aluminium factory Aldel had a fixed contract for the energy from 1990 to 2005. At the negotiations of the new contract, the price was too high for the company, and after a while they were forced to close. After a period of time, a new investor had success by the negotiations of the energy contracts, and relaunched the company by the name Klesch Aluminium. This new contract was a success, because a new cable was placed from Germany, where the energy market has better prices. The international competition was too high to maintain the market price for aluminium. (NRC, 2014) This same problem can occur when the energy-prices are increasing within the Netherlands as-well due to regulations of the consumption as described earlier in this paragraph.

Although there is development on the HVAC industry, the incentive to adopt these innovations are not directly available. Via subsidy and other stimulation programmes, these can be achieved, but are not directly adopted by the owner due to the high risks involved in the newest technology. This forms a real challenge how the adoption of new HVAC can be catalysed to face these challenges and strive to more CO_2 reduction.

9.8.4 Pillar 4 – Strategy

This last research pillar will be built upon the other pillars and will suggest a strategy to face the challenges and accelerate the adoption of the described innovations. At first, all challenges will be compared with some topics mentioned in the interviews. Based on this, a new business model is presented which potentially can resolve some challenges that are described in this research and thereby accelerate the adoption of SMART HVAC.

The major challenges presented in the previous chapters are: (1) Main drivers are not towards the same solution, (2) less knowledge for little companies, owners and users and (3) Business cases are not often feasible. These three major challenges have to be implemented in the strategy to (partly) solve these challenges and turn them into opportunities.

This chapter will define a business strategy which contractor companies can use to solve these challenges and enables a faster adoption of SMART HVAC and thereby the stimulates the reduction of CO_2.

9.8.4.1 Different contracts

The question how the suggested challenges of the interviewee can be solved are mainly focussing towards delivering a service. Mainly because owners of buildings are not fully aware of the possibilities, and therefore hire installation engineers to full fill their lack of knowledge. What clients are searching for is that installation companies taking over the risks of their activities and deliver a proper climate condition in the building [1,7]. If installation companies are willing to do this, they have to be rewarded for the quality they are delivering.

There are different type of contracts possible to serve this purpose. At first, the fee-based contract is a cost-reimbursable contract. This contract is based on hard-service parameters which are translated into cost-rates. [(winch, 2010)] For example a fee for each minute the temperature is between 19.5 and 20.5 degrees. The extent to which it deviates is punished by a no fee or even a fine. The investment of the realized design is for the contracting party and he will earn this back during the exploitation phase (if the performance of the asset is achieved).

Second methodology is the incentive contract. This contract is a combination of the fee-based contract and the lump-sum contract. The fee-based contract as described above has no cap on the maximal fee's. This might be not attractive towards contractors since not everything is known at the point of contracting. A cap on the maximal loss is combined with gainsharing between both parties. [(Winch,2010)] This gainsharing requires open insight into the costs and investments done by the contractor to determine both gains and losses.

For the suggested situation, a fee-based contract seems to be most feasible, since the incentive for the contract lies in the fee based rewards on their services. With this space they are able to innovate more and thereby earn more money. From the incentive contracts, the cap is very interesting and can be implemented in the fee-based contract by inserting a minimal fee and maximal fee. Due to this thresholds, the contractor has some certainty to innovate and has not directly the change to go bankrupt by one failing innovation.

These fee-based contracts are pushing the contractor towards thinking as total cost of ownership (Ellram, 1995). When the contractor / installation company is also thinking about the cost of ownership, the decisions made are not only the best for the short term, but also for the long term. This is much more aligned to the wishes of the clients.

9.8.4.2 Project stages

Although the contractor is focussing on a fee-based contract, there are multiple stages in which he can deliver the services. Delivering a service is transferring the responsibilities and thereby the risks to the contracting party. The different stages in a project lifecycle are: Design, Build, Finance, Maintain and Operate. All these stages are in a traditional process divided among different stakeholders in a project, as can be found in figure 10. These project stages are known to most actors in the construction industry, but to avoid misconceptions, the

In the design phase, the installations are developed. Traditionally this is done by the installation engineers who are advising the owner/client of the building. In modern contracts, this responsibility is moved towards the contractor, in combination with the build phase and are thereby called Design and Build contracts.

Assemble phase or build phase is the most common contracted piece of the complete lifecycle. In this phase the design is realized. The responsibilities of the design are often at the owner and the quality of the realization of the design is on the contractor.

Finance is usually provided by the owner. For this reason, the owners are often real-estate owners and develop multiple real-estate assets.

Maintenance was mainly executed by the installation companies, who already have the knowledge of the installation and their relations towards the manufacturers. Sometimes other parties are involved in this phase, but the contractors are focussing on receiving this part as well.

One step further into detaching risk from the client is adding an exploitation contract in it. One interviewee was telling they are having the first projects, where all faces of a lifecycle and all disciplines of the asset are pushed to the contractor side. A fully DBFMO contract for a museum. From managing the energy, towards cleaning and selling the tickets, everything was incorporated into the contract. The contractor was paid for their performance, which was based on multiple points.

In the current market, it seems that there are not that many companies who have the knowledge to run a fully DBFMO contract for utility buildings. Contractors are from origin more conductors of the supply chain and are therefore much easier to adopt this new position in the market [7].

But as mentioned earlier, many interviewees mentioned that transferring the responsibilities towards the market is a good motivation to align the drivers within the market. This can also be seen in the infrastructure market where DBFMO contract moved the responsibilities towards the contractor.

Besides aligning the drivers for both contractor and owner, putting the finance aspect in the contract resolves the business case problem as well. When the financial aspect is included into the contract, the owner does not have to investigate the project up front. This investment is a major issue for most owners, since there is a lot of risk involved. Contractors are more easily accepting this investment, since most of the work is executed by themselves and is therefore in their own control.

The challenge to improve the lack of knowledge is hard to cover with only a contracting strategy. The major companies who can handle these sizes of contracts have also the knowledge to include the newest developments, while others are not able to do this. So, the adoption of new innovation might be accelerated since bigger companies are conducting the complete project, but if the knowledge of smaller companies, owners and users will increase is not directly found.

9.8.4.3 Delivering a Service

Many interviewees suggested that services are upcoming and good for the stimulation of the innovations [3,6,9]. In the building industry, there is are two major example of a service. The first service model is called Light as a Service, developed by Phillips and the architect Thomas Rau [9]. This service contains a contract that Phillips is delivering light to the user within the building given a set of parameters, like light intensity, colour, consumption, etcetera. All these parameters are set into a contract and Phillips delivers the light and the owner pays a fee for each given period. If a light is broken, Phillips exchanges these lights and the owner of the building has not to take responsibility to take action. [9]

The second example of a service contract is on the supply side of the energy market. There, companies are serving energy as a service. These companies are called Energy Service Companies (ESCo's). ESCo's deliver energy instead of energy producing installations and therefore take the risk away from the client [3], which is what the clients are asking for [2].

Before the CaaS method is really described, two current models are developed to explain the different phases the current market is in. These models are (1) traditional model and (2) modern model as can be found in figure 16.

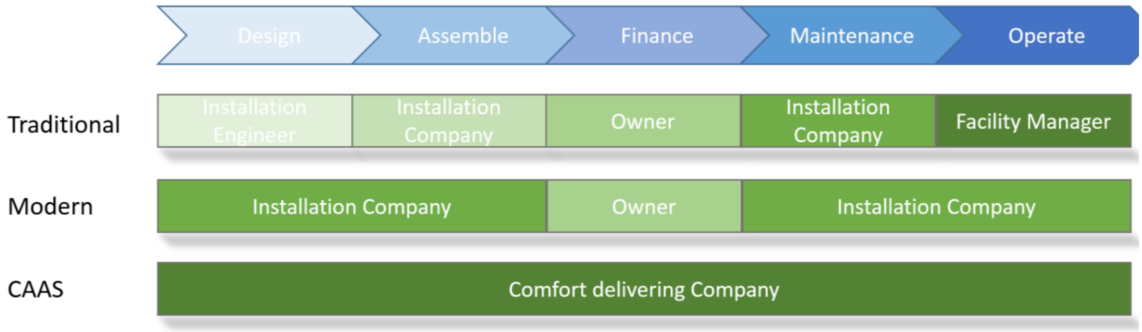


Figure 16 – Contract forms

In the traditional business model, a client asks for advice by installation engineers. These engineers help the owner develop their installation and create a contract for an installation company. This installation company agrees on the contract and get the installations from manufacturers, assembles these installations and installs them into the building. The owner hires a facility manager to operate the installations during the exploitation phase of the building. The installation company is often assigned to regulate the maintenance of the installations. It is also possible that Facility managers are having these expertise, but this seems to be less common.

The modern business model is mentioned by both installation companies which are interviewed. They described that they are involved in engineering and operating activities of project. For this research, this is called a modern contract. For this methodology, the installation company is involved in the design of the installation, towards the operation of the installation. The owner sets a set of requirements for the comfort, installations, and other subjects he is concerned about. This is step is reality, but not widely implemented into the market. This method forces the installation company to think more towards lifecycle thinking [7] which is a proper step forward.

Although the modern model is focusing more on life cycle thinking, the owner is always the financial provider in the building. This way, the incentive of the installation company is not to reduce cost for the owner itself. High investment cost, with high risk for the owner are not attractive towards owners.

9.8.4.4 Comfort as a Service (CaaS)

This service methodology can also be applied to the HVAC industry. For this concept, the comfort is delivered as a service. As mentioned before, comfort for HVAC are the state when the temperature of the building and its air conditions are in a way that the user of the building feels pleasurable physical ease (partly from Heritage Dictionary). Thus, the air conditions and the thermal radiation of the building to ease the users during their stay in the building.

These comfort parameters are quantitative and measurable parameters, which are included in the contract, since the fee is based on the performance of these parameters. The specific parameters which are included and which not is depending on the contract and the business model created for each owner.

This means that companies are not only selling the installations, but deliver comfort as their output. This movement is transferring the risks from the client towards the contractor with an incentive contract.

9.8.4.5 Characteristics CaaS

Comfort as a service is thus a fee-based contract model where the contractor is delivering a service, called comfort. The contractor is responsible for the agreed comfort. Deviating from these comfort level results in a fine. Complying with the comfort levels, means a fee for the contractor.

With this fine and fee system, the contractor is forced to minimize failures in the comfort levels with the least amount of money required to enhance this. This tension forces the contractor to use more long-term cost-efficient installations, which is in the end also the goal of the owner.

So, with CaaS, the drivers from both owner and contractor are at the same direction, called long-term cost-efficient. Together with this "as a Service", the investment cost of the installation is also spread among the contractual period. This means that the CAPEX will be minimized and the OPEX will be increased.

Besides the reduction of the investment, the risk of not meeting the comfort requirements are on the contractor. Meaning, the contractor is responsible for meeting the comfort levels. The extent to which the contractor is reliable for the comfort can be stated in the contract and is therefore not suggested in this research.

9.8.4.6 Legal Issues

In many cases, installations are a part of the building. The owner owns the building and thereby the installations. In this business model, the owner of the building is not the owner of the installations. This may cause a legal issue. But in article 5:101 par 1 BW, the real estate contains all that is in, up or above the asset and is inevitable connected to the building, without losing its functionality. Also, in article 3:4 BW, the contract can be including all attached assets in a building. This results in the conclusion that installations can be legally separated from the building and thereby by the owner of the building. This is also commonly used nowadays to rent a central heating system (for houses). This shows that it is possible to execute this CaaS model into a HVAC installation industry.

9.8.4.7 Benefits CaaS

Based on the literature and the interviews, this business model is likely to face the challenges found in this research and turn them into benefits. The major benefit is the fact that the main drivers to are in the same direction for the client as well as the contractor. This means improved quality and lower lifecycle cost. Currently, these drivers are often misleading each other due to the contractual responsibilities.

Additional advantages are more stimulation for innovation and improved legacy of the owner into more innovative energy, since the risks are transferred from the owner towards the contractor.

9.8.4.8 Challenges CaaS

Besides the benefits of the CaaS business model, there still tending to be some challenges to face.

At first, the longer contracting periods. Because the contractor is not familiar with these contract lengths, they might predict too advantageous. These unsecure predictions in combination with the transferred risks from owner towards contractor is a major risk for the contractor, and will therefore increase their price to handle these risks.

As described before, the ownership of the installations is a challenge, since the ownership of the current installations is on the owner side and contracts and financial politics rely on this ownership. By using CaaS, the ownership of the installation disappears and the building is reduced in asset value (for the owner), since the asset includes less.

The third challenge which must be considered is the Open data & Privacy standpoints. As described before, transparency about the use of the building might be valuable to others. With this business model, the contractor has access to a lot of user data. The extent to which this is visible is the question, and is yet no clear answer for.

The last challenge is the fact that clients tend to lose their knowledge, since the contractor provides this role due to the displacement of the risks. (Winch, 2010) The client does not have to afford an engineer and thereby the knowledge diminishes from the owner. This movement results can result in a more comforting position for the service delivering company, since they do not have to be leading edge. On the other side, the contractor will mainly focus on defining the correct performance indicators for comfort and the lowest price companies within the market can deliver.

9.9 Appendix 9 - Interview Transcripts

These interviews are removed from the published version for confidential reasons. If you like to get insight into these transcriptions, please contact the university or the author. The contact details are presented in the colophon at the beginning of this report.