BSc Integration Project

Faculty of Science and Engineering

Industrial Engineering and Management

Assessing and Improving the Current Energy Management Method at the UG Library

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Abstract

In light of today's concerns with environmental pollution and gas emissions, public buildings became the focus of energy improvements to reduce energy consumption. In the EU, public buildings are responsible for approximately 40% of the total energy consumption and offer significant opportunities for improved sustainable development of individual countries and the EU as a whole.

The Green Office, a department that focuses on the sustainability of operations at the University of Groningen, believes that the UG Library might consume excessive energy for a relatively few visitors during the extended evening openings. Therefore, the building has been assessed against the EPBD criteria and shortcomings of the current system were identified and quantified, where possible. Moreover, strategies and challenges in becoming an nZEB building are discussed, with brief long-term and more detailed short-term energy saving opportunities provided.

By carrying out a literature review, conducting interviews and a survey, as well as briefly inspecting the library's energy management, it became clear that further energy improvements can still be possible despite the library's certification as an Energy Label A building. While the annual energy reduction as a result of these changes seems minor, together they offer low- to no-cost solutions that can yield up to 17,370 EUR/year in savings and an approximately 10% decrease in energy demand.

1 Glossary of Abbreviations

AIDA – Affirmative Integrated Design Action

BaOpt – Bauer Optimalisering

CO2 – Carbon Dioxide

DOE – the U.S Department of Energy

ED – Energy Demand

EET – Energy Efficient Technologies

EPBD – European Performance of Building Directive

EPC – Energy Performing Certificate

HVAC – Heating, Ventilation and Air Conditioning

nZEB – Nearly Zero Energy Buildings

PE – Primary Energy

PED – Primary Energy Demand

PES – Primary Energy Sources

RE – Renewable Energy

RES – Renewable Energy Sources

RVO – Dutch Agency for Enterprises

SMART – Specific, Measurable, Attainable, Realistic and Timely

UG – University of Groningen

ZEB – Zero Energy Buildings

2 Common Energy Unit Conversions

Throughout literature review, multiple scientific papers and books that have been cited were published in the US, therefore the following conversion table has been compiled and consulted with in order to convert all data in the SI units or those mostly used in the EU (such as Lux and Watts).

Units (United States Measurement System)	**Multiplication Factor**	**Obtained Units (SI or other)**
Btu/hr	0.29	Watt
Btu/lb	2.326	kJ/kg
Feet	0.3048	Meters
Foot-candles	10.764	Lux
Inches	25.4	Meters
Square Feet	0.0929	Square Meters
Tons of cooling	3.517	kW

Table 1: Conversion of Units Reference

3 Assumptions

In order to carry out the energy redesign proposals, consumption and savings need to be estimated. Unfortunately, the needed data is not always available neither at the library, nor in scientific databases, thus certain assumptions had to be made. While these assumptions may affect accuracy or quality of the design, they are needed for calculation purposes. In this project, the list of main assumptions is provided below:

1. The UG Library is open 365 days a year from 8:30-00:00. Of course, it may be closed or open for reduced hours on some of the public holidays and unexpected circumstances such as the coronavirus pandemic, but this assumption is made for the ease of calculations, as it is true for almost all days in the year.

2. The UG Library consumes 1,765,000 kWh of electricity and 40.000 m^3 of gas per annum, which translates to 145,000 EUR/year and 18,000EUR/year respectively. The total energy cost is thus 163,000 EUR/year. This information comes from Kor Smit, a buildings expert at University of Groningen and will be taken as a fact as there are no other ways to estimate or validate this data. Similarly, the lighting estimation is assumed to be 7 W/m^2, based on one of the interviews with the UG Library employees and confirmation of the Facility Manager.

Contents

4 Introduction

The project discussed in this report aims to evaluate the current energy management at the UG Library against the identified EPBD criteria and propose potential methods to reduce the energy consumption. Located in the city center of the Northern Province of Groningen, the building has been majorly renovated in the years of 2014-2018. While the library's energy consumption has been reduced, the library is operating under extended open hours (8:30 until 00:00). Thus, the Green Office is concerned that the building is facing increased energy demand for a relatively few amount of evening visitors. This claim has been assessed by surveying the UG students to identify and estimate fluctuations in demand.

The Green Office is the problem owner of this project, as it is a university department that monitors and ensures the institution's sustainable operations. Due to large emissions produced by public buildings elaborated in literature review, the UG has a mission as a public educational organization to stay environmentally responsible. This project is of significant importance to the Green Office, as the UG the representatives of the institution stated that the university is “committed to more sustainability in education and research, but also in business operations, renovation and new construction projects” (University of Groningen, 2020)

In order to clearly address the concern, the Design Cycle is implemented and applied throughout the project. Moreover, the building is assessed against the EPBD criteria and shortcomings were identified. The findings also provide sources of potential difficulties in satisfying those criteria, as well as a financial sources overview. Finally, using estimation techniques discussed in Shapiro, 2014, potential energy saving solutions are described.

5 Methodological Framework: The Design Cycle

In order to implement a coherent and well-organized project, the methodology of the design science research is adopted. The visualization of the method is presented on the figure below:

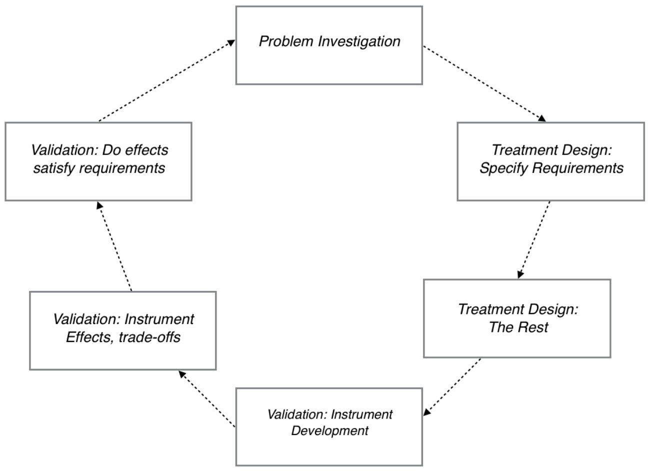

Figure 1: Design Cycle

The Design Cycle, discussed in Gorschek et al. (2006) and Peffers (2008), is a methodological approach to design projects that consist of specific steps. They are divided into 3 main groups: Problem Investigation, Treatment Design and Validation.

In the first step, Problem Investigation, stakeholder analysis, goal, conceptual problem framework, problem causes and mechanisms are discussed. In Treatment Design, project requirements, available treatments are found and/or designed. Lastly, Validation is concerned with a model or prototype is developed and its effects and trade-offs are explored. To complete the project at hand, this particular methodology is used a framework and serves as the main structure of the final report. Due to constraints mentioned further in the report, the Problem Investigation and Treatment Design are the main focused of the project.

6 Problem Investigation: Literature Review on Energy in Public Buildings

6.1 Significance of Energy Management in Public & Commercial Buildings

Initial literature research revealed that due to consuming a significant amount of energy throughout their operating time (Thormark, 2002), the energy consumption of buildings in the EU is responsible for 40% of the total energy consumption (Ardente, 2008). According to the study of Prasad, 2004, almost half of the materials produced in the world are allocated for buildings, which constitute 40-50% of the total greenhouse gas emissions.

The University of Groningen is concerned with its environmental footprint due to the current threats of climate change. As claimed by academics and policy makers, 40% of the total energy consumption in Europe is responsible for 35% of the carbon emissions (Dascalaki, 2008). Even though residential buildings constitute 60% of the total building sector (Poel, 2007), public and commercial building sector still presents a major stock and could contribute to immediate results, with a total potential of 28% energy reduction (Elkin, 2008). Thus, as a public building and an educational institution, the University of Groningen bears responsibility to operate sustainably. Since buildings are long-term constructions, they will consume a large amount of energy through the years and must be designed with respect to environmental aspects (Wan, 2010).

6.2 Sources of waste in Public Buildings

One of the studies that evaluated energy consumption of the building sector in Switzerland provided sophisticated insights into the topic (Wuest, 1994). According to its findings, roughly half of the country's energy consumption came from the building sector, meaning in some countries, public buildings may even have a larger impact on the country's emissions. Moreover, 50-70% of the energy consumption has been linked due to indoor air conditioning and sanitary hot water, whereas 10-20% is linked to construction materials production (European Commission, 2003). A 2008 study has found that a reduction of energy by 24-50% is possible in sustainable buildings. (Turner, Frankel 2008).

Another case study of a public student residence in Xanthi, Greece, showed that 84.7% of the total energy consumption was dedicated to space heating, losses to the environment and warm water, while the other 15.3% came from electric consumption for lighting, refrigerators, electric stoves, fans and other appliances (Kouloura, 2008). Furthermore, the study found that even after major renovations and improvements in the

6.3 Importance of Energy Label Certificates

Energy labels have become an important factor in pricing a public building in the recent years. The real estate transaction data in the EU includes a factor of energy performing certificates (EPCs) for non-residential estates. Those certificates are awarded through an energy performance assessment. An inefficient building can be labeled as a G, while highly efficient buildings are awarded with an A++. (Kok, Jennen, 2012) Since the UG Library is a level A building, it is considered to be an efficient building. In the province of Groningen, only roughly 35% of buildings are awarded a label of A++ - C, making the UG Library one of the most efficient buildings in the province compared to others. However, while the University claims that the UG Library is a sustainable building, the concern of the Green Office calls for an evaluation and the library must be assessed against existing sustainable building criteria.

7 Current State of the UG Library

7.1 General Building Information

The University Library is located in the city center of Groningen. The following facts have been collected from the interviews with the library employees and videos provided about the library. The building was designed in 1986 by Piet Tauber and has been majorly renovated throughout the years of 2014-2018. The recently innovated library provides various facilities available for students, researchers and staff, with a total capacity of 2100 flexible workspaces. These include tables with chairs, personal and group studios for 1-10 persons as well as computer seats. At the ground floor entrance of the building, a service desk is available for any questions, information or private studio bookings. Also, an automated computer-based self-service can be used to borrow/return books from the library. For example, upon return of a book the user can insert it into the machine and confirm the return on the screen by entering the details. The book is then delivered by a conveyor belt to a room where a staff member re-directs it where needed. There are in total 5 levels which include the ground floor and 4 additional levels which can be either accessed by a large staircase that is often used as a meeting ground or the elevators. Moreover, a smart sound zoning is implemented between the study floors and the staircase to prevent any noise disturbances in the building.

According to Kor Smit, an expert from the department of Energy and Water Management at University of Groningen, the library consumes approximately 1,765,000 kWh of electricity and 40.000 m3 of gas per annum, which translates to 145,000 EUR/year and 18,000EUR/year respectively.

7.2 Lighting: LED lamps, occupancy and daylight sensors

During an interview in the library, the Facility Manager provided some general information with respect to the current lighting system. The lighting power consumption in the library can be estimated at 7W/m^2 in common study rooms, studios, cafeterias and bathrooms. This statement was also confirmed by the mechanical engineer who also worked during the years of reconstruction, Jeroen van der Burg. When the library opens in the morning, one of the receptionists, Manon, turns on all the lights in the study areas at approximately 30% brightness. Upon students' arrival, the sensors installed above the tables detect presence and increase the brightness of the lights in the relevant study areas by a certain amount. This amount also depends on the level of daylight entering the room, meaning on a sunny day the lights in the library will be operating at a reduced brightness than at night. This smart system allows for a more efficient energy use that is directly based on demand in the building and amount of daylight in the building. Unfortunately, there is no data provided with respect to the exact parameters and actual coding of the lighting. Some photos for visualization are attached below:

Figure 2: Table lighting during daylight

Figure 3: Table lighting during daylight

Figure 4: Cafeteria lighting

Figure 5: Occupancy Sensor

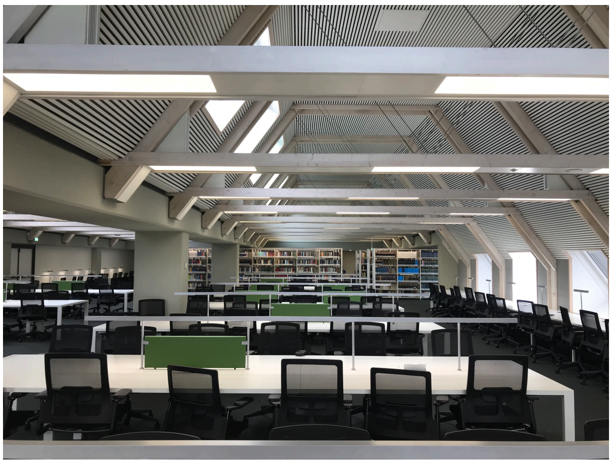

Figure 6: Study area

Using the archives and floor areas estimated in Treatment Design Section, it was possible to estimate the energy consumption of lighting in the building. Since the total area of all levels is 14,324m^2 and the maximum lighting intensity is 7W/m^2, the hourly consumption due to lighting is 100.260 kW. Assuming that lighting is on at this intensity for 15.5 hours every day for 365 days a year, the total yearly consumption of lighting is approximately 567,201 kW, which accounts for 25.6% of the yearly ED at the UB Library. However, the calculation does not take into account variations in intensity of the lighting due to sensors, thus it could be significantly lower. Nevertheless, this quick estimation shows that with the lack of information on lighting sensors, it would be unnecessary to focus the project on lighting, which seemed to be one of the main concerns of the Green Office.

7.3 HVAC: Heating, Cooling and Ventilation

In the same interview with the Facility Manager, the HVAC system has been briefly described and some elements were demonstrated. While similarly to the lighting, the library does not have detailed data with respect to consumption, it is known that the HVAC system consists of heating, cooling and ventilation elements that are coupled with thermostats and CO2 sensors. For example, if there are many students present at the library, the temperature and CO2 gases will rise, resulting in more intense cooling and ventilation from the HVAC system. All of these adjustments are pre-programmed by a third party and periodically checked for maintenance.

The ventilation system in the library is known as BaOpt (Bauer Optimalisering). While there is very limited English literature on this system, the University of Groningen published a press release in 2013, describing the functionality and effects of BaOpt system. According to the university, the system allowed for enhanced oxygen levels in the library and 30% energy reduction with respect to ventilation. One of the main advantages of the system is that it can get fresh air to more isolated parts of the rooms and maintain constant oxygen levels. This system is being heavily adopted in Germany and may become even more common in the coming years. As of 2013, the University of Groningen has been the first institution to adopt of the BaOpt system in the Netherlands.

Moreover, the UG Library is using groundwater in order to heat and cool the building more efficiently. According to the Facility Manager, there are pipes reaching down 100 meters in order to pump the underground water to use for cooling in summers, and for heating in winters. This is possible as the temperature of underground water remains constant through all seasons. The picture of the water pump is shown below:

Figure 7: ATES Pump for Underground Water Extraction

As can be seen on the photo, the pump and pipes located on the ground floor are in new condition with no visible signs of damage, pipe cracks or leakage. During literature review, it has been found that this system is called ATES. The underground water pumped in the summer into the building for cooling, after which the warmed water is disposed back underground until the winter season for heating. Due to additional savings in energy due to such system, ATES is widely implemented in the Netherlands since the successful trials in 1900 (Zeiler, 2016).

Furthermore, some of the heating systems present in the library were also demonstrated with photographs attached below:

Figure 8: Heating Installation 1

Figure 9: Heating Installation 2

As can be seen on the pictures above, the central heating system at the library is newly installed and has no signs of visible damage, cracks or leaks in the pipes. Moreover, all pipes are insulated for heat loss prevention, which is very important as energy losses to environment are a large source of energy waste in public buildings.

Unfortunately, the heating, cooling and ventilation systems are coupled together on all floors and are pre-programmed to operate based on certain temperature and oxygen requirements for each room. The Facility Manager stated that the heating and cooling have very limited room for improvement as significant differences in energy consumption can only be achieved if the entire system was replaced. However, given that those systems are new, it would not be an economically feasible option. Regardless, that claim cannot be tested to an accurate degree as there is no possibility to inspect HVAC due to the time and lockdown constraints at the moment of writing the report.

7.4 Students' Perception on the Library's Current Energy Efficiency

In the Google Survey filled by the UG Library visitors, one of the questions invited the participants to rate the library's electricity use on its efficiency from a scale of one to five. The purpose of this question is to visualize the students' perception on the library's environmental image. As can be seen in the chart below, most of the responders (49%), rated the building a "three", while 23.5% of the responders rated it a "two" or below. Oppositely, only two out of 51 responders rated the library a "five", meaning most of the responders (96.1% or 49/51 responders), believe there are at least some improvements to be made with respect to the buildings' environmental aspects. While the Facility Manager seemed fairly surprised by these numbers, he did not believe that there were any problems with respect to the library's energy use. One of the reasons that more than two-thirds of the responders believe the library deserved a "three or lower" could lie in the fact that there are very few press releases that explain and demonstrate the building's energy efficient tools, such as solar panels, underground water utilization systems, photo- and occupancy sensors, etc.

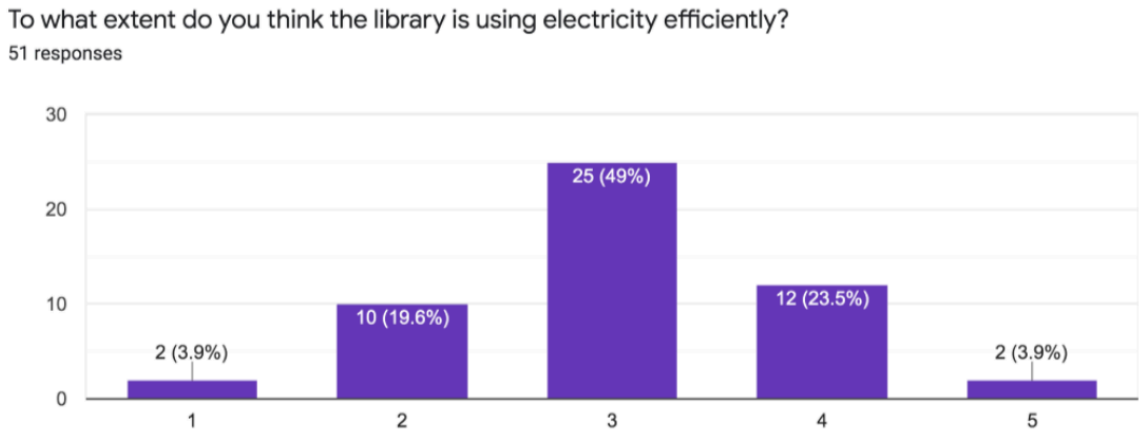

Figure 10: Survey Results on Students' Perception of Library Efficiency

8 System Description

In order to carry out a successful and meaningful research, it is important to understand the system as a whole and actors that participate in it. Defined by Calvano and John, 2014, a "system" demonstrates behavior that is more than the sum of its individual actors. In this case, the library is an "engineering system", as defined by Magee and de Weck, 2002, since it was constructed for a clear function that can be stated as "to provide comfortable study spaces and allow students of the UG to interact with the literature owned by the university". Attached below in the diagram, the library is the main body that has certain inputs, outputs, third-party actors and suppliers of the University Library.

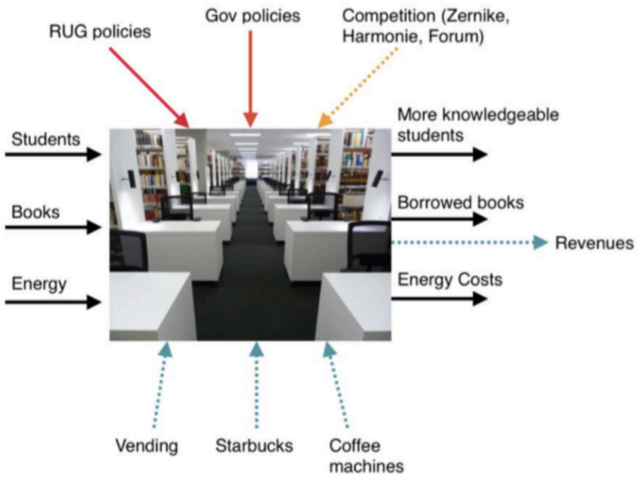

Figure 11: System Visualization with Inputs, Outputs and Other Factors

According to this system, the students, books and energy are main inputs to the library. The central goal is to provide educational facilities and an effective studying environment to the users by providing comfort and books. As a result, more educated students are the output of the library as they are assumed to come out with more knowledge upon leaving. The books are also a separate input as they are supplied and stored in the library to be borrowed by students and professors. The third input to the system is energy supply, which as mentioned before is electricity and gas, which is then used to power the building and result in financial costs for the University. It is also important to understand the outside factors that may affect the operation of the library. The government policies and UG policies regarding energy and sustainability may affect the way under which the library operates, shall maximum energy usages and sustainability laws be adopted. Lastly, it is important to recognize that the library has third-party suppliers that provide vending machines such as Douwe Egberts coffee, Cup A Soup, Vending machines for drinks and food. While these facilities increase energy consumption, they also provide revenues for the library as students spend money on them.

9 Stakeholder Analysis: The Green Office, the UG Library and the Students

Stakeholders are defined as important actors in a system and are affected if it undergoes a change. (Wierenga, 2014) In order to properly identify and analyze the role of each stakeholder, it is useful to map the actors that are or will be involved in the project during its development.

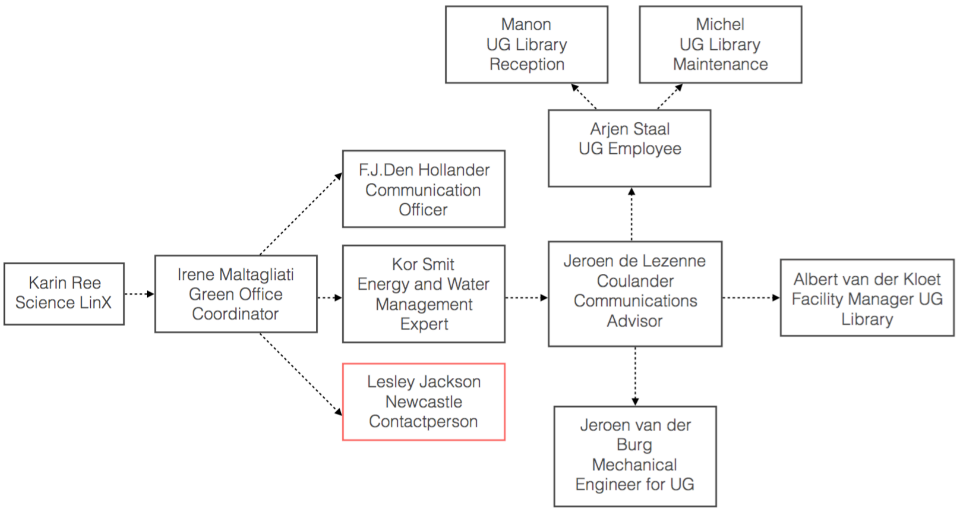

Figure 12: Persons Contacted and Interviewed During the Project

The figure above illustrates the persons already contacted in the course of the library energy re-design. In each box, the name and position of the person is provided. While black boxes represent some of the stakeholders who were successfully contacted, the red boxes represent individuals who have yet to respond to inquiries. Lastly, the arrows represent the contacts that were provided by the person in the relevant box.

Karin Ree, one of the project supervisors who works at Science LinX, has provided the contact of the Green Office Coordinator - Irene Maltagliati. During the first interview, Maltagliati has provided her wishes and expectations on behalf of the problem owner, the Green Office, with respect to the problem of inefficient energy use at the University Library. According to Maltagliati, the initial suggestion of implementing an energy management redesign has come from the Newcastle office, but the contact person Lesley Jackson could not be reached. However, the two employees of the University who worked on the Library renovations in the past years, Frank J. Den Hollander and Kor Smit - were successfully reached and provided some brief information about the library, further referring to Jeroen de Lezenne Coulander, who has been closely working with the renovations and was responsible for the press releases for the project. He was interviewed by email and provided some additional information on electricity in the building, also referring to Albert van der Kloet, facility manager of the library. In an additional interview, de Lezenne Coulander invited Jeroen van der Burg, a mechanical engineer at the University to help answer some of the technical questions about the library. In addition, provided the contact of Arjen Staal, who along with Manon and Michel arranged a special request entry to the UB in the closed hours due to the pandemic and accompanied the author for an interview with Albert van der Kloet.

As was also discovered in the course of the online interviews and email exchanges, each stakeholder has a varying level of understanding of the current energy situation at the library and potential solutions, which is described in design science theory. (Bossworth, 1995) In fact, most of the stakeholders seem to be only slightly aware of the Green Office's concern and did not provide any suggestions regarding possible improvements. According to Ian Alexander's 2005 work, each stakeholder can be specifically classified for a design project. Thus, all persons considered to be affected throughout the project, are listed as follows:

The Green Office, represented by Maltagliati, is the **Consultan**t of the project. The main concern of the problem for this organization is sustainable operation of University of Groningen facilities and the image of the University with respect to its environmental decisions as an educational institution. The Green Office does not determine the budget, limitations or any assistance for the project besides providing relevant contacts. They are only interested in finding a solution to what they believe is an inefficient energy management at the library and would like to see a redesign proposal that they could review and present to the library management Therefore, this stakeholder is considered to be contacted only in the beginning and at the end of the project, with minor updates in between.

Frank Den Hollander, Kor Smit, Jeroen van der Burg, Arjen Staal, Manon, Michel and Jeroen de Lezenne Coulander are **Maintenance Operators** of the library. They are responsible for working with the system to maintain its functionality. These University employees have worked on the renovation projects in the past years and are familiar with some aspects of the building. While they do not hold any power in deciding whether the project shall be continued or terminated at any point, they can provide useful information that might be needed to understand the state of art and to be consulted with when determining feasibility of certain solutions. They do not seem to show much interest in the project, but some of them would like to see the outcome of the redesign. However, it is important to note that Jeroen de Lezenne Coulander has been very responsive and seems more intrigued by the outcome of the design.

Albert van der Kloet, the facility manager of the Library is defined to be the **Sponsor** of the project. While he cannot cancel the project in his position, he is assumed to hold the authority to decide whether the proposed redesign will be feasible or not. He has low involvement and low interest in the project, but he might accept the proposal if the problem moved forward by the Green Office exists and needs treatment. Despite his statement during the interview that the library does not need any treatment, Ian Shapiro, the author of “Energy Audits and Improvements for Commercial Buildings” writes that it should not be assumed that even Leadership in Energy and Environmental Design (LEED)-certified or other enhanced buildings (such as Energy Label A and above buildings) have no room for improvement. Therefore, the building must be still inspected to a possible extent and sources of waste must be searched. (Shapiro, 2014)

The students are considered to be the **Functional Beneficiaries** of the project as they can benefit from the result of the redesign and are users of the Library. While they have no direct involvement in the project, its outcome may affect their comfort and feelings about the Library. Thus, their well-being must be considered at all times to avoid degrading their study experience by the redesign. The students are surveyed once during the project to estimate visitor data and evaluate their current experience with respect to lighting and energy awareness at the library.

10 Restrictions and Specifications

Every design project has its restrictions and specifications that must be mentioned to provide detailed context for the investigation. One may find the summarized limitations with respect to opportunities in the project listed below:

Time – this project is carried out within approximately three months. This project concerns assessing the current energy state proposing energy-saving solutions to the Library. It is therefore very similar to energy auditing, though on a small scale. In reality, scheduling and carrying out observations in public buildings for energy audits can consume up to three months, whereas seeking solutions and defining recommendations are normally done within another two to six months. (Shapiro, 2014) There are very strong time constraints as the project is performed solely and in a very short amount of time for a complex, five-level public building.

Limited Access to the Building – since most of the work was carried out during the coronavirus quarantine and a mandatory lockdown in the Netherlands, there was only a one-week window during which the library could be freely entered before it was announced closed until September. As a result, only one special visit to the library could be organized for inspection and was heavily supervised, while only one study area was allowed to be entered for observations and photos. Therefore, there was no possibility of free and numerous viewings. Consequently, the current state of HVAC, ATES, Lighting is difficult to assess.

Limited Access to Data – even though some archives such as floor plans and electricity specifications were shared by Jeroen de Lezenne Coulander, there was no data and details on photo- and occupancy sensors, as well as HVAC provided by the Facility Manager except for some verbal information and demonstration of some parts of the heating system. Previous energy audits on the building were requested, but not provided. The Library also does not hold accurate and well-measured estimation of insulation efficiency and could only provide partial information. Moreover, statistics on user visits registered in the entrance machines were not shared either. As a result, data on students must be collected and estimated through surveys.

11 Problem Statement

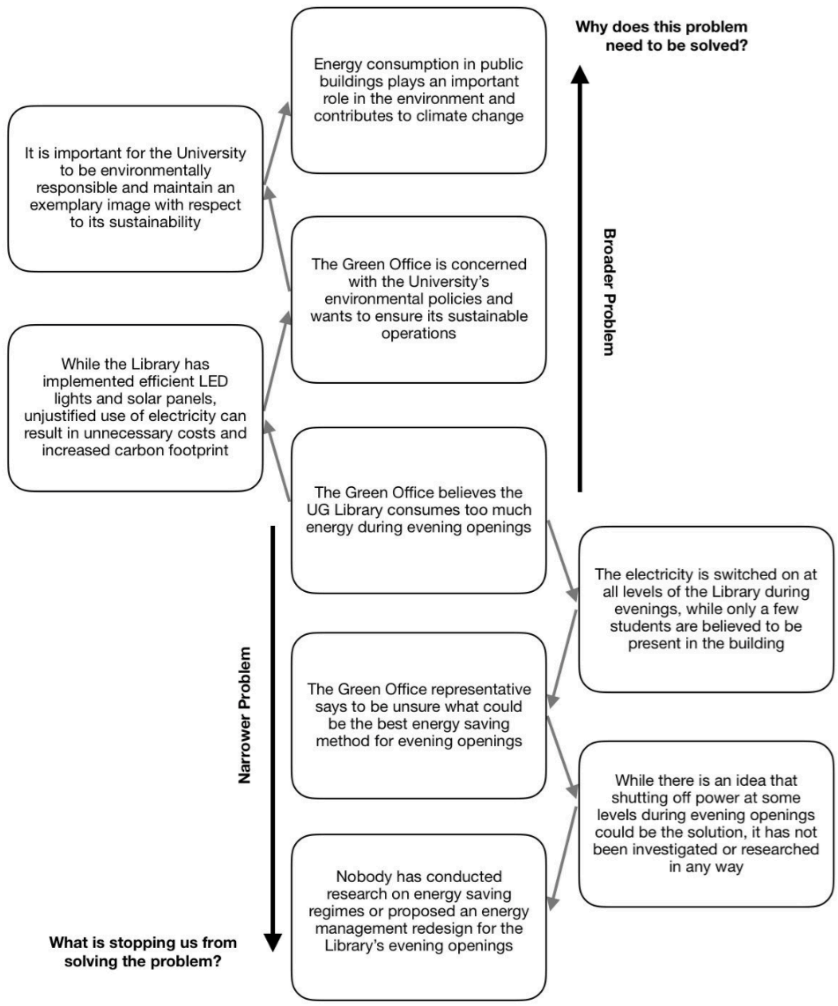

Figure 13: What & Why Model for the Project

In the figure above, the What & Why Model is illustrated to describe the specific and broad problem of the project. The model is useful for generating ideas and is well-known in problem solving processes in industrial contexts. (Annamalai, 2013) Constructing this diagram is crucial, as it greatly elaborates from a broad and specific scope on the problem prior to seeking solutions. Therefore, the following problem statement can be phrased:

"The Green Office needs an assessment of the current energy management at the UB and a potential redesign proposal concerning a more effective energy regime for the library's low-demand hours."

12 Scope of the Project

The scope of this project lies in investigating to what extent is the claim made by the Green Office on the UG Library's inefficient energy management for evening periods is accurate and proposing potential re-design recommendations to improve the existing situation. In order to do so, it needs to be researched to what extent the demand in the library is decreased in the evening hours and whether there are any variable costs that can be saved by a re-design of the current energy management.

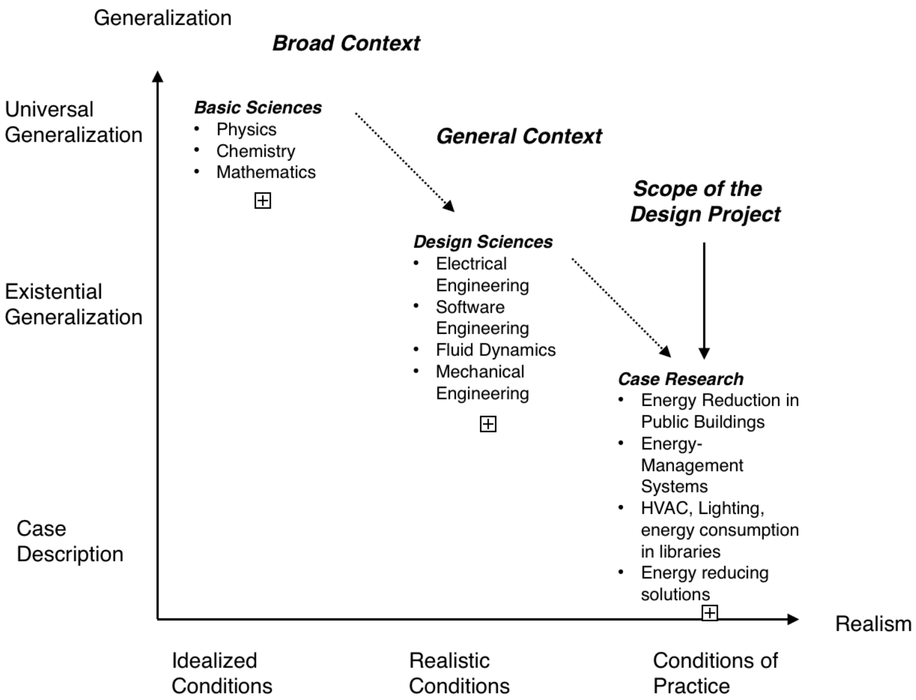

Figure 14: Visualized Scope of the Project

The diagram above illustrates the positioning of the project's scope by placing it on the matrix of generalization and realism, used in the literature "Design Science Methodology" by Wierenga, 2014 to describe the positioning of design projects. The model has been modified for the specified case by adding the context and scope into the diagram, as well as specifying the sciences and academic fields relevant to the project. Thus, by narrowing down the scope of the design from basic sciences to the case research, the broad and general context is shown, and the main focus of the research is clearly positioned.

13 Key Concepts

Energy audit (also known as energy improvements) - energy reducing solutions proposed to achieve sustainable and consistent savings in energy costs, while focusing on quality control, financial and operative maintenance aspects. They always aim to be unbiased and independent, without only reporting the information the owner/manager wants to hear (in this case, Albert van der Kloet) (Shapiro, 2014).

Transformational energy improvements – enhancements in the energy systems of older buildings that shape them to achieve the modern criteria of comfort, safety and health (Shapiro, 2014).

Energy Consumption in Public Buildings

Energy Efficient Technologies

Sources of Energy Waste in Public Buildings

14 Research Objective

Based on the previous information, a SMART goal for the project can be formulated as follows:

"The goal of this project is to provide the Green Office at the University of Groningen with an energy management overview that assesses the current state of the UG Library's energy data against selected criteria, identifies potential shortcomings of the current system and proposes possible solutions to improve the existing situation with savings estimations. Also, long-term recommendations are to be briefly described."

This is to be done by conducting interviews with the library's representatives; carrying out a literature review on the library's archives, energy auditing literature, EU building guidelines and research papers on energy in public buildings, as well as conducting a survey for collecting relevant data from students. The project is to be completed within a time frame of 3 months."

15 Research Materials

Gathering knowledge is the key component of any design research. Traditionally, knowledge can be divided into two groups – prior and posterior, where prior knowledge is available before the project, and the latter is produced as an outcome of the project (Wierenga, 2014). In this particular design project, several sources of prior knowledge are identified and listed below:

Scientific literature – Discovered mostly during literature research on scientific databases online, scientific literature, such as theory papers on relevant concepts, case studies on energy and public buildings, as well as research papers on reduction of energy in public buildings will be rigorously searched and used to construct knowledge and seek potential solutions.

Technical literature – Energy documents, floor plans and other technical documents provided by the employees of the UG Library are technical archive literature that can further aid in proposing meaningful solutions applicable in the given problem context.

Professional Literature – Audits and books written by one or several authors that provide guidelines and potential sources of waste in public buildings, while also proposing solutions where applicable. These books must be read prior to the design stage and used where necessary in order to identify potential shortcomings of the library's energy management and recommend solutions.

Oral Communication – Interviews are to be conducted with the Green Office Coordinator, Facility Manager and other UG Library employees to gather relevant information and contacts.

Data Collection – Online surveys are to be implemented and distributed among UG Library visitors to gather data on the beneficiaries of the building, that are otherwise not provided by the library managers.

16 Validation

The design project cannot validate the findings described in this report due to the fact that the savings estimations cannot be confirmed, or rejected quantitatively before they are implemented or simulated with specific data. Due to time constraints, the savings unfortunately cannot be validated within the scope of this particular project. However, the validation of this project can still be defined internally and externally.

The project is considered internally successful if it achieves its research objective. Therefore, if an overview that assesses the the UG library against selected criteria and provides energy recommendations is completed, the internal validity of the project is satisfied. The external validation can be achieved when other researchers can use the findings of this report for their work. The results of the UG Library project could be useful to other researchers who will further investigate the library and perhaps other similar libraries in the EU for energy management projects.

17 Research Questions

Based on the Problem Investigation elaborated previously, the following research questions have been formulated in accordance with the Design Science Theory. They are addressed in the Treatment Design and Instrument Development sections.

Question 1: To what extent does the UG Library need improvements in its current energy management system?

Question Question 1.1: What are the criteria in terms of the energy use of public buildings in the Netherlands?

Question 1.2: What are the current R- and U-values at the UG Library and to what extent can they be estimated?

Question 1.3: To what extent does the UG Library in its current state meet the requirements set by EPBD?

Question 2: What are the strategies, challenges and financial aspects with respect to the nZEB objective for the UG Library?

Question 2.1: What currently available strategies provide guidelines in achieving the EPBD objective in terms of nZEB?

Question 2.2: What are the difficulties the UG Library may face in achieving the nZEB objective?

Question 2.3: What funds, subsidies or loans is the UG Library eligible for and can apply for in order to finance investments related to achieving the nZEB goal?

Question 3: To what extent can the fluctuation in visitor demand at the library be estimated?

Question 4: What redesign solutions can be recommended to the UG Library in order to reach the nZEB objective by 2050?

Question 4.1: What immediate low- to no-cost solutions can be adopted by the UG Library, with respect to the fluctuations in demand, to reach the EPBD objective in terms of nZEBs by 2050

Question 4.2: What long-term and high-cost solutions can be adopted by the UG Library in order to reach the EPBD objective in terms of nZEBs by 2050?

18 Treatment Design: Specifying Requirements

18.1 EU Criteria and Objectives for Public Buildings

In order to achieve decreased energy consumption for public buildings in the EU, Energy Performance of Building Directive has been introduced. Considering climate and environmental situations in the countries in the Union, the commission was established in 2005 to ensure sustainable development and encourage energy reduction in non-residential buildings (EPBD, 2010). One of the requirements established by the commission was that all public constructions must be nearly zero energy buildings (nZEB) in the year 2020. Namely, articles 2 and 9 clearly state that all buildings must be nZEB when constructed after December 31, 2020. Additionally, all buildings constructed before this year have to achieve this goal by the year 2050. Therefore, the UG Library which was fully renovated by 2018, must achieve this goal within the next 30 years. According to the U.S Department of Energy (DOE), a ZEB can be defined as follows:

"An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy" (DOE, 2015)

Meanwhile, the EPBD, 2010 defined ZEBs as "Technical and reasonably achievable national energy use of >0 kWh/($m^2$2a) but no more than a national limit value of non-renewable primary energy, achieved with a combination of best practice energy efficiency measures and renewable energy technologies which may or may not be cost optimal."

As stated by the EPBD, achieving the target may not be cost effective for public and private institutions, but must be done nevertheless. Since these definitions are difficult to interpret quantitatively, AIDA (The Affirmative Integrated Design Action) assigned numerical values with respect to the nZEB target. Thus, in order for a building to be considered an nZEB, the primary energy demand (gas, coal, etc.) must fall between the values of no more than 50 to 60 kWh/m^2. Moreover, the RES (Renewable Energy Sources) must compensate for 50 to 70% of the energy consumption. (AIDA, 2013)

Furthermore, EPBD, 2010 establish criteria for new or majorly renovated buildings that must be already met by January 1, 2015 as summarized in Table 2.

Where R-value is thermal resistance and U-value is thermal transmittance. As can be seen by the units of the constants, both R- and U- values are calculated based on the surface area and thermal conductivity of a material K. Lastly, all non-residential buildings in the Netherlands must have an Energy Performing Coefficient of 0.8 or lower. Every year, the Dutch Agency for Enterprises carries out a random sample check to assess the buildings' energy performance with respect to the EPDB criteria, and if those are not met, the local

Component	Constant	Value Criteria	Unit
Floor	R-value	At least 3.5	m^2 x K/W
Facade	R-value	At least 4.5	m^2 x K/W
Roof	R-value	At least 6.0	m^2 x K/W
Transparent façade areas	U-value (average)	Façade: At most 65	W/m^2 x K

Table 2: R- and U-value requirements for a new or renovated building in the Netherlands (EPBD, 2010).

municipality is contacted to proceed with legal action (van Eck, 2016).

Therefore, the criteria found on these sources with respect to new public buildings in the Netherlands in the year of 2020 is summarized in Table 3 below:

Criteria	Required values	Units	Deadline
Primary energy demand (PED) (non-RES)	50-60	kWh/ m^2 x a	2050 - for buildings built after Dec 31, 2020
RES percentage	50-70	%	2050 – for buildings built after Dec 31, 2020
Floor R-value	At least 3.5	m^2 x K/W	Jan 1, 2015
Façade R-value	At least 4.5	m^2 x K/W	Jan 1, 2015
Roof R-value	At least 6.0	m^2 x K/W	Jan 1, 2015
U-value façade	At most 65	W/m^2 x K	Jan 1, 2015

Table 3: Compilation of Public Building Requirements in the Netherlands.

18.2 Gathering relevant data for Assessment

R-value is a scientific indication of heat resistance and is measured in m^2xK/W. Since the K value (thermal conductivity constant) varies from material to material, R-value of an insulation material changes accordingly. This value is often calculated to estimate the efficiency of insulation, which is an important factor in reducing heat loss to the environment. However, the R-value is not constant and can degrade over time due to rain or humidity. U-value, on the other hand, is given in the inverse units of the R-value and is used to evaluate heat resistance of windows. Since it also depends on the thermal conductivity of glass, the U-value varies by material. In general, the higher the R-value, the better is the insulation, oppositely, the lower the U-value, the better is insulation of window components. (Shapiro, 2014).

Thus, it is practically impossible to estimate the R- and U-values for the UG building without knowing the exact materials used for insulation and windows. During an email exchange with Jeroen de Lezenne Coulander, he mentioned that his colleagues did not possess detailed information with respect to those values, and could only provide an estimated R- and U-values for the façade and double-glazing windows. These values are presented below:

R-value of façade - 1.3 $\sim$ 2.5 $m^2 \times K/W$

U-value of double-glazing windows in the building – $2.8W/m^2 \times K$

Besides windows, the building has glass doors and other glass made components of unknown materials that unfortunately, cannot be estimated. Therefore, only the values provided by the library can be used for assessment against the EPBD criteria.

18.3 Assessing the UG Library Against the EPBD Requirements

Using the documents and information provided by the university employees Jeroen de Lezenne Coulander, Kor Smit and Albert van der Kloet, it is possible to assess the building's current state with respect to the requirements set by EPBD. Since primary energy consumption refers to energy consumption unrelated to RES, it can be estimated by calculating the total annual energy consumption per square meter, and subtracting the energy produced as a result of PVs installed on the roof.

Since the library classifies its total energy consumption into two categories – electricity and gas, where electricity and gas consumption are given in kWh and cubic meters respectively, gas needs to be converted to kWh as well to estimate the total annual energy demand. In order to do so, the metric value must be corrected for volume (multiplied by 1.02264), multiplied by the calorific value of gas (40.0) and divided by the kWh conversion factor of 3.6 (Byrom, 2019).

As a result, the gas consumption at the library is:

$$40,000m^3 \times 1.02264 \times \frac{40.0}{3.6} = 454,506.6667kWh = 454,507kWh \quad (1)$$

Therefore, the total energy consumption at the library is:

$$454,507 + 1,765,000 = 2,219,507kWh \quad (2)$$

Now, in order to find the energy demand per square meter, the area of each floor including the ground floor and the roof. The estimations provided in the table below are calculated by adding up the areas of all rooms using the floor plans provided by de Lezenne Coulander. All values are rounded to the nearest number. However, this number does

Building section	**Area** (m^2)
4th floor	2485
3rd floor	2776
2nd floor	2771
1st floor	2954
Ground floor	3338
Total (Rounded)	14,324

Table 4: Estimated Surface Area of Each Level of the Building

not indicate in any way whether the demand has been met with PES or RES, and if so, to what extent. According to Kor Smit, the PV farms on the roof of the building produce

64,000 kWh/year, so the total share of RES can be estimated:

$$64,000kWh/2,219,507kWh = 2.9\% \tag{3}$$

$$PED = TotalED–RES \tag{4}$$

$$PED = 2,219,507kWh–64,000kWh = 2,155,507kWh \tag{5}$$

And per unit of area;

$$2,155,507kWh/14,324m^2 = 150kWh/m^2 \tag{6}$$

Thus, combining this information with the R- and U- values provided by the library employees can be displayed in a table, and the percentage difference to the closes required value can be summarized below:

Criteria	**Required values**	**Units**	**Current value**	**Deadline**	**% difference**	**Status**
Primary energy demand (PED) (non-RES)	50-60	kWh/ m^2 x a	150	2050	-150	Insufficient
RES percentage	50-70	%	2.9	2050	-1624	Insufficient
Floor R-value	At least 3.5	m^2 x K/W	N/A	2015	N/A	N/A
Façade R-value	At least 4.5	m^2 x K/W	1.3-2.5 (Avg. 1.9)	2015	-81.3	Insufficient
Roof R-value	At least 6.0	m^2 x K/W	N/A	2015	N/A	N/A
U-value façade	At most 65	W/m^2 x K	2.8	2015	183.5	Sufficient

Table 5: Assessment of the library's energy indicators against the EPBD 2015 goals

Despite the missing values of the floor's and roof's R-values, there is a concerning gap between the expect 2015 values set by EPBD and actual energy indicators at the UG Library. In 2020, it appears that the UG Library is still 150% away from achieving the PED goal by 2050 as required by buildings constructed before December 31, 2020.

19 Validation: Instrument Development

19.1 Available strategies in achieving the EPBD objectives

In the Netherlands, the concept of achieving the state of a nZEB is also known as Trias Energetica and consists of three main steps (Han Vandevyere, 2016):

1. Reduction of energy demand
2. Implementation of RES
3. Efficient use of PES

However, these are general guidelines that provide limited information on the actual implementation and achievement of the nZEB objective. Additionally, a quick literature review has shown that despite frequent implementation of Trias Energetica, the results of innovated energy management were negative (Langlois, Hansen, 2012; Bleyl, 2014).

On the other hand, Athientitis and O'Brien, 2015 provide a more specific approach by discussing three traditional steps that can aid current buildings in reducing energy consumption in terms of the nZEB goal:

Passive Strategies: These steps include optimization of the insulation, orientation, implementation of natural ventilation and maximization of natural daylight. Moreover, they discuss the use of phase change materials (PCM)

Energy Efficient Technologies (EET): Innovative EETs include improved HVAC systems, efficient use of hot water, smart lighting and appliances systems.

RE Generation Systems: These systems include PV cells, wind turbines and solar connectors that can be used as means of RES for meeting the building's energy demand.

19.2 Difficulties and Challenges in Achieving the EPBD Objectives

Literature research has revealed that there are multiple limitations with respect to the nZEB implementation based on various social, conceptual and geographic factors. Some of these difficulties may be encountered by the UG Library and hinder the successful adoption of the nZEB objective encouraged and legislated by the EPBD. According to the review article on the drawbacks of nZEB published in 2018 by Harkouss et al., one may summarize the negative aspects of nZEB objective that may be faced by the UG Library below:

- Increased investment expenditures
- Shortage of experts to supervise and construct nZEBs
- Abstract and varying definitions of nZEBs
- Possibility of loss during selling of an nZEB due to large initial investments
- Absence of heating and cooling requirements for nZEBs

Even though the library underwent major renovations in the years of 2014-2018, the assessment against the EPBD criteria for newly renovated buildings has revealed that there are major improvements to be made with respect to decreasing PED and increasing RES use, as well as improving thermal insulation in the library. As stated by Jeroen de Lezenne Coulander, the library did not replace the façade during the renovations, so the insulation of walls has not been improved. Therefore, despite the installation of the solar panels, there are large investment costs to be made in order to achieve the objective of becoming an nZEB by 2050.

19.3 Financial Opportunities with Respect to the EPBD Objectives and the UG Library's Eligibility

Van Eck, 2016, discusses various sources of financial loans and subsidies that can be granted to public and private buildings in order to achieve the nZEB objective. However, not all funds can be applicable for the UG Library as it is owned by a public research university. In the table below, all sources of financial opportunities listed by EPBD with eligibility indication are summarized in table 6.

While the UG Library cannot apply for sources dedicated to private owners and social residences, there are multiple sources of subsidies, tax reductions, mortgage and loans for the university to apply for in order to fund additional investments needed to achieve long-term sustainability of the library. However, this is only a general overview and eligibility evaluation; it does not guarantee that each of the sources marked as "Yes" would provide financial aid to the UG Library.

Name	**Amount**	**Description**	**Eligibility**
SDE+	Not specified	Subsidies on investments in RES	Yes
EIA	Depending on the EPC	Fiscal reduction on innovative energy technologies	Yes
Mortgage	Max 25,000 EUR	Extra mortgage on investments that result in ZEB	Yes
National Energy Saving Fund (NEF)	300 million EUR	Loans on energy reducing technologies for private owners	No
STEP	400 million EUR	Social residency subsidies based on EPC	No
Funds for the Energy Saving Rental Sector (FEH)	75 million EUR	Low-interest loans for extreme energy renovations	Yes
Energie Prestatie Vergoeding	Not Specified	Customers of social ZEB residences partially pay the costs	No
SEEH	65 million EUR	Energy investment subsidies for private buildings	No

Table 6: The UG Library's Eligibility for Financial Sources Dedicated to the Achieving the nZEB objective

19.4 Evaluating the Green Office's Statement on Low Visitor Demand in Evening Hours

Prior to the renovations, the UG Library could host up to 1,500 students, whereas now the visitor capacity has been increased to 2100 workspaces with 152 computer seats. While the detailed statistics on visitors have not been provided by the Facility Manager perhaps due to privacy reasons, Albert van der Kloet shared some information about the library's use by the students. In 2019, the entrance machines at the UG Library have registered approximately 2.5 million visits, with a mean of 14,000 individuals visiting the building every day. According to the Facility Manager, the library is busy at all hours from early morning until midnight, especially during the exam periods.

It is important to look into the details of the visitor data in order to understand whether the Green Office is correct and the library does indeed have fewer visitors in the evenings. To evaluate the accuracy of this statement, a Google Forms survey has been created and 51 students from the University of Groningen were asked to answer some questions about their visits to the library. In the survey, students were asked on which days and hours do they normally study at the library. The summary of the answers is illustrated below in the form of bar charts:

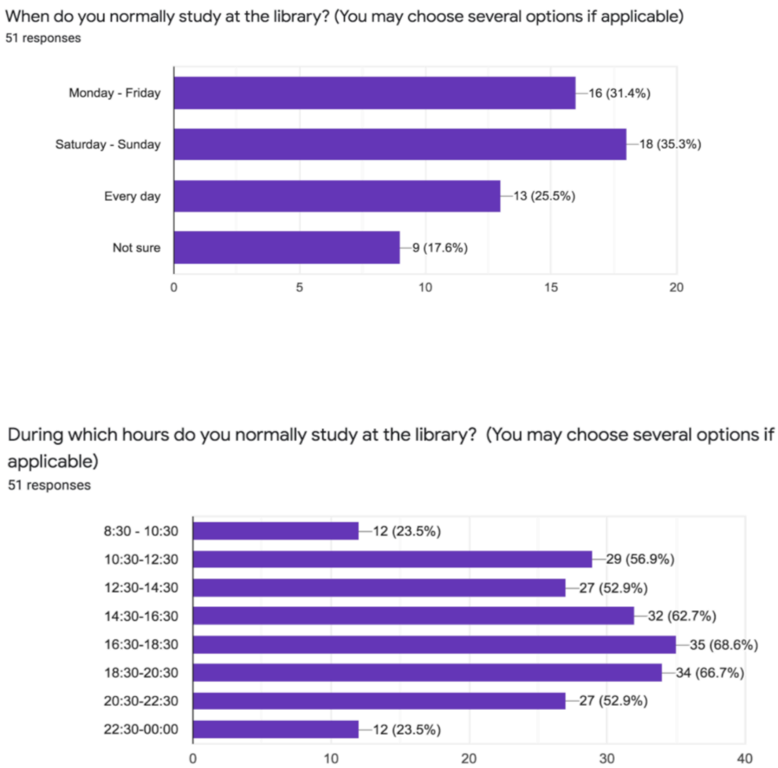

Figure 15: Results of Visitor Demand Survey

According to the answers provided by the students, Saturday and Sunday are the busiest days at the library accounting for 35.3% of the responders, while Monday to Friday were chosen by 31.4% of the responders. While the difference is not large, the weekends at the library do appear to be slightly busier; however, it is difficult to state that the number of visitors varies significantly throughout the week.

On the other hand, the hours of visits at the library differentiate at a larger scale. Contradicting the photos provided by the Facility Manager depicting a long line in front of the library during the mornings, only 23.5% of the responders stated that they visit the library between 8:30-10:30. However, the number roughly triples for the hours of 10:30-12:30. While the visitor demand fluctuates slightly during the hours of 10:30-22:30, (52.9-68.6%), there is a sharp drop in responders who stated that they study at the library during the hours of 22:30-00:00 (23.5%).

Despite the relatively short reach of the survey (51 students in a university of circa 32.7 thousand enrolled students), data suggests that the library does truly face a decreased demand during the evening periods. Naturally, one may argue that the statistical significance of such limited sample in a pool of many students is low, but due to the circumstances of coronavirus it is impossible to promote face-to-face survey completion at the library or university. Thus, the data relies only on the students that viewed and completed the survey shared on social media outlets. Despite an unwanted bias that may be present in the results, this is the only data available on visitor demand and will be assumed true for research purposes.

With this in mind, if roughly a quarter of the 32.7 thousand students come to the library during late hours of 22:30-00:30, there are still 8,175 people at the university that might potentially visit the library at these specific hours on any day. Assuming the unlikely scenario that only 1 in 10 of these students will study at the building on any given day, the library would have 818 students in the building and be approximately at 40% occupancy. It can then be concluded that the UG Library does have relatively fewer visitors during late hours, so the building can be assumed to have less than 50% of the total occupancy rate between 22:30-00:00.

19.5 Estimating Method for Energy Savings

In the book "Energy Audits and Improvements for Commerical Buildings", 2014, Shapiro discusses a simple calculation method that is often used in energy auditing projects to estimate isolated savings for a replacement of an individual energy component. The example given in the book with estimating light replacement savings, a general formula has been re-created that can be used to project savings in this design project:

$$\begin{aligned}\text{Original Energy Consumption: Component} \times \frac{\text{Energy Consumption (W)}}{\text{component}} \\ \times \frac{\text{operating hours}}{\text{year}} \times \frac{\text{kW}}{\text{Energy Consumption}} = \text{kWh/year}\end{aligned} \tag{7}$$

$$\begin{aligned}\text{New Energy Consumption: Component} \times \frac{\text{New Energy Consumption (W)}}{\text{Component}} \\ \times \frac{\text{New Operating Hours}}{\text{Year}} \times \frac{\text{kW}}{\text{New Energy Consumption}} = \text{kWh/year}\end{aligned} \tag{8}$$

$$\text{Savings EC} = \text{Original EC} - \text{New EC} \tag{9}$$

Where the component is the number of individual energy consuming items. This calculation is often used as it is considerably accurate for design purposes and not as time consuming as other methods. However, this calculation does not account for loss or gain of energy due to resistance and thermal conductivity. Thus, the operation of energy components has been idealized for design purposes.

19.6 Long-term energy redesign recommendations for the UG Library

19.6.1 Insulation

The first traditional strategy listed in Athientitis and O'Brien, 2015 is focused on Passive Strategies and includes insulation. As the assessment against the EPBD criteria revealed, the building's R-values for façade are not in line with the 2015 goal. That is a cause of concern and must be addressed in the near future. Although, it is important to note that the Communication Officer could only provide an estimate, as the R-values have not been accurately calculated. Chances are, however, that the roof and floors might also have insufficient insulation if they also have not been renovated during the years of 2014-2018. The details of long-term insulation solutions are not provided in this report, as it is more focused on the short-term solutions that could be accessed earlier in the project. Literature review must be performed in order to construct relevant selection criteria and assess various insulation materials. This could be a direction for further research.

19.6.2 PV Cells

Referring to the three traditional steps in implementing the Athientitis and O'Brien, 2015, one of the main strategies concerns RE Generation Systems. Even though the UG Library reports having 300 solar panels installed on the roof of the building, they do not produce a significant portion of the energy consumption (2.9%). Therefore, more efficient solar panels could increase the proportion of RES consumption in the library. In the feasibility review paper on solar energy by Paardekooper, 2015, one of the mentioned studies states that after examining 879 solar panels, the average price per wattage excluding installation costs is 1.09 EUR. However, purchasing and installing PV cells above 1.00 EUR/kW is economically infeasible, as over 200 solar panels can be purchased and installed for a lower price. There are approximately 20 modules for 0.80 EUR/kW and 70 modules for 0.90 EUR/kW. In addition, the average installation cost of PVs is 0.40 EUR/kW.

Therefore, assuming a likely scenario that the UG Library can replace the current PV cells for more efficient ones, or connect to a solar source off-site, they can achieve the 50% RES percentage (1,077,753 kWh). Then, taking into account average prices for PV cells and installation costs, the total costs for PV cells is as calculated below:

$$\text{Average price PV cell} + \text{Average installation costs} = 1.09 + 0.40 = 1.49\ EUR/kW \quad (10)$$

which would consequently require 1,605,852 EUR of investments. Further research can be constructed focusing on selecting PV cells based on relevant criteria and a detailed feasibility study can be performed.

19.7 Short-term energy redesign recommendations for the UG Library

The second traditional step discussed in Athientitis and O'Brien, 2015 concerns EET and includes improvements in usage of hot water, HVAC, lighting and other appliances. As mentioned in the Problem Investigation, the HVAC and Lighting Systems are difficult to assess with current limitations to detailed data and location. However, some of the other appliances present in the building are variable energy components, meaning they can be switched on and off at any time by the Maintenance Operators. During the observation of the Library and archive review, the following energy-intense components were identified:

- Elevators
- Vending Machines
- Hand-dryers

Therefore, each of those energy consuming components is analyzed in terms of the current wattage usage. Then, based on the visitor demand and literature review where applicable, a redesign in energy management of these components is proposed to reduce consumption.

19.7.1 Elevators

Literature review on elevators and escalators in public buildings revealed that those systems can be responsible for 5-25% of the total energy demand (Sachs, 2005, Liu, 2010). A simulation study on elevators revealed that in a mall building, the monitored elevator consumed approximately 34 kWh in 6 hours, which roughly equates to 5.67 kW per hour. Throughout these hours, the elevator was occupied and was running almost the entire timespan. In the standby mode, the elevator only consumed 1.45 kWh (Adak, 2013). There were no studies found on elevators in libraries, therefore for design purposes the elevators at the UG Library are assumed to be in operational mode throughout the open hours. Also, it is a good assumption as there are only two elevators for a building with five levels and 2100 seats. Thus, the current annual energy consumption of the two elevators that can be used by students is calculated below:

$$8kW \times 2\text{elevators} \times 15.5\text{hours} \times 365\text{days} = 90,520kWh = 45,260kWh\text{per elevator} \quad (11)$$

Which are responsible for 4% of the total energy consumption at the library just in operating modes. Shapiro, 2014, discusses that in energy auditing projects buildings with multiple elevators switch some of them off to reduce energy consumption. Assuming that the UG Library is at roughly 50% capacity after 22:30, there are 1050 students in the building which can use only one elevator to travel between 22:30-00:30. Right now, students can use both elevators during late evenings, which reduces waiting time, but increases energy consumption. Currently, the annual energy consumed between 22:30-00:00 by elevators assuming full occupancy is:

$$8kW \times 2\text{elevators} \times 1.5\text{hours} \times 365\text{days} = 8,760kWh \tag{12}$$

If only one elevator operated within those hours, the reduced energy consumption would be:

$$8kW \times 1\text{elevator} \times 1.5\text{hours} \times 365\text{days} = 4,380kWh \tag{13}$$

Which saves

$$8,760kWh–4,380kWh = 4380kWh/year = 321EUR/year \tag{14}$$

While this seemingly minor annual saving seems insignificant, long-term implementation of this scenario where elevators are not replaced can save 3210 EUR in the next 10 years with no initial investment needed. Of course, this may affect the comfort of students who will now face increased waiting times for the elevator, but it is not an essential component for students who are able to use the stairs. Moreover, the Adak study has shown that after 40 seconds of waiting for an elevator, a person decides to quit the line and take the stairs instead. This can improve the health of students who are able to walk the stairs due to movement, while still having one operational elevator between 22:30-00:00 for students with physical disability. In the worst case, students who are able to walk the stairs, but prefer elevators, will have a slightly increased waiting time during those hours.

19.7.2 Vending Machines

There are two vending machines on each floor of levels 1-4. During the interview with the Facility Manager, he mentioned that the vending and soup machines are supplied with energy 24/7, as the products in the machines need to stay cold. However, while examining the units, it was discovered that even during the quarantine, the vending machines are still operating around the clock while half-empty. The photos of the machines are shown on figures 16-17.

The current annual energy consumption of all vending machines in the building is calculated below:

$$(4 \times (1.5kW) + 4 \times (2.5kW)) \times 24hours \times 365days = 140,160kWh \tag{15}$$

Which is responsible for 6.3% of the building's yearly energy demand and translates to 10,293 EUR/year.

Inspecting the products in the vending machines, there seem to be no items that must stay below the room temperature, as chocolate, drinks and the conserved soups with snacks can be kept at room temperatures similarly to the supermarkets' conditions of storage. Therefore, machines on floors 4 and 3 could be shut off at 22:30 (during relatively lower visitor demand) until 8:00 of the next day in order to have 30 minutes for products to cool down before the arrivers to the library start purchasing them. Moreover, the vending machines on floor 1 and 2 could be also shut off after 00:00 and turned back on at 8:00 of the next day with the rest of the machines.

Shapiro, 2014, mentions that vending machines are inspected in energy auditing projects as they can consume a large amount of energy due to cooling. Though, by setting timers and efficient lighting inside the machines, or manually plugging them off when they are not needed, a substantial amount of energy and costs can be saved.

If the 4 machines on floors 3-4 are switched off after 22:30 until next day 8:00, and machines on floors 1-2 are also switched after 00:00 until 8:00, the reduced energy consumption is calculated below:

$$((2 \times (1.5kW) + 2 \times (2.5kW)) \times 14.5hours \times 365days) + ((2 \times (1.5kW) + 2 \times (2.5kW)) \times 16hours \times 365days = 42,340 + 46,720 = 89,060kWh \quad (16)$$

$$SavingsED = 140,160kWh - 89,060kWh = 51,100kWh \quad (17)$$

Which approximately translates to 3753 EUR/year. This is a significant improvement in energy and costs which can consequently save 37,530 EUR in the next 10 years, assuming that those machines will not be replaced.

Nonetheless, turning off vending machines earlier on higher floors may lead to longer waiting times for the machines on the lower floors, but can also encourage students to study downstairs during late hours, which automatically will reduce lighting and oxygen ventilation consumption on higher floors as students will occupy less spaces there. Further, there might be minor losses in revenues from the vending machines during 22:30 to 00:00 if students will prefer not buying drinks and snacks rather than traveling to the lower floors. Unfortunately, there is no data on vending machine revenues in the library and are difficult to estimate based on literature review. Regardless, the major savings in energy as a result of this redesign proposal can compensate for potential revenue losses.

19.7.3 Hand Dryers

All bathrooms in the UG Library are equipped with hand dryers. The dryers could not be inspected due to the building restrictions during the lockdown, but the floor plans indicate ten bathrooms in the building with one male and one female bathroom on each floor, with an exception of floor 2, where two additional bathrooms are available.

Figure 16: Vending Soup and Drinks Machine

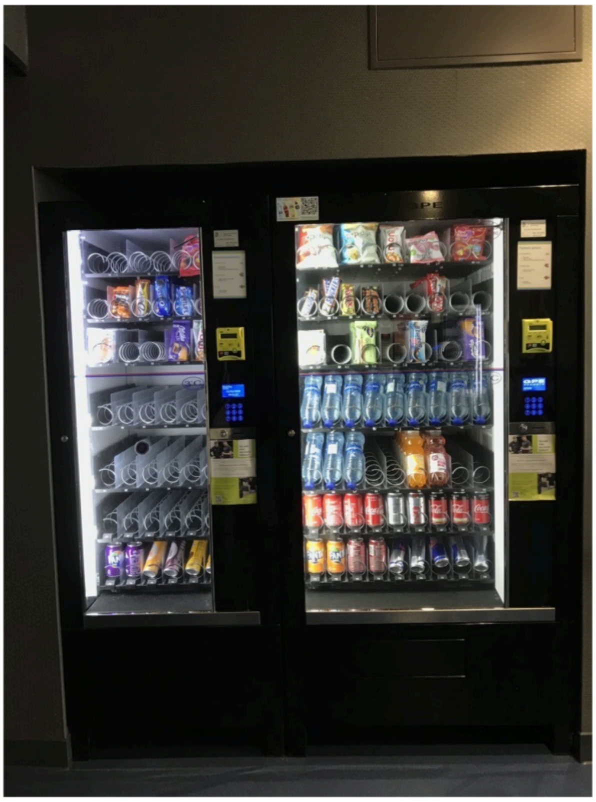

Figure 17: Vending Snack and Drinks Machine

Each bathroom seems to be equipped with two hand dryers according to the energy plans. That means, there are twenty hand dryers in the building with operating energy consumption of 1.6 kW/hour. Assuming that in a building of 2100 students, there is at least one person in every bathroom drying their hands, the annual energy consumption is calculated as follows:

$$(1.6kW \times 20dryers) \times 15.5hours \times 365days = 181,040kW \tag{18}$$

Which can make up to 8% of the total ED in the library and costs the building 13,296 EUR. This is a very large amount, and assuming that the hand dryers are used only for one-third of the open hours, they still consume

$$(1.6kW \times 20dryers) \times 5.17hours \times 365 = 60,386kW \tag{19}$$

Which accounts for 2.7% of total ED and costs 4,434 EUR a year.

From personal memory of visiting the library before the quarantine, the dryers installed in the bathrooms implement a blade design, where hands are placed between two walls of the dryer where warm air is applied. Shapiro 2014, discusses that hand dryers are inspected in energy audits, however there are no energy regulations with respect to these devices.

Further literature research into the topic revealed that hand dryers could be abandoned altogether in public buildings and substituted for more effective and safe hand drying treatments, such as use of recycled paper towels. A study on deposition of bacteria via hand dryers in bathrooms by Huesca-Espitia, 2018, provide evidence that harmful, disease-causing bacteria were identified in both male and female bathrooms and spread via intense hot air coming out of the dryers. Results of the experiments show that hand dryers create environment for pathogen spread, which questions the need for unnecessary and risk-posing hand dryers in the UG Library bathrooms. According to this study, students and employees who insert their hands into the dryers are at risk of landing a large variety of bacteria on their skin, some of which can cause illnesses. A number of other scientific studies on this topic discovered that hand dryers can spread pathogens from improperly washed hands, as well as land those bacteria on thoroughly washed hands when the dryer is used (Best EL, 2015, Best EL, 2014).

Therefore, the hand dryers could be further investigated for health safety and can be substituted for more cost-effective recyclable paper towels, potentially saving up to 8% of the energy consumption.

20 Conclusions

The project at hand adopts the Design Cycle and implements the methodological framework to address the concern of the Green Office with respect to the UG Library's energy management method. By carrying out a literature review on energy in public buildings, studying the archives provided by the library, conducting interviews with its employees and a survey for students, a general overview has been provided.

In the brief analysis of the current state of the UG Library, it has been found that the building has very limited data with respect to its energy details. However, it could be still estimated that lighting in the building is responsible for only 25.5% of the total ED, and could be potentially much lower due to occupancy and daylight sensors present in the library. Meanwhile, the ED of HVAC systems is difficult to estimate due to the complex system to which there was almost no physical access. While the insulation and condition of the demonstrated systems appear to show no signs of damage, the internal HVAC pipes could not be inspected.

After summarizing the EPBD criteria for new EU public buildings and assessing the UG Library's available parameters against them, it is concluded that the building does not comply with most of the requirements. There must be a 150% improvement in reducing PED, or 1624% improvement in the usage of RES. Further, the building's facade insulation value is 81% lower than the required values for 2015. In order to provide a start with achieving these goals, strategies, challenges, and financial opportunties with respect to nZEBs are briefly discussed. Also, short recommendations with respect to insulation and PV cells are described.

Assessing the Green Office's statement on lower demand during evening openings at the UG Library, it has been estimated that the building is under approximately 50% capacity in the hours of 22:30-00:00. After visiting the UG Library and analyzing the electricity components in archives, three sources of variable energy waste were found in elevators, vending machines and hand dryers. The proposed elevator management redesign suggests using only one elevator during 22:30-00:00, with estimated savings of 321 EUR/year. Secondly, the vending machines are recommended to be shut off after 22:30 until 8:00 next day on floors 4-3, and the machines on floors 1-2 are recommended to be shut off after 00:00 until 8:00 next day. Potential savings generated as a result of such redesign are estimated to yield 3,753 EUR per year. Lastly, due to recent findings on spread of pathogens through hand dryers, they are recommended to be replaced by an alternative, cheaper hand-drying techniques, such as recyclable paper towels. The current hand dryers can heavily consume up to 8% of the building's total ED, if assumed to be used at each moment of the open hours. Even under the assumption of operating slightly over five hours a days each, which is a valid assumption for 20 dryers used by 2100 visitors, the hand dryers in the building can consume 2.7% of the total ED and cost 4,434 EUR a year.

Therefore, while the seemingly minor energy components that are often disregarded due to more serious sources of waste in HVAC and lighting, the limitations with respect to data and access to building allowed for more focus on individual components shared by the library employees. If implemented together, the three redesign proposals are estimated to reduce the total ED by up to 17,370 EUR/year in costs and 10.5% in kWh.

21 Discussion

Throughout the project initiation and planning, various challenges affected the quality and depth of the final design. Initially, the presence of daylight and occupancy sensors in the building was not known by the author. As a result, the project was directed towards optimizing the lighting system with ultrasonic sensors for large spaces and infrared for smaller rooms, which would be coupled by daylight sensors to adjust accordingly. However, it was later revealed by Jeroen van der Burg that there are already some sensors implemented in the library. When the Facility Manager was finally reached in late May, he demonstrated occupancy and daylight sensors in the library, which made some of the existing results of the project irrelevant.

One of the limitations in planning is that the project was not viewed on a broad scale, so the discovery of EPBD criteria and their implementation was only introduced later in the project. Despite the challenges, a complete energy management overview has been provided, and while some of the recommendations are not explored in depth, the new focus of the report was identified and addressed.

22 Further Research

Having completed the project and designed the overview, some of the results suggest that further research is needed to address certain problems and solutions on a deeper level. Firstly, since the UG Library is shown to not comply with most of the current and future EPBD requirements, detailed data with respect to R- and U-values of the building must be calculated for further assessment. Moreover, a feasibility study is needed to provide the best insulation methods for the building and select more efficient PV cells. It is also important to estimate financial aspects of these solutions such as Return on Investment and Net Present Value. In addition, the Simple Payback Period must be calculated for both insulation and PV cells choices. Another topic of further research could be viewing possibilities of connecting the building to off-site RES, such as wind and solar farms. That way, the RES objective of 2050 can be achieved. Lastly, a more in-depth study can be performed on reviewing the UG Library's hand dryers in laboratory experiments to determine the presence of pathogens and assess potential health dangers. If similar results are yielded as in this project, the hand dryers can be sold and the capital can be re-invested into alternative hand-drying methods.

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