Building Energy Management Applications

Implementation of a Building Energy Management System, including Technical Audit and Measurement and Verification planning

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Energy Engineering and Management

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ABSTRACT

Global warming and energy supply security are two of the most urgent issues that are being addressed in the European Union. The building sector has a substantial share in both energy usage and CO_2 emissions. The residential and tertiary sector accounts for approximately 40% of the total final energy consumption in the EU.

In this thesis, the partial results of the evaluation of a cloud-based Building Energy Management System under development are shown. First, a technical audit was done in the building. After some insight to the implementation, the energy savings were determined with the measurement and verification process of International Performance Measurement and Verification Protocol. Then, the energy consumption forecasting feature of the system was evaluated. Finally, a business plan was created for the future distribution of this product.

The objective of the thesis was to introduce and evaluate the Building Energy Management System and finally, to develop a business model for the commercialization of the system. First, it was found, that the system reached modest energy savings in the summer in a pilot project in Barcelona. Second, the energy forecasting feature of the system has significant errors on an hourly basis; which is acceptable from a product under development. Third, a business plan is drawn up for the growing market of Building Energy Management Systems.

Key-words: energy, management, efficiency, measurement and verification, Building Energy Management System, BEMS

RESUMO

Esta tese descreve e analisa os resultados experimentais da implementação de um sistema de gestão de edifícios inovador. Para isso, foi desenvolvido em primeiro lugar uma auditoria técnica aos edifícios em estudo na cidade de Barcelona, de forma a caraterizar os principais equipamentos instalados e responsáveis pelo consumo de energia. Em seguida, foi implementada uma metodologia de monitorização e verificação baseada no protocolo IPMVP que permitiu avaliar o sistema de previsão do sistema de gestão de energia. Concluiu-se que a introdução deste sistema permitiu poupanças na ordem dos 5% durante a fase piloto no período de verão em Barcelona. Contudo, o sistema de previsão apresentou ainda erros significativos, pelo que se conclui que é necessário desenvolver mais os algoritmos de previsão em análise.

Foi ainda desenvolvido um plano de negócios para a implementação do sistema, do qual se conclui que existe uma oportunidade interessante para a comercialização deste sistema, desde que o sistema de previsão melhore o seu desempenho.

Palavras Chave: Gestão de Energia, Eficiência Energética, medição e verificação, previsão de consumos de energia, Sistemas de Gestão de Energia em Edifícios

Glossary

This section describes all notations and acronyms used in this thesis report

AHU	Air Handling Unit
BMS	Building Management System
BEMS	Building Energy Management System
BMC	Business Model Canvas
BT	Base Temperature
CDD	Cooling Degree Days
DR	Demand Response
DD	Degree Days
ECM	Energy Conservation Measure
ESCO	Energy Service Company
HDD	Heating Degree Days
HVAC	Heating, Ventilation and Air Conditioning
IPMVP	International Performance Measurement and Verification Protocol
SaaS	Software-as-a-Service
SCADA	Supervisory Control and Data Acquisition

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1 Introduction

1.1 Motivation

Global warming and energy supply security are two of the most urgent issues that are being addressed in the European Union. The CO_2 emissions in the EU-28 countries were around 4000 Million ton CO_2 in 2012 [1]. However, the CO_2 emission data show a decreasing tendency, the most significant drop was around 2008, due to the global financial crisis [1]. In addition to the severe effects of global warming, the European Union is facing serious energy dependency on fossil fuels that endanger the energy security in most of the member countries [2], [3]. In the Statistical Pocketbook 2015 written by the European Commission, it is illustrated clearly that more than 50% of the fuel consumption is based on imports from non-EU regions, which makes the EU economy vulnerable to changes in world market or politics [1].

Understanding the possible future consequences of these issues, the Member States of the EU set the 2020 targets; Reaching 20% lower CO_2 emissions compared to the 1990 level, increasing energy efficiency by 20% and increasing the share of renewable energy sources (RES) in the energy mix by 20% [4]. Also, the European Council set the target of reducing green house gas emissions 80-95% below the 1990 levels by 2050. These plans help to moderate the climate change and, also, the need for imported fuels. In order to provide practical and objective analysis to reach a low-carbon economy, the European Climate Foundation (ECF) developed the European Roadmap 2050 [5].

The building sector has a substantial share in both energy usage and CO_2 emissions. As seen in Figure 1, the residential and tertiary sector accounts for approximately 40% of the total final energy consumption in the EU, while in Estonia, Latvia and Hungary these two sector represent even more than 45% of the total final energy consumption [6], [7]. Moreover, these sectors are responsible for around 55% of the electricity consumption and 36% of the CO_2 emissions in the EU. Considering that the 35% of the building park is over 50 years old, there is a huge potential in energy savings and in lowering CO_2 emissions of buildings [8].

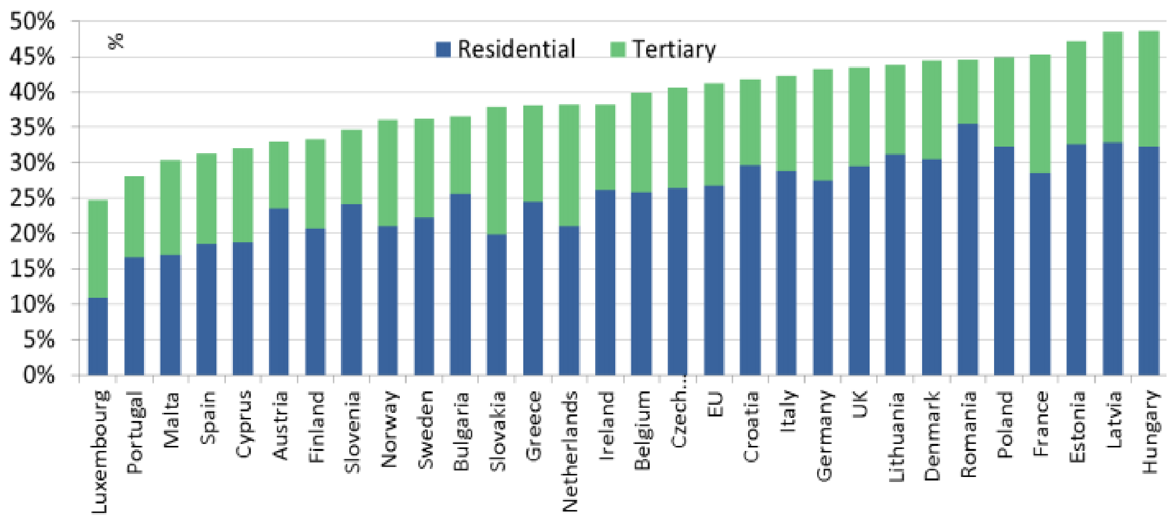

Figure 1 Share of buildings in final energy consumption in the EU, 2012 [6]

Around one third of the energy consumption of the building sector is for the European non-residential buildings. Considering the non-residential buildings, also called tertiary buildings, the share of different sub-sectors is illustrated in Figure 2. As seen in the figure, the subsectors of offices, hotels and restaurants consume around 30% of the energy of services [6].

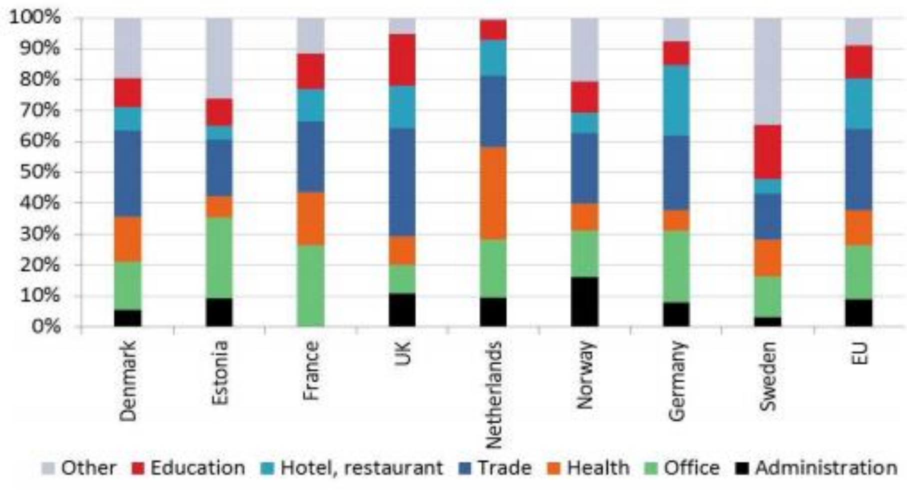

Figure 2 Energy consumption by subsector in services (2012) [6]

All in all, the tertiary sector consumes a significant portion of the final energy consumption and emits a considerable amount of CO_2. This gives the sector a critical role in reaching the EU's economic goals, in fighting against the global warming and therefore; foresees the development of new innovative products in the building and energy industry.

1.2 Objectives

The scope of the thesis is to give an introduction to demand side management methods generally, to introduce the commissioning of and evaluate a new Building Energy Management product. Firstly, energy savings are measured and verified that the Building Energy Management System in question can reach in the pilot projects. This verification is to be done following the IPMVP protocol. Secondly, the energy forecasts provided by the Building Energy Management System are evaluated. Finally, a business plan is created for selling the product.

1.3 Contributions

The thesis is evaluating a newly developed Building Energy Management System and a business model for its commercialization. There are lessons learnt from the implementation and use of the software and these are examined.

1.4 Structure of the thesis

The thesis is structured in 7 main chapters. Firstly, the issue of high energy consumption in the building sector is detailed in the introduction. Secondly, directly after the introduction, the thesis explains the different concepts and the state of art of the literature of demand side management, the ISO50001 energy management standard and the IPMVP protocol. Then, the BEEST project and the Building Energy Management System and its applications are explained. Later, the implementation process of the software is described and the pilot projects are introduced. In Chapter 5 the energy savings and the forecasted energy consumption are evaluated. Chapter 6 is introducing a business model for the commercialization of the system, while the last chapter is making conclusions about the thesis.

2 Concepts and State of the Art

2.1 Smart Grids

Thanks to the 20-20-20 plan and other incentives targeting reduced GHG emissions and fossil fuel imports, the importance of energy efficiency and low-emission power generation is increasing. As RES based power generation and electric vehicles (EVs) gain more and more ground, the burden of decentralized and intermittent energy feed-in heralds the development of smart grid concepts [9], [10].

According to D. Kolokotsa et al. (2016), “Smart grids are electrical power grids that are more efficient and more resilient and therefore, smarter than the existing conventional power grids” [11]. Being smart essentially means the ability of eliminating blackouts, increased renewable energy penetration, higher energy efficiency and lower energy costs. These features are realized through the incorporation of innovative information technology and the two-way communication between the energy providers and consumers. In smart power grids computers, automation systems, smart buildings, electric vehicles and other innovative smart technologies are cooperating with the grid to optimize energy generation and consumption. Such a system can be considered as the electric grid that can satisfy the needs of the 21th century; high efficiency, high reliability, modern communications infrastructure, modern sensors and meters and demand side management techniques. Thus, smart grids provide an ideal environment for smart applications in the building industry [11].

2.2 Flexibility of the Power Grid

The increased flexibility of the grid is one of the key characteristic that is important to reduce the fuel use and emissions. A flexible power grid is capable of handling decentralised renewable energy sources, provide higher reliability and able to handle demand peaks.

There are two main categories of sources of flexibility in an electrical power grid. These are supply side flexibility and demand side flexibility.

- Supply side flexibility that is achieved by dynamically fast responding conventional power plants, combined power generation, co-generation, energy storage and the control of renewable energy feed-in.
- Demand-side flexibility that is possible with Demand Side Management (DSM) services, like improved energy efficiency or load shifting [9], [12].

2.2.1 Demand Side Management

One of the most researched fields of flexibility is demand side management (DSM). DSM is aimed to improve the energy system at the customer side. It can range from improving energy efficiency with better insulation and better building materials to autonomous energy systems.

The development and implementation of DSM actions are driven by the fact that besides the increasing efficiency of new devices, the energy consumption is steadily growing. However DSM promotes decentralized energy generation, influencing loads is less expensive than building new power plants. [13]

The concept of DSM includes different approaches for manual energy conservation, energy efficiency programs and load management programs based on smart pricing [10]. DSM can be categorized according to the timing and the effect of the applied measures [13]:

- Energy Efficiency
- Time of Use (TOU)
- Demand Response (DR)
- Spinning Reserve (SR)

Energy Efficiency

All permanent changes on equipment or improvements on physical properties of the systems can be categorized as an energy efficiency measure (EE). These measures result in immediate and continuous energy and emission reductions, while other DSM methods are just shifting loads. Consequently it is the most widespread and primary method applied at in DSM. After improving efficiency, dynamic DSM methods can be implemented.

Time of Use

In case of TOU tariffs, energy prices are different in each period of the day to force consumers to reschedule their processes and energy consumption in order to minimize costs. The highest costs are in the periods of peak load, while significantly lower prices are offered in non-peak times. [10] The TOU price schedule is not changed frequently as it is included in the contracts between the consumers and the utilities.

Demand Response

In DR a signal (trigger) is sent by the Distribution or Transmission System Operator (DSO/TSO) containing price and/or command for load shifting. The reaction to the signal is not necessarily instantaneous; it may correspond to a time period on the next day.

DR does not necessarily reduce energy usage; it is only the changed behaviour of the consumer in response to a DR signal. If the performance of an air conditioning system is lowered for half an hour, then afterwards it takes more time to reach the same comfort level in the building on the former performance. It may end up in higher energy consumption or generate a new peak as a rebound effect.

Han et al. (2008) categorized DR programs as incentive based and time rate based [14]:

- Direct load control: the grid operator has access to the customers' equipment.
- Interruptible rates: a special contract with limited sheds.

- Emergency demand response program: DR is triggered with an emergency signal.
- Capacity market programs: DR is done when the grid requests.
- Demand bidding programs: bidding for DR actions.

Time based rates in DR:

- TOU rates: a simple price schedule.
- Critical peak pricing: price schedules with some flexibility.
- Real time pricing (RTP): customers are aware of and pay according to real time wholesale market prices.

According to Palensky et al. (2011), some of these DR measures are market based and some of them are physical in the sense that they are induced to conserve energy supply quality. The methods that are market based are the ones that include real time pricing, price signals and other similar contrPRODUCT 3. While, the physical DR programs are sending binding requests to trigger demand management if necessary. This may happen if the power line quality is decreased due to high demand, maintenance or failure of any device [13].

Spinning Reserve

SR is the fastest way to implement demand side management. Typically power plants are in charge of SR in the supply side management, but loads can act as negative SR in case the power consumption is correlated to the state of the grid in a smart way. If the frequency of the grid decreases, a consumer reduces its power need. Developed technology and communication system is needed to act as a negative SR.

2.2.2 Benefits of Demand Side Management

Due to the short occupancy periods, office buildings exceptionally fit for DSM purposes [15]. Arteconi et al. (2016) confirmed the demand-side flexibility potential for average sized office buildings [9].

A large variety of advantages can be gained with demand side management. Lower peak load prices, price volatility and reduced risks of black outs due to the reduced burden on the power system are the main economic advantages. According to Faruqui et al. (2012), between 5 to 10 billion dollars could be saved in the US by reducing the peak load by 5%. Also, the reduced consumers' energy bills and lower transmission and distribution investments is to be considered as a great economical advantage of DSM. [16]

In addition to the financial benefits, demand side flexibility contributes significantly to sustainability. Besides the reduction in direct GHG emissions, as at peak hours the increased energy needs are usually satisfied with less effective fossil fuel based power plants, less significant peak power allows the cheaper and easier integration of intermittent renewable energy based power plants.

Supplementary to local economic and environmental advantages, demand side flexibility allows improved energy exchange and generation allocation between countries that results in lower risk of blackouts, lower intermittency of the power system and generally less use of inefficient power generation methods [17].

2.3 ISO 50001

There are several ways to improve energy efficiency of buildings but tracking savings is an essential part of these projects. Monitoring energy savings has to be standardized to make it more effective and traceable. The ISO 50001 standard introduces a standardized way of energy management, while the IPMVP protocol creates the fundaments of the Measurement and Verification process.

ISO (International Organization for Standardization) is a group of national standards bodies. These ISO member bodies prepare standards getting together in technical boards for each project. Also, governmental and non-governmental organizations are involved in the creation of International Standards.

The ISO 50001 standard provides industrial and commercial facilities and organizations with a globally accepted framework for the implementation of energy management systems. It includes energy procurement and use while establishing a framework to implement strategies that can significantly reduce energy costs and CO_2 emissions. Also, the framework helps sustaining savings in the future.

Since its release in June 2011, thousands of companies of various sizes are using the ISO 50001 standard voluntarily to reduce costs and CO_2 emissions. Its main purpose is to make the implementation of energy management systems easier for companies [18].

The ISO 50001 is based on the Plan, Do, Check, Act (PDCA) framework that provides continuous improvement for organizations while implementing energy management into their everyday life.

- Plan: conduct energy audit, establish baseline, define Key Performance Indicators (KPIs), targets, objectives and action plan needed
- Do: implement the action plan
- Check: monitoring and measurement process, report results
- Act: take actions for continuous improvement

ISO 50001 provides several advantages and many ways to profit for organizations. Some of these are the following:

- Reduced costs of energy and production
- Reduced energy and CO_2 consumption
- Compliance with energy efficiency laws
- Increased competitiveness due to the lower costs
- Better company image

The standard requires the companies to hire personnel, create documentation and implement technology. The personnel can be an Environmental Manager or a Technical Auditor, who is responsible to do the documentation of the action plan, to supervise energy monitoring and saving verification and to conduct internal audits. In order to fulfil the duties of the personnel in charge, an energy management software is essential [19].

In Figure 3 the energy management model of ISO 50001 is visible. Along with the standard, when the energy audit and performance assessments are conducted and inefficiencies are identified, the possible retrofit options shall be identified. By using proper economic analysis tools, risk assessment methods and appropriate energy models, the preferred retrofit alternatives can be chosen and recorded in the energy policy by the management. Then, the ECM is implemented and commissioned taking into account that the process may interrupt the operation of the building or occupants. The final phase after the implementation of the ECM, that is also the first phase in the future, is the measurement and verification of savings and the continuous surveillance of the energy consumption data in the future. [20]

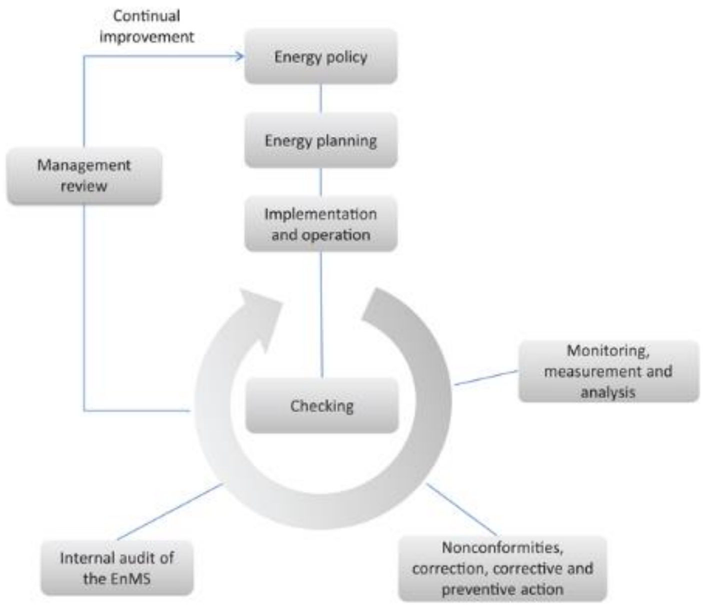

Figure 3 Energy Management System Model of ISO 50001 [18]

2.4 Measurement and Verification

The final phase of implementing demand side measures or energy efficiency measures is to validate and verify energy savings. Once the ECMs are implemented and set up, standard Measurement and Verification (M&V) methods, like the Best Practice Guide to Measurement and Verification of Energy Savings by AEPCA or the IPMVP protocol can be used to verify energy and economic savings. [20]

The International Performance Measurement and Verification Protocol (IPMVP) is published by the Efficiency Valuation Organization (EVO) to facilitate investment in demand management, renewable energy, energy efficiency and water efficiency projects.

IPMVP Volume I is a document that gives guidance for common practice in measuring, calculating and reporting results of energy or water efficiency projects in facilities. IPMVP introduces four different M&V Options matching the needs of different projects all around the globe. Thus, it guarantees transparency, reliability and consistency in savings reporting. Activities related to IPMVP can be in the form of site surveys, metering, monitoring, calculating and reporting energy or water use. [21]

In the following the most important steps, definitions, factors and requirements of Measurement and Verification planning, which were followed throughout the M&V process in the thesis, are explained.

M&V Option and boundary

IPMVP defines four different approaches, Option A, B, C and D for planning and conducting the M&V process. It is not always straightforward which IPMVP Option to use in each case. It is necessary to examine each project in detail and justify the chosen Option.

Option A is applied in case some of the parameters need to be estimated, meanwhile Options B is used if the key parameters of energy saving are measured directly on the field. For example a lighting retrofit project is Option A, because power draw is measured, while operating hours are only estimated. The measurement period ranges from short-term to continuous; routine or non-routine adjustments may be necessary in both cases.

Option C is the whole facility approach. This option is used when savings are determined on the facility or sub-facility level and continuous measurements are done throughout the post-retrofit period. Option C can only be effective, if the possible savings are significantly higher than the random energy variations.

Option D is used for calibrated simulations that are made in case there are no meters installed in the baseline period. The reporting period simulation is calibrated with gas or electricity meters' data and then used to simulate the baseline consumption. This option may need specific knowledge and experience in energy simulation [21].

The measurement boundary is a notional border, which is drawn around a system to determine the savings by any ECM. For example it can restrict the measurements to a certain level of the HVAC, to measure only the energy consumption of the chillers or boilers.

Interactive effects

Interactive effects are the energy effects that occur beyond the measurement boundary. It is important to estimate their magnitude to determine savings properly. An example of interactive effects is the heating effect of the light bulbs in a building.

Independent variables

The parameters that have measurable impact on the energy use and that are expected to change regularly are called independent variables. There are several factors like occupancy, solar irradiance, temperature, etc. that can be taken into account while choosing the most appropriate variable for the regression model. All the possible variables need to be considered and justified for being used or not, as an independent variable.

Key parameters

The key parameters are usually the energy consumption data of the building. Comparing these key parameters to the independent variable gives the correlation for the energy model. With the help of regression analysis, it is possible to draw this correlation and use it for the normalization of the consumption. In order to get proper correlations, it is advised to use as many the same source of data for calculations and evaluation in the baseline and in the reporting period. In addition, all the data sources, meters and sensors need to be calibrated to provide reliable and continuous data.

Base Temperature

It is crucial to consider the Base Temperature (BT) for the Degree Days (DD) calculations. Along with the ASHRAE 89 standard, the BT is around 65 F and 18.3°C in the UK. BT is the temperature above cooling is needed or below heating is needed in the building. In climates with heating and cooling season it is practical to define different BTs for different seasons.

Routine and Non-Routine adjustments

Any change in the facility size, the design or operation of systems, the schedule of occupants or any other non-routine variance can affect the energy consumption that reduces the reliability of the M&V plan. These effects are monitored and indicated and compensated by non-routine adjustments.

Routine adjustments are calculated with the help of identifiable energy-governing factors. Ambient temperature may be considered as an energy-governing factor that changes routinely.

Basis of adjustment

The pre and post retrofit measurements are adjusted in order to compare the two periods in fixed conditions and to see the effect of the ECM. To compare the measurements, two methods “Avoided Energy Use” and “Normalized Savings” can be applied.

- Normalized Savings

Normalized Savings means the cut in energy usage or energy cost that arose after the ECM was implemented compared to the energy usage or cost that would have arisen in case the building had been used in the same way as it was before, under normalized conditions. The normalized conditions can be an average of a longer period or the conditions under the baseline period. The conditions of the reporting period cannot be used. In case the conditions of the reporting period are used, the term of Avoided Energy Use or Savings is used.

Normalized savings are calculated in the following way:

Normalized Savings = (Baseline Energy + Routine Adjustments to fixed conditions + Non-routine Adjustments to fixed conditions) – (Reporting Period Energy + Routine Adjustments to fixed conditions + Non-Routine Adjustments to fixed conditions)

The engineer responsible for the calculations after the reporting period can also use the Avoided energy use approach.

- Avoided Energy Use

Avoided Energy Use means the cut in energy use that arose after the ECM was implemented comapred to the energy usage that would have arisen in case the building had been used in the same way as it was before, under the operating conditions of the reporting period. It is also called as Cost Avoidance or Savings.

Avoided Energy Use is calculated in the following way:

Avoided Energy Use = Adjusted-Baseline Energy – Reporting Period Energy + Non-Routine Adjustments of Baseline Energy to Reporting-period conditions

Adjusted-Baseline Energy: Baseline energy + Routine adjustment to reporting period conditions.

Adjusted-Baseline Energy is calculated by developing mathematical model that correlates with the original baseline energy data first, then inserting independent variables of the reporting period into the model to produce the adjusted-baseline energy use.

Baseline and Reporting Period

It is crucial to make a proper decision about the length of the periods. The baseline period needs to cover at least a whole operating cycle of consumption that may range from a few days to years. The reporting period (also called post-retrofit period) has to cover at least the same operational cycle as the baseline period. In the post-retrofit state, it is advised to make the same measurements as in the baseline with the same calibrated meters and sensors.

Quality assurance

According to the IPMVP protocol, to keep the quality of the M&V plan high, the recorded data need revision by multiple parties. Also, any decision related to adjustments are discussed and reviewed by the facility manager and the M&V agent.

In the following some of the numerous risk factors in M&V plans that may endanger the quality and reliability of a report are listed.

- Estimated readings: In case the energy data is obtained in the form of bills, the frequency of readings needs to be reviewed. Any significant vary due to rare readings needs to be modified to decrease the distortion of the results.
- Uncalibrated meters: Errors in measurement can have great effects on data and on the estimated energy savings.
- Unexpected changes in the building or in its use: Any changes in the building envelope, operation or use need to be noted as those may have a significant impact on the energy consumption.
- Incorrect data entry: Any mistake in the input data set may cause the distortion of the results; therefore it is important to review the data used in multiple ways.

2.5 BEEST Project

The main objective of the Building Energy Efficiency Management & Smart Grid Integration Tools (BEEST) project is to reduce energy costs in tertiary sector by developing a set of software (suite of applications) that works as a Software-as-a-Service (SaaS) on top of the existing Building Management Systems (BMSs) and optimizes the operation and energy management of buildings. The development of these apps is based on the following needs in offices and hotels:

- Optimization of facility management practices.
- Optimization of energy purchasing practices.
- Accessing the benefits of energy market deregulation.

The BEEST project is a KIC InnoEnergy Innovation Project. The aim of KIC Innovation Projects is to finance and support market-oriented projects in the states of research and development, business development and commercialization. The project is conducted by five individual companies and institutions with expertise on different fields: Comsa Corporación, Dexma and Tecnalia in Spain and Enervalis and EnergyVille in Belgium.

Figure 4 visualizes the responsibilities of different companies involved in the development of the products. Comsa Corporación is responsible for the Spanish pilot projects and the marketing strategies of the products.

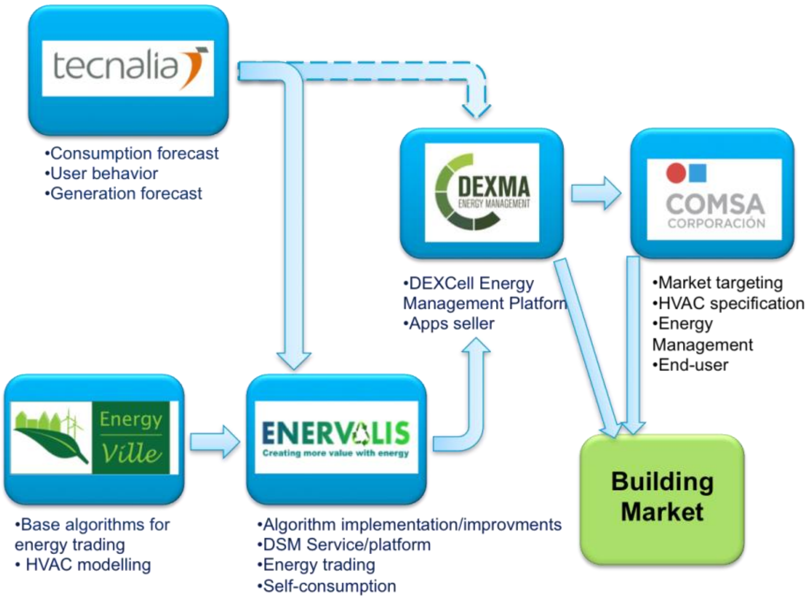

Figure 4 Companies' responsibilities in the BEEST project

START-UP

As an outcome of the BEEST project, the company called START-UP was created. The logo of START-UP is visible on Figure 5. The companies Comsa Corporación, Enervalis and KIC InnoEnergy created the joint-venture to sell the applications of this innovative Research and Development project.

START-UP LOGO

Figure 5 Logo of START-UP

The company is defined as a SaaS provider and offers the suite of apps to reduce commercial building energy consumption and energy unit price. As a SaaS provider, START-UP has partnership with Dexma who is competitor on the field of energy management. Dexma provides the Dexcell Energy Manager as a platform as of the applications. In addition, START-UP is doing marketing activities hand in hand with Dexma to create a stronger brand.

2.5.1 Dexcell Energy Manager

Figure 6 shows Dexcell Energy Manager that can monitor and create reports on energy and water use. Besides monitoring and reporting, the software can have alarms for different events and has a dashboard for apps that makes energy surveillance faster and more convenient. There is a market place in the software for free or paid custom apps.

Figure 6 User interface of Dexcell Energy Manager

The START-UP applications are designed to be apps of the marketplace and visible for the users of the Dexcell. If the potential customers of START-UP show interest, they are directed to the local distributors and partners of START-UP.

2.5.2 START-UP Apps

The suit of applications is providing new functionalities to the Dexcell Energy Manager. The Dexcell Energy Manager and the newly developed apps work as a top layer and control the existing BMS in the building. The apps are only used to control the HVAC system; therefore it is categorized as a Building Energy Management System (BEMS). However no or only minimal physical intervention is needed in the BMS system, the installation of additional energy meters may be necessary for the complete implementation of the solutions.

There are six individual applications under development or beta testing in the moment of the thesis. Their function is to make operations easier and more efficient for offices and hotels.

The following list contains the apps and their state of development in the moment of the thesis:

- PRODUCT 1 (installed, debugging and testing)
- PRODUCT 3 (installed, debugging and testing)
- PRODUCT 4 (under development)
- PRODUCT 2 (under development)
- PRODUCT 5 (before development)
- PRODUCT 6 (before development)

START-UP PRODUCT 1

The main functionality of the app is the energy demand forecast of the following 48 hours. The forecast is related to the HVAC energy consumption and is shown on a diagram on hourly basis.

The added value by the PRODUCT 1 app is the energy use awareness it provides. Knowing the forecasted energy consumption the facility manager can evaluate the HVAC system's performance and find malfunctions that may affect energy efficiency. The estimated energy bill savings depend on the advantages the user can gain by understanding and using this information to identify inefficiencies. The app provides energy forecast on the following energy consumptions:

- Electricity consumption of the building.
- Electricity consumption of HVAC system.
- Gas consumption of the building.
- Gas consumption of the HVAC system.

The facility manager checks the app on a daily basis to see the deviation of intervention is needed to the HVAC. Naturally, a proper forecast is only available if the building is regularly maintained and managed. In case the measured consumption is significantly different to the forecasted, there may be a failure of HVAC equipment.

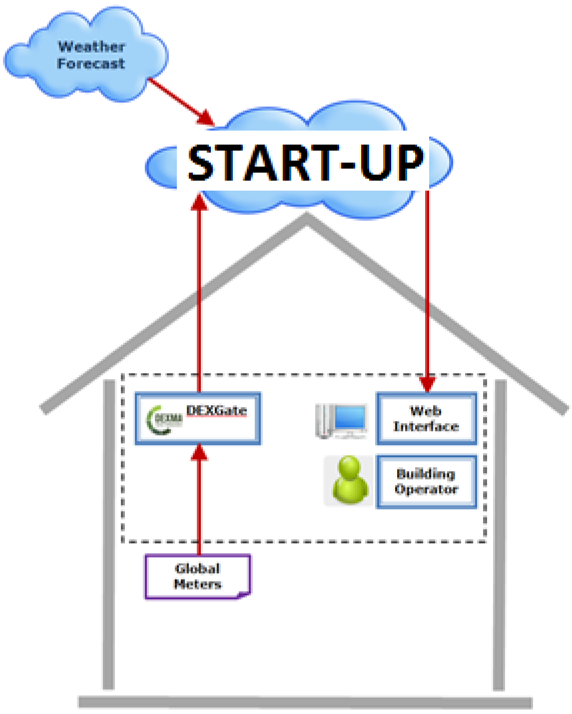

Figure 7 Information flow of START-UP PRODUCT 1 app

The app provides the information through the dashboard of Dexcell Energy Manager and its structure is shown on Figure 7. The data from electric meters, gas meters, energy meters, thermometers, or solar irradiance meters are sent through a gateway to the cloud system of START-UP. The app consists of a database of building, energy consumption data and the algorithms stored on the cloud. The algorithms create the energy consumption forecast and it is sent to the web interface, the Dexcell Energy Manager.

Figure 8 shows the data needed for the forecasting. The algorithm works as a black box model on a separate server. The inputs are the training data and using data.

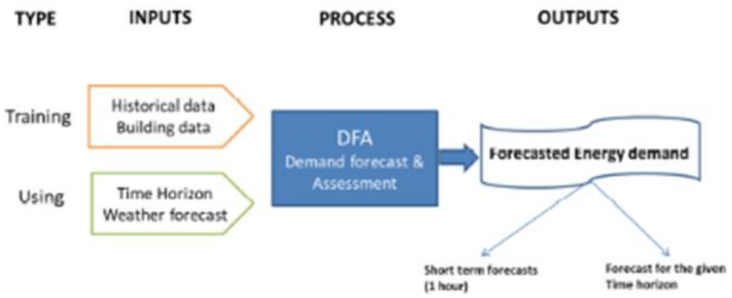

Figure 8 Inputs and Outputs of START-UP PRODUCT 1

The training data is essential for the algorithms to model the thermal behaviour of the building. The training data consists of historical data and building data. The historical data is a set of energy consumption data and weather data from the past three months, while the building data is made of simple static information about the building, thermal zones, control zones, working calendar or occupancy trends.

The using data set is the information that is needed to generate the 48 hour forecast continuously. It contains the latest energy use data from the Dexma Energy Manager platform and the latest 48 hour weather forecast from freely accessible weather stations.

On Figure 9 the output of the app, the forecasted energy consumption and the real energy consumption in a week of September is visible. The application is installed at several pilot projects and their results are evaluated later.

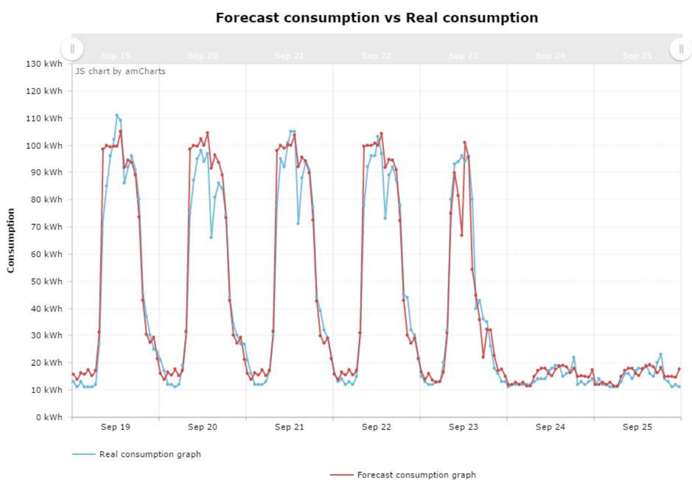

Figure 9 Screenshot of START-UP PRODUCT 1 results

START-UP PRODUCT 2

The START-UP PRODUCT 2 app is optimizing energy purchasing strategies and processes by providing active bill tracking functionality and reducing contracted power levels. The two main features of START-UP PRODUCT 2:

- Bill tracking with the Issue Manager: This feature is used by the Energy Procurement Manager (EPM) to interact with the utility company if any issue or request occurs related to billing. The application is implemented by the EPM and the utility company with different interfaces. The EPM can communicate any requests or errors, while the utility can access all the bills of the customer and solve problems efficiently.
- Contracted Power Optimization: The optimizer helps choosing the most cost effective contracted power values for each period of the day. The app takes into account the factor of overbilling and possible fines for exceeding the contracted power level. The output of the app is a contracted power schedule of for the building and an assumption of potential savings. Energy procurement rules, periods and prices are different in European countries; therefore different settings are needed for each country and market.

START-UP PRODUCT 6

The personnel in charge of energy purchasing are the target audience of this app. The START-UP PRODUCT 6 app helps optimizing purchasing electricity on the dynamic market where prices are changing real-time. The app is controlling the HVAC system in order to schedule consumption from periods with higher energy prices to periods of lower prices. The application is focusing on gaining financial benefits, while it takes the tenants comfort into account and keeps the conditions between the pre-set limits. In order to time energy consumption in the cheaper periods, the energy consumption forecasts of the START-UP PRODUCT 1 app is used.

START-UP PRODUCT 5

PRODUCT 5 is an app that enables the building operator to get involved in and take benefit of DR programs. The app controls the HVAC system and maximises the potential of DR by supplying flexibility to the local distribution system operator (DSO) and transmission system operator (TSO). The app is taking into account the building thermal behaviour, the BMS capabilities and the thermal comfort of tenants and provides control strategs to fulfil DR responsibilities.

PRODUCT 5 helps to provide flexibility towards the electric grid by suspending a non-critical part of the HVAC equipment for a certain number of times in a year, by request. These requests are triggered by the grid operator and the facility has to provide the contracted amount of power for the contracted time period when needed. Contracting for DR programs is a sustainable option for large facilities to lower their electricity bills and to take advantage of their buildings' thermal capacity.

The app is expected to reach an estimated saving of 5% of the yearly energy bill due to the revenues provided by the DR program.

START-UP PRODUCT 4

The following two applications are developed to reduce energy use in an intelligent way, while the occupants' comfort level improves. The algorithms behind the applications are based on Machine Learning Techniques and use occupancy and weather forecast data.

After a systematically executed training period, the START-UP PRODUCT 4 provides optimized schedules for the optimization of the HVAC system. The application processes the weather forecasts daily and provides suggestions on how to change HVAC settings as an output. These suggestions are shown on the PRODUCT 4 platform and contain the following information:

- An on/off schedule for the next 24 hours of the HVAC.
- An on/off schedule for the next 24 hours of free cooling.
- Internal temperature set-points schedule.

These abovementioned commands are the schedules for the HVAC system's different functions. The modification in the daily HVAC on/off schedule helps setting the optimal start up and shut down of the system and to decrease the operation hours, while the optimized free cooling schedule contributes to lower cooling needs in the control zones. Lastly, the schedule of set-points provides the optimal temperatures in each thermal zone according to the occupancy schedule.

PRODUCT 4 is commissioned if it is not possible to install START-UP PRODUCT 3, the fully automated application. To follow the recommendations of the app, the personnel in charge need to set up the HVAC system regularly. As the set up only consists of on/off schedules and temperature set points, it is estimated to take only 15 minutes a day.

Figure 10 shows the structure of START-UP PRODUCT 4. The measured values are uploaded to the START-UP cloud. The app consists of a database of building, energy consumption data and the algorithms stored on the cloud. The algorithms create the schedules and the interface where the commands are made visible for the building operator.

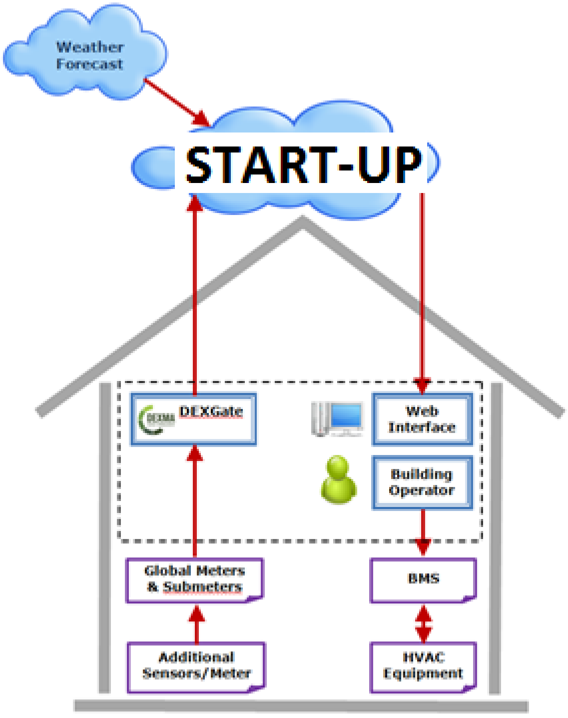

Figure 10 Structure of START-UP PRODUCT 4

START-UP PRODUCT 3

The aim of PRODUCT 3 is to reduce energy consumption of the building with automatic HVAC scheduling. The app is controlling the BMS automatically by sending the following commands directly to the BMS:

- An on/off schedule for the next 24 hours of the HVAC
- An on/off schedule for the next 24 hours of free cooling
- Internal temperature set-points schedule

The process of START-UP PRODUCT 3 is similar to the PRODUCT 4 with the difference of sending the commands directly to the BMS and overwriting its schedule regularly, instead of offering these schedules as suggestions for the facility manager.

Figure 11 shows the HVAC set point schedule for the ICAEN building in the PRODUCT 3 app. The HVAC on/off is in green and the temperature set points are in blue. This schedule is in an hourly resolution and is created on the night before. This schedule of the building shortened the cooling period by 2 hours by switching the cooling on later and off earlier than before.

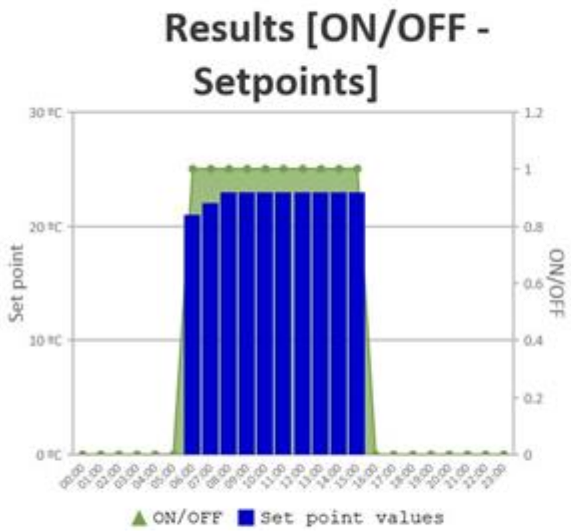

Figure 11 On/off schedule and set-points by START-UP PRODUCT 3

3 Methodology

The thesis is following the main steps of the practical implementation process of an ECM in a building then evaluates the results. The audit of the building, the implementation of the ECM, the data collection before and after the implementation and the calculation of normalised savings are those steps. Besides the verification of savings due to the START-UP PRODUCT 3 app, the results of START-UP PRODUCT 1 app is also evaluated. Finally it suggests a business plan for the distribution and selling of the START-UP products.

3.1 Technical audit

First of all, the pilot building is audited. The audit consists of practical and technical considerations as the pilot project is not expected to generate profits for START-UP or the building owner. In a real project, besides the technical feasibility, an economical feasibility study is also essential before the implementation of an ECM.

The audit is focusing on the following areas:

3.1.1 Building data

The facility and its energy systems is examined in details before implementing an ECM. The documentations, the blueprints and the energy consumption data set are provided by the facility manager of the pilot building.

First, the fuel types and energy consumption data are reviewed and the previous year's consumption data is collected and examined. The blueprints of the facility that illustrate the electrical, mechanical systems and construction details are used to identify the main energy consuming machines and to understand the HVAC system.

Then the presence or the possibility to install thermal sensors is examined. These are used by the BEMS in each thermal zone to keep the set point temperatures.

After reviewing all the information, the building operator is interviewed to provide practical insights to the maintenance and occupancy habits, the state of machinery and general condition of the facility and the use of the BMS and SCADA system. In addition, chillers, boilers, pumps, meters, piping, splits and the air handling units (AHUs) are documented on photos and in written form indicating their type and performance.

3.1.2 Building Management System

The BMS in the building is examined in details. The START-UP PRODUCT 3 is controlling the HVAC through the existing Building Management System. In order to send the orders to the BMS, the access and possibilities of control is checked. The orders of START-UP PRODUCT 3 are related to three main BMS functionalities. The functionality of using predefined schedules to switch the HVAC on/off, to set temperature set-points in different zones and to time free-cooling.

Additionally, the warranty time of the BMS and other systems are checked because of the risk of losing the warranty by intervening to the system. Another possible issue is the BMSs protection against third party intervention by a password. The information to access and connect the BMS system is asked from the facility manager. If it is not available and the BMS is not accessible, the commissioning may slow down or fail.

3.1.3 HVAC configuration

The relation between AHUs, Fan-coils, rooms and open spaces are examined to make a clear picture of the overall HVAC system and to set the thermal zones and control zones for START-UP PRODUCT 3. Besides the zoning, the HVAC communication architecture and the zones with sensors (physical data points) are clarified for practical reasons in the commissioning.

3.1.4 LAN

The START-UP Energy Controller unit is connected to the BMS through the LAN network of the building. The access information for the firewall and the permission to set it up is asked from the facility manager. It is necessary to allow the IP addresses of the hardware to the firewall to allow connection to the internet.

3.1.5 Users' behaviour

In an office building, with the intention of maintaining the comfort with the commands of START-UP PRODUCT 3, the users' intervention to the air quality in thermal zones needs to be as minimal as possible. The options for opening the windows, setting temperature set-points manually in the building are documented.

Lastly, all the data is documented and evaluated to decide on the details of the process of the implementation.

3.2 Implementation

First, as part of the implementation, the Dexma Dexgate data logger and gateway is installed at the site and connected to the internet to direct energy data to the Dexcell Energy Manager. There are new energy meters installed in the building as part of the pilot project, although these are not providing continuous data and not used in this thesis. The data of the energy meters is directed to the Dexcell Energy Manager.

Then, the Energy Controller unit is physically installed and connected to the internet and to the BMS. The Energy Controller unit is directing schedules downstream from the START-UP servers to the BMS, while the temperature data of the thermal zones are sent upstream from the BMS to the START-UP cloud. This unit is in control of the three BMS functions of HVAC on/off, temperature set-points and free cooling on/off.

Third, the data from the local data logger system is directed to the Dexcell Energy Manager. This Circutor system is gathering data from the electricity meters and gas meter for years and is used for the verification of energy savings.

Finally the START-UP PRODUCT 3 is trained with the data from the aforementioned three sources. This training period is necessary to create the energy model of the building in the START-UP servers. The set-point temperatures are set to different values for four weeks, between 23 and 26 ºC with a step of 1 ºC each week.

The energy consumption data, the weather data and the set-point scale is used by the algorithms to create the building model for the summer period. This training is necessary for the winter period separately.

3.3 Collecting energy data

By the time, the START-UP solution is installed and fully commissioned; the energy consumption data is logged. The Dexcell Energy Manager is used to monitor the energy consumption day by day to provide reliable data not only for the M&V process that evaluates the effectiveness of START-UP PRODUCT 3 but for the evaluation of START-UP PRODUCT 1 forecasted results.

3.4 Regression analysis

The linear regression was studied and used in practice by Legendre in 1805 and by Gauss in 1809 for determining astronomical observations. However, the term “regression” can be dated back to 1908, when Francis Galton, British biologist researched the relation between tall parents and tall children.

Regression analysis is a statistical process to estimate any relationship between a dependent variable and other independent variables. It helps understanding how the dependent variable varies when one of the independent variables is changed. The regression analysis is used for forecasting effects, forecasting trends or for causality analysis. The regression can be linear or non-linear. [22]

The two main types of linear regression are; simple linear regression (when there are two variables and the regression line is straight) and multiple linear regression (when there are more variables and the regression line is parabolic). [23]

In the energy model of ICAEN building there are two variables available for analysis; energy consumption and outside temperature. Consequently, the simple linear regression is used for constructing the model.

According to Yan et al. (2009), simple linear regression model can be stated in Eq 1: [23]:

$$y = \beta_0 + \beta_1 x + \varepsilon \qquad \text{Eq 1}$$

y – Dependent or response variable (Energy consumption)

β_0 – Constant or y intercept

β_1 – Gradient or slope

x – Independent or predictor variable (Degree Days)

ε – Random error

3.5 Measurement and Verification

The verification of the savings after the first summer months is done following the IPMVP protocol to provide realistic results of the M&V plan. The M&V option, the boundary, the independent variables, key parameters and the baseline and reporting period are defined first. The possible interactive effects are examined. Then the energy use and the historical weather data set are cleaned from the noise and unnecessary data points.

For the comparison of the weather and energy consumption data, the weather data is converted into Degree Days (DD) and the Base Temperature (BT) is calculated. It is a way to simplify ambient air temperature data, widely used among energy consultants and energy managers. DD can be used on daily, weekly, monthly or yearly basis and can be summed together.

There are two main types of DD; Heating Degree Days and Cooling Degree Days.

$$HDD_1 = (T_{mean} - T_{base,w}) * Days \quad \text{Eq 2}$$

$$CDD_1 = \left(T_{mean} - T_{base,s}\right) * Days \quad \text{Eq 3}$$

CDD_1 – Cooling Degree Days for one day

HDD_1 – Heating Degree Days for one day

T_{mean} – Daily mean ambient temperature

$T_{base,s}$ – Base temperature of the building in summer

$T_{base,w}$ – Base temperature of the building in winter

HDD, which is shown in Eq 2, is used in relation to heating in buildings. It provides measures of how much and for how long the temperature is below the base temperature. The standard value of base varies from building to building.

CDD, which is shown in Eq 3, is used in relation to cooling in buildings, for example in case of an air conditioned building in summer. It provides measures of how much and for how long the temperature is over the base temperature. [24]

Calculating HDD and CDD can be done on several ways. Generally, the difference between the daily mean outside temperature and the base temperature is calculated. In case of HDD, if the daily mean temperature is higher than the Base Temperature, the HDD is zero. Otherwise HDD is equal to the difference between BT and the outside temperature. The opposite is true for the CDD calculation. If the BT is higher than the outside temperature, the CDD is zero. To calculate HDD and CDD, the daily mean temperature can be calculated from the daily maximum and minimum temperature or on hourly basis. Using the daily mean temperature based on hourly temperature measurements gives better results.

The Base Temperature is the ambient temperature above which the heating or below the cooling of the building is necessary. The typical value needs to be determined for each building separately for the cooling and the heating season. The value of BT depends on the building inertia, climate, solar irradiation, type of use, comfort temperature or even on the environment it is built. To determine the corresponding BT, the DDs are calculated and the regression analysis is conducted with different BT values. To have the best correlation between energy use and outside temperature, the most realistic BT needs to be used. This can be decided by picking the highest Coefficient of Determination value in a practical interval.

The coefficient of determination, also called R^2, is a number that shows the proportion of change in the response (dependent) variable that is anticipated from the predictor (independent) variable. It is used in relation to statistical models, where the main purpose is to predict some future outcome or test hypotheses.

The coefficient provides information about the goodness of fit of a model, how close is the regression line to the data points. "With linear regression, the coefficient of determination is also equal to the square of the correlation between x and y scores." [21] R^2 is between 0 and 1, where 1 is the ideal match and 0 means that the dependent variable cannot be predicted.

In case of energy modelling with linear regression, the energy consumption is related to the DD in the heating or cooling season. The DD and the consumption are plotted on a chart in Microsoft Excel. The software offers the option to create the regression line on the chart and to calculate the simple regression model with the coefficient of determination.

Afterwards, the resultant regression equation is used to normalize the energy consumption to a fixed period previous the baseline period. The normalized energy savings then are translated into CO_2 and into financial benefits.

4 Case studies

In the BEEST project there are four pilot projects to test the START-UP applications. There are hotels and offices, buildings using only electricity or also natural gas, located in different climates and environment in Europe. The ICEAN building is the main pilot project for START-UP PRODUCT 3 and the measurement and verification plan is done for this building; therefore its quantities are explained in details. The other buildings are also used to gather data and experience on commissioning other apps.

4.1 ICAEN Building

The building belongs to the Departament d'Empresa i Ocupació de la Generalitat de Catalunya and provides office area for four institutions: Direcció General d'Energia, Mines i Seguretat Industrial, Institut Català d'Energia (ICAEN) and Agència Catalana de Consum. As it can be seen on Figure 12, the building is part of a multipurpose urban complex including apartments and offices.

Figure 12 Photo of ICAEN building [25]

The building was built in 2008 and it is in service since 2009. The total area of the building is 9157 m2, where 8362 m2 is air conditioned. Besides the ground floor, there are four floors above ground for offices and two basement floors for archives, warehouses and technical areas. The fourth floor has smaller area compared to the other floors. Also, there is a four floor high atrium at the main entrance that can be ventilated or air conditioned.

The horizontal shades against the solar irradiation on the Northern and Southern facades on Figure 13.

Figure 13 Shades on the façade on the left and entrance with the atrium on the right in ICAEN

Figure 14 shows a blueprint of the ICAEN building and the surroundings. As it is visible, the entrance is from in the inner garden of the complex.

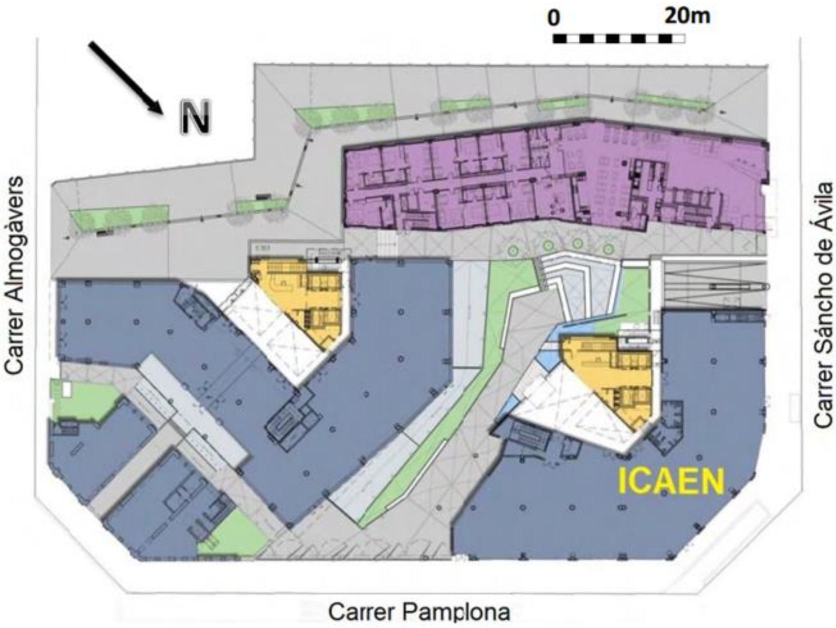

Figure 14 Position of ICAEN building [25]

HVAC System

The ICAEN office is equipped with a Building Management System (BMS) by SAUTER implemented in 2009. The BMS is handling the illumination, the heating, ventilation and air conditioning (HVAC) and the security system. Later, for the sake of the pilot project, the Dexcell Energy Manager platform provided by Dexma was installed. The platform works as Software-as-a-service (SaaS), gathering information from the building. Additionally, there is an energy monitoring system by CIRCUTOR, a company specialized on BMS solutions, collecting information from meters and sensors and transmitting it to the BMS.

Table 1 shows the two chillers and two boilers providing the cooling and the heating for the building. The hot water is produced with two ADISA Duplex 399 condensing boilers with the thermal performance of 417 kW_{th}. The cold water production is based on a pair of TRANE ECGAN 214 chillers with the thermal performance of 462kW_{th}. Additionally, there are several Mitsubishi split units in the building; however they are not in the scope of the project.

Table 1 Chillers and Boilers in ICAEN building

Task	Type	Thermal Performance	Number
Chillers	TRANE CGAN 214	461.8 kW_{th}	2 pcs
Boilers	ADISA Duplex 399	417 kW_{th}	2 pcs

The scheme of the hot water production system from the SCADA is shown on Figure 15. On the left hand side the two boilers are visible that produce the hot water and with the help of six pumps (on the bottom) the water is directed to the following units:

- Air Handling Units: CL-1, CL-2, CL-3
- Air Handling Unit: CL-4
- Fan-coils

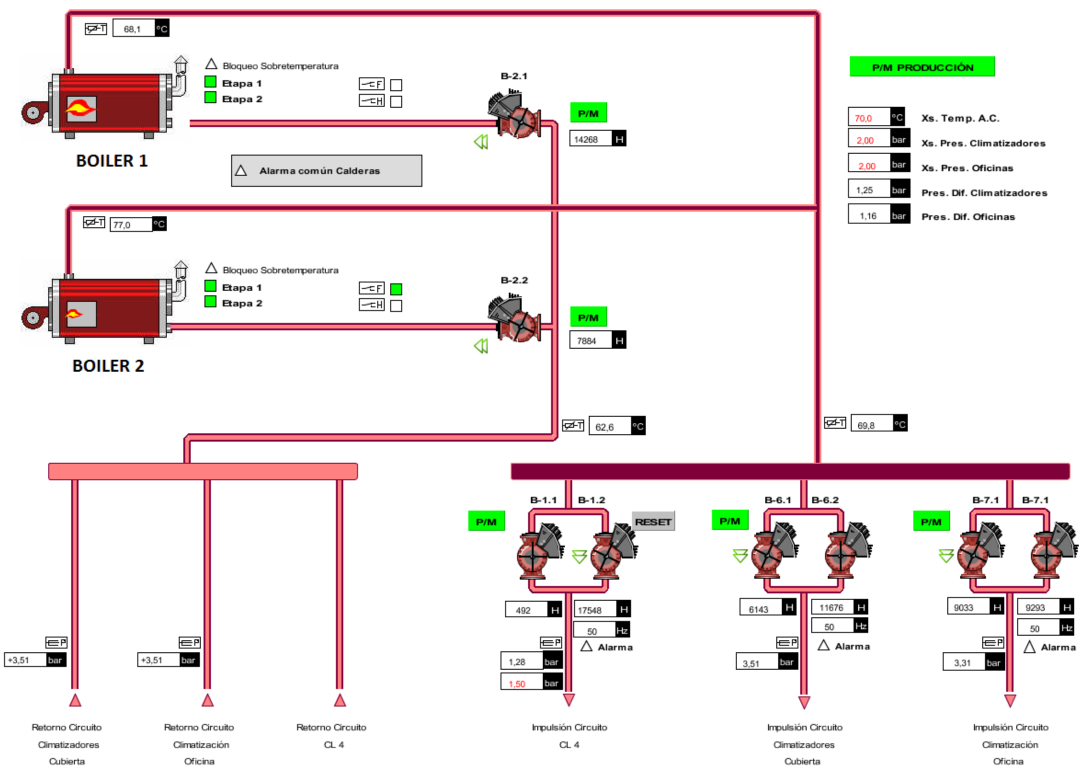

Figure 15 Scheme of boilers in ICAEN

The photo of Figure 16 is taken of one of the boilers in the office building. There are two ADISA condensing boilers providing the hot water placed next to each other.

Figure 16 Photo of one of the boilers on the top floor of the ICAEN office

The scheme of the cold water production system from the SCADA is shown on Figure 17. The cold water is produced by the two chillers (on the right), then with the help of six pumps (on the bottom) the water is directed to the following units:

- Air Handling Units: CL-1, CL-2, CL-3
- Air Handling Unit: CL-4
- Fan-coils

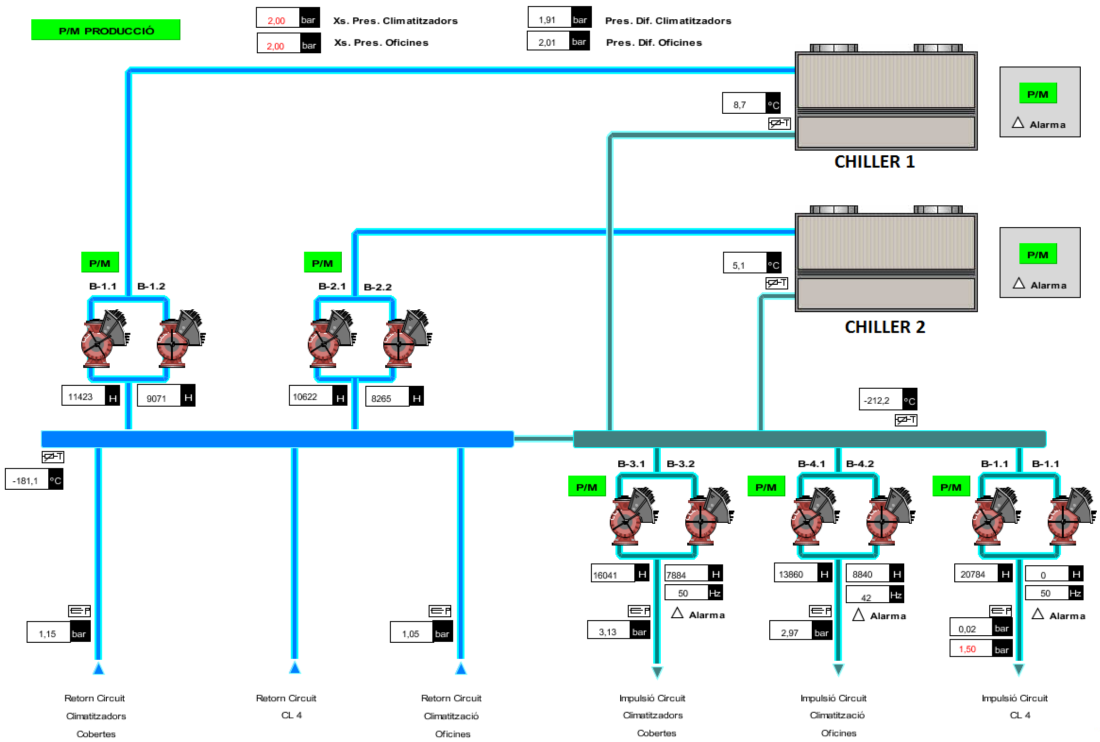

Figure 17 Scheme of chillers in ICAEN

Figure 18 is taken of one of the chillers in the office building. There are two similar chillers placed next to each other providing the cold water for air conditioning.

Figure 18 Photo of one of the chillers in ICAEN

There are four Air Handling Units (AHUs) in the building. Two of them (CL-1 and CL2-) are responsible to provide preheated or pre-cooled air to the offices. The preheated or pre-cooled air from CL-1 and CL-2 is distributed with air ducts in every floor in the false sealing. Then the fan-coils installed in the false ceiling temper this preheated or pre-cooled air to the set-point temperatures and introduce it to the office rooms. It is shown on Table 2 that the AHU CL-3 is providing tempered fresh air directly for the atrium and the ground floor, while the forth CL-4 has the same duty for the file storage space underground.

Table 2 Air Handling Units in ICAEN

Air Handling Unit	Zones	Heating Performance	Cooling Performance
CL-1	Floor 1,2,3,4	92.5 kW_{th}	122.1 kW_{th}
CL-2	Floor 1,2,3,4	61.8 kW_{th}	83.8 kW_{th}
CL-3	Atrium and ground	36.3 kW_{th}	45.5 kW_{th}
CL-4	Archive	35.9 kW_{th}	55.9 kW_{th}

As it can be seen on Figure 19, the office rooms are located along the facade, while the elevators are in the middle of the building. There are four thermal zones on each of the first, second, third and fourth floors. These thermal zones are called L1, L2, L3 and L4 in every floor. The AHU CL-1 is providing air to the L1 and L2 thermal zones, while CL-2 is providing air to the L3 and L4. The AHU CL-3 is responsible for the atrium and the ground floor, CL-4 is for the Archive space.

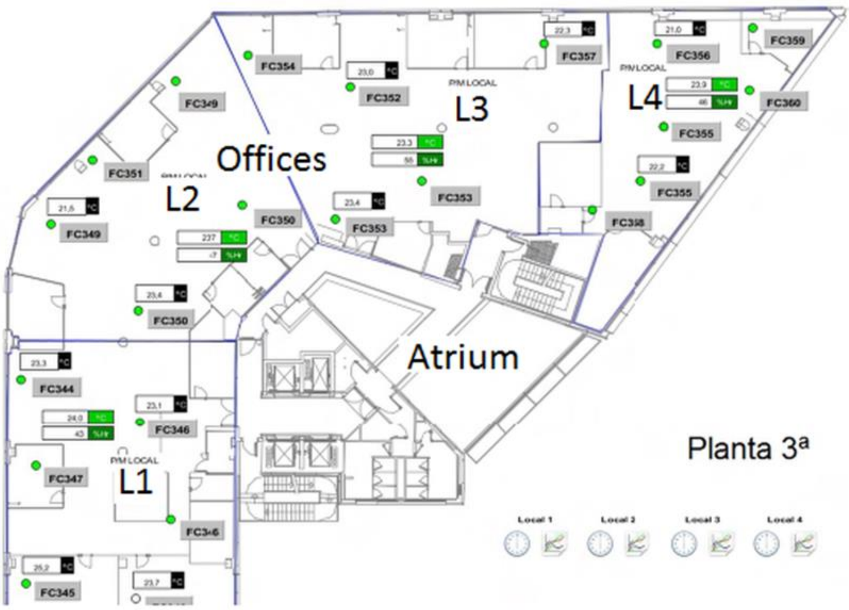

Figure 19 Blueprint of the third floor in ICAEN building [25]

4.2 Av. Roma 25

The building is situated in the heart of Barcelona at Av. Roma 25. The building functions as the office of Comsa Corporación and Comsa Service. As the Comsa Group is highly involved in the development of the suite of apps, the company offered its facility to be a pilot project and to test the applications. The building is visible on Figure 20.

Figure 20 Comsa office at Av. Roma 25, Barcelona [26]

The building's area is 2636 m2 and has 7 floors. The building uses electricity for heating and cooling. There are fourteen Air Handling Units in the building and the total cooling performance is 574 kW while the heating performance is 640 kW.

The Dexcell Energy Manager platform monitors the electricity consumption of the building and the START-UP PRODUCT 1 is providing 48 hour energy forecasts.

4.3 NH Waalwijk

Figure 21 NH Waalwijk [26]

The NH Waalwijk Hotel is shown on Figure 22. It is situated in Waalwijk, The Netherlands. The BMS installed is Siemens Desigo Insight while the DEXCell Energy Manager is installed for energy monitoring.

There are three condensing boilers for heating (3x185 kW) and two other (230 kW) for DHW production. Three AHUs are installed in the building. One for the common areas and the restaurant, the second is for the kitchen and the last one is providing heating or cooling for the meeting rooms. The heating need of the rooms is satisfied by radiators, while there are split units for cooling.

4.4 De Lijn Gentbrugge

Figure 22 De Lijn Gentbrugge [26]

The De Lijn building in Gentbrugge was built in 1980 and it was renovated in 2005. There are two wings of the building; one is from 1980 and the other is from the year of renovation.

There are two condensing boilers (270 kWh_th each) in the building. The hot water from the boilers are directed into two directions; First the air is preheated in the two AHUs on the building, second the water is sent to the climate bars to reheat the air from the AHUs before it is entering the rooms. Besides the heating provided by the AHUs, there are radiators on each floor.

In the cooling season two chillers are providing cold water for the AHUs. The cold water then sent to the climate bars to cool down the air entering to the rooms. Besides the cooling provided by the AHUs, there are two split units that serve the air-conditioning of the server rooms.

The building has temperature sensors on every floor and a SCADA is visualizing the HVAC in details.

5 Results

5.1 Measurement and Verification in ICAEN building

The ICAEN building is the first pilot project for commissioning and testing START-UP PRODUCT 3, the app which provides automated control over the BMS. PRODUCT 3 is being tested, while START-UP PRODUCT 1, the app that forecasts energy consumption on hourly resolution, is functioning. To verify the savings reached by the START-UP PRODUCT 3, the Measurement and Verification plan is created according to the IPMVP protocol.

The Measurement and Verification plan is defined for this building to test the energy savings of the START-UP PRODUCT 3 application. The basic points and requirements of M&V planning are listed then the energy consumption data used is introduced.

M&V Option and boundary

First, Option C is justified as the PRODUCT 3 is installed on top of the existing BMS and manages the complete HVAC system that consists of several Air Handling Units (AHUs) and is present in most of the sections of the building. Also, the ECM is intended to reach more than 10% energy savings that satisfies the requirement of the minimum 10% energy saving posed by the IPMVP protocol. The energy consumption of the chillers and boilers is measured directly with gas and electric meters; consequently no other consumption affects the measurements.

The BEMS affects the HVAC in the whole facility, regardless floors and zones. Accordingly, the boundary of the M&V project is set as the chillers and boiler units of the HVAC system. Measurements take into account that the energy needed for pumps and other peripheral equipment are independent of the cooling or heating loads. These peripheral consumptions create a base load and are excluded from the metering.

Interactive Effects

In the case of ICAEN pilot project there is no interactive effect due to the direct electricity metering before the chillers and the fact that the boilers used for heating are the only gas consumers. The effect of the lighting is very low due to the LED based system.

Key parameters

The key parameters are energy consumption of the boilers and chillers. The energy consumption is compared to the ambient temperature and provides the correlation for the energy model.

Independent variables

The following independent variables were considered and used or discarded from the analysis:

- The occupancy is constant and following the same weekly pattern, therefore it is not included in the regression as an independent variable.
- However, the solar irradiance is measured by several weather private stations; the data is not constant and reliable. It is not included as an independent variable in the regression model.
- There is constant and reliable data about the ambient temperature and it is used as an independent variable. The correlation between this weather condition and the building's energy needs can be seen on the regression model.

Routine and Non-Routine adjustments

Routine adjustments are calculated from the identifiable energy-governing factors. In the case of ICAEN project, the ambient temperature is considered to be the energy-governing factor that changes routinely.

Besides the routine adjustment, non-routine adjustments are also important to monitor and indicate. Change in the facility size, the design or operation of systems, the type or schedule of occupants or any non-routine variance can affect the energy consumption that reduces the reliability of the M&V plan.

Measurements

All the data sources, meters and sensors are calibrated to provide reliable data. In order to get proper correlations, the same sources of data are used for the calculations and evaluation in the baseline and in the reporting period.

Table 3 lists the meters used to verify energy savings. There are two electricity meters (one for each chiller) and a main gas meter. The only gas consumer in the building is the two condensing boiler; therefore it gives a realistic correlation between the energy used for heating and the gas consumption.

Table 3 Meters in ICAEN building

Function	Name	Unit
Chiller electric meter	EDS_Clima_Enfredadores_1	kWh_{el}
Chiller electric meter	EDS_Clima_Enfredadores_2	kWh_{el}
Gas consumption	Total_Gas	m^3

For the baseline summer season the electrical energy meters, EDS_Clima_Enfredadores_1 and EDS_Clima_Enfredadores_2 recorded the electricity consumption directly of the two chillers. The measured data set exclude the consumption of pumps and other peripheral equipment, hence directly connected with cooling needs. The daily data is directly used for the regression analysis, in electric kWh unit. The electricity measurement data is logged in the Circutor system's memory. In the baseline period this data is saved in txt files and difficult to manage, while in the reporting period, the Circutor system is forwarding the logged data to the Dexcell Energy Manager that is providing an easier data management.

For the heating season, the gas meter “Total_Gas” is used as the heating system is the only gas consumer in the building. The log of the measurements is stored in the Circutor system in the baseline period. Later, it is directed to the Dexcell Energy Manager in the reporting period.

Defining Baseline period

On Figure 23 the energy consumption of the chillers in the baseline period is shown in electric kWh and the gas consumption of the boilers are shown in cubic meters. The baseline period is considered from the 1st of May 2015 until the 30th April 2016, while the reporting period is the one year period after the implementation of the ECM.

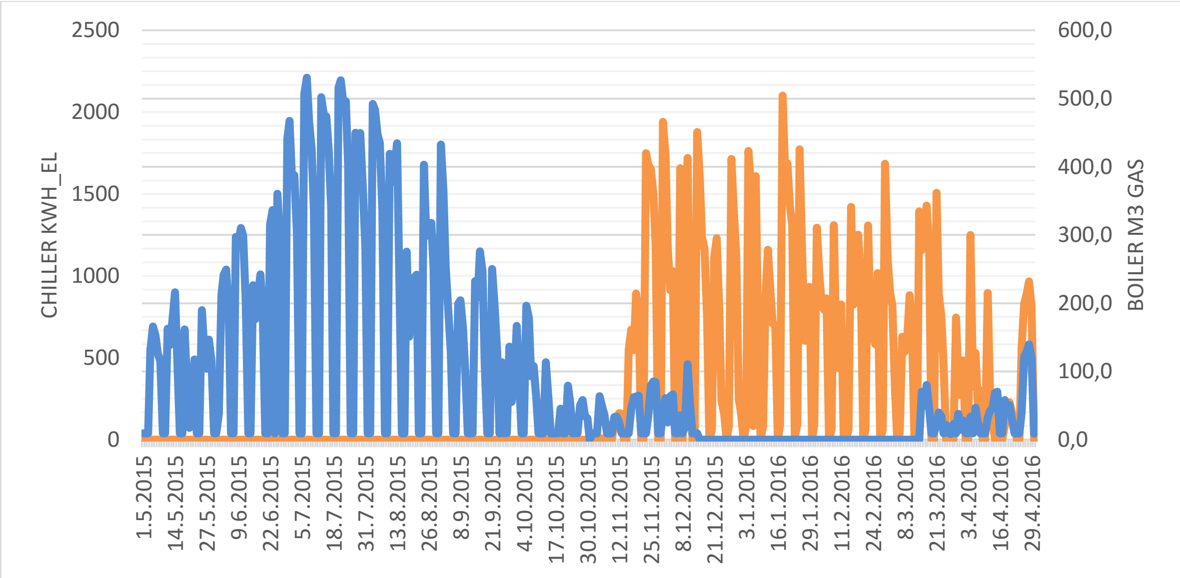

Figure 23 Energy consumption of heating and cooling in the baseline period

It is visible on Figure 23 that in October and May of the baseline period there is no significant heating or cooling need. It is also visible that in the months of November and April there is a mix of cooling and heating. This phenomenon is due to the big difference in daily minimum and maximum temperatures [27]. As a consequence May, October, November and April are considered to be transitional months. In the regression analysis the regression equation is determined using June, July, August and September for the summer season, while the December, January, February and March for the heating season. However the regression equation is calculated in both seasons based on four months, the normalized energy savings for the transitional period are calculated assuming the same thermal behaviour.

Normalized energy savings

The normalized energy savings method is a practical way to examine the energy consumption of a building in different periods and weather conditions. Due to the type of data and resources available, the Degree Days

(DD) method is applied in the analysis. In the normalizing process the use of fine weather data, properly chosen base temperature and carefully handled data is required to have satisfying results.

Weather stations

For calculating the DD, accurate weather data is crucial. In most of the cases, buildings do not have their own weather stations. For this reason, it is important for the energy saving calculations to look for other weather data sources.

Ideally, the closest weather station with available data provides the most accurate data for the building being analysed. However, data quality and coverage are the most important features of data sets that need consideration. Generally, weather stations of airports have free and high quality data sets.

In the case of the ICAEN building, the weather station of the El Prat Airport is 17 km away. While the building is in the city surrounded with blocks of flats and offices, the airport is outside of the city without any surroundings. Therefore, the personal stations in the neighbourhood are considered instead of the airport. After examining several options, the IBARCELO253 weather station proves to have the most coherent and realistic data from the same environment. The position of the station is shown by Figure 24. It is approximately 600 meters away from the ICAEN building and has enough historical data for the energy analysis.

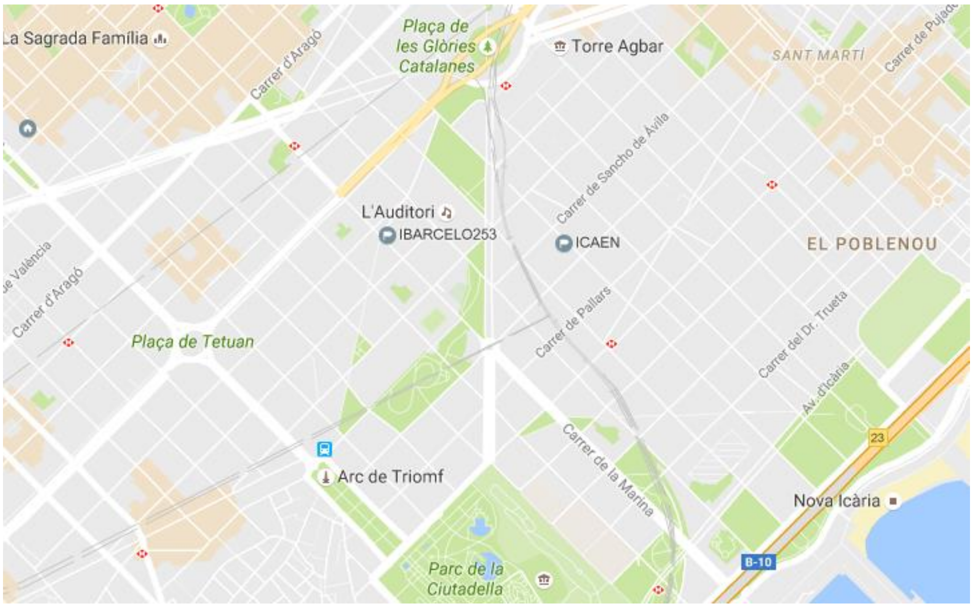

Figure 24 The location of the weather station and the ICAEN office [26]

Base temperature for summer

The BT is chosen for the building for the cooling season based on the historical energy consumption. The following diagram shows the R^2 values for different base temperature in summer.

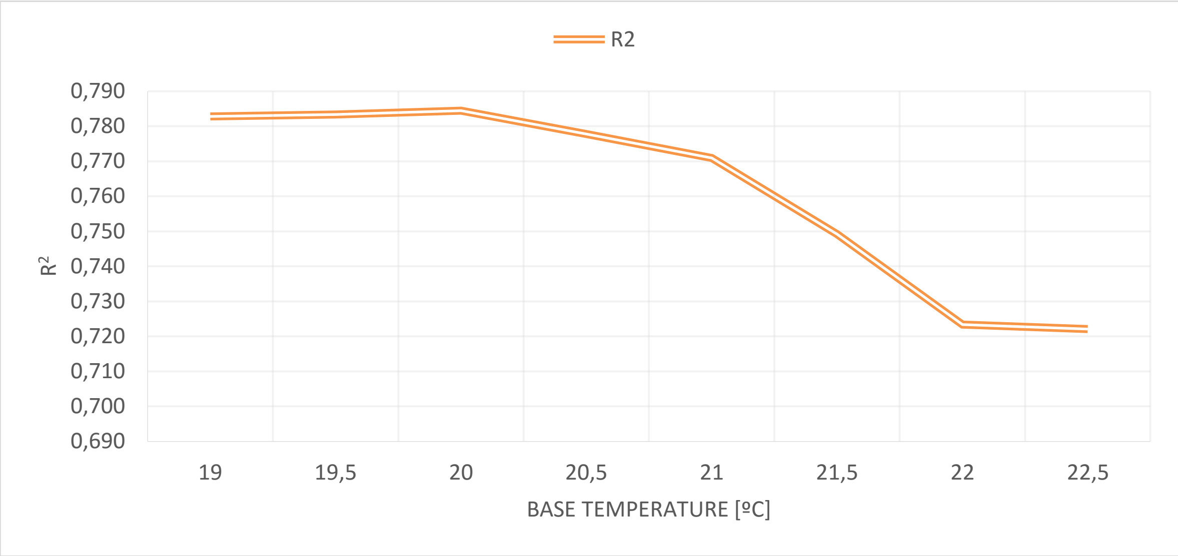

Figure 25 R^2 values for different Base Temperatures

It is visible on Figure 25 that the highest R^2 value is above 0.78 at 20 °C. This BT value is the highest; therefore used for the summer analysis.

Linear regression analysis for summer

In summer, the regression analysis is calculated for the Cooling Degree Days (CDD) and the electricity consumption. Only weekdays are taken into account in the regression analysis as the office is out of use on the weekends. Table 4 shows the official local and national holidays that are removed from the dataset in order to improve the accuracy of the energy model.

Table 4 Number of removed holidays

Month	Holidays removed
January	2
March	2
June	2
September	2
October	1
December	3

Determining the relation between the weather conditions and the energy consumption is an iterative process. The CDDs and electricity consumption of every day of the summer period are listed and different techniques are tried in order to find the best correlation and to find the highest R^2 value.

First, all the seven days of the week is used to determine the correlation. Using these data gives a poor correlation of R^2=0.4. The main reason for the poor results are the fact that the office is out of use on the weekends, the energy use is close to zero on Saturday and Sunday.

Finally, only the weekdays are used in the process and weekends are neglected. This approach gives much higher R^2 value. After removing the holidays and wrong data points, the highest regression value is R^2=0.78. This is above the minimum of R^2=0.75 suggested by the IPMVP protocol and can be considered as satisfactory.

The linear regression in the summer period can be seen on Figure 26. The electricity use of the chillers and the CDDs are compared and the Coefficient of Determination with the regression equation is visible.

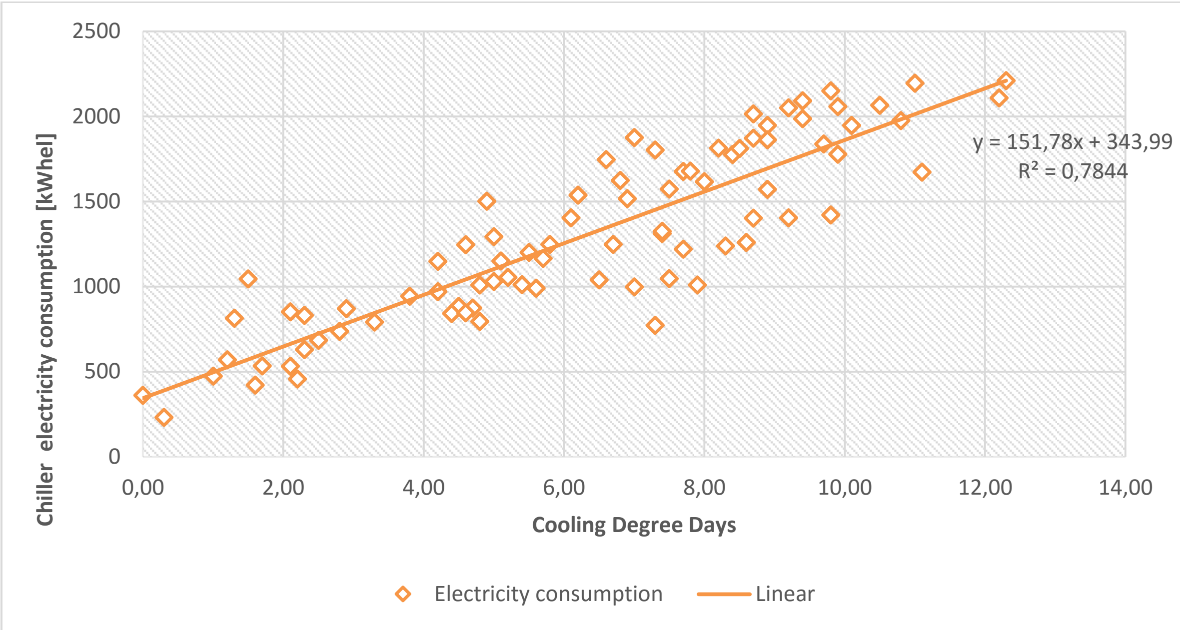

Figure 26 Linear regression analysis for CDD and electricity consumption

The result of the regression analysis is shown as Eq 4. This equation is used for normalising the baseline summer period.

$$y = 151.78x + 343.99 \qquad \text{Eq 4}$$

$$R^2 = 0.7844$$

Linear regression analysis for winter

After examining the winter data set, one can conclude that the relation between HDDs and heating energy consumption is not logical. In other words, the energy used according to the gas meter for heating is not correlated with the outside temperature. However the data set gives a positive slope, the regression analysis on daily basis provides the value of R^2=0.1 that is unacceptably low.

These results of the regression analysis based on daily HDDs and energy consumption can be seen on Figure 27.

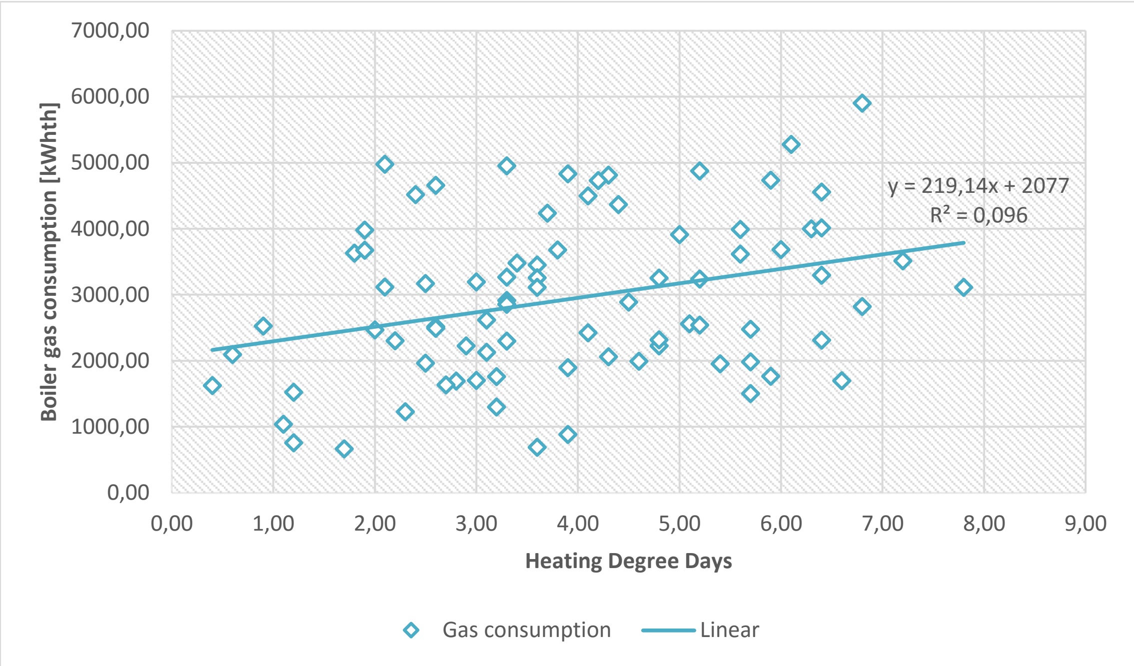

Figure 27 Regression analysis for HDD and gas consumption on daily basis

On Figure 27 another approach is shown where the monthly consumption data is compared to the monthly sum of HDDs. After summing up the daily data to each month, the regression line has the negative slope. It implies that there is less energy used for heating on colder days and it is unacceptable.

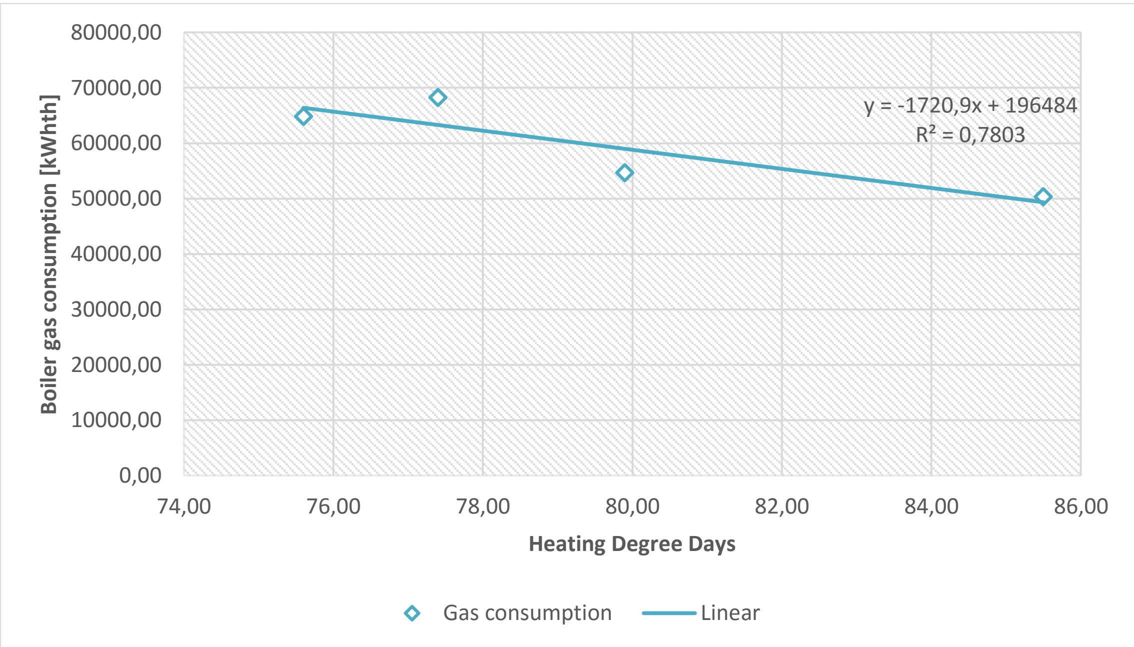

Figure 28 Regression analysis for HDD and gas consumption on monthly basis

To address this problem and find out the reasons behind the low quality data set, the maintenance staff is asked to do a comprehensive test and check the HVAC system in the building.

After checking the status of each fan-coil in detail, it is concluded that several sensors and valves are out of order. There are 75 fan-coils in the system and 20 out of them have no or false temperature data. Also, the valves are not set properly in many cases. As a result of the unveiled issues, the interference between cooling and heating is also possible if the temperature sensors are sending false data.

As a result of the low quality data set, the savings of the ECM cannot be calculated for winter with this approach.

Normalized energy consumption

Normalization is a process that makes the comparison of different years' data possible. Normalizing energy data to fixed conditions is necessary to calculate normalized energy savings. There are two ways of fixing conditions for calculating normalized savings; to use the conditions of the baseline period or use a period before the baseline. In order to increase the quality of the weather normalization, a longer period's average can be used.

First, in the weather normalization process the weather data between 2013 and 2015 is used. The average number of CDDs and HDDs in each month is determined from the data set. Also, the average number of weekdays of these months is filtered from the eleven year-long period.

Then, the regression equation of the reporting period is determined using the same base temperature for the DD as in the baseline period. Eq 5 is the regression equation in the reporting period. It does not give the same R^2=0.78 value as the baseline period, only R^2=0.70, that increases the uncertainty in the calculations.

$$y = 151{,}5x + 301{,}03 \quad \text{Eq 5}$$

$$R^2 = 0.7031$$

The CDDs and number of days are multiplied by the baseline and reporting periods' equations' fixed and load sensitive components. These equations are following the consumption pattern and embody the behaviour of the HVAC in the given period; therefore by introducing the days and CDDs of the fixed period, the result is the normalized energy consumption.

On Table 5, only the summer months are shown. The normalised savings cannot be calculated in the winter period due to the lack of reliable data. On the left, the average number of weekdays and the sum of CDDs in the fixed period is shown, then the fixed and the load sensitive components of each period. Finally, the normalised savings are visible in each month and summed up on the bottom.

Table 5 Calculation of normalised energy savings

	Fixed Period		Adjusted Baseline Period			Adjusted Reporting Period			
Months	n	CDD	Fixed Component (343,99*n)	Load Sensitive Component (151,78*CDD)	Total	Fixed Component (301,01*n)	Load Sensitive Component (151,5*CDD)	Total	Total Normalized Savings
January									
February									
March									
April									
May	22	45	7599 kWh	6840 kWh	14439 kWh	6650 kWh	6827 kWh	13477 kWh	962 kWh
June	21	83	7380 kWh	12596 kWh	19976 kWh	6458 kWh	12573 kWh	19031 kWh	945 kWh
July	22	142	7630 kWh	21532 kWh	29163 kWh	6677 kWh	21493 kWh	28170 kWh	993 kWh
August	22	142	7599 kWh	21590 kWh	29189 kWh	6650 kWh	21550 kWh	28200 kWh	989 kWh
September	21	83	7380 kWh	12596 kWh	19976 kWh	6458 kWh	12573 kWh	19031 kWh	945 kWh
October	22	50	7630 kWh	7527 kWh	15158 kWh	6677 kWh	7513 kWh	14190 kWh	967 kWh
November									
December									
Total	131	545	45219 kWh	82681 kWh	127900 kWh	39569 kWh	82529 kWh	122098 kWh	5802 kWh

Savings

It is important to translate the results of the normalisation into financial gains and CO_2 emissions to evaluate the environmental effect and pay-back time of the ECM.

Table 6 shows the normalised electricity consumption, CO_2 emissions and the energy costs in the Baseline period and the Reporting period in summer. Accordingly, the savings of the ECM of the summer period, considering only the energy used by the chillers is 877 €, which is equal to 5%.

Table 6 Chiller energy consumption

Period	Chiller	Emission	Cost
Baseline	127900 kWh	39 tCO2	19.326 €
Report	122098 kWh	37 tCO2	18.449 €
Saving	5802 kWh	2 tCO2	877 €

Table 7 shows an approximation of possible savings after the implementation of the ECM. The same percentage of summer savings (5%) is assumed to be saved in the winter period

Table 7 Boiler energy consumption

	Natural gas	Emission	Cost
Baseline	306462 kWh	56 tCO2	12.136 €
Report	291139 kWh	53 tCO2	11.529 €
Saving	30646 kWh	6 tCO2	1.214 €

Table 8 shows the prices and emissions of electricity production on the Iberian Peninsula and natural gas. The source of the values is the Generalitat de Catalunya [27].

Table 8 Price and CO_2 emission of electricity and natural gas

Natual Gas		**Electricity**	
Price	CO2 emission	Price	CO2 emission
40 €/MWh	184 gCO2/kWh	151 €/MWh	302 gCO2/kWh

Lastly, the assumed energy savings are summed up in Table 9. The expected total energy bill saving is 2090 € per year with an accuracy no better than ±22.5% with 90% confidence, or 470 € per year. 7 tCO_2 less emission is expected.

Table 9 Energy and CO_2 emission savings

Period	**Cost saving**	**CO2 savings**
Cooling	877 €	2 tCO2
Heating	1.214 €	6 tCO2
Total	2.090 €	7 tCO2

5.2 Results of START-UP PRODUCT 1

In the following the electric energy consumption forecasts of the buildings are examined in September. The algorithm behind the START-UP PRODUCT 1 app is trained with three month of historical data of energy consumption and weather data in each building.

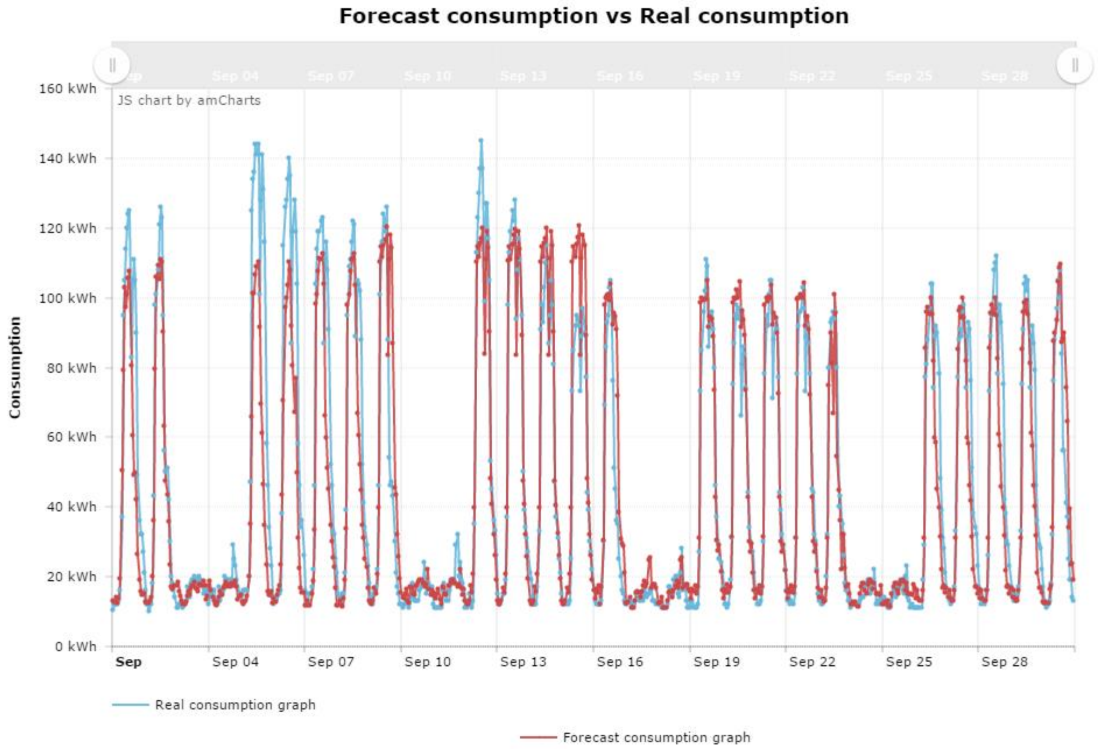

Figure 29 Forecasted total energy use in Av. Roma

On Figure 29 and Figure 30 it is visible that the algorithm realized the energy consumption tendencies in the buildings. In the two office buildings, in ICAEN and AV. Roma, the weekly pattern is clearly visible. There is significant energy consumption on weekdays, while on weekends energy use is limited to some basic appliances like the security or telecommunication system. Besides the weekly pattern, the daily start-up times are also assumed properly by the algorithm.

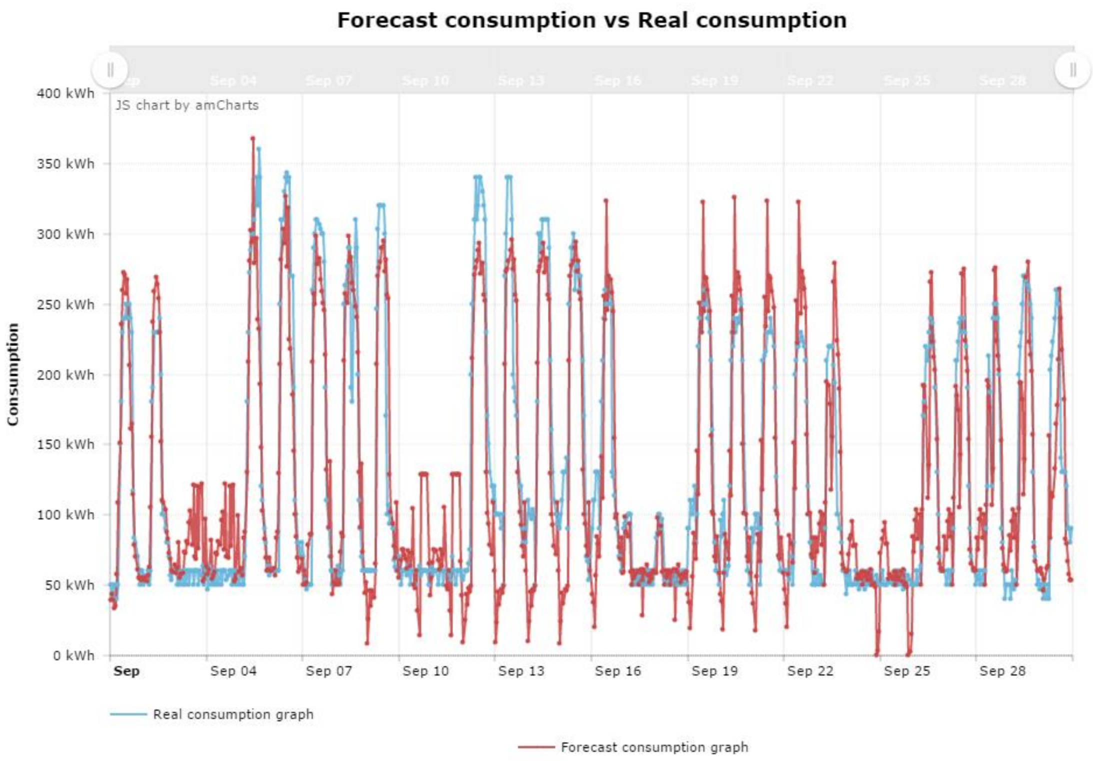

Figure 30 Forecasted total energy use in ICAEN

It is visible on Figure 29 and Figure 30 that the maximum energy needs forecasted are different in many days. The error of the forecasted values compared to the real values is 20.3% in Av. Roma and 30.4% in ICAEN on an hourly basis, while 13.3% and 11.9% respectively on a daily basis. Considering the sum of these values for the month, the error is 5% in Av. Roma and 1.8% at the ICAEN building.

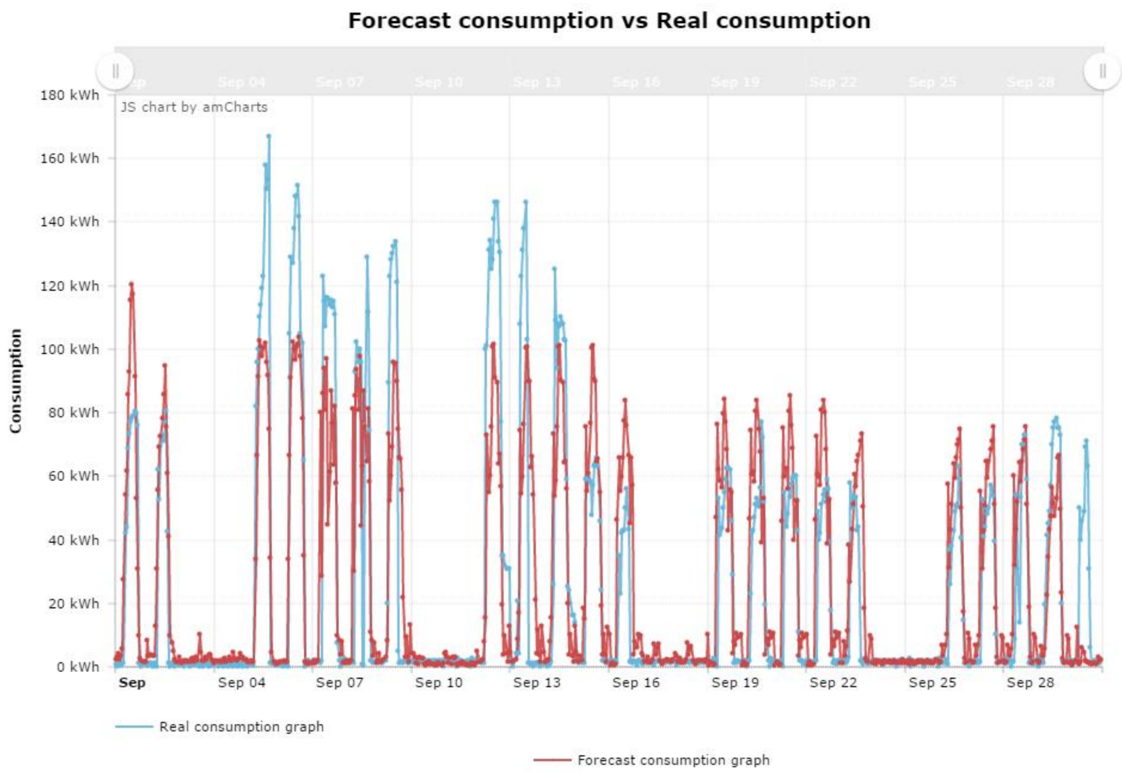

Figure 31 Forecasted HVAC energy use in ICAEN

Besides the total electric energy consumption, the HVAC energy consumption is forecasted in the ICAEN building. As seen on Figure 31, the forecast of HVAC energy consumption is following the weekly trend, however the hourly energy forecast has an average error close to 400%, while 42% error in the daily values. Considering the error of the monthly energy use, it is 3.6%, which is a significantly lower value compared to the hourly and daily error.

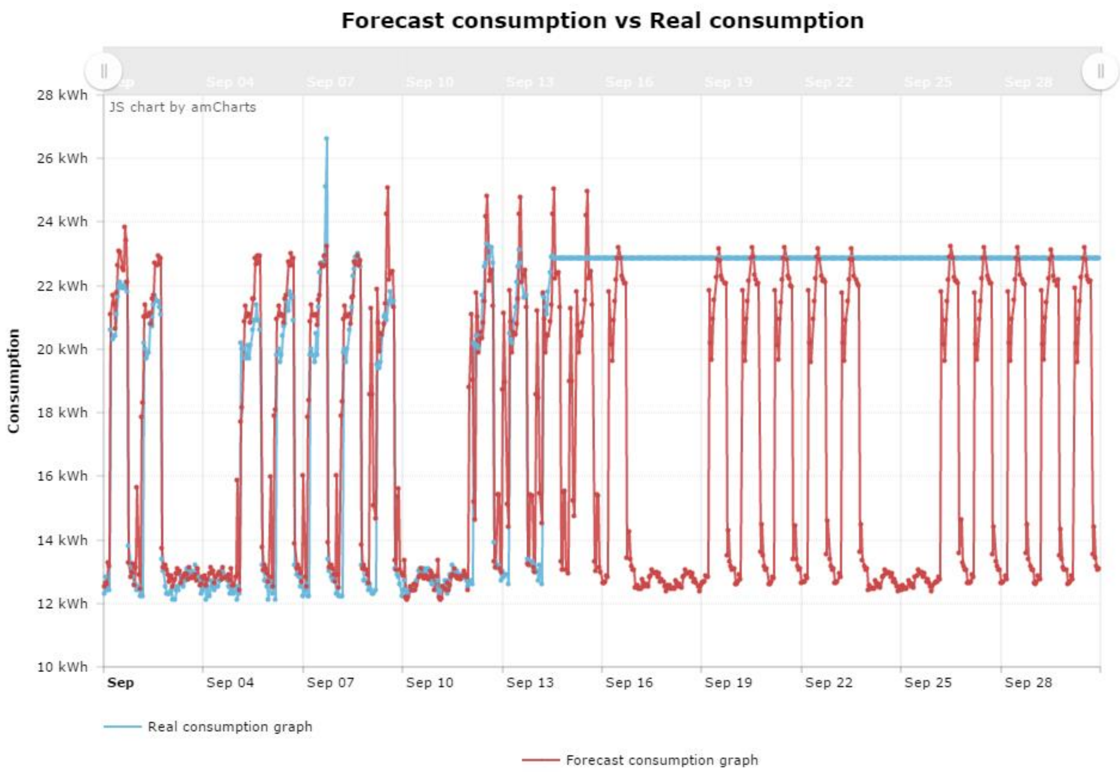

Figure 32 Forecasted total energy use in De Lijn Gentbrugge

The horizontal line on Figure 32 means the lack of energy data. There is a lack of energy consumption data in De Lijn Gentbrugge from mid September. The communication between the START-UP servers and the data logger does not work for several weeks. However, the data logger is being changed by the company responsible, the results cannot be evaluated.

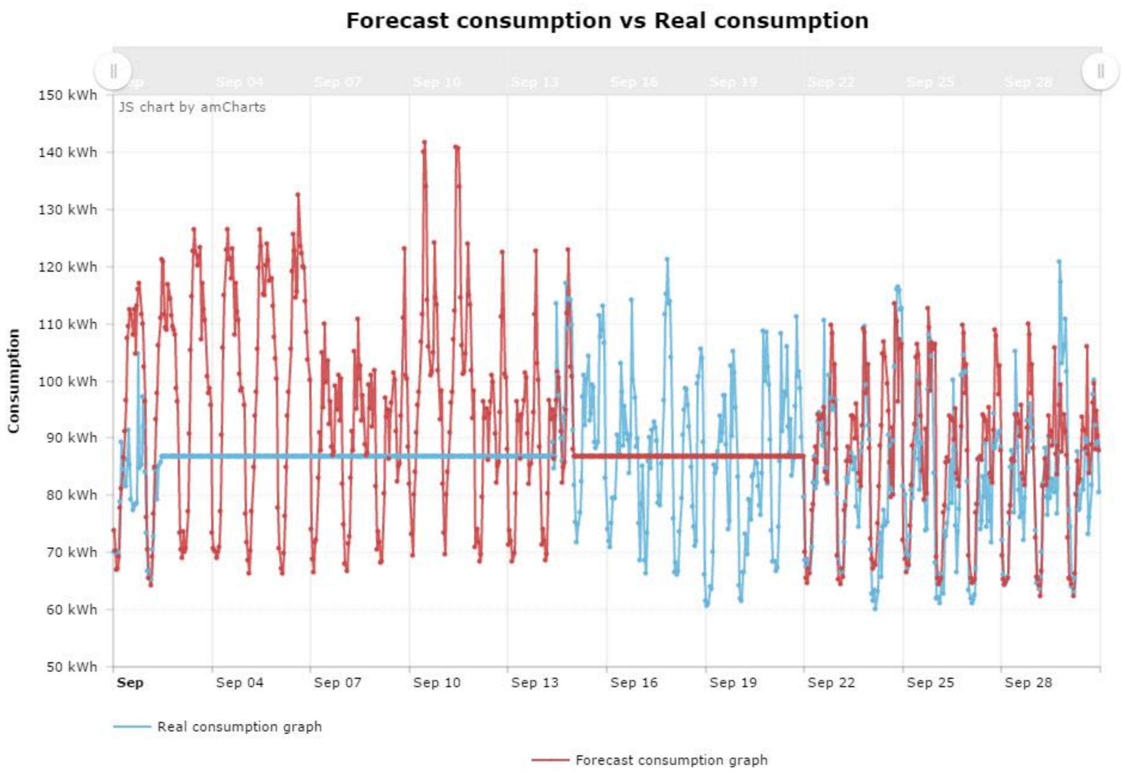

Figure 33 Forecasted total energy use in NH Waalwijk

In addition to De Lijn Gentbrugge, the results in NH Waalwijk visible on Figure 33 cannot be evaluated either. Due to the failure of the data logger, the energy use data between the 2nd and the 15th of September is missing. The company responsible for maintenance restarted the electricity meter on the 15th of September. The START-UP PRODUCT 1 started forecasting on the 22nd September again.

The summary of the results is shown on Table 10.

Table 10 Summary of PRODUCT 1 errors

	Av. Roma	ICAEN	NH Waalwijk	Gentbrugge
Hourly	20.3%	30.4%	-	-
Daily	13.3%	11.9%	-	-
Monthly	5%	1.8%	-	-

6 Business plan for Partners

Real estate companies, ESCOs and facility managers are continuously fighting to comply with soaring energy bills in hotels and office buildings, while it is essential to maintain the comfort level for their customers. By implementing the START-UP suit of apps, that helps reducing energy bills, these companies can make a step forward to generate higher profits in the very competitive field of facility management.

The START-UP suit of apps can reduce energy bills up to 20% by offering innovative solutions, like:

- Increased energy awareness.
- Optimized energy purchasing strategies.
- Automated HVAC scheduling.
- Exploit the opportunities of demand response programs.
- Access the electricity wholesale market.

Partners of START-UP are eligible to sell and commission the suit of apps and make significant profit on various ways.

6.1 Partnership with START-UP

Partners of START-UP are companies that sell, install and put START-UP Building Energy Management System apps into operation. In exchange for these services, Partners receive incomes from the customers, the end-users.

6.1.1 Requirements for Partners

Future Partners need to fulfil the following conditions:

- Have experience in office or hotel building auditing.
- Can integrate hardware, software and complete solutions in offices, hotels.
- Have experience in BMS and HVAC commissioning.
- Have the potential and capacity to reach a great number of customers.

Commissioning the BEMS is different in every office or hotel building. A high level of proficiency is desired from the Partner; therefore START-UP provides training related to the install and use of START-UP hardware and software. The training equips Partners with the knowledge needed to commission the specific applications. After the training, Partners are capable of auditing and commissioning the START-UP apps independently. For further issues with START-UP products the support of START-UP is available.

6.1.2 Benefits of being a Partner

eQuialtiq provides Partners with the following benefits:

- Direct income from selling the START-UP solutions.

- Selling an innovative product without investing in R&D.
- Access to the market of smart technologies.
- Access to new customers with sophisticated needs.
- Improved visibility and reputation by the industry.

6.1.3 Potential Partners

In this section an evaluation of potential and future Partners can be found. The first Partners of START-UP are companies involved in the BEEST project, in which the suit of apps is developed. Later, Partners from every corner of Europe are welcome to sell START-UP products.

Comsa Service

Comsa Service is part of the Comsa Group. The company is already involved in the BEEST project that is developing the products of START-UP. This department of the Comsa Group is involved in the ICAEN and other pilot projects in Barcelona, responsible for installing and commissioning the START-UP applications. It involves the installation of sensors, meters, the responsibility of the training the software, communicating results, etc.

The wide variety of services and experience makes Comsa Service to be an ideal Partner of START-UP:

- Comprehensive and specialized maintenance: Comsa Service offers multidisciplinary maintenance for a wide range of applications, like technological and technical consulting or regular, preventive, predictive, corrective maintenance.
- Facility management: This company offers services related to operational management of fixed assets, such as offices, museums, shopping centers and industrial facilities.
- Maintenance engineering: They conduct technical audits in order to diagnose malfunctions of facilities, and energy audits to review compliance with different energy and safety regulations.
- Conduct feasibility studies for the implementation of projects.
- Energy Service Company (ESCO): Comsa Services is involved in energy efficiency projects as an ESCO, providing services such as design, financing, and execution of installations, energy management and maintenance [28].

Enervalis

Enervalis is specialized on decentralized, scalable and secure SaaS middleware solutions, used for electric vehicle, smart building and Micro-grid projects. Enervalis is a shareholder of START-UP and owns skills that make them a Partner of START-UP, too. Enervalis has the following responsibilities with two pilot projects in Belgium:

- Installing energy meters and sensors to existing HVAC systems.
- Integrating the Dexma DEXCell Energy Management software.
- Commissioning of gateways, making communication with the cloud system possible.

- Connecting the Energy Controller unit to the BMS [29].

Sauter Controls

Sauter has experience of more than 100 years in the building industry, providing the latest building automation solutions, facility management, project engineering, building certification energy management and OEM solutions internationally. Sauter is involved in the ICAEN project, renovating the ICAEN building's HVAC system. [30]

6.2 Market analysis

6.2.1 Market and Growth

Based on a BSRIA market research, the global market for BEMS was worth $3 472 million in 2014. This means 14% growth compared to the previous year. Of this, the EU accounts for 45%, $ 1 562 million, with a growth rate of 10% per year. However, the market in the EU is more mature compared to the other parts of the World, the expected growth rate between 2015 and 2020 is 12% [32].

As can be seen on Figure 34, the 75% of the potential BEMS market is West and Central Europe, while for Eastern Europe only 2% of the market share is assumed.

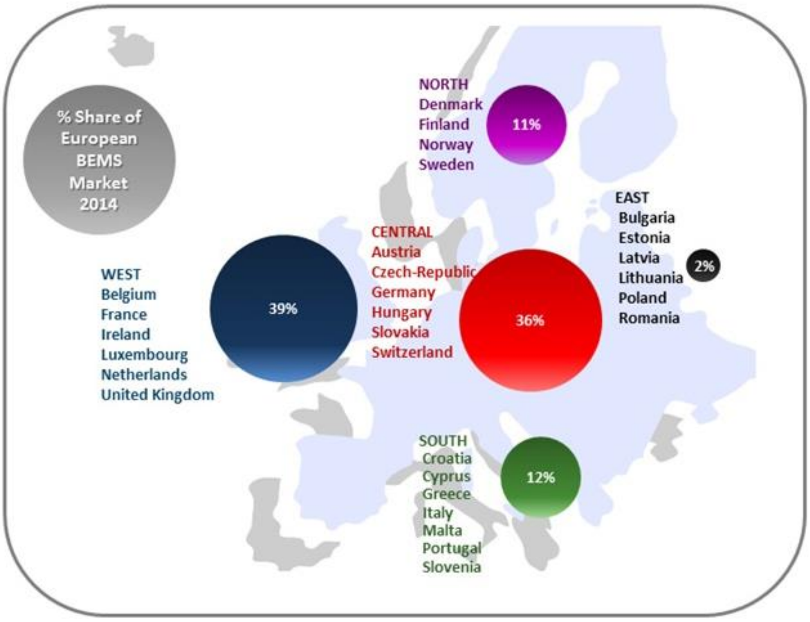

Figure 34 The BEMS market in Europe in 2014 [33]

6.2.2 Target Market

The eQulatiq apps can be used in buildings that meet certain requirements of size, consumption and purpose of use. The target market for START-UP apps are offices and medium/large sized hotel buildings that has outdated BMS systems. The minimum area for an economically feasible commissioning is 5000 m2. These are commercial buildings, with the intention to maximize profits, therefore they pay attention to energy bills.

Due to the presence of the START-UP shareholders and first partners in the same time, the first target markets are Spain and Belgium. However, the PRODUCT 3 and the PRODUCT 1 application are possible to be used in any building that meet the basic requirements, which means that in the future Partners in any country may appear.

6.2.3 Competitor Analysis

There are numerous companies offering services and products for the same customer segment. Some of them are offering complete solutions including self-branded hardware, while there are companies offering SaaS. The market is expanding rapidly and besides the key vendors, some start-ups are also getting a share on the market. In the following, some of the companies and their products are examined. [23], [31]

BuildingIQ

BuildingIQ was founded in 2009 in Australia and now has offices in the USA as well. Among others, Siemens and Schneider Electric are investors in the company. The main product of the company is a software that automates and optimizes the HVAC system.

The main functionalities and services that the company offers are:

- HVAC automation
- Analyzing demand response capacities
- Participation in demand response programs
- Automated Measurement and Verification calculation
- HVAC schedules 24 hours in advance
- Building portfolio management for facility managers
- Comfort complaint management
- One day energy consumption forecast of HVAC
- Remote control for HVAC

The company offers a fast implementation scaling around 5 weeks and compatibility with most of the BMS systems. The main focus of the products are office buildings. BuildingIQ has 10 to 50 employees and tracks 1.8 million m2 area of commercial buildings [31].

One of the competitive advantages of START-UP is utility bill management in PRODUCT 2 and the involvement in the electricity wholesale market by PRODUCT 6 app.

EnerNOC

The company was established in 2001 and offers cloud-based services, listed in the following:

- Optimizing energy procurement
- Utility bill management
- Sustainability tool that helps improving energy management activities

- Participation in demand response programs
- Analysis of the whole facility to find inefficiencies
- Energy efficiency project tracking
- Helps choosing ideal sustainable energy systems for the facility

EnerNOC employs 1000-5000 people. The company offers access to numerous demand response programs and offers services for both facility managers and real estate companies. The company is involved in several demand response programs in the USA [32].

Johnson Controls

Johnson Controls is a multinational company that offers building efficiency solutions, sell and commission energy storage systems and batteries, and, also, design and produce seats for the automotive industry. The company offers complete BMS solutions that include various services.

Johnson Controls was established 130 years ago and is present in more than 150 countries and possesses a leader position on its markets. Therefore; it is possible to implement the START-UP suite of apps on old Johnson Controls BMS systems. According to the services and products the company offers, Johnson Controls is more likely to be a partner in the future than a competitor.

Besides Johnson Controls, there are several multinational companies offering complete BMS solutions. Siemens' Desigo, Honeywell's ComfortPoint or Schneider Electric's SmartStruxure are competitors of the START-UP applications. Their experience, customer base is enormous and can reach any continent. Many of their services are competitors of START-UP apps.

Generally they offer the following features:

- Energy awareness by energy consumption monitoring
- Reliability by standardized and certified hardware
- Framework to reach high BMS standards
- Graphical user-friendly interface
- Remote access, control and diagnosis via internet
- Applications with integrated weather and sun irradiance information
- Offers for new and retrofit projects [33]

Siemens

Siemens has more than half million employees and has yearly revenues up to 100 billion dollars. It was founded in 1847 by Ernst Werner von Siemens in Germany.

The Siemens Desigo is used for optimizing the building's HVAC system and for controlling lighting, shading and fire and security systems. One of the highlighted features of the products is that the system can take the sun position into account and set the lighting and shading system accordingly. Also, office use information is used when optimizing HVAC performance.

Siemens has another competing system on the market. It is called Navigator. Navigator is a cloud-based platform that provides analytical and reporting capabilities. The Navigator suite of apps has used friendly dashboards to see the most important KPIs, can create environmental reports automatically, evaluate the performance of the HVAC system, help with utility bills, reduce energy prices and offers project energy project management features [34].

All in all, Siemens can provide the same functionalities as START-UP, however it is the mix of two of their products, therefore in a project-based way. START-UP has the advantage to offer similar functionalities in one platform, even for smaller commercial buildings. Siemens Desigo counts with to 20% energy savings, same as START-UP.

Schneider Electric

Schneider Electric is one of the biggest players on this market segment having 140000 employees and being present in more than 100 countries.

Smartstruxure is a complete energy management solution for buildings from Schneider. It integrates hardware and software and combines engineering, installation and services in one in a future proof integrated system. Smartstruxure provides a user-friendly interface, distance access to the energy systems and many other services that are desired by the customers. The software is claimed to save up to 30% on energy costs [35].

6.2.4 Differentiation and Positioning

It is important to highlight that this market is growing and these multinational players are present in every corner of the world and probably can meet most of the needs of their customers and compete with START-UP.

START-UP provides an extendible, flexible, multi-vendor compatible and automatic solution to reduce energy bills up to 20% with a low pay back time. This is done by reducing energy consumption, buying energy in a lower price, decreasing contracted power or gaining incomes from DR services. This solution guarantees the cost and time effective commissioning.

6.2.5 Risks

This Business Plan is for a general case, featuring the prerequisites, benefits and revenue streams of a random company that is evaluating the possibility of becoming a Partner of START-UP. Accordingly, several assumptions and estimations are may be inaccurate.

Sources of uncertainty:

- Sales forecast data
- Project costs
- Commissioning

- Issues with HVAC system (obsolete technology, incompatibility, failures)

Consequences of uncertainties:

- Project budget overrun
- Late commissioning
- Failed commissioning
- No sales
- Failure of the venture

6.3 Management Plan

The company works as a Partner of START-UP and cooperate in every issues. It is in common interest to perform a high number of projects for both companies and employees.

The Partner works as a licensed distributor of START-UP products and does the commissioning and the licensing for new customers.

Products

The applications are sold in packages. These packages of apps depend on the marketing strategy and compatibility between each other. Table 11 shows the packages for START-UP applications.

Table 11 Packages of applications

Packages	Apps
Silver	Dexcell Energy Manager + PRODUCT 1
	Dexcell Energy Manager + PRODUCT 2
Gold	Dexcell Energy Manager + PRODUCT 1 + PRODUCT 4
Platinum	Dexcell Energy Manager + PRODUCT 1 + PRODUCT 3
Iridium	Platinum + PRODUCT 5
	Platinum + PRODUCT 6

It can be seen that it is possible to purchase the PRODUCT 1 and PRODUCT 2 app alone. However, to run the other applications, PRODUCT 1 is inevitable to install. Besides PRODUCT 1, PRODUCT 3 is also needed for PRODUCT 5 and PRODUCT 6, which means that to use PRODUCT 5 and PRODUCT 6 it is essential to purchase the Iridium package.

Table 12 shows the type of energy savings with the START-UP apps. PRODUCT 1, PRODUCT 4 and PRODUCT 3 are focused on direct energy savings, while PRODUCT 2, PRODUCT 5 and PRODUCT 6 are apps to reduce the energy bills. Important to note that PRODUCT 4 and PRODUCT 3 cannot be used in the same time, these apps are mutually exclusive. The same is true for PRODUCT 2, PRODUCT 5 and PRODUCT 6.

Table 12 Type of energy savings with START-UP apps

Apps	Energy savings	Energy cost/unit
PRODUCT 1	+	
PRODUCT 4	+	
PRODUCT 3	+	
PRODUCT 2		+
PRODUCT 5		+
PRODUCT 6		+

6.4 Business Model Canvas

The business model explains how Partners can create and deliver value to their customers with the START-UP products, following the structure of the Business Model Canvas (BMC) proposed first by Alexander Osterwalder. [36]

On Figure 35 the BMC is shown. The BMC consists of the key partners, key activities, key resources, the value proposition, customer relationships, channels, customer segments, cost structure and the revenue streams. These parts of the canvas are explained in the following.

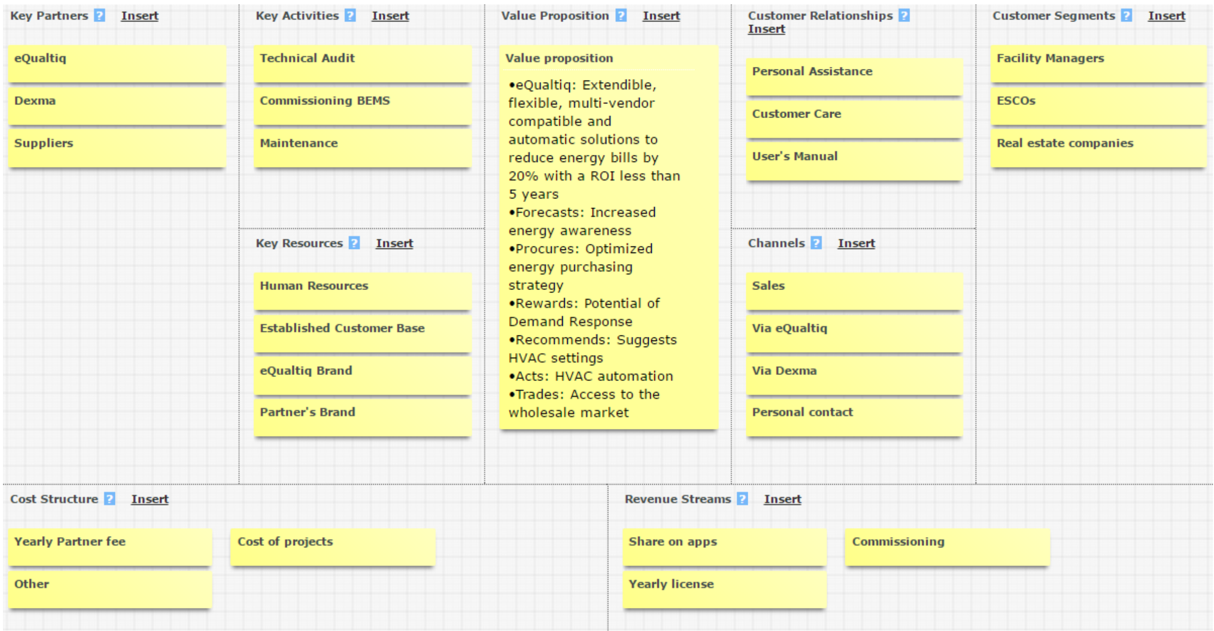

Figure 35 Business Model Canvas of START-UP insert as appendix [37]

Customer Segments

- Facility Managers
- ESCOs
- Real estate companies

The main customers are the group of people or companies that the Partner aims to reach and serve.

Along with the Value Proposition, owners and operators of facilities over 1000 square meters who want to reduce energy bills. These customers are facility managers and energy engineers responsible for facilities or real estate companies owning offices and hotels. Additionally, ESCO companies are potential customers. ESCOs finance and implement energy efficiency projects on third party buildings and consider energy bill savings as revenues.

Customer Channels

- Sales
- Marketing
- Via START-UP
- Via Dexma

Customer Channels describes the way how the company connects and transfers its Value Proposition to the Customers.

There are several different ways to communicate the Value Proposition of START-UP products to the Customer. These channels vary in every company and cannot be defined here. Most of the companies are having a mix of Customer Channels. Owned Sales is possible through the Sales force and a website, while START-UP and Dexma provide Partner Sales, by guiding Customers to the Partners.

Customer Relationships

- Personal Assistance
- Customer Care
- User’s Manual

Customer Relationships describes what sort of relationships the company builds with the Customers. These relationships are driven by the following motivations of customer acquisition, customer retention or the increase of sales.

Customer Relationships are different in every case. Personal Assistance is supposed to be the most direct way to reach the Customers. Also, Manuals and Customer Care are available for the products to help Customers with their daily routine.

Key Resources

- Human Resources
- Established Customer Base
- START-UP Brand
- Partner’s Brand

Key Resources describes the most important assets necessary for the business model. Without Key Resources the business model is unable to generate the Value Proposition or Revenues.

Human Resources and the Established Customer Base play an important role as assets. The engineering experience and knowledge is inevitable for proper commissioning. An Established Customer Base is important to distribute the new and innovative START-UP products. Also, the use of the START-UP brand increases confidence in the products.

Key Partnerships

- START-UP
- Dexma
- Suppliers

Key Partnerships contains the group of partners and suppliers that are essential for the business model. Partnerships are used to optimize the business models, to reduce risks or to acquire resources. The main types of partnerships defined are strategic alliances, partnership with competitors, joint ventures and buyer-supplier relations.

Partners have strategic alliance with START-UP and Dexma. Services like helpdesk, trainings, the Dexma platform and the START-UP apps. Suppliers provide materials or they are sub-contractors in any phase of commissioning, for example electricians.

Key Activities

- Technical Audit
- Commissioning BEMS
- Maintenance

Key Activities indicates activities that are needed for the business model to work. It is different in every field. Technical Auditing and Commissioning are field works that are essential to make the START-UP products work. Also, maintenance is necessary to keep the customer satisfied.

Value Propositions

- Generally: Reduced energy bills
- PRODUCT 1: Increased energy awareness
- PRODUCT 2: Optimized energy purchasing strategy
- PRODUCT 5: Potential of Demand Response
- PRODUCT 4: Suggests HVAC settings
- PRODUCT 3: HVAC automation
- PRODUCT 6: Access to the wholesale market

Value Propositions are the services and products that create value for the Customers by offering a solution for a problem or satisfying specific customer needs. These can be recognized or unrecognized customer needs, customize products to specific needs or offer a better deal in price-sensitive segments.

The value proposition of START-UP products is generally to reduce energy bills. This is done by reducing energy consumption, buying energy in a lower price, decreasing contracted power or gaining incomes from Demand Response services with the help of the START-UP apps.

Cost Structure

- Yearly Partner fee
- Cost of projects
- Other

Cost Structure includes all costs in the business model. Costs are usually minimized; however it is less important in value-driven companies, than in cost-driven ones. The fixed cost of an eQuatiq Partner is the Yearly Partner fee, which is explained later. Additionally, costs occur in every project. The costs of commissioning consist of labour costs, material costs and other costs, and these are directly related to the number and type of projects. Also, the percent after every sold license is calculated as a cost for the licensed Partner.

Revenue Streams

- Share on apps
- Commissioning
- Maintenance

Revenue streams are the lifeblood of companies. There are one-time customer payments, like the incomes from commissioning the projects, while recurring revenues are the share from yearly app fees.

6.5 Financial Plan

Revenues

The revenues are the incomes that the customers pay to the company for services and products. There are two main sources of revenues for the Partner companies. First, an income is due when the START-UP software and other necessary hardware are commissioned. Secondly, from the yearly fees of the software package installed, that is in this example is the Platinum package, which price at 10409 €.

Table 13 shows the revenues from projects. The values are calculated by adding 20% profit on personnel, material and other costs.

Table 13 Revenues from commissioning the Platinum package

	Revenues for a Platinum project
Platinum licence	10.409 €
Personnel	7.900 €
Material	11.837 €
Other	10.560 €
Total	40.706 €

Costs

Personnel cost, material cost and license cost are directly related to the commissioning of projects for each customer and it is called direct costs. Direct costs are visible on Table 14 The license cost means the 70% of the sold licenses that is due to START-UP. The difference between the direct costs and the revenues gives the operational earnings.

Besides the project related expenditures, the Partner has fixed costs, called overhead costs are visible in Table 15. On top of the yearly Partner fee of 5000 € that provides the right to sell the solutions, the rent of the office, administration personnel and the cost of a one-time training is included in the overhead costs. The difference between the operational earnings and the overhead costs gives the value of the gross income (EBIDTA). The 15% taxes are paid after the gross income.

Table 14 Direct costs of a project

	Direct cost per project
Personnel	7.182 €
Material	10.761 €
70% of licences	7.286 €
Total	25.229 €

Table 15 Overhead cost of a Partner

	Overhead costs
Office	6.000 €
Administration	3.600 €
Partner fee	5.000 €
One time training	5.000 €

Cash Flow

It is visible on Table 16 that the sales are forecasted following the stages of product life cycle. The Partner is assumed to have 5 customers, based on the assumption of Comsa Service, the first potential Partner of START-UP. In 2017 more than 44000 € profit is expected. Then, until the fourth year a rapid increase in revenues are expected. This rapid increase in sales is due to the supposed growth stage in the product life cycle. It is clearly visible, that after 2021 the sales are slowing down, but still more than 300000 € profit is expected.

Table 16 Calculation of cash flow

Cash flow	2017	2018	2019	2020	2021	2022	2023
Revenues							
No of projects	5	12	15	18	20	21	22
Income: projects	203.532 €	488.476 €	610.595 €	732.713 €	814.126 €	854.832 €	895.539 €
Income: yearly license	- €	5.205 €	17.695 €	33.309 €	52.045 €	72.863 €	94.722 €
Revenues	**203.532 €**	**493.680 €**	**628.290 €**	**766.022 €**	**866.171 €**	**927.695 €**	**990.261 €**
Direct cost per project							
Personnel cost	35.910 €	86.184 €	107.730 €	129.276 €	143.640 €	150.822 €	158.004 €
Material cost	53.805 €	129.132 €	161.415 €	193.698 €	215.220 €	225.981 €	236.742 €
70% of licences	36.432 €	87.436 €	109.295 €	131.153 €	145.726 €	153.012 €	160.299 €
Direct costs	126.147 €	302.752 €	378.440 €	454.127 €	504.586 €	529.815 €	555.045 €
Operational earnings	**77.385 €**	**190.929 €**	**249.850 €**	**311.895 €**	**361.585 €**	**397.880 €**	**435.216 €**
Overhead costs							
Office rental	6.000 €	6.000 €	9.000 €	9.000 €	18.000 €	18.000 €	27.000 €
Administration	9.000 €	16.560 €	19.800 €	23.040 €	25.200 €	26.280 €	27.360 €
One-time training	5.000 €	- €	- €	- €	- €	- €	- €
Yearly Partner fee	5.000 €	5.000 €	5.000 €	5.000 €	5.000 €	5.000 €	5.000 €
Overhead costs	25.000 €	27.560 €	33.800 €	37.040 €	48.200 €	49.280 €	59.360 €
Gross income	**52.385 €**	**163.369 €**	**216.050 €**	**274.855 €**	**313.385 €**	**348.600 €**	**375.856 €**
Taxes	7.858 €	24.505 €	32.408 €	41.228 €	47.008 €	52.290 €	56.378 €
Profit (net income)	**44.527 €**	**138.863 €**	**183.643 €**	**233.627 €**	**266.377 €**	**296.310 €**	**319.478 €**

Figure 36 shows the cash flow diagram of a Partner. The rapid increase in the first years and the slower development in the last years are visible.

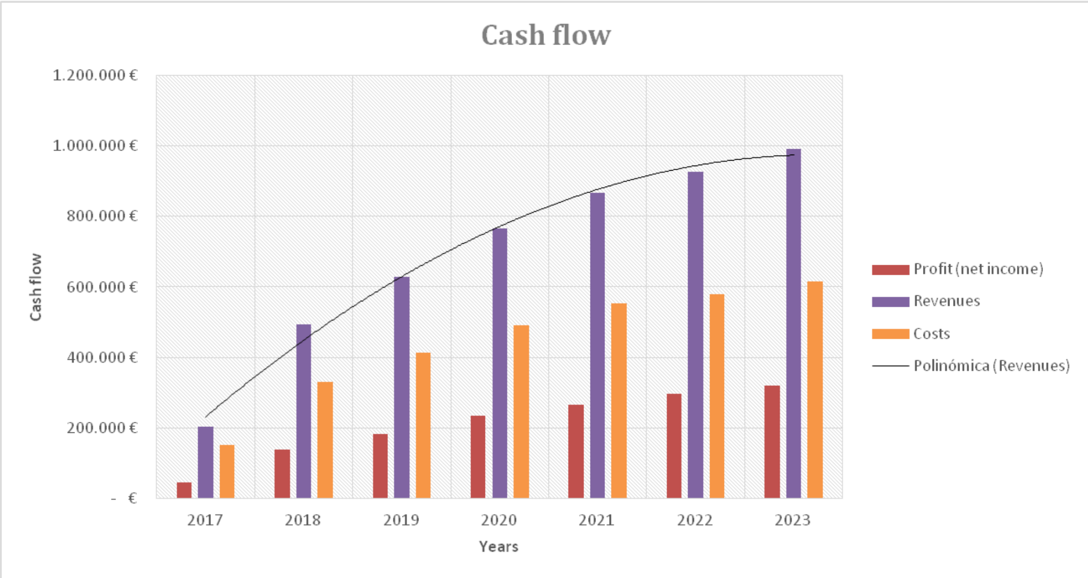

Figure 36 Cash flow of a Partner's sales of START-UP products

7 Conclusions

In this thesis, the energy savings reached and the results of the energy forecasts of a Building Energy Management System were evaluated. The energy savings were calculated into money and CO_2 savings, while the accuracy of the forecasted energy values was analyzed. The following conclusions were made:

- The regression analysis only considers one independent variable, the ambient temperature and provides an R^2=0.78 and R^2=0.70 in the baseline and the reporting period respectively. According to the IPMVP the suggested minimum R^2 value is 0.75. It means that ambient temperature is not strictly correlated to the energy consumption in this building.
- The calculated energy saving is 5% compared to the last year's energy consumption in the summer. This means 877 € and 2 tCO_2 savings. Assuming the same percent for the whole year, the energy saving is equal to 2090 € and 7 tCO_2. However the pay-back time is more than 20 years, it is not an aspect to take into account at this pilot project.
- The energy forecasts provided by the software have an error on the total energy use of 30.4% and 20.3% on hourly basis, 11.9% and 13.3% on a daily basis and 1.8% and 5.0% on a monthly basis. This means, that the START-UP PRODUCT 1 app needs further testing and development to improve the outputs and to be a successful product.
- The global market for BEMS was worth $3 472 million in 2014 and a 12% of growth is expected between 2015 and 2020. This means that the development of the product is reasonable and the potential market is present.

The thesis objectively evaluates the partial results produced by the Building Energy Management System being developed and provides a suggested business plan for the future distributors of the product. It found, that the pilot project managed to save 5% energy in the summer (that may be the result of errors) and provide hourly energy forecasts with an error between 20.3% and 30.4%.

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