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TOWARDS A SUSTAINABLE CHURCH

AN EXPLORATORY RESEARCH INTO THE SUSTAINABILITY PERFORMANCE OF CHURCH BUILDINGS IN APELDOORN

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Apeldoorns Beraad van Kerken

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Colophon

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Abstract

Could believing in sustainability lead to sustainable belief? Religious communities in the Netherlands are dealing with the effects of societal change. Due to a decline in active church members, there is a decrease in income, while the costs stay the same or rise. Solution strategies focus on improving the occupancy rate of the building through multifunctional use or finding alternative housing, taking the current church building out of service. Simultaneously there is a movement of religious communities that focus on sustainability and improving the sustainability performance of their building. The turn towards to sustainability has two motivations, on the on hand there is a sense of duty from religious conviction, on the other hand, sustainability is a way to alleviate the pressure from the operating costs.

The Triple Bottom Line is the framework for sustainability in churches. Still, a common approach or method for sustainability projects is not available, as well to indicate how sustainable a church building is. The goal of this research project is to develop a method or tool that makes it possible to measure the sustainability of a church building, which will aid religious communities in their quest to a more sustainable church. Which has lead to the following main research question: '*How can the sustainability performance of churches in religious use be assessed and be improved*?' Three sub-questions and their answers support the answering of the main question.

The first sub-question is: *'How to assess the sustainability performance of churches?'* Answered by doing a broad literature study. The theoretical background presents general theories on sustainability and sustainable building. As well as, their link to church buildings and an overview of recent publications on church buildings. The results, specified to church buildings, form the basis for the framework of six maturity levels. A list of 55 yes or no statements determines the maturity level. The use of a bar chart to display the results makes scores per level visible and provides insight into the improvements. Conditions for passing a level are passing the previous level and obtaining at least half of the score in the level.

The second sub-question is: *'What is the sustainability performance of churches in Apeldoorn?'* Answered by testing the developed framework. The results of the framework and the prior knowledge from interviews showed some discrepancies, indicating a validity problem. As well as some issue coming from the 'Werkgroep Duurzaamheid', the users of the framework. Adding mandatory requirements and reviewing the statements on clarity and function leads to an improved sustainability assessment framework.

The third sub-question is: *'How could the sustainability performance play a role in the transformation of churches?'* Answered by looking at a broader application of the framework. Solution strategies for dealing with the societal change do not include sustainability measures, even though they could have potential. This research project proposes a joint approach including sustainability. The framework of maturity levels for the sustainability performance of church buildings could offer insight into the current level and improvements. It stays difficult to assess the true potential of sustainability as a strategy for the mitigation of risks is uncertain. As a single approach sustainability stays risky, without better knowledge and insight into the effects measures will have. These uncertainties do not mean there is no potential as a preventive measure or in combination with other approached. One could argue that sustainability should be an approach to bring it to the attention religious communities on the possibilities, keeping in mind the restrictions.

The study defined a sustainable church on distinct levels; a means to assess this level and application options for the framework. This answers the main question the maturity levels assess the current level and provide insight into the improvement required for other levels. The current improved sustainability assessment framework requires testing on independent cases, to ensure the validity. After which there are several option for further research. Focused on the framework, research can consider correlations between quantified parameters and the maturity levels. Another option is broadening the topics of the framework, including all efforts from the religious communities. Finally, there is the direction of the role of sustainability in the spectrum of transformation processes and the proposed applicable model. Validation of the applicable model is a research topic. As well as, further defining the potential role of sustainability in this model.

Preface

As I am writing this, I am in the finishing stages of this research project. Writing the final pieces of text, checking on punctuation, and process received feedback, as well as writing this. At the start of this project, I was happy to have found a research topic close to my heart, as well as a subject that has utility. During the project, I sometimes questioned myself on this enthusiasm and wondered when, and if, there would be a good ending. Now I am nearing the end, the doubt has become less, as I can honestly say I am happy with the report that lies in front of you.

The goal of this master thesis was to find a way to measure the sustainability performance of a church building. After an extensive literature study, partly included in the second chapter of this report, a research proposal was formulated. Especially at the beginning of the project, I had difficulties linking the plan to the actual project. The start was difficult, and for a long time, many separate parts did not seem to connect. Luckily for me it finally did, a major relief as you understand, after which the project calmly continued. Another small setback and a bit of disappointment on my side were the results of testing the framework. I leave it to you, the reader, to judge the usefulness of the results of this project. I for one hope that, however minor, it will contribute towards more sustainable churches in the Netherlands.

In addition to growing within my studies, obtaining knowledge about church buildings, as well as personal growth due to new experiences and skills. For this, I must thank several people. First the people from the Werkgroep Duurzaamheid: Bert Brouwer, Henk Oostenbrugge, Theo van Driel, and Teun Wolters, for allowing me an insight into their work and activities, and improve my minute keeping skills. Teun I want to thank especially, as he made time for weekly meetings, has read all different version of my work and offered feedback on each. I would also like to thank the people from the Energiefabriek in Apeldoorn, for providing me with a place to work, listen to me talk about churches, offer feedback, and other knowledge on many subjects. My supervisors at the University, Bram Entrop and Joop Halman for their patience and feedback. Finally, I want to thank the religious communities in Apeldoorn that participated in the study, without you this would not have been possible at all.

Ankeneel A. Breuning
Apeldoorn, 13 July 2017

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List of abbreviations

ABvK	Apeldoorns Beraad van Kerken (Apeldoorn's Summit of Churches)
BCA	Benefit-Cost Analysis
BREEAM	Building Research Establishment Environmental Assessment Method
CBS	Centraal Bureau voor de Statistiek (Central Bureau of Statistics)
CIO-K	Interkerkelijk Contact In Overheidszaken-Kerkgebouwen
CSR	Corporate social responsibility
CvK	College van Kerkrentmeesters
EkDE	Ede's kerkelijke platform voor Duurzaamheid en Energiebesparing (Ede's churchly platform for Sustainability and Energy saving)
EPC	Energy performance coefficient
EVK	Energie voor Kerken (Energy for churches)
FH	Friendly Heating
GHG	Greenhouse gases
IEA	International Energy Agency
IEA	International Energy Agency
JLK	Jachtlaankerk
KMS	Kerk & Milieu/Samenleving (*Church & Environment/society Bennekom*)
KPI	Key Performance Indicator
LEED	Leadership in Energy and Environmental Design
MCAM	Multi Criteria Analysis Methods
nZEB	Nearly Zero-Energy Building
O.L.V.	Onze Lieve Vrouwe ten Hemelopnemingkerk
OHK	Open Hofkerk
RC	Roman Catholic
RCE	Rijksdienst voor het Culturele Erfgoed (National office for cultural heritage)
RH	Relative Humidity
SB	Sustainable Building
SD	Sustainable Development
T	Temperature
TBL	Triple Bottom Line
WDH	Werkgroep Duurzaamheid
ZEB	Zero-Energy Building

List of Definitions

Goal	A broad primary outcome
Strategy	The approach to achieve a goal
Objective	A measurable step to achieve a strategy

1 Introduction

The Apeldoorns Beraad van Kerk (ABvK), founded in 1968, is an ecumenic platform that represents several denominations [1]. Dividable into four main categories [2], Roman Catholic (RC), Protestant Church in the Netherlands (PKN), Orthodox Reformed, and other Christian churches. The ABvK organises joint activities for the connected religious communities, residing in 28 buildings. Several working groups are active within the ABvK, to work together on different topics. One of the subjects is sustainability, and how to aid churches in becoming more sustainable, which is the direction of this research project. This chapter presents the problem, followed by the research method, and a reading guide.

1.1 Problem Analysis

This section raises the problems that churches have. The first part of this section provides the motivation and context of the project. The second part describes the problems churches are dealing with, as well as specific problems concerning sustainability. The final section describes the relevance of this project.

1.1.1 Motive and Context

In the Netherlands are several initiatives for making church buildings more sustainable. ‘Groene Kerken’ (green churches) is a platform that aids churches that want to become more sustainable and facilitates sharing of experiences to learn from each other [3]. The sustainability of churches is a complex problem, which includes many aspects. The ABvK established a working group that focusses on sustainability and educating citizens on its importance [4]. An additional intention is to make their church buildings more sustainable, using a broad definition, including ecologic, social, and economic aspects. Currently, there are several projects on the sustainability of the buildings, in various stages of implementation, but a common procedure or approach is missing.

1.1.2 Background

In the past century secularisation was an important process in the Netherlands. There are, for example, less religious people, as the decennial research, God in the Netherlands, shows [5]. The results Table 1 show there are fewer theists; people that believe in a God, who takes care of humanity. An extensive survey of the active population, done by the Centraal Bureau voor de Statistiek (CBS) in the period 2010-2014, shows a different trend. For example, in the municipality of Apeldoorn, the number of people affiliated with a church is 47 percent. However, the percentage of people that visit a service monthly is only 16.4% [6]. It might not be clear how many religious people there are, and regional differences can be noted, the general trend is a decrease of religious involvement and attendance at services [7]. Some communities of faith are forced to mergers with another religious community [8], making one building redundant. Other faith communities use their building multifunctional, which supplies extra income but also presents diverse kinds of challenges.

Table 1 Faith in God or a higher power in the Netherlands (%). [5]

	1966	1979	1996	2006	2015
Theists	47	33	24	25	14
Somethingists	31	40	39	36	28
Agnostics	16	18	27	26	34
Atheists	6	9	10	14	24

The societal changes force churches to adapt to survive; these adaptations must fit in the teachings of the church. Churches that become redundant can be repurposed or demolished, if chosen for the second religious, cultural, and historical heritage could disappear. Repurposing, however, is not an easy task as (previous) users often feel attached to the building. Another up and coming way is adapting the church building, for example, optimisation of the energy use, and reducing the energy costs. An added benefit of this movement is that it also improves the sustainability of the buildings. Sustainability can directly be linked to the teachings of the church and is a central theme in the Bible directly and indirectly mentioned in over a thousand verses [9]. Giving one example from Genesis: *The LORD God took the man and put him in the Garden of Eden to work it and take care of it.*[1]'To work', refers to the cultivation of crops, using the land for sustenance, while take care means to guard, monitor, protect

([1] *God, de HEER, bracht de mens dus in de tuin van Eden, om die te bewerken en erover te waken* (vlg. Gen. 2, 15). De nieuwe bijbel vertaling and have oversight [10]. Humanity is part of God's creation but is not placed above it [11], there must be a balanced reciprocal relationship between humans and nature [10]. All in all, it seems that churches have, from a religious point of view, an obligation to become more sustainable.

The wish to become more sustainable is certainly existing, practical application, however, is difficult. Lack of technical knowledge, economic means, user comfort and environmental factors, are just a small sample of the barriers. As noted before there are several initiatives to assist churches in their quest to sustainability, such as Green Churches [3], but also the Laudato Si' movement [12], a response to the encyclical letter written by Pope Francisco under the same name. In addition to the initiatives, a broad arraignment of tools, methods and guidelines is available. Nonetheless, an unambiguous and standardised approach is still missing, as well as a definition of a sustainable church. Existing methods, building assessment tools such as BREEAM [13], are often building specific [14] or their definition of sustainability does not match the common ecclesiastical definition for sustainability [13], making it difficult to apply them to churches. A method that assesses the sustainability performance of a church building could aid religious communities in the process towards reaching a sustainable church building, and it could stimulate others to start the process. *The non-existence of an unambiguous assessment method for the sustainability of churches limits the application of sustainability as an approach to deal with the societal change that affects religious communities*. In the theoretical background, Chapter 2, discusses more in dept the definition of sustainable, existing assessment tools and specifics on church buildings.

1.1.3 Relevance

In the Netherlands, in 2008, there were approximately 4200 church buildings. The expectation was that in the following decade 1200 of these church buildings would be taken out of service [2]. The scenario of two building closures per week has yet not been the case. In average, it could still happen as many communities of faith struggle to keep afloat. Religious communities have a strong need and wish to be more sustainable. On the on hand to save money in the long term, on the contrary from a religious perspective of taking care of creation and thus reducing the impact on the creation. Assessing the sustainability performance of a church building requires a method that can assess the current level of sustainability, and what the effect of adjustments and measures is considering economic, ecological, and social factors. The method could aid religious communities in planning a sustainability project and inspire them to do so. Potentially the developed tool could help communities that need to choose between different buildings or alternative housing. Overall, the application of a sustainability assessment tool seems wide and is certainly relevant for churches that have a wish to improve the performance of their buildings.

1.2 Research Methodology

The research methodology describes the set-up of the research project, based on the motive and short background of the problem. The first section describes the research aim and scope. Followed by the research questions and design.

1.2.1 Research Aim and Scope

The current sustainability assessment tools are not specific enough to assess a church building, because of their constructive and occupancy characteristics, and due to their specific view on sustainability. This research project aims *to develop a method to assess the sustainability performance of a church building that is in religious use*. The method must account for the specific architectural and occupancy characteristics of a church. Churches often have recognisable architectural features, and even though they differ strongly from each other, they differ more from other buildings. Occupational characteristics are the frequency of use, primarily on Sundays [15], [16], and the fact users are sitting. In addition to the features, the method must correspond to the ecclesiastical vision on sustainability, thus including economic, ecological, and social factors as much as possible.

The general purpose of this research project is *to develop a method or tool that measures the sustainability, or lack thereof, in Christian churches that are in use as a place of worship in the Netherlands*. Sustainability is defined using economic, ecological, and social factors adapted to the characteristics of the building and occupants. The study applies the framework to churches in Apeldoorn, selected together with the 'Werkgroep Duurzaamheid' (WDH).

1.2.2 Research Questions and Design

The research follows an exploratory research design. In an exploratory design, there is a focus on gaining insight and developing theories for further studies. Currently, a method to assess the sustainability performance of churches is not available, exploring the possibilities for such a tool is part of this project. Which leads to the following main question:

How can the sustainability performance of church buildings in religious use be assessed and be improved?

The first research question (Q1): '*How to assess the sustainable performance of churches?*' is the first step towards answering the research question. Part of this step is a broad theoretical background study, linking the information to church buildings when required and possible. The result is a *Sustainability Assessment Framework* [A].

The second research question (Q2): '*What is the sustainability performance of churches in Apeldoorn?*' is the practical part of the project. The question aims to test the validity and reliability of the tool. The cases studies [B] take place in Apeldoorn and result in an *Improve Sustainability Assessment Framework* [C].

The third research question (Q3): '*How could the sustainability performance play a role in the transformation of churches?*' is the last step of the research. This question aims to broaden the scope and consider the application of the framework. The theoretical background presents publications on current models, guides, and reports for struggling religious communities [D]. The result of this question is a proposal for an *applicable model* [E] for the transformation of religious communities that includes sustainability as an approach.

Summarizing, development of a preliminary version of the framework based on literature and validation of the first version based on case studies in Apeldoorn. Finally, placement of the framework in a broader perspective of adaptation models for churches, resulting in an applicable model. Below an overview of steps taken in the research project, as well as a visual presentation in Figure 1.

[A] Development of the sustainability framework applicable for churches, based on information available in literature (*Q1; Section 2 & 0*);
[B] The practical part of the study tests the validity of the framework. Improvements to the framework based on the results. Additionally, it gives insight into the current sustainability performance of the studied church buildings (*Q2; Section 0*);
[C] Validated and improved sustainability assessment tool (*Section 0*);
[D] Literature study into the available models, guides, and reports on adapting churches to the current social climate, for example on repurposing of the buildings or multifunctional use (*Section 2*);
[E] The role the sustainability assessment tool could play in other models for churches. A concept of a possible model that integrates different tactics including the tool (*Q3; Section 0*).

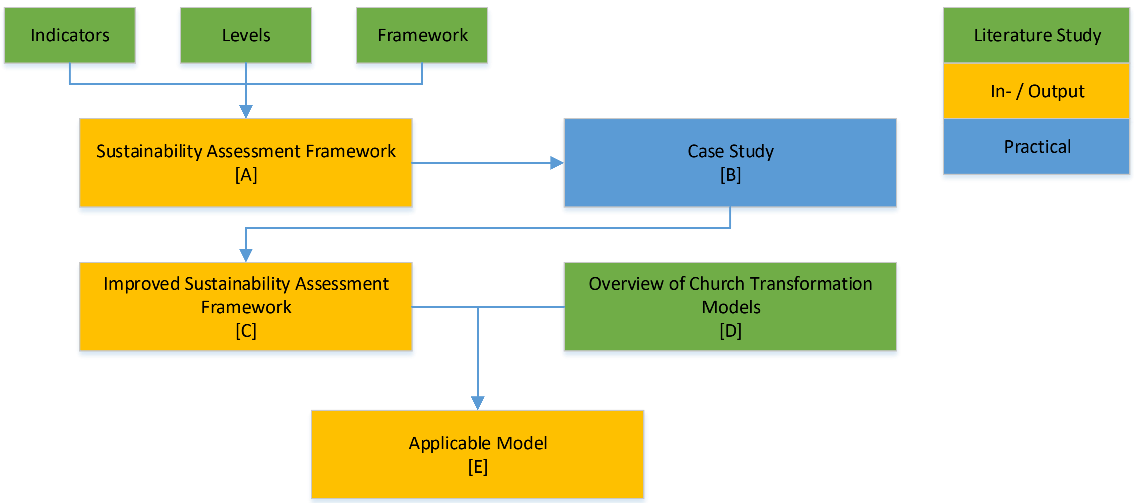


Figure 1 Visualisation of the research design.

1.3 Reading Guide

The reading guide presents the general content per section, starting with the second section. Section 2 presents the theoretical background describing general aspects applied in the other sections. Appendix A. is part of this chapter. Section 2.1 starts with defining sustainability for this research project. Section 2.2 considers sustainability assessment tools and their structure, also introducing maturity levels. Section 2.3 presents some general information on church buildings, current approaches dealing with issues including a corresponding list with recent publications. The section, like the following three, finishes with a conclusion (2.4) presenting relevant findings.

Section 3 presents the steps used for developing the framework. Appendix B. is part of this section. Section 3.1 offers an overview of strategies and measures, divided into categories, which could improve the sustainability performance of a church building. Section 3.2 elaborates on sustainability levels and what could be the best options. Section 3.3 further defines the framework; ending the section with a conclusion in section 3.4. The application of the framework developed in the previous section is part of the fourth chapter. Section 4, linked to Appendix C., presents the practical part of the research project. Section 4.1 describes the case area and the cases. Section 4.2 presents the results of the application of the framework, including a short reflection. Section 4.3 contains a discussion of the validity and reliability of the tool, followed by the improved version of the framework in section 4.4. The final part 4.5 is a preliminary conclusion.

Section 5 presents a proposal for the application of the framework, or more generally what role sustainability can play in the transformation process. Section 5.1 presents the transformation process, putting the terminology presented in section 2.3 into perspective. Section 5.2 reflects upon the role of sustainability, using knowledge from the case studies. Section 5.3 proposes an applicable model that includes sustainability. Section 5.4 concludes the section. Section 6 contains the overall conclusion in which answers the research questions (6.2). First there is the discussion which reviews the whole research and possible further research (6.1). Followed by Section 6.3 which are the recommendations for the WDH. After which the bibliography and appendices follow.

2 Theoretical Background

In the first section presents several general definitions and which definition applies to this project. The next section focusses on sustainable assessment tools, their structure, and alternatives. The third section focusses on church characteristics and the current developments on churches, as well as research and publications on the matter. Finally, there is a preliminary conclusion. The theoretical background functions as a preparation to answer the first research question (Q1). The information is further specified towards church buildings in the next section to function as a basis for the development of the *Sustainability Assessment Framework* [A]. The section on churches buildings is relevant for the third research question. Part of this section is an *Overview of Church Transformation Models* [D] that form the input for the *Applicable Model* [E].

2.1 Sustainability

The most used and accepted definition of sustainability or sustainable development (SD) originates from the Brundtland committee in 1987 (Table 2). The table shows predecessor definitions, but mainly definitions that followed Brundtland. There are significant similarities between the younger definitions and the one formulated by the Brundtland Committee [17].

Table 2 Definitions of Sustainable Development.

Authors	Definitions of SD	Ref
Vitruvius (†15BC)	Venustas (Beautiful/pleasant), Firmitas (strong/durable) and Utilitas (useful), a beautiful sound usable building, usable for many years.	[18], [19]
Kasthofer (1818)	Wenn nicht mehr jährlich darin (im Wald) Holz gefällt wird, als die Natur jährlich darin erzeugt, und auch nicht weniger.	[20]
Brundtland Committee (1987)	Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (i) The concept of *needs,* the essential needs of the world's poor, to which overriding priority should be given; and (ii) The idea of *limitations* imposed by the state of technology and social organisation on the environment's ability to meet present and future needs.	[21]
IUCN/UNEP (1991)	Improving the quality of human life while living within the carrying capacity of supporting ecosystems	[22]
ICLEI (1996)	Development that delivers basic environmental, social, and economic services to all residences of a community without threatening the viability of natural, built, and social systems upon which the delivery of those systems depends.	[23]
Mitlin & Satterthwaite (1996)	(i) Minimising use or waste of non-renewable resources including fossil-fuel energy sources, minerals, and cultural and historical assets; (ii) Sustainable use of finite renewable resources such as fresh water; (iii) Biodegradable wastes not overtaxing capacities of renewable sinks; (iv) Nonbiodegradable wastes/emissions are not overtaxing (finite) capacity of local and global sinks to absorb or dilute them without adverse effects.	[24]
Hay & Mimura (2006)	In short, sustainability is achieved only when there is full reconciliation between (i) Economic development; (ii) Meeting, on an equitable basis, growing and changing human needs and aspirations; (iii) Conserving limited natural resources and the capacity of the environment to absorb the multiple stresses that are a consequence of human activities	[25]

However, accepted the Brundtland definition might seem, it is also controversial. For example, what are the 'needs' of the future generation [26], and how can it be known what is 'needed' now and what is 'needed' in the future [27]. What exactly is considered sustainable remains a vague and complex concept; which makes it difficult to define or measure [28]. Still, sustainability is accepted by the general public as a common goal [29], that is required for a maintainable future [30] [31], making it a popular research field [32]. Even though there are different definitions in use, there are similarities, of which four are noticeable [33], [34]. The first is that most definitions are intergenerational and mention future generations. Secondly, there is a layered structure in which local, regional, national, and international differences are important. Thirdly, there are several dimensions, often depending on the discipline of the study. Finally, the interpretation and application of definitions remain a point of discussion. In this thesis, the Triple Bottom Line (TBL) is the definition and framework for sustainability; described in the next section.

2.1.1 Triple Bottom Line

Sustainability as a triangular concept, making a distinction between environment, economy, and social equity, is a commonly used and accepted framework. Referred to as the sustainable triangle or the three pillars of sustainability, it places economic vitality, environmental integrity and social equity as the cornerstones of sustainability [35]. Young [36] described a stool with three legs, which represent the three pillars, each leg is equal and essential for sustainability; as people should live in harmony with the environment taking into consideration the well-being of individuals and the environment now and in the future. In response to Young's definition, there are objections, especially considering the equality of the legs. According to Rapport [21] and Dawe & Ryan [22], a healthy ecosystem is essential for healthy people, communities, and a sustainable way of living. Making it necessary to consider some interrelation between the legs of the stool. In 1997, Elkington developed the Triple Bottom Line (TBL), based on Young's model, but including interrelation.

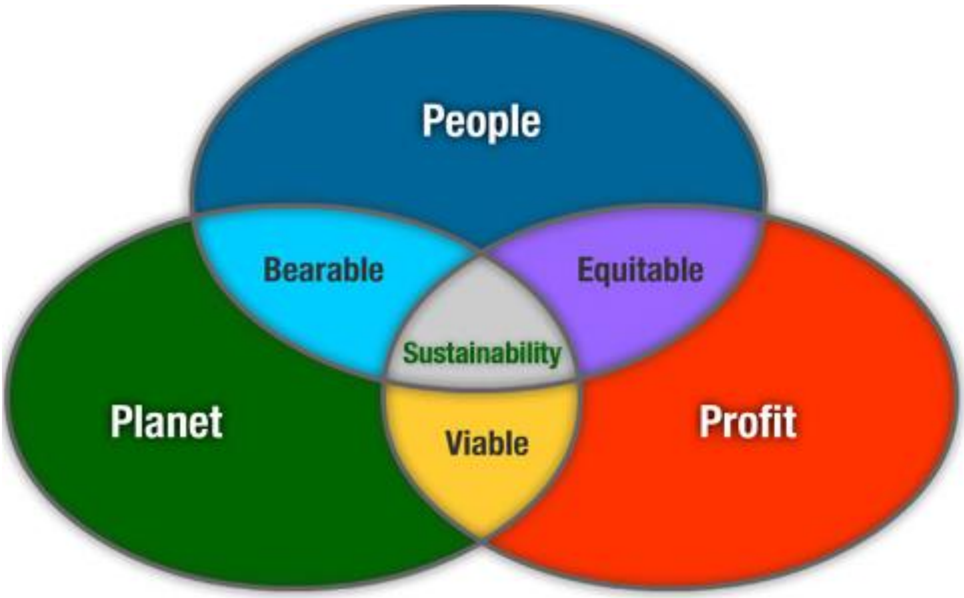


Figure 2 Diagram as introduced by Elkington.

The TBL often referred to as the 3P's of sustainability, simply the 3P's, or People Planet Profit. 'People' represents the social dimension, 'Planet' accounts for the environmental dimension, and 'Profit', sometimes referred to as 'Prosperity' [37], describes the economic dimension. A balance or harmony between the three dimensions is essential [13], [38], [39], as is visualised in Figure 2. Sustainability is achieved: '*when there is a reconciliation between, (1) economic development; (2) meeting, growing and changing human needs and aspirations on an equitable basis; and (3) conserving limited natural resources and the capacity of the environment to absorb the stresses that are the consequence of human activities'* [25]. The previous statement becomes a useful definition, especially considering business management, for which the TBL was developed [38]. Directly applying this definition to churches, however, leaves some unclarities. On the one hand, the definition is too broad, including unrequired aspects, on the contrary, specific building aspects are missing. To be able to evaluate church buildings the next section explores sustainable building and sustainable building strategies.

2.1.2 Sustainable Building

SB or green building is a concept that starts with understanding the impact of a building on the environment and tries to amplify positive and mitigate negative impacts during the life cycle of the building [40]. A building is sustainable when there is an integrated quality, based on the economic, social and environmental performance [41]. Important to note is that this is required for the whole life cycle of the building from design until demolition and waste disposal [14], [42]. Often a fourth pillar is added, one that considers technical aspects [43], [44]. Table 3 gives an example of principles belonging to this concept of SB.

Table 3 Principles of sustainable building adjusted from [44].

Pillar	Principle
Social	Improve the quality of life;
	Provision for social self-determination and cultural diversity;
	Protect and promote human health through a healthy and safe working environment
	etc.
Economic	Ensure financial affordability;
	Employment creation;
	Adopt full cost accounting;
	Enhance competitiveness;
	Sustainable supply chain management.
Biophysical	Waste management;
	Prudent use of the four generic construction resources (water, energy, material, and land)
	etc.
Technical	Construct durable;
	Functional;
	Quality structure;
	etc.

2.1.3 Sustainable Building Strategies

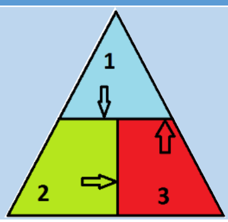
Sustainable building strategies can be as broad as SB, but often there is a clear focus on energy use during operation. The objective of the project can define and distinguish a specific type of building. Table 4 presents an overview of specific building types, that corresponds with an elaborate description in Appendix A1. Energy use is the focus of defining these different building types, for example, the specific energy demand of the building or the source of energy used.

Table 4 Types of buildings.

Type	Name
1	conventional building or standard building;
2	low energy building;
3	passive building;
4	nearly zero-energy building (nZEB);
5	zero-energy building (ZEB);
6	zero-carbon building.

A commonly accepted strategy for energy management in SB is the three-step-strategy by Lysen [45]. The Trias Energetica consists of three steps: prevention, renewable, and efficiency (Table 5). As stated previously, and presented in Table 3, SB has other aspects than energy. Four additional triads can describe the other aspects [46]. Land-use (Trias Toponoma), transport (Trias Poreutica), water (Trias Hydrica), and materials (Trias Hylica), were added. This research project focusses on the Trais Energetica as it is the most important factor for the sustainability of church buildings. In the case of repurposing or multifunctional use of the building other Triads become relevant [47]–[50].

Table 5 Trias Energetica. [45], [46]

No	Name	Description	
1	Prevention	Reduce energy demand by preventing the use of energy	
2	Renewable	Use sustainable renewable sources	
3	Efficiency	Meet the energy demand that remains and requires fossil fuels as efficient as possible	

The types of houses relate to one or more of the three steps of the Trias Energetica. A low energy building, for example, fits mostly in the first step, as the design of the building leads to the low energy demand. It is possible to meet the remaining energy demand with renewable sources (step 2), but not needed as it is for a nZEB. The definition of ZEB is still controversial, and there is no real consensus. For example, Laustsen [51] claims that a ZEB can also be a conventional building as long as it uses renewable energy, while Torcellini et al. [52] states that a combination of measures should significantly reduce the energy need, making it possible to meet the remainder with renewable sources. Furthermore, there is a discussion on the origin of the renewable energy; the European Parliament states energy must be generated on-site or nearby [53], while others include off-site options or do not define the issue [54].

Both discussions on the definition of a ZEB and the importance of the energy source are still ongoing, without a clear direction as for now. The definition used from now on is a building that has an on-site power generation that meets the energy demand. If this is not the case, but the building uses an off-site source, it falls into the category of zero-carbon buildings. To be considered a ZEB, the on-site sources must meet the energy demand of the ZEB, which requires efficiency measures. Appendix A1 supplies visualisation of the Trias Energetica and the different building types. The combination of the Trias and the building types can aid the religious community to shape the sustainability objectives for their church building. It can help formulate strategies and select measures; as presented in chapter 0.

2.2 Sustainability Assessment Tools

After formulation of the strategy, it is important to know what the effect is on the sustainability of the building. The sustainability performance of buildings is becoming more important [55], similarly the assessment methods. Methods are referred to as 'Environmental Building Performance Assessment' (EBPA) [13], 'Building Environmental Assessment' (BEA) [14], [55], [56], 'Building Sustainability Assessment' (BSA) [57], [58] and 'Green Building Grading (GBG) [59]. The terms, used interchangeably, describe a wide verity of comparable tools. The first comprehensive tool was the Building Research Establishment Environmental Assessment Method (BREEAM) [13]. BREEAM is also the most used tool [60], having different versions for different types of buildings and countries. Figure 3 shows a schematic diagram of BREEAM, with on the left groups of indicators, in the middle the aggregation by weighting and finally a score, that correlates to a rating.

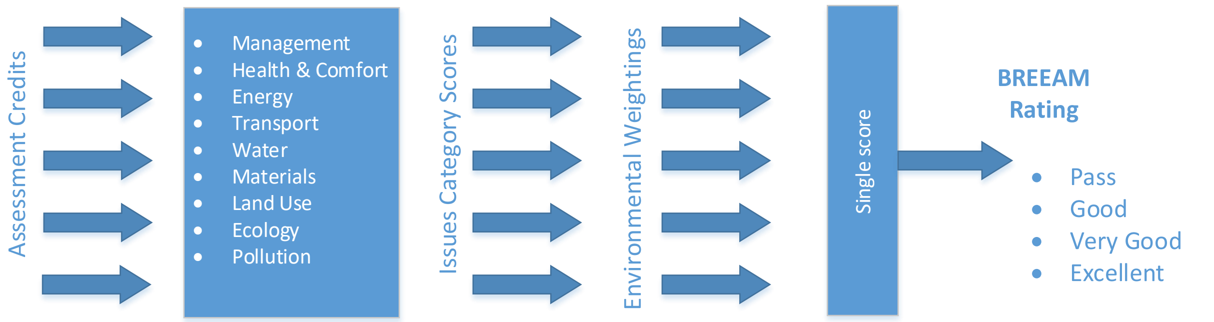


Figure 3 Schematic diagram of BREEAM. [61]

Currently, many tools are available, for example, applicable to a different building or using a different approach to sustainability. Many countries develop their versions, due to the use of local indicators, and deviating building norms [62]. Tools can be divided based on several typologies. For example, assessment and rating [13], the ATHENA Assessment Tool Typology [63] or categorising based on what is measured [58], [64]. Finally, the EAI Annex 31, that presents five levels [65] provides the most information about the content of the tool. Categorising tools seems to be important for comparing results, as only tools within a category can be compared [63]. When selecting a tool, it is important to look at what is assessed, by whom and when; how is an assessment done; what methods and data sources are; and, finally, what is the final result and how is it expressed [14], [57].

Although there are many tools available, conforming to the TBL principles, there are significantly fewer. Often economic factors are not included [13], as money often was not an issue in past building projects. Currently, economic factors become more important, for instance, the U.S. Green Building Council (USGBC) has approved a pilot that adds a benefit-cost analysis (BCA) to LEED (Leadership in Energy and Environmental Design), making it possible to do a TBL analysis [66]. Other established tools that do use three pillars are DGNB certification system, SBTool, and EcoProp [13], [57], [60], [67]. The application of the TBL and the specific building type of a church makes it difficult to select an existing tool. Adapting an existing tool or developing a new tool could be a possibility. Exploring the general components of an assessment tool helps to obtain knowledge about both options.

2.2.1 Structure of an Assessment Tool

A sustainability assessment tool consists of three major components. Firstly, there is a set of criteria, which expressed and measured in indicators, they form the structure of the tool. Secondly, the number of points or credits to a specific performance, this is the scoring. Finally, there is the presentation of the results, the output of the tool. [68] For the application of the TBL it is important that the criteria express the three dimensions including the overlap. The following sections will pay attention to the three components.

2.2.1.1 Body of the Tool

Indicators are used to make criteria measurable or predictable [69], it provides a sign or signal from an individual source of several sources the relays a complex message [70]. The three primary goals of the application of indicators are simplification, quantification and communication [71]. For the selection of indicators, several techniques were developed, for example, based on different types of indicators [72], or priorities such as mandatory, desirable, inspirational and non-active indicators [73]. Spangenberg et al. [74] show that there is yet an unambiguous technique to select indicators. Also, the number of available indicators is significant, as well as the possibility of formulating one specifically for the project.

Table 6 Sample of standards in the construction industry updated from [75].

Standard	Standard title	published
ISO 21929-1:2011	Sustainability in building construction - sustainable indicators, Part 1: Framework for development of indicators for buildings.	Nov-11
ISO 21930:2007	Sustainability in building construction - environmental declaration of building products.	Oct-07
ISO 21930	Sustainability in buildings and civil engineering works - Core rules for environmental declaration of construction products and services used in any construction works.	Draft
ISO 21932	Sustainability in building construction – terminology.	May-08
ISO 21932:2013	Sustainability in buildings and civil engineering works - A review of terminology.	Nov-13
ISO 15392:2008	Sustainability in building construction - general principles.	May-08
CEN EN 15643-1	Sustainability of construction works - integrated assessment of building performance. Part 1: a general framework.	Dec-10
CEN EN 15643-2	Sustainability of construction works - integrated assessment of building performance. Part 2: Framework for the assessment of environmental performance.	May-11
CEN EN 15643-3	Sustainability of construction works - integrated assessment of building performance. Part 3: Framework for the assessment of social performance.	Apr-12
CEN EN 15643-4	Sustainability of construction works - integrated assessment of building performance. Part 4 framework for the assessment of economic performance.	Apr-12
NEN 7120	Terms, definition, and methods for the calculation of energy performance and related indicators of a building or part of a building. Usable for dwellings, residential and utility buildings, new as well as existing.	Oct-2012

Table 6 presents several frameworks holding universal sets of indicators. The regularly update frameworks, developed by (inter)national non-governmental organisations, are part of regulations. Still, many researchers choose to develop their own set of indicators, partly because there is no unambiguous technique to select indicators [74], partly because the universal and standardised sets are incomplete [75]. Also, the selection of criteria and indicators can strongly depend on the project and the project's stakeholders [73]. Indicators often used for church buildings are investment costs, energy costs, monumental value impact, preservation factor, and thermal comfort [16], [76], [77]. Assessment of measures targeted towards a balance between conservation/preservation of the church building and its interior and thermal comfort during services. The goal for evaluation in this research project is towards the sustainability of the building which needs an additional indicator. The additional indicator expresses how much greenhouse gases the church energy use causes emits, as an indicator of the environmental sustainability of the building. Economic sustainability expressed through the investment costs and the energy costs savings. Finally, social sustainability expressed by the impact on the monumental value, impact on the preservation factor and the thermal comfort. Chapter 0 describes the criteria in detail. In the next section presents the scoring of criteria and their link to the indicators.

2.2.1.2 Scoring and Weights of the Tool

The criteria are scored, most often by assigning a point value per element [78]. Cole [56] states, that scoring and weighting remains a controversial aspect, with as a primary concern the absence of an agreed theoretical and non-subjective basis for deriving weighting factors. The scoring of qualitative and quantitative criteria requires a different approach, but a mixture is possible if scoring is done as objectively as possible [79].

In the case of an existing building, it is also possible to compare to the previous situation, as well as the effect of other measures and their effect on this situation. In the case of churches, comparing measures to each other and their influence on the initial situation leads to a score. When more data is available to further development of the tool could make it possible to compare different church buildings. Quantified benchmarks or criteria could, if possible, be a valuable addition. However, this requires extensive data collection for a large variated group of church buildings, enabling seeing patterns and relationships. The number of churches selected for this study is too low to make a founded conclusion on the matter; it is part of Chapter 0. Chapter 0 further explains the indicators and scores per indicator.

2.2.1.3 Results of the Tool

Figure 4 visualises different levels of indicators aggregation, in which the lowest level presents the separated indicators, the second tier groups of indicators, and the final level all indicators become part of one index, this is done through numerical integration [80], [81]. An overall index is an often-used method to present the score of a building. Tools such as BREEAM use a single index. BREEAM uses a scale of 'Pass', 'Good', 'Very Good', and 'Excellent' (Figure 3). LEED and DGNB use similar methods. Main differences are in the presentation of buildings that do not pass the threshold score [79]. SBTool, however, uses a radar chart to present the score of various categories (Figure 4). Other options can vary from a bar chart or present all indicators separately. The choice depends on the user of the tool; one index is easy to understand for everybody, while a radar chart needs some more comprehension, a list of all indicators will require knowledge about sustainable building to interpret the data.

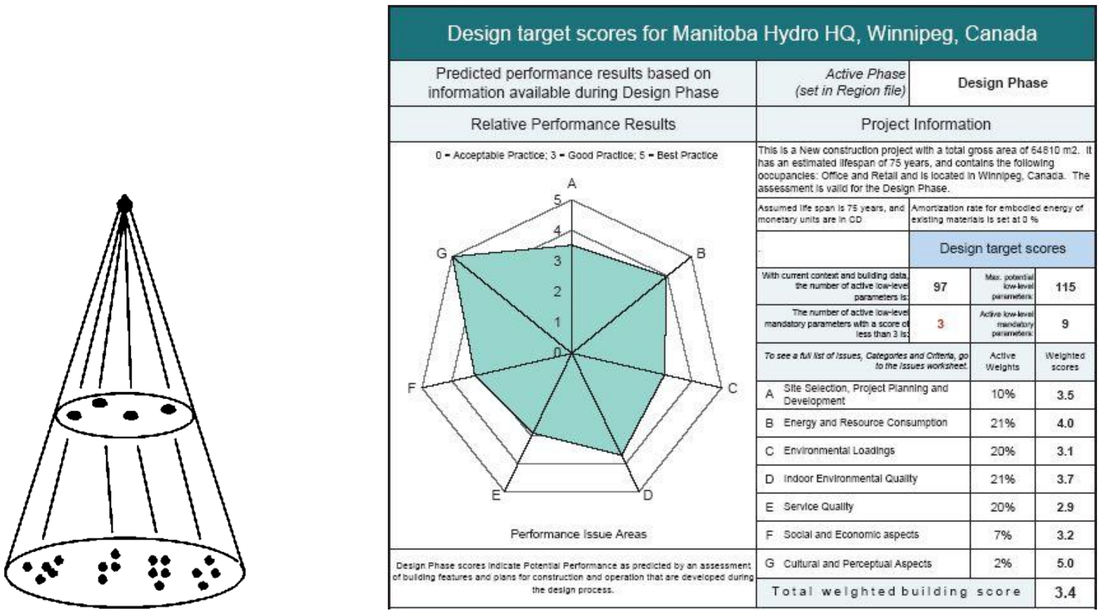


Figure 4 Levels of indicator aggregation [81] (l); Results of a project assessed using SBTool [82] (r).

Equation 1 Diaz-Balteiro equation.

$$\frac{Score\ - Minimum\ score}{Maximum\ score\ - Minimum\ score} = Normalised\ score\ between\ 0\ and\ 1$$

The score a tool wants to present sets the steps required to come to an outcome. The first step is normalisation, which is not always needed [83], as generally, the final index is dimensionless. Normalisation can be done, by using a reference number [81] or the Diaz-Balteiro [58], [67], [84] equation (Equation 1). This equation considers positive and negative effects of an indicator, making it preferable. Figure 5 presents a step-by-step approach for developing an index, standardisation is not required, but if possible it would make projects comparable [85].

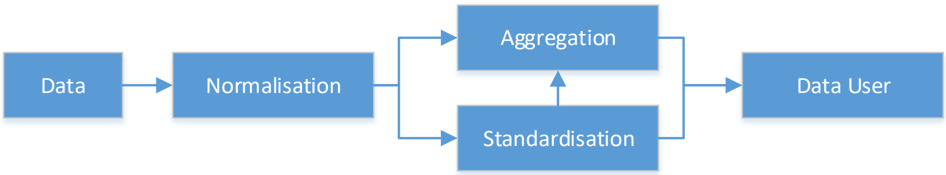


Figure 5 Step by step approach to developing an index. [85]

For aggregating the indicators there are several methods, the easiest being adding all the values together, but there are many more complex multiple criteria analysis methods (MCAM's). MCAM's are used more and more in sustainability assessment [86] and are expected to become only more important in the future [87]. Appendix A2 Table 24 presents several single approach MCAM's; there are many others, as well as approaches that combine one or more methods. Using one of these or similar methods it is possible to include economic, social and environmental indicators into the analysis [20], and come to an index that is a balance of the best alternatives [88]. The for this project selected criteria will be normalised using Equation 1 and scored. Finally, exploring a weighted score. The connections between the measures and the sustainability of a church building are difficult to express. Also, is the consideration or churches, at this point, need an index of the sustainability of their building, or that they need another measure of sustainability. An alternative could be maturity levels, which allows for adding quantified benchmarks or criteria later.

2.2.2 Maturity Levels as an Assessment Tool

In corporations, sustainability becomes more important because of legislation, but also other factors influence the process. Corporate sustainability is a major factor; it is an upcoming term that is slowly replacing similar concepts such as corporate social responsibility. Figure 6 presents a schematic representation of corporate sustainability, which shows the TBL. Baumgartner & Ebner [89] suggested adding maturity levels, to express the development of a company regarding sustainability. They propose four levels, in which the lowest level (level 1) expresses a corporation that is just starting and the highest level (level 4) a company which has sustainability integrated into all the operations. Amini & Bienstock [90] write:' *The addition of the concept of maturity or sophistication by Baumgartner and Ebner provides the possibility of developing a rubric that might enable organisations to track their progress concerning sustainability efforts and activities.*'

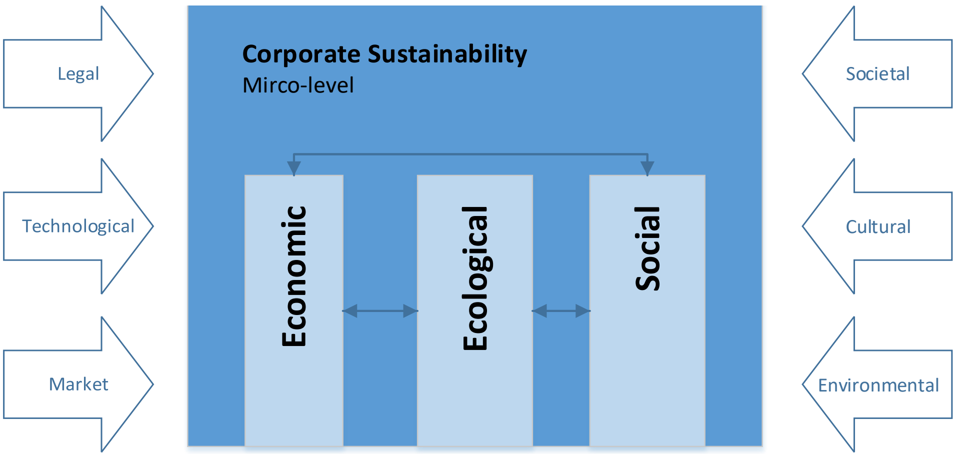


Figure 6 Sustainable development, corporate sustainability and their interactions. [91]

The proposed levels, presented in Figure 7, link to the levels of sustainability strategies and competitive strategies. For SB maturity levels could be helpful, especially in existing buildings. Determining the maturity level could offer a quick insight into the current implementations and how to mature. For religious communities, maturity levels could provide a straightforward insight into their building, without the need to excessively analyse data. It also gives an indication of improvements, for example, the energy use per square meter. Currently, the focus will be on the individual church building, however like the criteria it could be possible after further research to add quantified benchmarks. Reseach could be interesting as it combines the advantageous of maturity levels, but also those of quantifiable indicators. It makes a comparison between church buildings simpler and more straightforward.

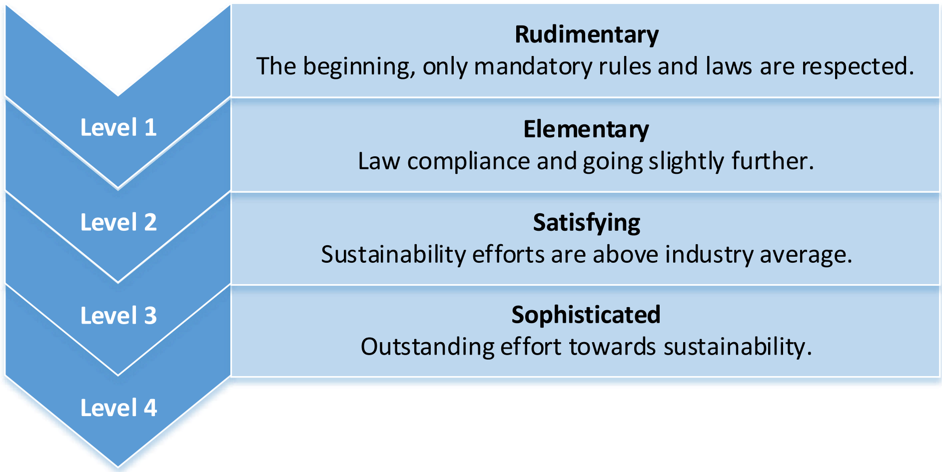


Figure 7 Visualisation of the maturity levels by Baumgartner & Ebner, adapted from [89].

2.3 Church Buildings

The chapter started with sustainability in general and defined as it applies to this project. The TBL is the framework, as the attention for the ecological, environmental and economic fits within the vision of the religious communities and the WDH [4]. The TBL developed for business requires some adjustments to apply it to a building. Exploring SB lead to several building types and matching strategies; strategies that mainly focus on energy use. The overall performance of a building has become more important; tools can aid here. In section 2.2 explored sustainability assessment tools; some existing tools, following the general content and structure of a tool. Assessment tools are often environmental, occupational, building and system specific, making it difficult to apply them to different types of buildings freely. The development of a tool is a complex process that needs common characteristics between the assessed buildings. The previous section presented maturity levels as an alternative to a more traditional format. Maturity levels of sustainability assess the progress of the building, based on the measures taken. This chapter explores the topic of this research project; Christian churches in religious use and their communities.

2.3.1 Characteristics and Definitions

Church buildings are often characteristic, because of their architecture and their function. As stated in the introduction there were around 4200 Christian church buildings in religious use in 2008 in the Netherlands [2], with an expectancy a closure of 1200 buildings in the following decade. The different church buildings in the Netherlands have similarities, but also many differences. When looking into churches, it is often useful to categorise them, for example on size, shape, construction or style period [2]. Style periods correspond strongly with the construction period of a church building, as the build year is often unknown the construction period applies as a typology instead of the other two [2], [15], [16]. Table 7 presents characteristics used to categorise church buildings. There is a consensus about these categories; there are differences related to the occupancy and the relation between the construction period and style. Roeterink et al. [2] presented that version as stated in Table 7, while Ketel & Scheele [16] do not differentiate on where the multifunctional use takes place, but the amount of use, more specifically the balance between multifunctional and religious use. The three categories are: (1) solely religious; (2) primarily religious; and (3) primarily multifunctional use [15]. In practice, the difference between these categories will not be so significant, for example, in the case of primarily multifunctional use, it needs some form of spatial integration. In the building and style period. The are some differences between the range of the period and the corresponding style; this can be explained by the fact the Roeterink et al. [2] presents a national overview, while other projects are more regionally orientated [15], [16].

Table 7 Different categories for church building typology used in an inventory research on church buildings. [2]

Occupancy	Denomination	Size	Shape	Building period	Building style	Monum.
Religious use	Roman Catholic Church	Small 0-250 m2	Basilica	>1560	Medieval	National
Separated multifunctional and religious use	Other Catholic Churches	Medium 250-500 m2	Central-plan	1560-1799	Classicism	Local
Integrated multifunctional and religious use	PKN (Protestant Church of the Netherlands)	Large 500-1000 m2	Cruciform	1800-1849	Revivalism (Neo)	No
	Other Protestant Churches	Extra-large +1000 m2	Box shaped	1850-1899	Modernism	
	Foreign Orthodox Churches		Other	1900-1940	Post-war modernism	
				1941-1969		
				After 1970		

Research into the relationships between the characteristics and the sustainability performance of the church building does not exist. The fact that there is no clear relationship between the construction period and the energy use was noted [16]. Between denomination, habits can significantly influence the energy usage, for example in RC churches it is common wear a coat on (requiring a lower comfort temperature) [92]. Also, there are important interior differences between denomination that influence the necessary conservation and preservation factor. Before comparing church buildings on their sustainability performance, the relationship between the distinctive characteristics must be clear and how they influence the energy usage and the possibility of implementing measures. Measures are unavoidable as many remaining religious communities deal with high operating costs, due to the energy use of the church building. Solutions, currently, focus on finding additional income by increasing the utilisation of the building or finding less expensive housing. Taking the church out of service if this is successful. Table 8 provides an overview of the terminology starting with the two main approaches, split into more detailed directions, the final column offers a concise description of each term. Changing the use of the church as well as taking the church out of active service is a complex process, in which many different stakeholders and their religious and emotional considerations play a role [93], [94].

Table 8 Terminology related to the adaptation of churches. [95]– [98]

	Terminology		Description:
Retain	Refocus		The building remains in use, customised to meet the specific needs of the community or surroundings.
		Renewal of the traditional identity	The modern approach to identity and traditions to reach new audiences.
		Remodel for religious use	Adapting the church building to current needs of the community.
	Secondary function		The original function remains, other functions are possible.
		Multifunctional use without radical remodelling	Next to the religious function, active use for a variety of cultural and social activities.
		Remodelling maintaining a reduced religious space	Radical remodelling that makes separated use for a variety of functions possible.
		Partially repurposed	A different name for the previous definition.
		Multifunctional use	Secondary function in time; use the building for other activities, outside religious activities.
		Shared use	Secondary function in space, simultaneous use of the building.
		Shared use by other religious community	Providing other faith communities, the opportunity to make use of the building.
Dispose / sell	Repurposing		Utilise the building in a different function than the original function.
		Transformation of new functions	The buildings religious function stops; requires searching for another function.
	Reuse		The religious function remains, but the user changes.
	Demolition		Demolish the building making it possible to reuse the ground.

2.3.2 Current Approaches

Three reasons have churches reduce their energy usage: 1) religious beliefs, the impact the religious community makes on the creation; 2) cost reduction; and 3) uncertainties regarding the tax cut deal. Churches currently profit from a tax advantageous, as they only pay half of the energy taxes [99]; a change would mean a significant rise in costs. There is a movement towards greener church buildings in the Netherlands. It is not a strategy on an equal footing with refocussing or adding a secondary function; mainly due to a missing common approach to become a sustainable church building and lack of definition for such a building. Research conducted focusses on the repurposing of church buildings, compared to studies into other facets. Some research projects concentrate on the energy use in church buildings.

There are many publications on church buildings are from all time periods and places. Topics vary from preservation of the church and its interior to the function of a church building in an area, to the possibility of multifunctional use or finding a fitting new purpose for a church. Most publications are advisory reports or manuals, some, however, provide a practical tool or are part of bigger projects. Table 9 presents an overview of several publications, including a concise description the main developer, some of the main references, and a page number that to the appendix, which includes an elaborate description. The publications below all have a direct connection to the Netherlands and are about churches, expect the last method which is a method for monuments. The method, already used in churches, is the only existing method the approaches a building assessment tool. Other methods offer a single direction approach, in which step-by-step do not include the decision moment to use a certain strategy. Chapter 0 explores the possibility of an approach that includes different strategies. Previously, Chapter 0 studies the role of sustainability as a strategy and methods to get insight into the sustainability level of a church building. Testing and reviewing the developed method is part of Chapter 0.

Table 9 Overview of several available publications on churches.

Name	Description	Developer	Ref.	P.
Aanpassen van kerkgebouwen in religieus gebruik	Remodelling churches in religious use to adapt to the future.	Rijksdienst voor het Cultureel Erfgoed (RCE)	[8]	66
Toolkit duurzaam kerkbeheer	A toolkit on sustainable governance of the church building and religious community.	Groene Kerken (*Green churches*)	[100]	67
Benchmarktool	Benchmark tool for energy use in churches, comparing performances.	Energie voor Kerken	[101]	68
Klimaatbeheersing in monumentale kerken	Indoor climate control in monumental churches and how to measure and obtain a pleasant climate and simultaneously preserve heritage.	RCE	[102]	68
Kerk&Milieu/Samenleving (KMS) methode	Study on the heating systems in church and the influence of changing the base temperature on performance.	Werkgroep Kerk & Milieu/Samenleving Bennekom	[15], [16]	68
Verwarmen van monumentale kerken	Heating monumental churches, a study on different heating systems and a choice method.	Friendly Heating Initiative	[76], [92], [103], [104]	69
Functiekeuzemodel	User function model provides a guided process for the choice of new functions for a church building.	B.J. Schrieken	[47]	69
Transformatiemeter	The method provides insight into the transformation potential of a church building.	N. v.d. Vlist	[49]	70
Kerkbestemming	Provides insight into different options of repurposing and makes a comparison between buildings possible.	L. Kellendonk & H. Schout	[105]	70
Duurzame monumenten (DuMo)	Combined approach bases on GreenCalc+, which balances the sustainability performance (Du) and the monumental value (Mo)	RCE & Stichting Bouwresearch (SBR)	[106], [107].	71

2.4 Preliminary Conclusion

The subsections in this section form the background for answering the research questions. The following sections elaborate on the background further applying and adapting it to church buildings. This section presents the important preliminary conclusions from the sections above.

Religious communities pursue a definition of sustainability considering ecological, social, and economic factors. The TBL framework aspires to find a balance between these three factors, making it an applicable framework for expressing the sustainability of a church building. However, the application of the TBL framework limits the number of suitable existing tools. This number is further restricted by the characteristics of churches, the building, but especially the occupancy characteristics differ from other buildings. When considering adapting or developing a tool or finding an alternative method to assess the sustainability the TBL still is relevant. Six criteria express the three dimensions: 1) amount of greenhouse gases emitted; 2) impact on the monumental value; 3) impact on the preservation factor; 4) the thermal comfort in the building; 5) investment costs; and, 6) cost savings. Comparing the measure to other actions and their effect on initial situation leads to a score. In the future, it might be possible to add more quantifiable criteria and compare church buildings on various levels. A constant attention for and progressive improvement of the sustainability of the building considering the TBL makes the building a sustainable church. Chapter 3 presents the development of a method to assess the sustainability performance of church buildings. The chapter explores the development of a tool like existing sustainability assessment tools, and the possibility of maturity levels.

Religious communities decide to become greener, for example, because of religious reasons or due to high exploitation costs. In the second scenario improving the sustainability performance is not a common strategy. Common approaches are the multifunctional use of the church building or finding alternative (less expensive) housing. Different research projects, manuals and advisory reports aid religious communities in adapting to the changes in society. Similar reports are available about energy usage related topics; however, the approach is different. Still many of the available materials can be useful to formulate a method to assess the sustainability of a church building. Section 5 studies the potential role of sustainability in a broader scheme of transformation approaches.

3 Development of the Assessment Framework

This section applies the theory from the previous sections to church buildings. The first sub-section presents four main strategies that are suitable to improve the sustainability performance of the church building. Each main strategy presents several methods, measures or actions that can be beneficial. The next sub-section focusses on how these measures affect the sustainability performance criteria, as well as the set-up of the framework. Thirdly, presenting the development and refinement of the framework. Finally, finishing with a preliminary conclusion. This section answers the first research question: '*How to assess the sustainable performance of churches?*' Which results in a *Sustainability Assessment Framework* [A] (Figure 1).

3.1 Strategies for Churches

Common reasons for religious communities to become more sustainable are their religious beliefs [10], [11], or out of necessity due to a lower income [5]–[7]. Other reasons or combinations are possible, but these are most common. Sustainability measures can reduce the energy costs, lowering the overall operational expenses of a building. The lower costs could make the cost manageable again for the community. The three-step-strategy of the Trias Energetica (2.1.3) and the different building types can aid religious community in the formulation of goals, objectives, strategies and finally the corresponding measures. Similarly, the incentives can lead to goals and objects, as well as several strategies. Table 10 gives an overview and the related building type. Some strategies can have a positive effect on multiple objectives; these are additional effects and benefits, it is not the focus.

Table 10 Goals, objectives, strategies and building types are corresponding with the incentives for churches.

Goal	Strategy	Objective	Building type
Preserve and protect the creation	Contract with a 100% green energy supplier	Zero carbon emission	6
	Generate renewable energy on-site		5.4
Being able to keep the building	Reduce energy demand	Reduce energy cost	2
	Improve energy efficiency		
	Generate renewable energy on-site		5
	Energy management		

Retrofitting is the process of applying modern technologies to the building that were not present when constructed. Refurbishment means cleaning, decorating, and re-equipping the building. Retrofitting and refurbishment are options to improve the sustainability performance of a church building. Demand site management, both demand reduction and efficiency improvement, energy usage patterns, and supply side management can improve the overall energy performance of a building Considerations between measures depend on several factors, such as the goal of the project, the budget, and the characteristics of the building. The following sections present suitable measures for churches placed into four categories that link to the strategies formulated. Contracting at a 100% green energy supplier is part of the renewable energy. Specific measures link to the categories: Energy Management (M; Table 11), Energy Demand (D; Table 12), Energy Efficiency (E; Table 13), Renewable Energy (R; Table 14). The last column of each table contains page numbers that link to a description in the appendix.

3.1.1 Energy Management

Human factors or energy usage patterns are part of the most uncertain reduction strategies. However, the reductions can be significant [16]. The building uses energy while occupied and when it is not. Research shows that in office buildings in warm regions, depending on the occupants' behaviour, the energy usage outside of opening hours can exceed the power usage during opening times [108]. Unnecessary use of equipment, heating, or lights that stay on result in unnecessary energy usage.

Table 11 Energy management measures, their description, and page number in the appendix.

No	Measure	Description	P.
M1	Monitor & Register	Recording energy data offers insight into energy use; how much use and when use takes place.	75
M2	Goals, Objectives & Strategies	Clear goals to structure and plan the project. Targets and strategy are directly related.	75
M3	Energy official	A person that is responsible for the progress review of the project.	75
M4	Controlling the system	Optimise the operation of the system to improve the efficiency of energy used.	75
.1	Thermostat	Optimise use of the thermostat through automatic control and zoning.	75
.2	Basic temperature	Lowering the temperature of the building when not in use.	75
.3	Occupancy	Policy for additional use outside the normal use	76
M5	Awareness	Create awareness with the users of the building.	76

If, there is a caretaker (NL: Koster) that regularly checks the church building or the use is frequent this might not be a significant addition to the energy costs. However, in the case of a church building used once or twice a week and not regularly checked it could become significant. Part of changing the behaviour of the occupants of the church building is awareness. The communities have an excellent platform to reach their religious community and make them aware of their behaviour they display. However, to connect with them and make an impact it is important to lead by example. Through the formulation of goals, objectives, and strategies, in which the religious community can participate, sustainability becomes something tangible and real. Table 11 and Appendix B1 show measures that focus on preparing a sustainability project and first action in the rear of energy management.

3.1.2 Energy Demand

Adapting the building characteristics of the building envelope can reduce the heating and cooling demand. The envelope is what separates the indoor and outdoor environments [109], components are the roof, exterior walls and doors, windows, and floor. Insulating the building envelope can significantly reduce the energy demand of the building [110]. The thermal conductivity constants of the materials used in combination with the applied thickness play a significant role in the heat transfer of the envelope. Also important is gap prevention, because of the risks of thermal bridges. In Appendix B2 Table 28 presents the three most important terms, which have a significant effect on the energy demand. Directives are available for the required value of these concepts, depending on the building type. Conventional buildings (type 1) must correspond to the building codes valid in the construction period (Appendix B2; Table 29), when remodelling a building separated norms are available ((Appendix B2; Table 30). For specific house types such as passive houses (type 3) (Appendix B2; Table 31) or nZEB (type 4) (Appendix B2; Table 32) criteria or average numbers are available to reach the required energy performance. The planning and execution of insulating the envelope components depend on factors such as building characteristics, financial means, and energy goals.

Table 12 Energy demand measures, their description, and page number in the appendix.

No	Measure	Description	P.
D1	Double-skin façade	Adding a second envelope to (parts) of the building.	77
D2	Airtightness	Preventing infiltration by closing creaks, seams, gaps in the envelope.	77
D3	Insulation of the Envelope	Improving the thermal resistance of the envelope	78
.1	Wall	Adding internal, external or cavity insulation to increase the U-value.	78
.2	Roof	Creating a warm of a cold roof.	79
.3	Floor	Adding insulation underneath, in between or on top of the existing floor.	79
.4	Glazing	Improving the U-value of the window or add a specific cover.	79

3.1.3 Energy Efficiency

For energy efficiency, it is possible to look at big systems, such as the heating system. Another way is to look at specific equipment and appliances and improve those. For example, a small link in a larger system is the boiler, replaceable with a high-efficiency model. Research into the heating of churches shows a struggle to find a balance between energy efficiency, conservation and preservation, and thermal comfort.

Table 13 Energy efficiency measure, their description & page number in the appendix.

No	Measure	Description	P.
E1	Heating system	Comparing different heating systems.	80
.1	Warm air	A fast responding system through the distribution of warm air.	80
.2	Floor	Low-temperature evenly distributed system.	82
.3	Infrared	Local direct system, adjustable to the number of people present.	83
.4	Radiator and convector	Heats through convection or a combination with radiation.	83
.5	Local (pew)	Direct system attached to the benches/pews.	84
E2	Current heating system	Optimise the current system.	85
E3	Other energy use	Energy usage due to other sources than heating.	85
.1	Lighting	Analyse the energy use of lighting and improve efficiency.	85
.2	equipment	Reducing energy used by replacing equipment.	85

3.1.4 Renewable Energy

Renewable energy is a way to reduce the impact of the building due to the emission of greenhouse gases. It could also lead to cost reduction. Except for an initial investment and future maintenance cost, the energy is free. If the production is larger than the demand, it is possible to sell back to the grid. Other measures can influence the effect of generating on site. An example is solar panels, they generate electrical power, making it beneficial to have an electrified heating system.

Table 14 Renewable energy measures, their description & page number in the appendix.

No	Measure	Description	P.
R1	Procurement	Procure sustainable energy or join a collective.	87
R2	On-site generation	Energy production on the building footprint or surrounding area	87
.1	Wind turbines	Placement of a turbine on top of the building or a pole on the property	87
.2	PV panels	Solar panels placed on the roof or construction on the property	88
.3	Solar Collectors	On the roof; is applicable in combination with a conventional boiler system	88
.4	Heat pump	Recovers heat from the environment and delivered to the system.	88
.5	Hybrid heat pump	A heat pump that works in combination with the existing boiler; reducing overall gas use.	89
.6	Thermal conversion	The combustion of biomass in a stove. Works like a boiler	89
.7	Micro combined power and heat	Heat system that provides heat and electricity. Previously the energy losses of a boiler were 20%. In this case, losses are 5%.	89
R3	Combination and optimisation	Look for measures that complement each other and improve the overall efficiency of the system	90

3.2 Sustainability Levels

The first step in the development of the framework was a MCAM. Table 15 presents a description of the refined indicators from section 2.2.1.1. The last column provides a link to the corresponding tables in Appendix B7, which introduces the rating scales of the different criteria. Each measure was individually scored based on an average situation and effect, as well as relative to each other. Using Equation 1 the scores were normalised, this equation was choosing to take into account the negative scores. Finally, the scores were added up to a total score per measure, presented in Table 44.

Table 15 Dimensions, indicators & description.

Dimension	Indicator	Description	
Economic	Investment Cost	An estimation of the investment cost.	Table 38
	Energy Cost Reduction	An estimation of the potential savings on energy cost.	Table 39
Ecological	GHG Emission Savings	The potential reduction of emissions.	Table 40
Social	Monumental Value Impact	The impact on the monumental value of the building.	Table 41
	Preservation	The effects the indoor climate and the preservation.	Table 42
	Thermal Comfort	An estimation of the effects on the thermal comfort.	Table 43

Simply adding the scores does not help in the selection of measures, applying a method from Table 24, for example, the SAW method multiplies the scores with weights and adds up the numbers. As well as comparing the measures within their categories, did not provide additional insight, this has several reasons. Firstly, some steps serve as a predecessor for other measures, making them required even though their effect is marginal. Secondly, measures can affect performances of other actions. Finally, effects of measures strongly depend on the church building, making it difficult to make a general analysis. An individual analysis per church building is a complex and time-intensive process, undesirable for the framework. Maturity levels would be a more suitable choice for religious communities.

The maturity levels presented in the theoretical background (Chapter 2) were adapted for church buildings. Six levels were defined Level 0: ‘Starting Point’, where the religious community has no awareness regarding the sustainability of their church building. Finally in Level 5: ‘Optimised’, the whole church building performs according to the set criteria and even higher, sustainability is part of the everyday management of the religious community. In Appendix B8 each level is further explained. Table 16 provides a short description, as well as a link to the measure from the previous section (3.1). Some actions are part of two levels, as either the activity is repeated at this level, reviewed or expanded. In the next section discusses the application of the maturity levels.

Table 16 Maturity Levels of Sustainable Performance.

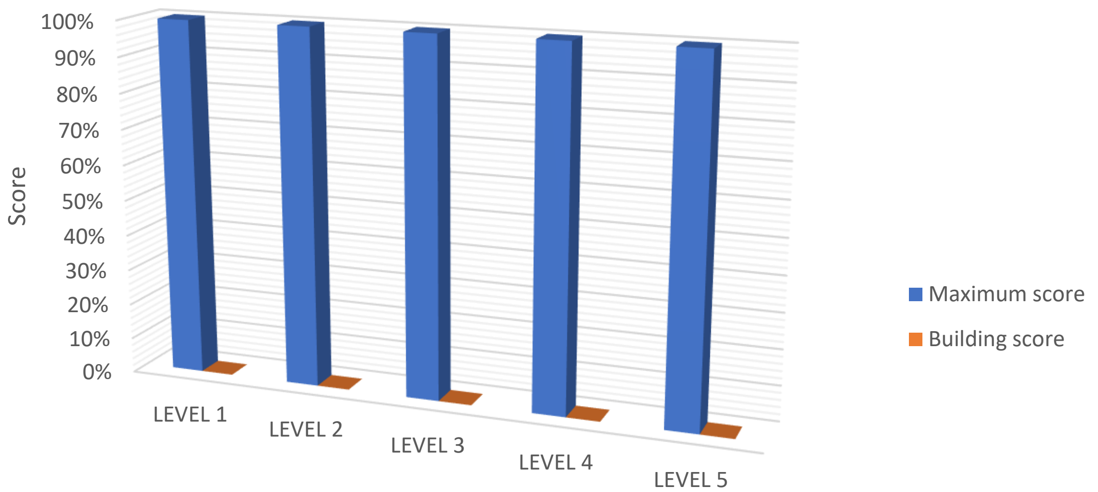
	Description	Measures	P.
Level 0: Starting Point	No awareness	-	93
Level 1: Initiated	The religious community is becoming aware and gains insight into the current situation.	M1, M5	94
Level 2: Managed	The formulation of goals, objectives, and strategies.	M2	94
Level 3: Defined	The implementation of measures without a significant investment.	M4, M5, D2, E2, E3, R1	94
Level 4: Institutionalised	Implementation of measures that require investment.	D1, D3, E1, E2, E3, R2	94
Level 5: Optimised	Improved system; constant reviewing of actions.	M3, R3	94

3.3 Framework: Establishing the Maturity Level

A list of 55 question each answered with a yes or a no. A positive answer grants a point, in the cause of negative answers there is no credit. The maximum score per level is 100%. Table 17 shows the number of question per level; each question belongs to one level. Figure 8 presents a graph with the scores, blue presents the maximum rating, orange the score for the church building. Church buildings can score on all the levels; passing a level requires passing the previous level and earning most points of the level. Appendix B9 holds a complete list of the questions and elaboration on the questions. Results of first application of the framework are part of the next chapter. The chapter includes a review of the performance of the tool and the results from the cases.

Table 17 Statements per Level.

	No. of Q.
Level 0: Starting Point	0
Level 1: Initiated	7
Level 2: Managed	9
Level 3: Defined	23
Level 4: Institutionalised	9
Level 5: Optimised	7
Total	**55**



	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Maximum score	100%	100%	100%	100%	100%
Building score	0%	0%	0%	0%	0%

Figure 8 Maturity Levels; score per level.

3.4 Preliminary Conclusion

The previous chapter formulated a definition for a sustainable church: '*a church building where there is continuous attention for an active improvement of the sustainable improvement of the building, considering the TBL*.' How sustainable building is can depend on many several aspects. There are many measures, on various levels and in different areas, that can improve the sustainability performance of a church building. Scoring the actions and comparing the scores do not offer enough insight or ability to make a judgement what is the best choice. Measures that are predecessors have a changing effect will not have a fair score. The measures form the basis to formulate six maturity levels. Starting at the beginning in which there are no actions to improve the sustainability of the church building and ending with an integrated and optimised level of sustainability for the building. Answering 55 questions determines the sustainability level of a church building, each question belongs to a specific level. A positive answer grants a credit. A building can pass to the next class when completing the previous level and scores at least half of the points. Testing of this version of the framework takes place in Apeldoorn. Reflection on the functioning of the framework based on the results will lead to adaptations or proposals for adjustments. Which answer the first research question: '*How to assess the sustainable performance of churches?*'

4 Testing of the Assessment Framework

The fourth section of this report presents the practical part of this research project. This part aims to test the developed framework from the previous section. The first subsection describes the case selection including the description of the area and the cases. The second section focuses on the results of the application of the framework, presenting the results per church building. Following in the third section, there is a reflection on the validity and reliability of the framework. Validation is also approached from the client's point of view. This section about testing the framework concludes with a preliminary conclusion. This section is the *Case Study* [B]. It answers the second research question (Q2): '*What is the sustainability performance of churches in Apeldoorn?*' The result of the section is an *Improve Sustainability Assessment Framework* [C].

4.1 Case Selection & Description

The selected churches are in Apeldoorn. Apeldoorn is an important city in the province of Gelderland and one of the biggest municipalities in the Netherlands. The red area in Figure 9 shows the municipality in 2016; the dark grey area shows the province of Gelderland. All selected cases are all in Apeldoorn to prevent local differences. The ABvK, in particular, the WDH, provided information and helped to make the selection. The final selection depended on the willingness of religious communities to participate.

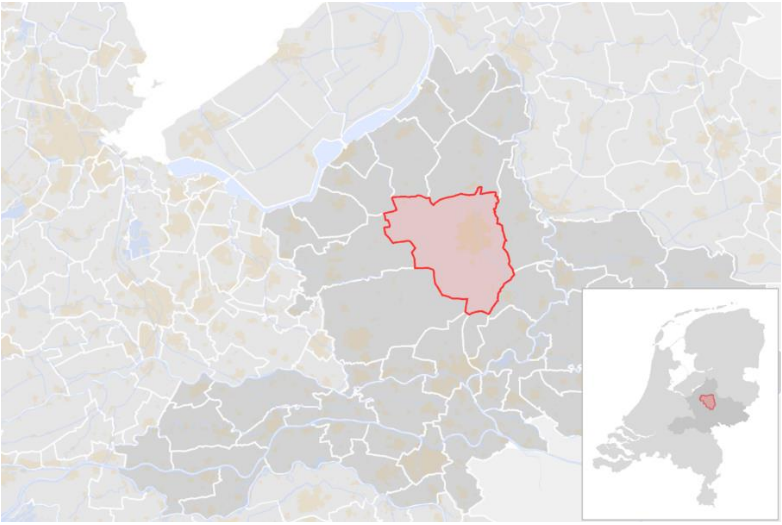


Figure 9 Municipality boundaries of Apeldoorn. (CBS 2016)

The church buildings reviewed are the 'Onze Lieve Vrouwe Ten Hemelopnemingkerk' (OLV), the Open Hofkerk (OHK) and the Jachtlaankerk (JLK). Table 18 presents the different church building typologies, presented in Table 7, for the three buildings. There are differences in denomination, community and building characteristics, but also regarding sustainability. The approach to sustainability differs, but also the implementation level. Appendix C1 presents a more elaborate description of the location, the church building, and other peculiarities, as well as some pictures and the current approach and measures regarding the sustainability of the building.

Table 18 Basic information on the OHK & OLV.

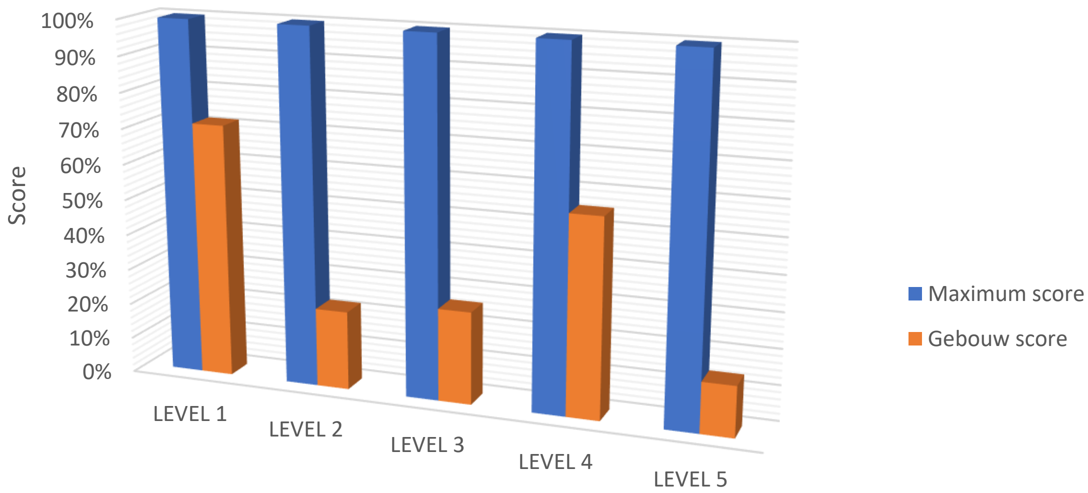
Category	OLV	OHK	JKL
Denomination	RC	PKN	PKN
Occupancy	Religious use	Religious use	Religious use
Shape	Cruciform	Other	Other
Construction year	1895	1966	1952
Period	1850 – 1899	1941 – 1969	1941-1969
Style	Revivalism	Post-War Modernism	Post-War Modernism
Monumental status	Yes [111]	No	No

4.2 Presentation of Results

Appendix C2 presents the individual answers to the questionnaire. In this section presents the results, including a review and reflection. Starting with the OLV, followed by the OHK.

4.2.1 Onze Lieve Vrouwe Tenhemelopnemingkerk

As stated in the description the RC community in Apeldoorn has been reviewing their heating system, as the system was old. Due to the discovery of asbestos, it was possible to make a more in-depth consideration of the system. In addition to the renewal of the heating system other actions took place, but not for the entire building. These partial measures do not add to the score, as a point counts considering the application in the whole building. Figure 10 presents the results per level, which corresponds to the expectations. The total improvement of the heating system is the reason that the church scores overall, but remains in *Level 1* when considering the requirements to pass to the next step. There are no further plans in addition to the review of the heating system. The fact there are no further plans, is the main reasons the church is not able to reach a prominent level of maturity.

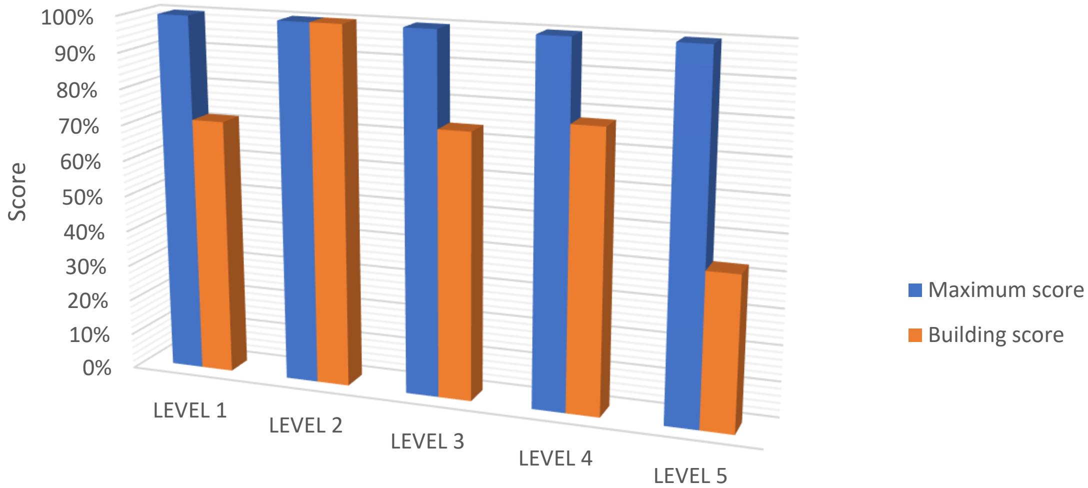


	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Maximum score	100%	100%	100%	100%	100%
Gebouw score	71%	22%	26%	56%	14%

Figure 10 Scores per level for the OLV.

4.2.2 Open Hofkerk

The OHK used a thorough approach including extended data sets, calculations, and lists of building characteristics. The community of the OHK implemented several (small) measures, but funding problems caused the discontinuation of the project. This current makes the results of the framework unexpected. The building scores high in all levels, even the final, even though it does not pass this level. Overall, the OHK would be a *Level 4* sustainable church, which does not correspond looking at the actual implementation level of measures. An explanation for the results is the thorough, broad preparation of the OHK, as they formulated goals and plans for all levels. The value of formulating plans seems to be too high, preparing is important, but implementing even more so.

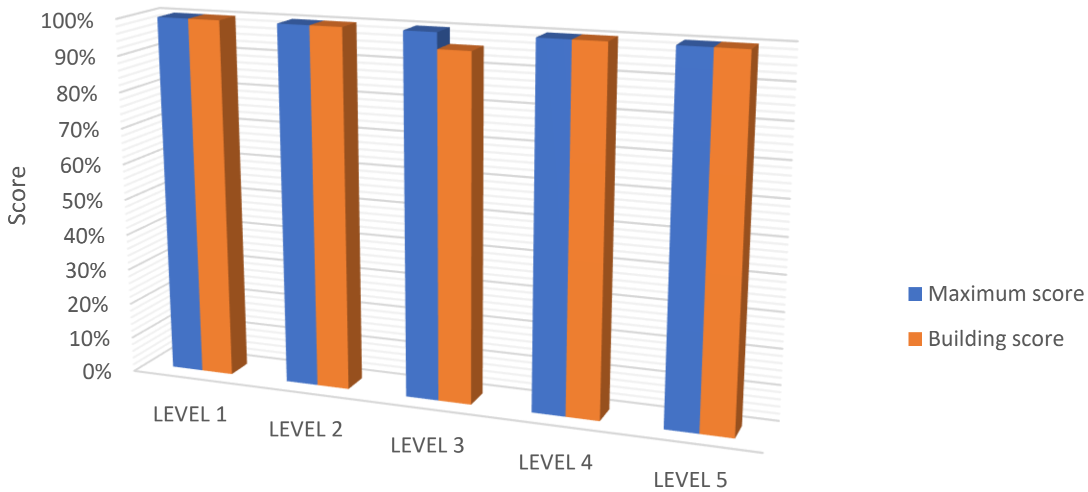


	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Maximum score	100%	100%	100%	100%	100%
Building score	71%	100%	74%	78%	43%

Figure 11 Scores per level for the OHK.

4.2.3 Jachtlaankerk

On the JLK there is an official advisory report regarding the energy use of the building. The report describes the building, the energy use, energy balance, and reduction options. Currently, many of these advices are implemented, and the sustainability project is in its finishing stages. Figure 12 presents the results of this project with a broad approach. The only credit not scored is on planning activities around religious services. Due to the prominent level of multifunctional use of the JKL, this is not possible or relevant. The JKL is a highest scoring case study with a *Level 5* qualification. The level is as expected due to the elaborate preparation and the implementation level.



	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Maximum score	100%	100%	100%	100%	100%
Building score	100%	100%	96%	100%	100%

Figure 12 Scores per level for the JLK

4.3 Validity & Reliability

Determining the validity and reliability of the framework is important to judge its usefulness for further research. The next section presents the validity, followed with a concise review on the reliability of the framework.

4.3.1 Validity of the Framework

Determining the validity of the framework is difficult, as it measures a previously undefined concept. The use of literature and publications about churches, but also from other related fields, such as SB and corporate sustainability, ensured the validity of the framework as much as possible. The application of the tool showed a content validity problem, further analysed below. The improvement of the content validity could further improve the overall validity as it could improve the definition of a sustainable church building.

Reviewing the substance of the framework showed the questionnaire awards 31 credits for planning the project; actions such as formulating goals, measuring values, or comparing values. This effect becomes evident in the case studies, a lack of implementation of measures, did not negatively affect the maturity level. The assumption that plans automatically lead to implementation does not correspond with reality. For example, due to a break from policies or changes in management plans can change which should affect the maturity level of the building. When filling out the questionnaire plans should be relevant, excluding shelved action plans. On top of this, the framework needs modifications to improve its performance, presenting a better ratio between planning, and implementing. An improvement could be setting mandatory requirements per level. These selected questions need a positive answer to pass a level. An alternative would be to review the questionnaire and make changes, either by making planning less relevant or by making implementation more important. A third possibility would be to add quantified benchmarks to the various levels of the framework, explored in the last section.

4.3.2 User Validity

In addition to the reviewing the results from the case studies and the validity of the framework based on these results; there is the validity of the user. Presenting the framework to the workgroup was the used method. The WDH is the client and the first user of the framework. During a workgroup meeting, the first version of the tool was presented to the members. The first part consisted of reviewing the statements on clearness, relevance, and an overall understanding of the question. The second part focussed on the method and the presentation of the results.

4.3.2.1 Part 1: Reviewing the Framework Statements

Reviewing the statements showed some overlap between statements, which would allow a reduction of the number of statements. A reduction is desirable as it would make the process of filling out the framework less time-consuming. It, however, should not reduce the amount of information obtained from the religious community. Also, some of the statements required some clarification, by adding definitions to concepts or concise reformulations.

A more structural point was the YES/NO-structure. One of the workgroup members expressed the opinion of it being too rigid. Answering a statement with YES or NO does not allow for nuances, it does not show the story behind the score. Another point of critique is that the interviewee answers positively, defending their organisation. The workgroup member in question suggested changing the scale to a Likert scale. A five-level Likert allows for nuances in the scores, it, however, also complicates the framework and the interpretations of the scores. Another workgroup member dislikes the idea of a Likert scale as the framework would lose its unambiguity. He argues in favour of a dual scale as it forces religious communities to choose as there is no middle way. Both arguments have merit depending on the individual statements, thus requiring a detailed review of the statements and the scoring structure.

4.3.2.2 Part 2: Reviewing the Framework Output

This part of the framework discussed the output of the framework. During the discussion, there was a strong divide between the workgroup members. The opinions on the framework differed due to the contrasting point of views on its application and on the definition of a sustainable church. The framework in its current form assesses the sustainability of the church building based on the plans and implementations. It does not specify the measures or their economic, ecological, and social performance. The result of the framework is an insight into the current level of sustainability. As well as improvements through reviewing the statements that have a negative score. A part of the workgroup agreed with this approach, while others focussed on the economic resources not affecting the sustainability. As well as, the organisational aspects that influence the sustainability of a church building.

The first point of critique requires returning to the start of this project. The purpose of this study was *to develop a method or tool that measures the sustainability, or lack thereof, in Christian churches that are in use as a place of worship in the Netherlands*. The starting point when considering *measuring the sustainability* was the TBL. This level of detail was not possible, due to a lack of knowledge on the interrelations between measures. Lowering the detail level allows for assessment of the sustainability level of a church building. Differentiating the sustainability level based on the economic resources of the religious community would require more research. This option is more elaborately part of the recommendations. The second point of critique is part of the next section on the application of the framework.

4.3.3 Reliability

The reliability of the framework depends mostly on the honesty and understanding of respondent. In the project, next to the framework, an interview took place at the church and their current situation and actions. This information verified the answers to the questionnaire. If there is no prior knowledge about the church building, a request of proof could be part of the framework. Overall, the framework is reliable, especially when including proof. Important to note here is the fact that plans need to put into actions, or an intent to continue the process. For example, in the OHK there are detailed plans, but no resources or possibility to continue.

4.4 Improved Assessment Framework

The first version of the assessment framework deals with several problems, the main problem being the content validity. As well as adaptions to unclear statements as mentioned by the WDH. The improved version does not include a review of the YES/NO-structure, as this would change the framework drastically. The benefits of an adaptation of the structure requires additional research that was not part of this research project. Mandatory requirements are the first step towards solving the validity problem. Followed by a review of the statements by reformulating, combining, and removing statements. The review of statements leads to a second version of the assessment framework. Finally, presenting improvements that require additional research.

Table 19 Original maturity level, Level after adaptations to the framework & Level in the improved version.

	OLV	OHK	JLK
Original Assessment Framework	Level 1	Level 4	Level 5
Original Assessment Framework including mandatory requirements	Level 0	Level 2	Level 5
Improved Assessment Framework	Level 0	Level 2	Level 5

4.4.1 Mandatory Requirements

In this case, some questions are mandatory to pass to the next tier, considering them essential for a sustainable church building on this level. Also, some measures become partly optional, as within the group a set number requires implementation. For example, in the case of similar measures that reach the same target or complement each other. The three distinct types are: 1) Mandatory; 2) Partially Mandatory; and, 3) Optional. Mandatory actions ensure the continuation of the sustainability project or ensure the undertaking and implementation of certain steps. Partially mandatory are groups of actions with a pre-described achievement number. Optional actions are actions that will contribute to a more sustainable church building but not essential for the continuation of the project. Some are sub-actions of other measures, and a combination might be possible.

In the review of the questionnaire to add the three types of requirements. Appendix C3 presents the suggested additions. In addition to the previous demands of passing the previous level and obtaining half of the credits, the mandatory statements require passing. Adding these conditions lead to new performances, as visible in Table 19. These results correspond more with expectations, especially for the OHK that goes from *Level 4* to *Level 2*. The level of the OLV goes from *Level 1* to *Level 0*, caused by the fact that there are no additional plans to make the building more sustainable. Even though there is progress due to the improvements in the heating system, further action plans or recording of the energy use are not available. The JLK shows no change in level; it remained at *Level 5*. In general, the mandatory requirements improve the results of the framework, balancing planning, and implementation better.

4.4.2 Reviewing Statements

In addition to the mandatory requirements for each level, there was a review of the statements on their formulation and functionality. The review resulted in a reduction of eight statements as presented in Table 20. Through combining statements information or in some cases simply deleting, as another statement described the same action in a better manner. Table 19 describes the results of the improved assessment framework, obtained using the data from the cases. The buildings score in the same Level as in the framework with additional requirements. Appendix C4 & Appendix C5 present the adapted statement list.

Table 20 Number of statements per Level.

	No. of Q.
Level 0: Starting Point	0
Level 1: Initiated	5
Level 2: Managed	7
Level 3: Defined	22
Level 4: Institutionalised	7
Level 5: Optimised	6
Total	**47**

On a statements level, there are some minor differences, but no major differences. The improved assessment framework seems just as effective as the framework with additional requirements, but a more concise. Additional testing on independent cases would be the next step. The current reuse of cases forms an example of how the improved framework could work. It, however, is not a scientific basis for the validity of this improve version.

4.4.3 Additional Improvements: Quantified Benchmarks

In addition to the current improvements, there are enhancements that require more research. Adding quantified requirements to the framework is a possibility as mentioned in earlier sections. Quantified requirements such as energy use, comfort level, or RH fluctuations offer information about the sustainability of the building. Possibilities depend on the relationship between the quantified values and the maturity levels. These relationships are unestablished; determining this would require extensive research into church buildings, their quantified performance, and their sustainability performance. The study should include churches with diverse types of church buildings, as presented in Table 7 and varying levels of sustainability. The study would help to refine the definition of a sustainable church and, depending on the results, improve the framework.

4.5 Preliminary Conclusion

This section answered the second research question: *'What is the sustainability performance of churches in Apeldoorn?'* By applying the assessment framework from section 0 to three cases. The three churches are part of the ABvK. The OLV is a RC church in the city centre of Apeldoorn. It is the only remaining RC church in Apeldoorn as the other buildings ceased to serve as places of worship to cope with the costs. The OHK is a struggling PKN community in Kerschoten, a reconstruction area of national importance according to the RCE. Recently, the community of the OHK decided to take their building out of service, due to lack of financial funds to continue the sustainability project. The JLK is a PKN community in a different area of Apeldoorn, that has expanded their building a few years back. Currently, it is in the finishing stages of a broad sustainability project. The results of the framework showed a range of maturity levels; a similar image is expected for the other churches in Apeldoorn. The differences occur due to the variety of approaches towards sustainability. As well as, differences in resources between the communities.

The results of the OLV corresponded with the expectations; it clearly showed the improvement of the buildings heating system. The improvement of this one system leads to credits on every level for this aspects. The final level of sustainability was not very high, as there are no further plans to improve the buildings. Applying the tool to the OHK, resulted in an elevated level of sustainability. The high maturity did not correspond with the expected level, as the community of the OHK set-up a very detailed and elaborate project plan. However, mostly unimplemented due to a lack of funding. Planning and ambitions are important, however, to reach higher levels of sustainability there also should be the realisation of these plans. The final case showed this; the JLK combined thorough preparation with implementation and scored at the highest level.

The improved assessment framework finds its basis in the original version of the framework, the results from the case studies, and input from the users. Studying the results and the content of the tool showed a validity problem. The number of credits for activities relating to planning or preparing for implementation was too high. Reaching an elevated level of sustainability maturity is possible by formulating plans without implementing them. Other issues in the first version of the framework are an overlap between statements and unclarities in the formulations. The improved framework differs from the original framework due to the addition of mandatory requirements and a reformulation of statements. The mandatory requirements framework solves the validity problems as it enforces implementation to pass levels. The reformulation of statements reduced the total number due to combining or removing redundant statements.

The presented improved framework shows potential but requires testing on independent cases. Testing on other cases ensures the validity of the adapted framework. Another option to consider is quantified benchmarks or ranges. For example setting a required RH range or maximum energy usage for the church building. Currently, the relationship between these values and the maturity level is unknown. For further improvement of this framework, it could be an interesting area to research.

5 Application of the Assessment Framework

Up to now, the focus was on church buildings in religious use and how they can become more sustainable. The introduction presented a short background to the problems of religious communities. The theoretical background contained a section on church buildings. This section elaborated further on religious communities, their buildings, and problems. It also introduced several methods to deal with these issues. This section answers the third research question (Q3): '*How could the sustainability performance play a role in the transformation of churches?*' The desired result of this section is an *Applicable Model* [E]. The input for obtaining this model are the *Improve Sustainability Assessment Framework* [C] and the *Overview of Church Transformation Models* [D]. The first section presents a short recap on the overview [D]. Followed by the proposed applicable model and a reflection on the role of sustainability in this model. Finishing the section with a preliminary conclusion.

5.1 Transformation Processes

Transformation processes are the all the methods and approaches to help religious communities deal with the changes in society. Secularisation is one of the main forces that requires religious communities to transform and adapt. Jelsma [95] presented seven transformation categories. Table 21 provides the categories and a brief description.

Table 21 Transformation Strategies. [95]

No.	Category	Description
I	New identity	Renewal of the *traditional identity* of the religious community. A modern approach towards the identity and traditions to reach a *new (target) audience*.
II	Multifunctional use	*Multifunctional use of the church building without remodelling*. The building is next to the religious function used for a variety of cultural and social activities. This is *multifunctional use in time*.
III	Remodel	*Remodelling of the church building for religious use*. Remodelling can modernise a layout that does not correspond with current requirements. There is often a combination with multifunctional use.
IV	Partially repurposed	*Remodelling of the church building maintaining a smaller religious space*. The new smaller place of worship allows for multifunctional use of the rest of the building for a wider variety of functions. This is an example of *multifunctional or shared use in space*
V	Reuse	*The religious community leaves the building, but the function remains*. Another religious community uses the church building as their place of worship.
VI	Repurpose	*The religious community leaves the building and the function changes*. The new user transforms the church building for their purpose.
VII	New Building	A religious community can decide to *construct a new building*.

Missing from these categories are several options for alternative housing. Construction, a new building, is not the only option. As well as, the possibility of demolishing the church building. Figure 13 presents a schematic overview of this adapted version. Religious communities have three main choices: Retain the church building, find alternative housing, and sell the current building. Figure 13 shows a connection between *Alternative Housing* and *Sell Building* as these options affect each other. A successful sale of the church building will have a positive effect on the budget for alternative housing. In the same way that difficulties in selling will often cause difficulties for alternative housing plans.

In Table 21 and Figure 13 there is no mention of the problems that require solutions. A solution based approach corresponds to the approach seen in publications to aid religious communities. Adapting the solution to match the problem. Reflection on the success of the solution takes place afterwards. If a solution turns out to be unsuccessful,continuation steps are unclear. A publication with a different approach is from Stadig [112]. This manual for church leaders presents a systematic model starting with a problem analysis. The determined problem guides the reader towards appropriate solutions, as well as additional options if effects are insufficient. The downside of this manual it does not include all the transformation processes. There is a focus on multifunctional use or several types of alternative housing. The lack of the other options could deprive religious communities of reaching their optimal solution. Also, the manual, as well as the transformation processes, misses sustainability as a solution. The next section reflects on sustainability as a transformation process.

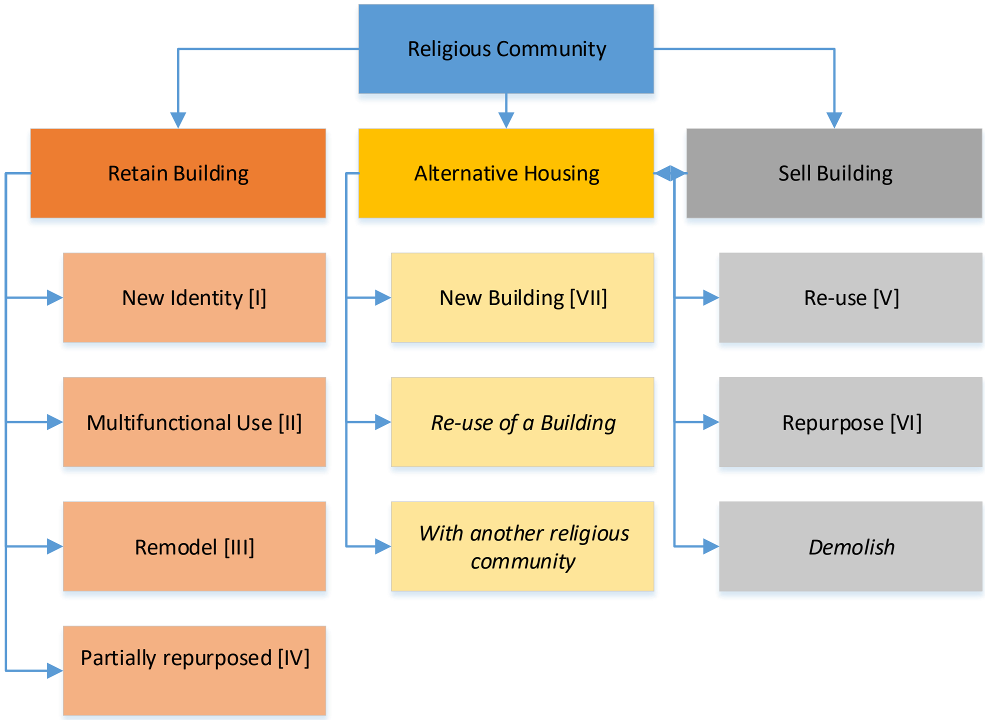


Figure 13 Adapted version of the transformation categories

5.2 Sustainability as a Transformation Process

Discussions on transformation processes do not include sustainability There are religious communities that use sustainability as an adaption method. Often these communities have people with relevant (technical) knowledge or find support with initiatives such as 'Groene Kerken'. Difficulties in planning sustainability projects seem not to be in the technical aspect but in other areas.

The OHK in Apeldoorn forms an excellent example, there was a planned project, but no funds for implementation. Measures that make a church building more sustainable, often result in a cost reduction, but also requires an investment. The investment and the payback period will limit the first monetary benefits from the measure. Applying actions that do not require an investment would allow direct benefits. On the long term, this is not sufficient, as reduction remain marginal. Successfully execute sustainability project requires funding, making alternative funds a more long-term solution. Crowdfunding could collect as much of the investment as possible, which is a serious possibility. It does require time and effort to design it properly, especially the structure of funding. Finally, there is the possibility of exploring available funds or special loans, for example from the local or national government. Also, some businesses are willing to fund sustainability projects. Several possibilities can help mitigate the pressure of the investment costs. It is important to ensure that the financial situation of the church improves, avoiding risks as much as possible.

Another difficulty is the time available. The time between detection of the problem and starting to work towards the solution is critical. Early on problem detection allows more time to solve the problem. However, early on detection is often not the case. A limited period might not leave a window for the implementation of sustainability measures. Several issues, such as the previously discusses investment sum, but also the time needed to implement plans and see results. For churches with immediate problems sustainability is a risky strategy, as uncertainties about the costs and the benefits remain even with planning. A risk mitigating strategy could be combining approaches exploring both sustainability improvements and occupancy efficiency. The religious community must look critically at their situation and weigh the different options against each other while keeping in mind the period for reaping the effects of measures.

Determining the potential of sustainability as an independent transformation process remains difficult. There are cases where that proof successful, but also cases in which it is not. Key factors seem to be the size of the problem, the available funds and time, and the current situation of the building. In this last factor, the *Sustainability Assessment Framework* could support the religious communities. The results provide a quick insight into potential improvements. The framework reduces the time previously needed to plan the project. The reduced time, however, does not provide additional insight into the reason for failure or success of sustainability as a transformation process. Exploring the factors for failure and success would make is possible to judge the potential of sustainability. The next section presents a proposed scheme of transformation processes, and process or actions related to the adaptation of religious communities. The proposed model requires additional research for validation and verification. As well as, indicators on when a certain process is appropriate and when not.

5.3 Proposed Model for Transformation

The first two sections presented the current transformations processes and the potential role of sustainability. In this section presents this role in a proposed model for transformation. Even though this is not common practice the model starts with defining the problem, just as Stadig [112]. Also similar is the systematic approach, differences are the included categories. The model includes all categories from Figure 13 as well as sustainability. Table 22 presents the individual components by their identification number in the figure, their link to Figure 13 and a concise description. The goals of the proposed model is to return to the problem and present different solutions in one scheme. Figure 14 presents the proposed model.

Table 22 Components of the proposed model of transformation processes

		Component	Description
1		Ecclesial & Financial Situation	Analysis of the situation and problems
2		Improving Sustainability of the Building [*III*]	Functions as preventive measure or out of conviction
3			
	.1	Reduce Energy Costs	Sustainability measures to reduce the exploitation costs
	.2	Improve Occupancy Efficiency	Generate additional income by increasing the users
	.3	Less Expensive Housing	Alternative housing with lower exploitation costs
4		New Identity [*I*]	Renewal of the traditional identity to reach a new audience
5		Sustainability Assessment Framework	Providing insight into the current level of sustainability
	.1	Energy Management	Sustainability measures in distinct categories
	.2	Energy Demand Reduction	
	.3	Energy Efficiency Improvement	
	.4	Renewable Energy	
6			
	.1	Partially Repurposed [*IV*]	Remodelling keeping a smaller religious space
	.2	Multifunctional Use [*II*]	Finding additional users in time.
7			
	.1	New Building [*VII*]	Constructing a new building
	.2	(Re-)use of a Building	Finding housing in an existing (church) building
	.3	Merging with another Religious Community	The religious community cease to be independent
8		Sell Building	Selling the church building by finding a new building
	.1	Reuse [*V*]	Finding another religious community that can use the building
	.2	Repurpose [*VI*]	Another user that uses the church building in another function
	.3	Demolish	Taking down the building; the ground sold
9			
	.1	In Their Building	Merging with another community in their building
	.2	In Their Building; (too) High Exploitation Costs	Merging with another community, problems remain
	.3	Building is taken out of Service	Both communities decide to go to another church building

Determining the situation and the problem is the first step in Figure 14. The two main problems are high exploitation costs and a declining religious community size. The third category of communities has no immediate problem. The situation of the faith community determines the appropriate form of action. An appropriate response can be one action or a combination of actions. In some cases, finding the best solution requires exploring several options. For example, if the exploitation costs are too high reducing the *energy costs* [3.1] might not be sufficient, requiring *improving the occupancy efficiency* [3.2] at the same time. Another example is *less expensive housing* [3.3] that relates to the *sale of the current building* [8]. Sustainability can function as a preventive measure, but also as a solution. As stated in the previous section it is difficult to determine when it is an appropriate approach. When it sustainability is suitable requires additional research into the success and failure of a similar project. An additional topic of research is the validation and verification of the proposed model.

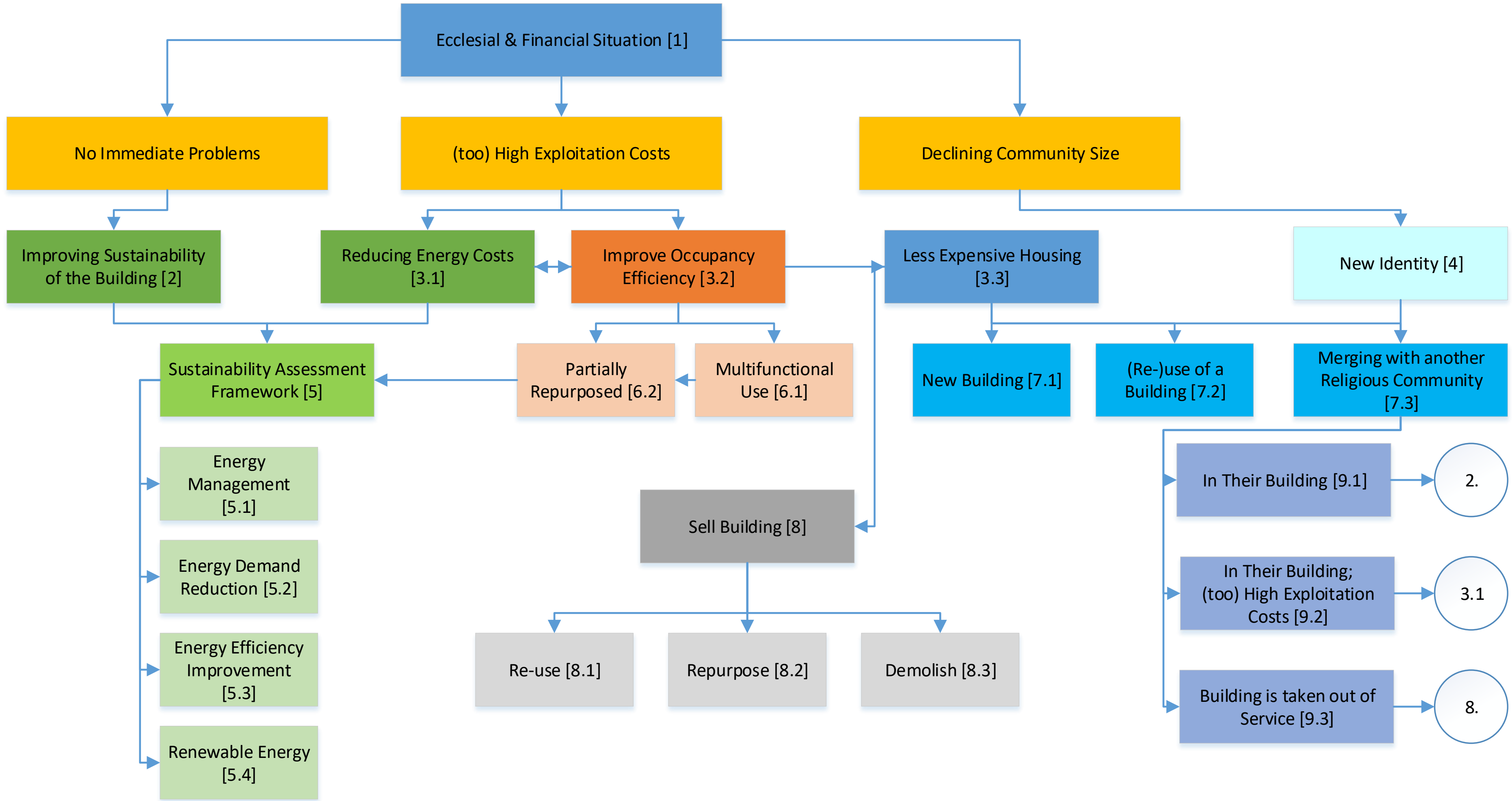


Figure 14 Proposed model for the transformation of church buildings.

5.4 Preliminary Conclusion

This section answers the third research question (Q3): '*How could the sustainability performance play a role in the transformation of churches?*' Answered by presenting a proposition for an *Applicable Model* [E].

The current transformation processes and publications focus on the solution; first selecting a solution and formulating measures accordingly. Limiting the option of combining and comparing solutions. Starting at the problem does allow these options. It also makes adding sustainability as a solution possible. Sustainability is usable as a preventive measure for religious communities without immediate problems. As well as, a means to lower exploitation costs. The potential of this role is uncertain as a sustainability project requires resources such as capital and time. The availability might depend on the problems of the religious community. Defining the potential of sustainability requires additional knowledge on the success and failure factors of a sustainability project. Information on these factors can help formulate the application rate. Currently, the role of sustainability is mostly preventive, a solution in the case of minor problems, or combined with another approach.

The applicable model applies the assessment framework to provide a quick insight into the sustainability of a church building. Aiding religious communities in seeing the possibilities in a short amount of time. Further, it provides an overview of the typical transformation process or related actions. As well as, combinations or processes that take place simultaneously. The applicable model is a proposed model that requires validation and verification, through further research.

6 Discussion, Conclusion & Recommendations

This section starts with the discussion, followed by the conclusions that come from the research project. Finally, presenting some recommendations to the WDH.

6.1 Discussion

As said in the introduction a general approach for improving the sustainability performance of church building was missing. Also, a concrete definition for a sustainable church building even seemed to be missing. Sustainability is defined by using the TBL [3], [4], and is not limited to a church building. This research project needed a definition of a sustainable church. The definition formulated using definitions from sustainable building in combination with the accepted framework for religious communities and the definition of a 'Groene Kerk' by the Groene kerken initiative. Additional research could improve the definition of a sustainable church by adding quantified performance indicators. Quantified indicators would aid religious communities, and improve the quality of the *Improved Sustainability Assessment Framework.* If there is no relation between the *maturity levels* and quantified performance the current function of the framework remains. It provides an overview of steps for planning and implementing a sustainability project, while simuntaniously giving insight into the progress.

The chapter on the case studies includes an elaborate discussion on the validity of the framework. The content validity and comments from the users formed the basis to adapt the original version of the assessment framework. The review resulted in an *Improve Sustainability Assessment Framework*. This version needs additional testing on independent cases. The currents tests showed positive yet unreliable results, as the input came from the cases used to test the original version of the framework.

The basis for the proposed model for transformation processes are publications, and practice in Apeldoorn. Two uncertainties remain one is the validity of the proposed applicable model. A validation step is not part of study, but essential before application. A second uncertainty is the role of sustainability as a solution for problems. The potential role of the assessment framework is clear; providing a quick insight into the current level of sustainability and improvements. The risks of sustainability as a solution strategy remain unknown. Sustainability is effective as a preventive measure or in combination with another transformation process. As an independent problem solver, it requires research to estimate the potential. For example, by considering the success and failure factors of sustainability projects for church buildings.

Overall, the study defined a sustainable church on distinct levels; a framework to assess the level and application options for the framework. The studied explored various aspects of a sustainable church building provided an overview and translated this to a framework of maturity levels. The assessment framework requires additional testing but forms a first step towards making the sustainability of a church building assessable.

6.2 Conclusion

The question sought to answer in this project is as follows: '*How can the sustainability performance of churches in religious use be assessed and be improved?*' A literature study forms the basis of the developed framework; a framework that can assess the sustainability performance of a church building. As well as offer insight into improvements. Testing the framework took place in Apeldoorn. Finally, proposing a combined approach for transformation including a potential role for sustainability.

The energy use relates strongly to the sustainability performance of a church building, making it the focus of the framework and suggested improvements. The energy use regards the absolute energy use, not considering the source. Dividing the measures, conform multiple SB-strategies, into four categories: (1) *Energy Management*; (2) *Energy Demand*; (3) *Energy Efficiency*; and, (4) *Renewable Energy*. These classes structure the different actions and offer an overview to facilitate actions that match the objectives. Six criteria, coming from literature, express the TBL performance of a measure. The six criteria: (1) *Investment Costs*; (2) *Energy Cost Reduction*; (3) *GHG Emission Savings*; (4) *Monumental Value Impact*; (5) *Preservation*; and, (6) *Thermal Comfort*. Individually scoring action on the criteria due to the observed interrelations between the measures. The best way to overcome this problem is to assess the sustainability of a church building using maturity levels. The six maturity levels describe the awareness of sustainability within the community, formulation of plans, the progress of implementation, and expresses the degree of integration of sustainability. The maturity levels are: (0) *Starting Point*; (1) *Initiated*; (2) *Managed*; (3) *Defined*; (4) *Institutionalised*; and, (5) *Optimised*. A list of 55 statements determines the actions a religious community has taken and decided the level of maturity. The results provide insight into the status of the building, and what further steps are available to improve.

Case study tests in Apeldoorn show a strong content validity problem. From the 55 statements, at least 31 statements relate to measuring, preparing, planning, or comparing. Making a church building highly sustainable by preparing and taking minor measures; this should not be the case. The WDH, as the user of the framework, reflected upon the content and found some unclarities, redundant statements, and overall formulation issues. The solution selected for the content problem is mandatory statements, reducing the influence of planning. A reduced and reviewed list of 47 statements forms the improved sustainability assessment framework.

The proposed applicable model requires additional research, as validation was not part of this research project. The potential role of sustainability for transformation processes comes with risks. The extent of possible risk mitigation is uncertain. Sustainability is a single approach is only applicable as a preventive approach or when problems are small. In any other case, it is important to keep in mind the constraints and consider a joint approach.

Concluding the sustainability of a church building is assessable by a framework of maturity levels. The maturity levels provide insight into the current level of sustainability but also where improvements are. However, there are several options to improve the assessment framework. As well as, application possibilities that require further research. Leading to the proposal of a research agenda:

(1) Additional testing to the improved sustainability assessment framework to ensure the validity of the updated version.
(2) Refine the definition of a sustainable church, among others by adding quantifiable parameters.
(3) Collect data on the quantified parameters in a wide variety of church buildings. As well as, determining the maturity level by applying the framework. The combination of quantified data and the maturity level enables a study into the correlations between the parameters and the maturity level. If there is a correlation present a new framework that includes quantified requirements.
(4) The improved understanding of relationships allows for an improved assessment framework. A next step could be broadening the included topics. The current focus is the church building and energy use. Other topics influence the sustainability performance of the building.
(5) Consulting experts on the validity of the proposed for the transformation of church buildings.
(6) Exploring the potential of sustainability projects for struggling religious communities. Studying the success and failure factors in past projects. As well as, the role of the assessment framework.
(7) A better understanding of the potential of sustainability allows for broadening the scope. Defining the role of sustainability within the model for transformation; including when it is applicable and how. The model aids religious communities in selecting actions to adapt to the future. By presenting an overview of all possibilities with estimated success ratings.

The presented agenda shows two topics on being the assessment framework, the other the applicable model. Splitting the agenda at point 5 is possible. Research on the applicable model can link to the assessment framework. As well as, approached separately. Focussing on the role of sustainability and leaving out the function of the assessment framework.

6.3 Recommendations

The first recommendation concerns the management and planning of sustainability project. In particular, the role the WDH could have. A hypothesis at the start of this research project was the lack of technical knowledge forming a barrier for a movement towards sustainable churches. This assumption turned out to be false, based on the available literature and contact with several religious communities. What seems to be the most difficult is the planning of the project, especially obtaining resources. For example, planned projects are incomplete due to lack of funding. For the communities in question, it is not always clear why. Decision made by other stakeholders lead to incomprehension, disappointment, and irritations within the disadvantaged religious community. Early on stakeholder consultation could work preventive and is a known technique in project management. In this process, the WDH could play a facilitating role. Firstly, due to their neutral and independent position, the workgroup can be a go-between. Secondly, the workgroup members have a broader view, enabling them in providing insight into the decision-making structures and stakeholders for the specific communities. This could aid religious communities into talking to the right people at the start of preparing a project. Overall, the

WDH is a stable neutral factor in an arena where the players and the role of the players change. To optimally utilise this function the WDH should profile itself, be aware what is going on in religious communities, actively reach out to offer support, but also be approachable.

Approachability of the WDH is immediately the second recommendation. One of the motivations for this study was the desire of the workgroup to support religious communities, in Apeldoorn or other regions, in becoming more sustainable. However, in Apeldoorn awareness of the task groups existence, activities and support are limited. To play a supportive role the name recognition needs to improve.

Depending on the desired use for the framework additional research is interesting. In the research agenda mentions several options. One that deserves mentioning is adding additional categories to the framework. In addition to measures in relation to the building, religious communities partake in many other activities. Separating waste streams, reducing waste streams, using fair trade projects are a fraction of actions by religious communities. The framework excluding these efforts from the maturity levels, as the overall effect on the sustainability of the building is marginal. Still, it would provide satisfaction to the religious communities to see all their efforts included.

Bibliography

[1] 'Start | Apeldoornse beraad van kerken'. [Online]. Available: http://www.apeldoornsberaadvankerken.nl/cms/. [Accessed: 28-Oct-2016].

[2] N. Roeterdink, J. de Jong, L. Tilleman, R. Wierenga, and P. van Geel, 'Onderzoek herbestemming kerken en kerklocaties; een inventarisatie vanaf 1970', Bisdom Haarlem, Bisdom Rotterdam en Projectbureau Belvedere, Haarlem, Inventarisatie, Dec. 2008.

[3] 'Groenekerken.nl - Kerken kiezen voor duurzaamheid', *Groenekerken.nl*. [Online]. Available: https://www.groenekerken.nl/. [Accessed: 03-Nov-2016].

[4] Werkgroep Duurzaamheid, 'Duurzaamheid vanuit het Apeldoorns Beraad van kerken (werkgroep) [Sustainability from the ABvK (workgroup)]'. Apr-2015.

[5] T. Bernts and J. Berghuijs, *God in Nederland 1966-2015*, 1st ed. Utrecht: Ten Have, 2016.

[6] CBS, 'Kerkelijke gezindte en kerkbezoek in 403 gemeenten, 2010/2014 (18 jaar en ouder 1)'. CBS, mei-2015.

[7] Hans Schmeets, 'Bevolkingstrends 2014: De religieuze kaart van Nederland, 2010–2013 [Population Trends 2014: The Religious Map of the Netherlands, 2010-2013]', Centraal Bureau voor de Statistiek, Den Haag, Sep. 2014.

[8] Rijksdienst voor het Cultureel Erfgoed, 'Een toekomst voor kerken; Handreiking voor het aanpassen van kerkgebouwen in religieus gebruik [Brochure]'. Rijksdienst voor het Cultureel Erfgoed, Jan-2012.

[9] 'The Bible Goes Green: New Bible with Recycled Paper, Soy Ink and Green Verses', *EcoSalon*, 06-Jan-2009. .

[10] Paus Franciscus, *Laudato si'; Over de zorg voor het gemeenschappelijke huis [Encycliek]*, 1st ed. Baarn: Adveniat Geloofseducatie B.V., 2015.

[11] H. van der Spek and G. Olbertijn, *Duurzaam ondernemen; Een praktisch werkboek [Sustainable Enterprise; A Practical Workbook]*. Putten: CBMC Nederland, 2011.

[12] 'Laudato Si' - De zorg voor ons gemeenschappelijk huis | Welkom'. [Online]. Available: http://laudato-si.nl/. [Accessed: 03-Nov-2016].

[13] G. K. C. Ding, 'Sustainable construction--the role of environmental assessment tools', *J. Environ. Manage.*, vol. 86, no. 3, pp. 451–464, Feb. 2008.

[14] A. Haapio and P. Viitaniemi, 'A Critical Review of Building Environmental Assessment Tools', *Environ. Impact Assess. Rev.*, vol. 28, no. 7, pp. 469–482, Oct. 2008.

[15] 'Kerkverwarming in Edese kerken; voor een beter binnenklimaat, minder CO2-uistoot en lagere energiekosten', Ede's kerkelijk platform voor Duurzaamheid en Energiebesparing (EkDE), Ede, 2012.

[16] D. Ketel and R. Scheele, *Duurzame kerkverwarming [Sustainable Church Heating]*. Bennekom: ZWO-taalgroep Kerk & Milieu/Samenleving, Bennekom, 2014.

[17] P. Glavič and R. Lukman, 'Review of sustainability terms and their definitions', *J. Clean. Prod.*, vol. 15, no. 18, pp. 1875–1885, Dec. 2007.

[18] K. Steemers and S. Manchanda, 'Energy efficient design and occupant well-being: Case studies in the UK and India', *Build. Environ.*, vol. 45, no. 2, pp. 270–278, Feb. 2010.

[19] 'Worstelen met duurzaamheid | kennisbank BestaandeWoningBouw'. .

[20] E. D. Özdemir, M. Härdtlein, T. Jenssen, D. Zech, and L. Eltrop, 'A Confusion of Tongues or the Art of Aggregating Indicators—Reflections on Four Projective Methodologies on Sustainability Measurement', *Renew. Sustain. Energy Rev.*, vol. 15, no. 5, pp. 2385–2396, Jun. 2011.

[21] World Commission on Environment and Development, 'Our Common Future', Oxford University, Oxford, New York, Apr. 1987.

[22] D. A. Munro, M. W. Holdgate, and W. W. F. for Nature, *Caring for the Earth: A Strategy for Sustainable Living*. published in partnership by IUCN, UNEP, WWF, 1991.

[23] (International Council for Local Environmental Initiatives) ICLEI, *The Local Agenda 21 Planning Guide: An Introduction to Sustainable Development*. IDRC, 1996.

[24] D. Mitlin and D. Satterthwaite, 'Sustainable development and cities', in *Sustainability, the Environment and Urbanization*, Earthscan, 1996, pp. 23–62.

[25] J. Hay and N. Mimura, 'Supporting climate change vulnerability and adaptation assessments in the Asia-Pacific region: an example of sustainability science', *Sustain. Sci.*, vol. 1, no. 1, pp. 23–35, Oct. 2006.

[26] M. Redclift, 'Sustainable Development: Needs, Values, Rights', *Environ. Values*, vol. 2, no. 1, pp. 3–20, Feb. 1993.

[27] M. Redclift, 'Sustainable development (1987–2005): an oxymoron comes of age', *Sustain. Dev.*, vol. 13, no. 4, pp. 212–227, oktober 2005.

[28] Y. A. Phillis and L. A. Andriantiatsaholiniaina, 'Sustainability: an ill-defined concept and its assessment using fuzzy logic', *Ecol. Econ.*, vol. 37, no. 3, pp. 435–456, Jun. 2001.

[29] R. W. Kates, T. M. Parris, and A. A. Leiserowitz, 'What is sustainable development? Goals, indicators, values and practice', *Environment: Science and Policy for Sustainable Development*, vol. 47, no. 3, pp. 8–21, Apr. 2005.

[30] D. Laws, R. W. Scholz, H. Shiroyama, L. Susskind, T. Suzuki, and O. Weber, 'Expert views on sustainability and technology implementation', *Int. J. Sustain. Dev. World Ecol.*, vol. 11, no. 3, pp. 247–261, Sep. 2004.

[31] R. W. Scholz, *Environmental Literacy in Science and Society: From Knowledge to Decisions*. Cambridge University Press, 2011.

[32] Y. Kajikawa, 'Research core and framework of sustainability science', *Sustain. Sci.*, vol. 3, no. 2, pp. 215–239, Oct. 2008.

[33] P. Martens, ‘Sustainability: Science or Fiction?’, *ResearchGate*, vol. 2, no. 3, pp. 70–70, Sep. 2007.
[34] J. Grosskurth and J. Rotmans, ‘The Scene Model: Getting A Grip On Sustainable Development In Policy Making’, *ResearchGate*, vol. 7, no. 1, pp. 135–151, Jan. 2005.
[35] K. Kastenhofer and C. Rammel, ‘Obstacles to and potentials of the societal implementation of sustainable development a comparative analysis of two case studies’, *Sustain. Sci. Pract. Policy*, vol. 1, no. 2, pp. 5–13, 2005.
[36] J. W. S. Young, ‘A Framework for the Ultimate Environmental Index – Putting Atmospheric Change into Context with Sustainability’, *Environ. Monit. Assess.*, vol. 46, no. 1–2, pp. 135–149, 1997.
[37] ‘Wat is People, Planet, Profit’, *wattanders*, 2010. [Online]. Available: http://wattanders.nl/duurzaamheid/duurzaamheidsmeting/wat_is_people_planet_profit/. [Accessed: 07-Nov-2016].
[38] J. Elkington, *Cannibals with Forks; The Triple Bottom Line of 21st Century Business*, 2nd ed. Oxford, UK: Capstone Publishing Ltd, 1999.
[39] T. Wolters, *Sustainable value creation; As a challenge to managers and controllers*, 1st ed. Apeldoorn: Wittenborg University Press, 2013.
[40] ‘What is green building? | U.S. Green Building Council’. [Online]. Available: http://www.usgbc.org/articles/what-green-building. [Accessed: 17-Nov-2016].
[41] G. John, D. Clements-Croome, and G. Jeronimidis, ‘Sustainable building solutions: a review of lessons from the natural world’, *Build. Environ.*, vol. 40, no. 3, pp. 319–328, maart 2005.
[42] O. Ortiz, J. C. Pasqualino, and F. Castells, ‘Environmental performance of construction waste: Comparing three scenarios from a case study in Catalonia, Spain’, *Waste Manag.*, vol. 30, no. 4, pp. 646–654, Apr. 2010.
[43] P. O. Akadiri, E. A. Chinyio, and P. O. Olomolaiye, ‘Design of A Sustainable Building: A Conceptual Framework for Implementing Sustainability in the Building Sector’, *Buildings*, vol. 2, no. 2, pp. 126–152, May 2012.
[44] R. C. Hill and P. A. Bowen, ‘Sustainable construction: principles and a framework for attainment’, *Constr. Manag. Econ.*, vol. 15, no. 3, pp. 223–239, mei 1997.
[45] E. Lysen, ‘The Trias Energica: Solar Energy Strategies for Developing Countries’, presented at the EUROSUN Conference DGS Sonnenenergie Verlags-GmbH, Freiburg, Germany, 1996.
[46] A. G. Entrop and H. J. H. Brouwers, ‘Assessing the Sustainability of Buildings Using a Framework of Triad Approaches’, *J. Build. Apprais.*, vol. 5, no. 4, pp. 293–310, 2010.
[47] B. J. Schrieken, ‘Geloof in Transformatie; Een keuze- en haalbaarheidsmodel voor de functie na transformatie van kerken uit de wederopbouw.’, Technische Universiteit Delft, Delft, 2000.
[48] R. Geraedts and T. van der Voordt, *Transformatie van kantoorgebouwen: thema’s, actoren, instrumenten en projecten*. Rotterdam: 010 Publishers, 2007.
[49] N. v. d. Vlist, ‘Vlist, N. v. d. (2004). Geloofwaardige Transformatie. Technische Universiteit Delft, Delft.’, Technische Universiteit Delft, Delft, 2004.
[50] L. Grootswagers and H. Westerbeek, ‘Religieus ErfgoedWijzer Gelderland. Gids tussen regels en mogelijkheden | Kennis- en projectenbank herbestemming’. Erfgoed.nu, 2010.
[51] J. Lausten, ‘Energy efficiency requirements in building codes, energy efficiency policies for new buildings’. International Energy Agency (IEA), Mar-2008.
[52] P. Torcellini, S. Pless, M. Deru, and D. Crawley, ‘Zero Energy Buildings: A Critical Look at the Definition’, in *Conference Paper NREL/CP-550-39833 June 2006*, Pacific Grove, California, 2006.
[53] European Parliament, *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings*. 2010.
[54] A. J. Marszal *et al.*, ‘Zero Energy Building – A review of definitions and calculation methodologies’, *Energy Build.*, vol. 43, no. 4, pp. 971–979, Apr. 2011.
[55] D. Crawley and I. Aho, ‘Building Environmental Assessment Methods: Applications and Development Trends’, *Build. Res. Inf.*, vol. 27, no. 4–5, pp. 300–308, Jul. 1999.
[56] R. J. Cole, ‘Emerging trends in building environmental assessment methods’, *Build. Res. Inf.*, vol. 26, no. 1, pp. 3–16, Jan. 1998.
[57] J. Andrade and L. Bragança, ‘Sustainability assessment of dwellings – a comparison of methodologies’, *Civ. Eng. Environ. Syst.*, vol. 33, no. 2, pp. 125–146, Apr. 2016.
[58] L. Bragança, R. Mateus, and H. Koukkari, ‘Building Sustainability Assessment’, *Sustainability*, vol. 2, no. 7, 2010.
[59] M. Y. L. Chew and S. Das, ‘Building Grading Systems: A Review of the State-of-the-Art’, *Archit. Sci. Rev.*, vol. 51, no. 1, pp. 3–13, Mar. 2008.
[60] N. Larsson, ‘Research Information: Green Building Challenge ’98 – International strategic considerations’, *Build. Res. Inf.*, vol. 26, no. 2, pp. 118–121, maart 1998.
[61] S. Seo, S. Tucker, M. Ambrose, P. Mitchell, and C.-H. Wang, ‘Technical Evaluation of Environmental Assessment Rating Tools’, Research and Development Corporation, Victoria, Australië, PN05.1019, Dec. 2005.
[62] L. Reijnders and A. van Roekel, ‘Comprehensiveness and Adequacy of Tools for the Environmental Improvement of Buildings’, *J. Clean. Prod.*, vol. 7, no. 3, pp. 221–225, Mar. 1999.
[63] W. B. Trusty, ‘Introducing an assessment tool classification system’, *ResearchGate*, vol. 1, p. 2, Jan. 2000.
[64] R. S. Srinivasan, W. W. Braham, D. E. Campbell, and D. C. Curcija, ‘SUSTAINABILITY ASSESSMENT FRAMEWORKS, EVALUATION TOOLS AND METRICS FOR BUILDINGS AND ITS ENVIRONMENT–A REVIEW’, presented at the

Proceedings of Building Simulation: 12th Conference of Intl Building Performance Simulation Association, Sydney, 2011, pp. 350–357.
[65] S. Nibel, T. Luetzkendorf, M. Knapen, C. Boonstra, and S. Moffat, 'Annex 31 Energy Related Environmental Impact of Buildings', IEA, Hertfordshire, UK, 2005.
[66] 'New LEED Pilot Credit for TBL Analysis', *Impact Infrastructure Inc.* .
[67] R. Mateus and L. Bragança, 'Sustainability assessment and rating of buildings: Developing the methodology SBToolPT–H', *Build. Environ.*, vol. 46, no. 10, pp. 1962–1971, oktober 2011.
[68] R. J. Cole, 'Building environmental assessment methods: clarifying intentions', *Build. Res. Inf.*, vol. 27, no. 4–5, pp. 230–246, Jul. 1999.
[69] A. Hammond, 'Environmental Indicators: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development', *ResearchGate*, Jan. 1995.
[70] J. C. Kurtz, L. E. Jackson, and W. S. Fisher, 'Strategies for evaluating indicators based on guidelines from the Environmental Protection Agency's Office of Research and Development', *Ecol. Indic.*, vol. 1, no. 1, pp. 49–60, Aug. 2001.
[71] S. Geissler and T. Macoun, 'Austrian State-of-the-Art Report. CRISP Project: Marne-la-Vallee', France, 2001.
[72] S. Dammann and M. Elle, 'Environmental indicators: establishing a common language for green building', *Build. Res. Inf.*, vol. 34, no. 4, pp. 387–404, Jul. 2006.
[73] H. ALwaer and D. J. Clements-Croome, 'Key performance indicators (KPIs) and priority setting in using the multi-attribute approach for assessing sustainable intelligent buildings', *Build. Environ.*, vol. 45, no. 4, pp. 799–807, Apr. 2010.
[74] J. H. Spangenberg, S. Pfahl, and K. Deller, 'Towards indicators for institutional sustainability: lessons from an analysis of Agenda 21', *Ecol. Indic.*, vol. 2, no. 1–2, pp. 61–77, Nov. 2002.
[75] G. Fernández-Sánchez and F. Rodríguez-López, 'A Methodology to Identify Sustainability Indicators in Construction Project Management—Application to Infrastructure Projects in Spain', *Ecol. Indic.*, vol. 10, no. 6, pp. 1193–1201, Nov. 2010.
[76] H. L. Schellen, 'Heating monumental churches: indoor climate and preservation of cultural heritage', Technische Universiteit Eindhoven, Eindhoven, 2002.
[77] D. Camuffo, *Church Heating and the Preservation of the Cultural Heritage. Guide to the Analysis of the Pros and Cons of Various Heating Systems*. Milano: Mondadori Electa S.p.A., 2006.
[78] R. C. Retzlaff, 'Green Buildings and Building Assessment Systems: A New Area of Interest for Planners', *CPL Bibliogr.*, vol. 24, no. 1, pp. 3–21, Aug. 2009.
[79] A. Sharifi and A. Murayama, 'A critical review of seven selected neighborhood sustainability assessment tools', *Environ. Impact Assess. Rev.*, vol. 38, pp. 73–87, Jan. 2013.
[80] S. Bell and S. Morse, *Measuring Sustainability: Learning From Doing*. Routledge, 2013.
[81] O. Lindholm, J. M. Greatorex, and A. M. Paruch, 'Comparison of Methods for Calculation of Sustainability Indices for Alternative Sewerage Systems—Theoretical and Practical Considerations', *Ecol. Indic.*, vol. 7, no. 1, pp. 71–78, Jan. 2007.
[82] iiSBE, 'Manitoba Hydro - SBC08 Canada', *Case Study 3: Manitoba Hydro Head Office, Winggipeg, MN*, 2008. [Online]. Available: http://iisbe.org/iisbe/sbc2k8/teams/canada/Manitoba_Hydro/can_Man_Hydro.htm. [Accessed: 07-Jun-2017].
[83] D. Tyteca, 'On the Measurement of the Environmental Performance of Firms— A Literature Review and a Productive Efficiency Perspective', *J. Environ. Manage.*, vol. 46, no. 3, pp. 281–308, maart 1996.
[84] L. Díaz-Balteiro and C. Romero, 'In search of a natural systems sustainability index', *Ecol. Econ.*, vol. 49, no. 3, pp. 401–405, Jul. 2004.
[85] X. Olsthoorn, D. Tyteca, W. Wehrmeyer, and M. Wagner, 'Environmental indicators for business: a review of the literature and standardisation methods', *J. Clean. Prod.*, vol. 9, no. 5, pp. 453–463, oktober 2001.
[86] P. Zhou, B. W. Ang, and D. Q. Zhou, 'Weighting and Aggregation in Composite Indicator Construction: a Multiplicative Optimization Approach', *Soc. Indic. Res.*, vol. 96, no. 1, pp. 169–181, Mar. 2010.
[87] D. Jato-Espino, E. Castillo-Lopez, J. Rodriguez-Hernandez, and J. C. Canteras-Jordana, 'A Review of Application of Multi-Criteria Decision Making Methods in Construction', *Autom. Constr.*, vol. 45, pp. 151–162, Sep. 2014.
[88] G. K. C. Ding, 'Developing a Multicriteria Approach for the Measurement of Sustainable Performance', *Build. Res. Inf.*, vol. 33, no. 1, pp. 3–16, Jan. 2005.
[89] R. J. Baumgartner and D. Ebner, 'Corporate sustainability strategies: sustainability profiles and maturity levels', *Sustain. Dev.*, vol. 18, no. 2, pp. 76–89, maart 2010.
[90] M. Amini and C. C. Bienstock, 'Corporate sustainability: an integrative definition and framework to evaluate corporate practice and guide academic research', *J. Clean. Prod.*, vol. 76, pp. 12–19, Aug. 2014.
[91] D. Ebner and R. J. Baumgartner, 'The Relationship Between Sustainable Development and Corporate Social Responsibility', presented at the Corporate Responsibility Research Conference 2006, Dublin, 2006.
[92] D. Limpens-Neilen, 'Bench Heating in Monumental Churches Thermal Performance of a Prototype', Technische Universiteit Eindhoven, Eindhoven, 2006.
[93] A. van der Lingen and J. H. Uytenbogaardt, 'Een protestantse visie op het kerkgebouw met een praktisch-theologisch oogmerk; Discussienota van de Protestantse Kerk in Nedeland'. PKN, Jun-2008.
[94] Nederlandse bisschoppen, 'Rooms-Katholiek visie op het kerkgebouw'. Sep-2008.

[95] T. Jelsma, 'Van traditioneel gebruik tot herbestemming - Transformatie als kans voor kerk en samenleving', in *Meer dan hout en steen - Handboek voor sluiting en herbestemming van kerkgebouwen*, 2011.
[96] J. Martens, 'Revitaliseren, herbestemmen of slopen? Toekomstperspectieven voor kerkgebouwen', Katholieke universiteit Leuven, Leuven, 2003.
[97] 'Multifunctioneel gebruik | Kennis- en projectenbank herbestemming'. [Online]. Available: http://www.kennisbankherbestemming.nu/kennisdossiers/religieus-erfgoed/praktijk/multifunctioneel-gebruik. [Accessed: 22-Nov-2016].
[98] 'Gebruik kerkgebouwen | CRKC'. [Online]. Available: http://crkc.be/gebruik-kerkgebouwen. [Accessed: 22-Nov-2016].
[99] Belastingdienst, 'Teruggaafregeling energiebelasting kerken en instellingen'. [Online]. Available: http://www.belastingdienst.nl/wps/wcm/connect/bldcontentnl/belastingdienst/zakelijk/overige_belastingen/belastingen_op_milieugrondslag/teruggaafregelingen/teruggaafregeling_energiebelasting. [Accessed: 23-Nov-2016].
[100] 'Homepage', *Toolkit Duurzaam Kerkbeheer*. [Online]. Available: https://www.groenekerken.nl/duurzaamkerkbeheer/. [Accessed: 23-Nov-2016].
[101] 'EVK: Benchmark'. [Online]. Available: http://energievoorkerken.nl/benchmark. [Accessed: 23-Nov-2016].
[102] M. Stappers, E. Neuhaus, and G. van Kempen, 'Klimaatbeheersing in monumentale kerken', Rijksdienst voor het Cultureel Erfgoed, Amersfoort, Sep. 2016.
[103] N. Aste *et al.*, 'Sustainable church heating: The Basilica di Collemaggio case-study', *Energy Build.*, vol. 116, pp. 218–231, maart 2016.
[104] 'European Commission : CORDIS : Projects & Results Service : Friendly heating: confortable to people and compatible with conservation of art works preserved in churches'. [Online]. Available: http://cordis.europa.eu/project/rcn/61586_en.html. [Accessed: 23-Nov-2016].
[105] L. Kellendonk and H. Schout, 'Kerkbestemming', Delft, 2014.
[106] 'DuMo prestatie | De duurzame monumenten Prestatiekaart van Nederland'. [Online]. Available: http://www.dumoprestatie.nl/. [Accessed: 24-Nov-2016].
[107] 'Duurzame Monumentenzorg (DuMo) - SBRCURnet'. [Online]. Available: http://www.sbrcurnet.nl/producten/infobladen/duurzame-monumentenzorg-dumo. [Accessed: 24-Nov-2016].
[108] O. T. Masoso and L. J. Grobler, 'The dark side of occupants' behaviour on building energy use', *Energy Build.*, vol. 42, no. 2, pp. 173–177, Feb. 2010.
[109] S. B. Sadineni, S. Madala, and R. F. Boehm, 'Passive building energy savings: A review of building envelope components', *Renew. Sustain. Energy Rev.*, vol. 15, no. 8, pp. 3617–3631, oktober 2011.
[110] Y. Xing, N. Hewitt, and P. Griffiths, 'Zero carbon buildings refurbishment—A Hierarchical pathway', *Renew. Sustain. Energy Rev.*, vol. 15, no. 6, pp. 3229–3236, Aug. 2011.
[111] 'Rijksmonument 8161 - Rijksdienst voor het Cultureel Erfgoed'. [Online]. Available: https://monumentenregister.cultureelerfgoed.nl/monuments/8161. [Accessed: 17-Mar-2017].
[112] D. Stadig, 'Help, onze kerk loopt leeg! Een kleine handleiding voor kerkbestuurders'. Rijksdienst voor het Cultureel Erfgoed, 2016.
[113] I. Sartori and A. G. Hestnes, 'Energy use in the life cycle of conventional and low-energy buildings: A review article', *Energy Build.*, vol. 39, no. 3, pp. 249–257, maart 2007.
[114] A. Audenaert, S. H. De Cleyn, and B. Vankerckhove, 'Economic Analysis of Passive Houses and Low-Energy Houses Compared with Standard Houses', *Energy Policy*, vol. 36, no. 1, pp. 47–55, Jan. 2008.
[115] European Commission, 'LOW ENERGY BUILDINGS IN EUROPE: CURRENT STATE OF PLAY, DEFINITIONS AND BEST PRACTICE'. European Commission, 25-Sep-2009.
[116] 'Low energy, passive and zero-energy houses | Our energy'.
[117] V. Badescu and B. Sicre, 'Renewable energy for passive house heating: Part I. Building description', *Energy Build.*, vol. 35, no. 11, pp. 1077–1084, Dec. 2003.
[118] B. Risholt, B. Time, and A. G. Hestnes, 'Sustainability assessment of nearly zero energy renovation of dwellings based on energy, economy and home quality indicators', *Energy Build.*, vol. 60, pp. 217–224, mei 2013.
[119] A. J. Marszal and P. Heiselberg, 'A Literature Review of Zero Energy Buildings (ZEB) Definitions', *MyScienceWork*, Jan. 2009.
[120] G. A. Mertz, G. S. Raffio, and K. Kissock, 'Cost Optimization of Net-Zero Energy House', pp. 477–487, Jan. 2007.
[121] 'Waarderingscriteria | Rijksdienst voor het Cultureel Erfgoed'. [Online]. Available: https://cultureelerfgoed.nl/dossiers/waarderen-van-cultureel-erfgoed/waarderingscriteria. [Accessed: 01-Feb-2017].
[122] 'Uitgangspunten voor advies', *Rijksdienst voor het Cultureel Erfgoed*. [Online]. Available: https://cultureelerfgoed.nl/onderwerpen/advies/uitgangspunten-voor-advies. [Accessed: 04-Apr-2017].
[123] 'Welkom op CIO web', *Interkerkelijk Contact Overheidszaken*. [Online]. Available: http://www.cioweb.nl/. [Accessed: 23-Nov-2016].
[124] 'Kerk in Actie', *Kerk in Actie*. [Online]. Available: https://www.kerkinactie.nl/. [Accessed: 23-Nov-2016].
[125] 'HOME kms'. [Online]. Available: https://kms-bennekom.nl/. [Accessed: 17-May-2017].
[126] D. Camuffo *et al.*, 'An Advanced Church Heating System Favourable to Artworks: A Contribution to European Standardisation', *J. Cult. Herit.*, vol. 11, no. 2, pp. 205–219, Apr. 2010.

[127] E. A. Beun, ‘Geloof, Hoop en Samenwerking; De positie van waarde van religeus erfgoed in het herbestemmingsproces’, Technische Universiteit Delft, 2015.
[128] L. Kellendonk, ‘Methodiek herbestemmen kerken | Loes Kellendonk Architectuur’. [Online]. Available: http://www.loeskellendonk.nl/projecten/methodiek-herbestemmen-kerken/. [Accessed: 12-Jun-2017].
[129] ‘Duurzaamheidsonderzoek Religieus Erfgoed Deventer; Verduurzamingsmogelijkheden religieus erfgoed op basis van zes casestudies [Sustainablility Research Religious Heritage Deventer; Preservation of Religious Heritage Based on Six Case Studies]’, Nederlands Instituut voor Bouwbiologie en Ecologie, NIBE bv, Bussum, 23.033.13.07.002 bd/kj, Aug. 2012.
[130] ‘Religieus Erfgoed Deventer | Gemeente Deventer’. [Online]. Available: https://religieuserfgoed.deventer.nl/religieuserfgoed. [Accessed: 24-Nov-2016].
[131] H. van de Ven, E. J. Nusselder, M. Haas, and B. Dulski, *Handboek duurzame monumentenzorg: theorie en praktijk van duurzaam monumentenbeheer*, 1st ed. Rotterdam: SBR, 2011.
[132] ‘Artikel 5.3 Thermische isolatie [Article 5.3 Thermal Insulation]’. [Online]. Available: http://www.bouwbesluitonline.nl/Inhoud/docs/wet/bb2012_nvt/artikelsgewijs/hfd5/afd5-1/art5-3. [Accessed: 12-Apr-2017].
[133] ‘Passivhaus Institut’. [Online]. Available: http://www.passiv.de/en/03_certification/02_certification_buildings/04_enerphit/04_enerphit.htm. [Accessed: 12-Apr-2017].
[134] H. Erhorn and H. Erhorn-Klutting, ‘Selected examples of Nearly Zero-Energy Buildings; Detailed Report’, Concerted Action Energy Performance of Buildings, Sep. 2014.
[135] H. Poirazis, *Double Skin Facades - Literature Review Report*. [Publisher information missing], 2004.
[136] B. Nordquist, S. Elfborg, A. Vrbanjac, P. Wallentén, and J. Stein, ‘ENERGY SAVING BY ADDING A GLASS-FAÇADE TO A BRICK BUILDING’, *MyScienceWork*, Jan. 2013.
[137] ‘Home - SBRCURnet’. [Online]. Available: http://www.sbrcurnet.nl/. [Accessed: 12-Apr-2017].
[138] Milieucentraal, ‘Milieucentraal’, *MilieuCentraal.nl*. [Online]. Available: https://www.milieucentraal.nl/. [Accessed: 18-Apr-2017].
[139] C. Younes, C. A. Shdid, and G. Bitsuamlak, ‘Air Infiltration Through Building Envelopes: A Review’, *J. Build. Phys.*, vol. 35, no. 3, pp. 267–302, Jan. 2012.
[140] Historic Engeland, ‘Insulating Solid Walls’, Historic England, v1.1, Apr. 2016.
[141] R. Walker and S. Pavía, ‘Thermal performance of a selection of insulation materials suitable for historic buildings’, *Build. Environ.*, vol. 94, Part 1, pp. 155–165, Dec. 2015.
[142] S. Rhee-Duverne and P. Baker, ‘Research into the thermal performance of traditional brick walls’, English Heritage, London, 2013.
[143] Historic Engeland, ‘Insulating Pitched Roofs at Rafter Level’, Historic England, v1.3, Jan. 2016.
[144] Historic Engeland, ‘Application of Part L of the Building Regulations to Historic and Traditionally Constructed Buildings’, Historic England, 2012.
[145] J. M. Schultz, K. I. Jensen, and F. H. Kristiansen, ‘Super insulating aerogel glazing’, *Sol. Energy Mater. Sol. Cells*, vol. 89, no. 2–3, pp. 275–285, Nov. 2005.
[146] ‘Monumentenglas heeft een isolatiewaarde tussen enkel glas en HR++ glas’. [Online]. Available: http://houhetwarm.nl/isolatie/monumenten/monumentenglas-heeft-een-hoge-isolatiewaarde/. [Accessed: 20-Apr-2017].
[147] A. Lyons, ‘Chapter 13: Insulation Materials’, in *Materials for Architects & Builders*, 4th ed., Oxford, UK: Elsevier Ltd., 2010.
[148] E. Cuce, P. M. Cuce, C. J. Wood, and S. B. Riffat, ‘Toward aerogel based thermal superinsulation in buildings: A comprehensive review’, *Renew. Sustain. Energy Rev.*, vol. 34, pp. 273–299, Jun. 2014.
[149] D. Camuffo and A. della Valle, ‘Church Heating: A Balance Between Conservation and Thermal Comfort’, in *Contribution to the Experts’ Roundtable on Sustainable Climate Management Strategies*, Tenerife, Spain, 2007.
[150] L. Samek *et al.*, ‘The impact of electric overhead radiant heating on the indoor environment of historic churches’, *J. Cult. Herit.*, vol. 8, no. 4, pp. 361–369, Sep. 2007.
[151] van Schijndel, ‘Optimal setpoint operation to reduce peak drying of a church organ’, *Int. J. Multiphysics*, vol. 2, no. 1, pp. 21–35, Jan. 2008.
[152] D. Camuffo, ‘Chapter 2B - Humidity and Conservation’, in *Microclimate for Cultural Heritage (Second Edition)*, Boston: Elsevier, 2014, pp. 77–118.
[153] D. Chitnis, N. Thejo kalyani, H. C. Swart, and S. J. Dhoble, ‘Escalating opportunities in the field of lighting’, *Renew. Sustain. Energy Rev.*, vol. 64, pp. 727–748, oktober 2016.
[154] A. J. Marszal, J. S. Bourrelle, E. Musall, P. Heiselberg, A. Gustavsen, and K. Voss, ‘Net Zero Energy Buildings - Calculation Methodologies versus National Building Codes’, presented at the EuroSun Conference, Graz, Austria, 2010.
[155] ‘EVK: Home’. [Online]. Available: http://www.energievoorkerken.nl/. [Accessed: 10-Apr-2017].
[156] ‘Over KerkStroom’. [Online]. Available: http://www.kerkstroom.nl/over-ons. [Accessed: 10-Apr-2017].
[157] Rijksdienst voor Ondernemend Nederland and Centraal Bureau voor de Statistiek (CBS), ‘Protocol Monitoring Hernieuwbare Energie (herziening 2015)’, Utrecht, 2015.

[158] A. D. Peacock, D. Jenkins, M. Ahadzi, A. Berry, and S. Turan, 'Micro wind turbines in the UK domestic sector', *Energy Build.*, vol. 40, no. 7, pp. 1324–1333, 2008.

[159] 'GreenSpec: Housing Retrofit: Solar Hot Water Heating'. [Online]. Available: http://www.greenspec.co.uk/building-design/solar-hot-water-heating/. [Accessed: 10-May-2017].

[160] K. Klein, K. Huchtemann, and D. Müller, 'Numerical study on hybrid heat pump systems in existing buildings', *Energy Build.*, vol. 69, pp. 193–201, Feb. 2014.

[161] S. Heinen, D. Burke, and M. O'Malley, 'Electricity, gas, heat integration via residential hybrid heating technologies – An investment model assessment', *Energy*, vol. 109, pp. 906–919, Aug. 2016.

[162] 'Daikin Altherma Hybrid Heat Pump'. [Online]. Available: http://hybridsimulator.daikin.eu/en/Default/Index. [Accessed: 04-May-2017].

[163] 'Pelletketel CV prijzen - Pellet CV kopen | Artelpelletkachels.nl'.

[164] M. Knowles, I. Burdon, and B. Beith, *Micro Energy Systems: Review of Technology, Issues of Scale and Integration*. John Wiley & Sons, 2004.

[165] Onbekend, *De Rooms Katholieke Mariakerk 1950 - 1960 [Roman Catholic Maria Church]*.

[166] A. van Dijk, J. van Nes, E. Ippel, and Kleinleugenmors, *Apeldoorn Onze Lieve Vrouwe ten Hemelopneming [Our Lady Ascension]*.

[167] 'De Emmaüsparochie [The Emmaus Parish]'. [Online]. Available: http://www.emmaus-apeldoorn.nl/. [Accessed: 17-Mar-2017].

[168] W. Verbruggen-Jansen, *Boerhaavestraat 1966-67 Openhof Kerk*. 1966.

[169] 'Open Hofkerk opent haar deuren tijdens de Open Monumentendagen', *Apeldoorndirect*, 27-Aug-2015. [Online]. Available: http://www.apeldoorndirect.nl/stad/open-hofkerk-opent-haar-deuren-tijdens-de-open-monumentendagen-20150827/. [Accessed: 17-Mar-2017].

[170] Open Hofkerk, 'Protestantse Wijkgemeente Open Hofkerk'. [Online]. Available: http://www.openhofkerk.net/. [Accessed: 17-Mar-2017].

[171] Rijksdienst voor het Cultureel Erfgoed, 'Apeldoorn Kerschoten; een wederopbouwgebied van nationaal belang, nr. 13 [Apeldoorn Kerschoten; A Post-War Reconstruction Area of National Importance, no. 13]'. .

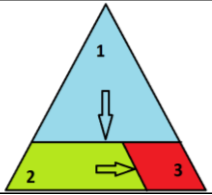
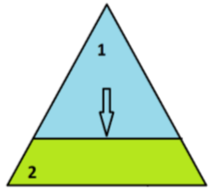
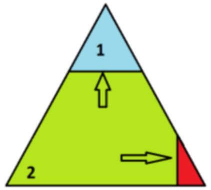
[172] 'Jachtlaankerk', *Jachtlaankerk Apeldoorn*.

Appendix

Appendix A.

Appendix A1 Types of Buildings

Table 23 Types of buildings, their description, and a visualisation of the Trias Energica.

	Type	Description		Trias energica
1	Conventional building or a standard building	Referred to as conventional, is a building built according to common practice in a specific country and period [113], meeting the corresponding minimal legally required energy standards [114].		
2	Low energy building	Referred to as low-energy, is a building built according to special design criteria aimed at minimising the building's operating energy [113]. The annual energy demand will be ≤40-60 kWh/m² [115].		
3	Passive building	Extreme low-energy building [116], making it a specific type of low-energy. Designed to maximise the exploitation of passive technologies [113], [114], [117], obtaining a comfortable indoor climate in summer and winter without a conventional heating system. The annual energy use for heating is ≤15kWh/m² and a limit for total primary energy usage ≤120kWh/m² [115].		
4	Nearly zero-energy building (nZEB)	A Building with an extremely high energy performance. The energy remaining energy demand that is close to zero must be met by renewable sources [53], [118].		
5	Zero-energy building (ZEB)	A building that annually supplies as much energy to the grid as it uses [51], [119], [120]		
5.1		***Net Zero Site Energy***	*'A site ZEB produces at least as much energy as it uses in a year when accounted for at the site.'*	
5.2		***Net Zero Source Energy***	*'A source ZEB produces at least a much energy as it uses in a year when accounted for at the source. Source energy refers to the primary energy used to generate and deliver the energy to the site.'*	
5.3		***Net Zero Energy Cost***	*'In a cost ZEB, the amount of money the utility pays the building owner for the energy the building exports to the grid is a least equal to the amount the owner pays the utility for the energy services and energy used over the year.'*	
5.4		***Net Zero Energy Emissions***	*'A net-zero emissions building produces at least as much emissions-free renewable energy as it uses from emission-producing energy sources.'* [52]	
6	Zero-carbon building	Buildings that over a year do not use energy that causes carbon dioxide emission, either by producing enough energy themselves or other CO_2 free sources [51], [119], [120].		

Appendix A2 List of Single Approach Multi-Criteria Analysis Methods

Table 24 Examples of single approach MCAM. [87]

Abbr.	Method	Description
AHP	Analytic hierarchy process	Structured technique for analysing MCDM problems per a pairwise comparison scale.
ANP	Analytic network process	Generalisation of the AHP method which enables the existence of interdependencies among criteria.
COPRAS	Complex proportional assessment	Stepwise method aimed to rank a set of alternatives per their significance and utility degree.
DEA	Data envelopment analysis	A non-parametric system for measuring the efficiency of a set of multiple decision-making units.
-	Delphi	An iterative method designed to obtain the most reliable consensus of a group of experts responding to a series of questionnaires.
DRSA	Dominance-based rough set approach	Derivation of rough set theory which allows defining an MCDM problem through a series of inference rules of the type 'if… then.'
FSs	Fuzzy sets	Extension of the traditional concept of the crisp set which states that the belongingness of an element to a set may vary within the interval [0, 1].
GT	Game theory	Area of applied mathematics that studies the interaction of formalised structures to make strategic decisions.
HOQ	House of quality	House-shapes diagram the transforms user demands into quality design criteria through a relationship matrix and a correlation matrix.
MAUT	Multi-attribute utility theory	The methodology employed to make decisions by comparing the utility values of a series of attributes regarding risk and uncertainty.
MAVT	Multi-attribute value theory	A compensatory technique that converts the attributes forming an MCDM problem into one single value through the called value functions.
MCS	Monte Carlo simulations	Non-deterministic methods used to find approximate solutions to complex problems by experimenting with random numbers.
MEW	Multiplicative Exponential weighting	Aggregative scoring system in which alternatives are evaluated by the weighted product of their attributes
PROMETHEE	Preference ranking organisation method for enrichment of evaluations	The family of outranking method based on the selection of a preference function for each criterion forming an MCDM problem.
SAW	Simple additive weighting	Technique aimed to determine a weighted score for each alternative by adding the contribution of each attribute multiplied by their weights.
SMAA	Stochastic multi-objective acceptability analysis	The methodology that determines the acceptability index of an alternative as the variety of measurements making it the preferred one.
UT	Utility theory	A method for measuring the degree of desirability provided by tangible and/or intangible criteria through their utility functions.

Appendix A3 Tools for Sustainable Building Management

Remodelling Churches in Religious Use [8]

This brochure, by the RCE, focusses on churches in religious use that are national monuments. The goal is to be able to continue the original use through adaptation or remodelling of the building. Important is to maintain the monumental value while doing so. Three main steps are a distinguished: 1) assessment of the monumental value of the church building; 2) the orientation phase; and, 3) the design phase.

Monumental Value

The start of the process is assessing the value of the church building as a monument. Assessment is done to see, or the church is a monument, and as inspiration for the design. Furthermore, it can be important to know the monumental value for future requests of advice or permits for plans. The RCE has a list of criteria to assess the monumental value of the building, part of the building or surroundings. This list is nationally used can be divided into five main categories: 1) cultural historic value; 2) architectural & artistic historical value; 3) situation & ensemble value; 4) integrity & recognisability; and, 5) rarity [121].

Orientation Phase

The orientation phase serves as a preparation for the actual remodelling plan. The five steps provide insight into the difficulties that could arise when starting the project. The orientation must make it possible to come to a plan that is feasible, supported by the stakeholders and do justice to the characteristics of the building.

Table 25 Steps in the orientation phase.

Step		Description
1	Internal consensus	Knowing the demands and wishes of the parish and who is authorised to decide;
2	Consolation	Early consultation with stakeholders, experts, and authorities, to share experiences and knowledge;
3	Exploratory research	Exploratory research into wished, (financial) possibilities and required permits, Cultural, historical, architectural, and archaeological research, documentation of inventory and a feasibility study;
4	Permits	Orientation on permit procedure, establish required permits;
5	Consensus	Consensus between church and authorities. Permits or the obligation to get consent from the (local) authorities depends on the final plan.

Design Phase

The RCE provides six general design principles that correspond with their philosophy on maintaining monuments. The principles are: 1) justice to the cultural-historic meaning; 2) conserve historic parts; 3) attention for characteristics; 4) customisation; 5) reversibility; and, 6) quality of design & craftsmanship [122]. The brochure, developed specifically for churches, translates the general principles to practical tips for designs. Providing tips about the use of space, the cohesion of new and existing parts, spatial and cultural quality and more.

Toolkit Sustainable Governance [100]

'Groene Kerken' is a movement of churches that desire to be and actively try to be greener [3]. A church can register with the initiative, after which they display it on the website. The website includes a picture, a list of the implemented measures and plans. As well as contact information, so that other churches that are interested in a certain topic can contact churches that already have experience in this direction. The movement works on good faith that connected churches have done and are going to do what they wrote on their application. There are feedback moments, through contact with the religious communities to keep the information on the website up-to-date. Also, each church gets a sign (Figure 15), to attach to the façade of the building.

Figure 15 Sign when a church becomes part of the Groene Kerken movement.

'Groene Kerken' also provides a toolkit (Figure 16). The toolkit provides a broad range of measures that churches can implement to become more sustainable. Several alternative measures differing in level of sustainability, or, for example, in investment or invasiveness. Also included are additional information, tips and links, and contact information for churches with experience with a specific measure. Subjects variate from reducing water and energy requirements to using fair trade coffee. Five main categories are used to provide structure: 1) energy & management; 2) structural management; 3) greenery & grounds; 4) financial management; and, 5) facility management [100]. The toolkit remains a collection of a wide range of measures, not providing a stepwise approach or a starting point.

Figure 16 Screenshot of the toolkit provided by Groene kerken. [100]

Benchmark Tool for Energy Use [101]

Energie voor Kerken (EVK) is a collective, for churches and monasteries, which provides them energy at low cost. Currently, the initiative from CIO-K (Interkerkelijk Contact In Overheidszaken-Kerkgebouwen) [123] and energy advisory agency Hellemans Consultancy B.V. provides 100% green energy at a fine price. Also, they provide insight into costs, payments, and money flows in general, as well as supporting churches in reducing energy need and upgrading sustainability performance. Part of supporting churches is the benchmark tool on energy use. This tool is available for members and allows them to compare their energy usage to other participating churches. A guide, compiled together with Kerk in Actie (*Church in Action*) [124], provides practical tips to improve the sustainability performance of church buildings.

Indoor Climate Control in Monumental Churches [102]

This guide, from the RCE, provides a four- to six-step model, depending on the measuring results. The goal of the guide to improve the comfort level and the conservation of inventory, by optimising the energy system. Relevant parameters are the humidity, the relative humidity, and the temperature fluctuations. Optimisation of the energy system for comfort and conservation can also make the energy system more efficient.

Table 26 Steps in for indoor climate control in monumental churches.

Step		Description
1	Inventory	Multiple wishes and problems can require a solution. Having a clear inventory is important to prevent solving one problem while another becomes worse.
2	Measurements	Measuring the temperature and RH. Measurements should take place inside the organ, areas where people can reside and in the inflow pipe of the heating system.
3	Data analysis	A specialist should analyse the data;
4	Existing system	Based on the analysis adjustment of the operational settings to the pre-set requirements can take place;
5	Replacing	In case there is an outdated system or a system incapable of dealing with the new settings, replacement is the best option;
6	Humidification	If the RH is still not sufficient, humidification is a last resort

Church & Environment/Society Method [15], [16]

The KMS-method is a method developed by a working group under the same name in Bennekom. The KMS is an ecumenic task force, that primarily focusses on creating awareness concerning sustainability in the broadest sense of the concept [125].The developed method was published in a book by Ketel & Scheele [16], as well as in a report on church buildings in Ede [15], and can assist other churches in becoming more sustainable. Providing rules of thumb, generated from measurements in a variety of churches in the Netherlands. These mathematical rules allow for an improvement of the indoor climate and a reduction of the energy demand. There are three: 1) lowering the (basic) temperature; 2) Insulation of the outer shell; and, 3) management of the energy system. A recommended period of at least three weeks of T and RH measures form the basis. Also, a daily notation of the energy numbers provides insight into the use of energy, especially the when and why. Degree days expand the data for other days of the year. The basic principles for all strategies are to establish an acceptable comfort level, as well as a climate that is optimal for preservation and conservation of the building and its interior while using energy as efficient as possible.

Heating of Monumental Churches [76], [92], [103], [104]

The Friendly Heating Project (2002-2005) [104] studied and evaluated different heating systems about their potential impact on historical artworks in historic churches. The project searched for an optimum between user comfort and art conservation. Several research institutes and universities have participated in the project. Eindhoven University of Technology (TU/e) has participated, for example, with a dissertation on heating monumental churches, the indoor climate and preservation of cultural heritage. This study, among other things, provided a checklist for the selection of a heating system. Another contains an in-depth analysis of bench heating [92]. All findings combined form the basis for European standardisation and legislation. The draft of key recommendations in CEN/TC346 standard prEN 15759 – '*Conservation of Cultural Property – Specification and control of indoor environment – Heating of places of worship*', are based on the results of the Friendly Heating Project [126]. The different research projects have made it possible to make a founded choice between heating systems, conservation, and thermal comfort while dealing with different circumstances, locations, and conditions.

Appendix A4 Tools for Repurposing Churches

Function Choice Model [47]

This model contains a structured study of 19 alternative functions for churches that lose their function. The tool assesses the alternative on several aspects and compares them. It makes a founded decision between functions and church buildings possible, as it provides an insight into the success of repurposing it could guide the difficult process. The model has nine steps, stated below, from problem identification to the decision to continue or stop the project.

Table 27 Steps in the function choice model.

Step		Description
1	Problem identification;	Determine that something needs to change in the real estate stock. For example, due to the financial situation or mergers;
2	Define policy by church board and authorities;	Church: formulate conditions and requirements for disposing of a building. Who are the stakeholders and who decides? Authorities: anticipate vacancy, actively participate in repurposing, provide support;
3	Building a team	Early on formation of a group, of representatives of the church board, the municipality and a project developer, could prevent future delays. For example, due to the ability to discuss difficulties immediately before continuing the process.
4	Building selection	Requiring a decision on which church remains a place of worship, often done based on the distribution of churchgoers, location, capacity, maintenance, cost, structural state, and/or cultural, historical value;
5	Veto-criteria	Exclusion of certain functions because of a variety of reasons, from building and location characteristics to spatial planning or church policy;
6	Choice of function	The building and location assessment lists construction, and location requirements for the functions, as well as the importance of these demands. Calculation of the potential after excluding the impossibilities due to the veto-criteria. A ranked list of options is the output of this step.
7	Preliminary design.	Sketches of how a new function fits in the building making the challenges visible. Insight into unique design options, revenues and costs of the project are important;
8	Feasibility study	This step presents an outline design for three or four choices. There is a clear focus on the financial feasibility and the cultural, historic conservation factor;
9	Go/no go.	At this point, the church must decide, or the selected function is acceptable, and the project can continue. If not, the next step is to find out why.

Schrieken [47] adapted the valuation criteria from the RCE [121] specifically for churches. This tested method could help religious communities get an indication of the cultural, historical value of their church building. It is an indication, as it is not an officially recognised method.

Transformation Measurer [49]

A method based on the transformation potential of office buildings [127], but adapted to vacant churches. The method is, especially, useful for project developers, without experience in dealing with church buildings. It will provide an idea of an appropriate new function in an early stage of the project. Important to note is that the analysis uses assumptions, which endangers the objectivity of the result. Figure 17 displays the five-step-model, as well as a presentation of the outcome (right).

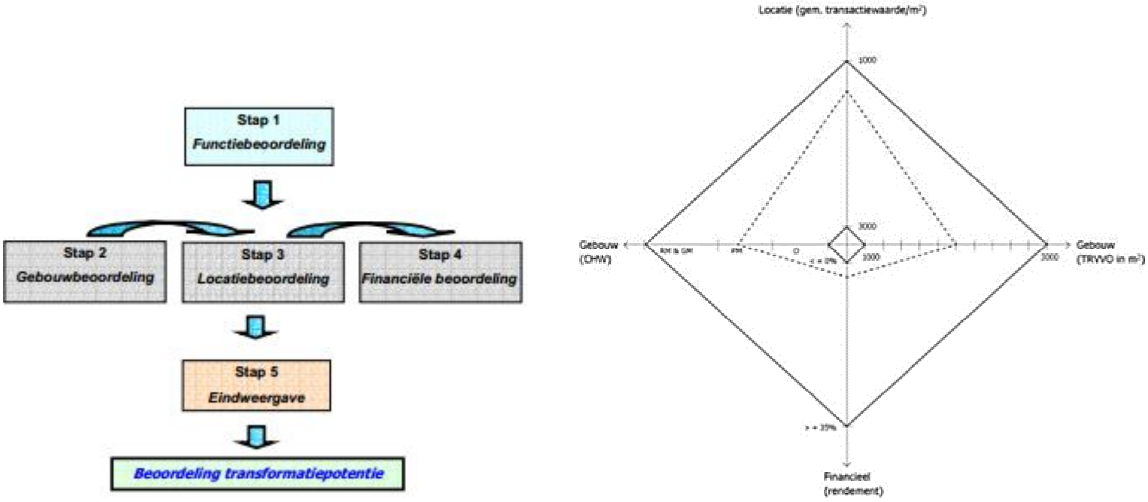


Figure 17(l) scheme of the method [49]; (r) Final results is the visual presentation of the four steps via [127].

Church Purpose [105]

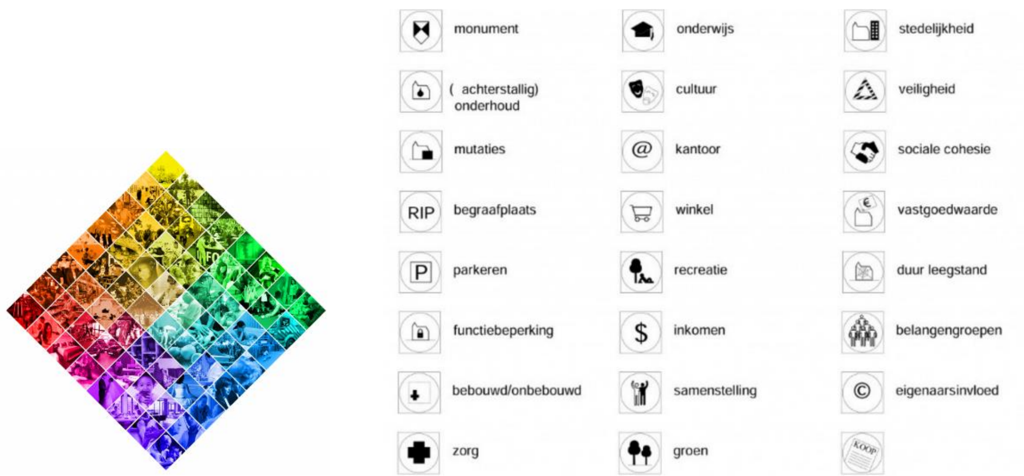


Figure 18 Ambience pane and possible functions. [128]

In 2008 a collaboration of two architecture firms started to develop this method. The goal was to develop a method to find a new purpose for the tenantless religious property. A key step was developing a method to take inventory of the current state of the empty building and to find factors usable to find a new function successfully. There is a differentiation between public and private functions, and commercial and non-commercial. The outcome, presented in icons, expresses the function chances and problems. Figure 18 shows an example a ‘Sferenruit’ and functions. The method is still under development [128].

Appendix A5 Combined Approach

This method differs from the previously mentioned methods in several ways. Firstly, it is the only method not unique to churches but monuments. Secondly, it is the only method that combines sustainability performance of the building with multifunctional use and repurposing. Specifically developed to assist owners of a monument in the sustainable management of their building. The Stichting Bouwresearch (SBR; the foundation of building research), RCE and Rijksgebouwendienst (national building agency) developed the method and published a guide that integrates a sustainability performance with a cultural, historical value, as well as a software application. The method was successful in churches in Deventer [129], [130]. Duurzame Monumentenzorg (DuMo, sustainable monument care) consists of two parts, a sustainability index (Du) and monumental value (Mo) [131]. There must be a balance between the two aspects, as illustrated in Figure 19. The Du-index is based on principles in GreenCalc+ making labelling possible. The Mo-value, expressed in three categories, indicates the changes that are possible without affecting the monumental value of the building. The method also presents twenty strategies for adapting monuments, adaptable to the specific building, as, especially with monuments, every building is different.

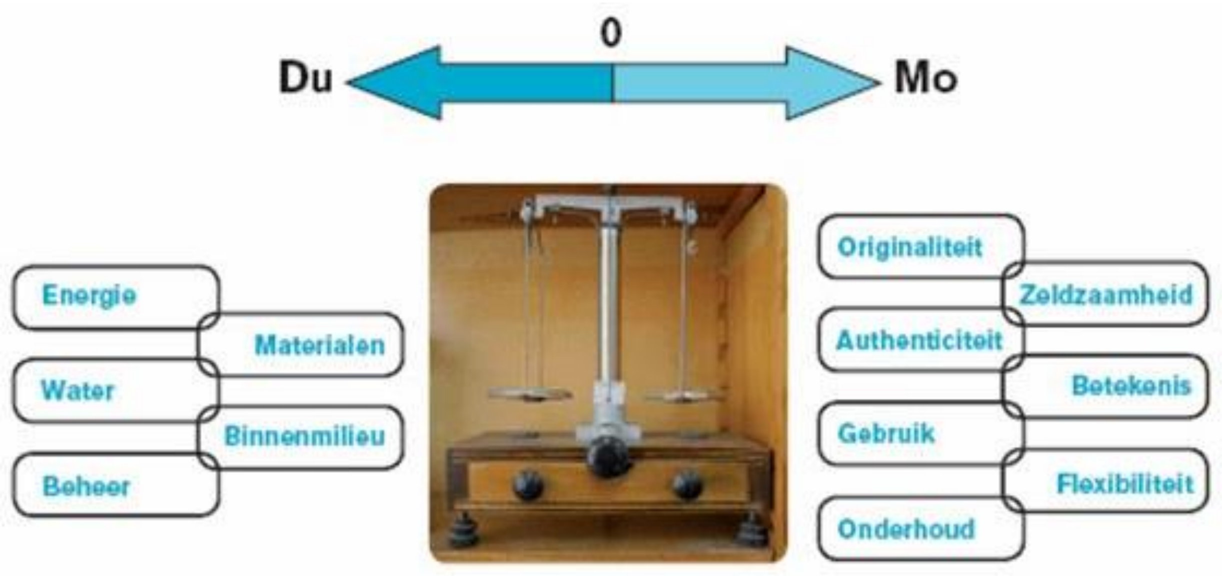


Figure 19 Balance between Du and Mo. [131]

Appendix B.

Appendix B1 Energy Management

Energy management has two sides, one focusses on the administrative matters, while the other focusses on controlling the system. Shaping the project by formulating goals, creating awareness within the religious community, and starting to implement available measures towards the improvement of the operational side is part of energy management. While the amount of energy savings of is unsure, it can be a significant [15], [16].

Monitor and Register [M1]

The first step is gaining insight into the energy use, the amount, when, and where use takes place. Monitoring and registering provide the insight required to estimate the effect of measures and reflect on the actual effect. There should be records of the meter readings, the frequency depends on the use of the data and can change over time. Understanding the energy usage makes it possible to review the energy contract. Contract negotiations or joint procurement can result in cost reductions. Also, it is important to consider the size of the energy contract as when the energy demand reduces during the project.

Goals, Objectives, and Strategies [M2]

Before starting it is important to have a status quo and definition for the desired situation. The desired situation helps to formulate goals and to set objectives. Objectives should be **s**pecific, **m**easurable, **a**chievable, **r**ealistic, and **t**ime-bound. An example can be a 10% reduction of the energy costs from the initial situation within a year. Trade-offs are between objectives are possible for instance or changes from short term to a long-term aim. A clear hierarchy between objectives could help prevent conflicts. Furthermore, it is important to make someone responsible for the management of goals, implementations of plans and procedures and the progress thus far, to keep an overview and control of the project.

Review Progress [M3]

Reviewing the progress and the effect of already implemented measures is important; the effects can differ from the theorised effect. These differences can influence further plans. Measures can become redundant, or more profitable, requiring adjustments to the plans. Through managing the progress and adjusting plans accordingly, the chances of reaching the goals become higher.

Controlling the System [M4]

While preparing and shaping the project the other side of energy management can be away to start already. Savings through management can be up to ten percent are possible [16], depending on the settings of the system, the success of implementation, and possibly other factors. A wide variety of measures, big and small, is possible to optimise the system and reduce the overall energy use. Heating mainly causes the power use, other systems, such as the lights and energy usage, due to equipment, might seem less important. However, as the heating system becomes more efficient, the other sources of energy use will be more significant.

Thermostat [M4.1]

The thermostat is a crucial tool to control the heating system; settings decide the temperature of the building at a given time. The location of the thermostat influences the effectivity of the scheme. Spaces only need heating when occupied; splitting the system into zones makes this possible. In the case of radiators, thermostatic valves are a possibility. Zoning provides more control, as it allows for rooms to have an individual heat demand through the settings of the local thermostat. Automatic control and fixed settings of the thermostat prevent unnecessary use due to people forgetting to turn it down. Overruling the automatic controls should be possible but by a limited group of individuals. Manual control is important, as there are necessary services, such as funerals and weddings, that take place outside the regular schedule of services. Applying a smart thermostat would save time for the caretaker as he does not have to be physically present to control the system. Also, depending on the capabilities of the system is can anticipate on specific circumstances and optimise accordingly.

Basic Temperature [M4.2]

Strongly related to the thermostat is the core temperature of the building. The core temperature is the temperature maintained when the building is not in use. In the Netherlands, this temperature is between the 14 and 17 °C [16]. This temperature is quite high considering most churches are used once or twice a week [15], [16]. In addition to energy savings, a lower basic temperature has a positive effect on the relative humidity, which is better for the conservation and preservation of the church building and its interior [15], [16], [77]. Research showed that lowering the temperature 1 °C will result in a reduction of energy use of the church hall around 7.5% annually [16]. The reduction strongly depends on the occupancy of the building; making this a crucial factor when considering lowering the basic temperature.

Occupancy [M4.3]

The use of a church in fluences the overall energy usage and the best settings of the system. Churches, primarily in religious use, are, used for the weekly services. The rest of the week there might be some activities, but most of the time the building is empty. Additional activities should take place in fitting rooms that limit unnecessary heating of other areas. Also, by combining activities on consecutive days, corresponding to the service. Combining makes it possible to optimally use the rest heat, as the building does not cool down all the way to the core temperature. The cooling down becomes more important when usage takes place outside the regular religious community-related activities. When considering letting the building (or parts) the compensation should cover the cost made or more depending on the revenue model.

Insight and Awareness [M5]

To calculate, for example, fair prices, insight into the energy use and understanding of the system is essential. The knowledge about the costs is a way to create awareness. Awareness within the religious community can further improve the energy efficiency of the church building. Furthermore, the church can set an example of good practice. This example could inspire the members of the church and others to consider sustainability in other areas of their life.

Appendix B2 Thermal Insulation

Table 28 Concepts necessary for insulating a building.

	Description	Sym.	Unit
Thermal conductivity	Property of material to conduct heat	k, λ, or κ	[W/(mK)]
Thermal resistance	Ability of heat to transfer through the material(s)	R = d/λ	[(m^{2}K)/W]
Thermal transmittance	Overall heat transfer coefficient	U = 1/R	[(W/(m^{2}K)]

Table 29 Thermal insulation of building components according to the building directive (bouwbesluit). [132]

Building component		Value	unit
Vertical exterior partition	≥	4.5	[(m^{2}K)/W]
Horizontal external partition	≥	6.0	[(m^{2}K)/W]
Ground floor	≥	3.5	[(m^{2}K)/W]
Basement wall or floor	≥	3.5	[(m^{2}K)/W]
Window, door, and frame*	≤	2.2	[(W/(m^{2}K)]
***total average**	≤	1.65	[(W/(m^{2}K)]

Table 30 Thermal insulation of building components insulation when remodelling (building directive). [132]

Building components			Insulation[2]	Unit
Floor	≥	2.5	2.2	[(m^{2}K)/W]
Facade	≥	1.3	1.0	[(m^{2}K)/W]
Roof	≥	2.0	1.7	[(m^{2}K)/W]
Windows	≤	2.2		[(W/(m^{2}K)]

Table 31 EnerPHit criteria for refurbishment using Passive House components. [133]

Components		Value	Unit
Exterior insulation	≤	0.15	[(W/(m^{2}K)]
Interior insulation	≤	0.25	[(W/(m^{2}K)]
Glazing		Ug-g*1.6 ≤0	
Window vertical & doors	≤	0.85	[(W/(m^{2}K)]
Window slanted	≤	1.0	[(W/(m^{2}K)]
Window horizontal	≤	1.1	[(W/(m^{2}K)]

[2] The general R-value of the addition insulation material to reach the overall R-value of the components

Table 32 Range of U-values realised for the building components in the collected nZEB examples. [134]

Building component	U-value [W/(m²K)]		
	Average	Lowest	Highest
Wall	0.29	0.065	1.97
Window	1.16	0.7	4.5
Roof	0.14	0.06	0.55
Ground	0.29	0.07	1.97
Door	0.98	0.68	2.19

Appendix B3 Reduction of Energy Demand

Double-skin Façade [D1]

In this option, a second envelope, primarily made from glass, is covering the building or parts of the building. Several different types are available, depending on the glass used, type of ventilation applied, and the width of the air cavity [135]. A double-skin façade is especially useful for the preservation of the building. It covers like a dome-like construction, protecting the building from affection by the environment. The dome works like a greenhouse retaining solar heat, reducing the heating demand in the building. In summer time, however, it could cause overheating, thus needing ventilation even though in some cases there is shading. Mechanical ventilation allows automatic control, and by adding heat recovery, it will not require additional energy, as well as possible cooling [136]. Figure 20 shows a picture of a 'dome-like' structure and a partial application. Figure offers a schematization of different wall types and a double skin façade.

Figure 20 Added glass façade (l); cavity on west façade (m); an example of a climate window (r). [136], [137]

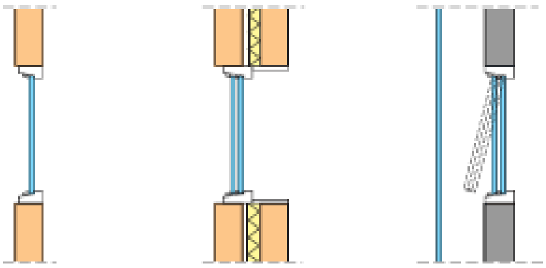


Figure 21 Single façade + glazing (l); Cavity wall & insulating glazing (m); Double skin façade & insulation glazing (r). [137]

Prevent Infiltration [D2]

Improving the airtightness of the building will reduce heat and cooling losses. There should be a distinction between ventilation, which is the intentional introduction of outside air and infiltration which is the flow of outside air into the building through unintentional openings in the building envelope. Figure 22 shows a typical infiltration and ventilation airflow of a building. In the Netherlands around five percent of the energy use of a single family home is caused by infiltration [138]. The number will depend on the building shape and condition, as well as the location and the local climate.

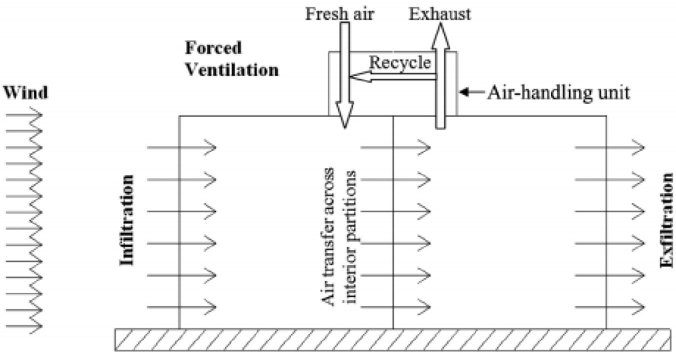


Figure 22 Typical infiltration and ventilation airflow. [139]

For churches a general list was provided where cracks, seams and gaps can often be found [100]:

- Cracks (a joint between rotating and fixed part) of windows and doors;
- Seams (a joint between fixed part) at the junction of window frames on the facades;
- Seams at the connection of the facades and roof to the building walls;
- Seams at the connection of the facades on the ground floor;
- Insulation of roof ridges;
- Insulation of penetrations;
- Mailbox.

Weather stripping of a building is an activity executable by the faith community, with materials available at doing-it-yourself shops. Important to note here is that it is important to keep in mind before improving the airtightness of the building that the ventilation system is functioning. Depending on the church building it might be necessary to hire a contractor, for example, because of the height of the building.

Insulation of the Envelope [D3]

The overall thermal resistance of the envelope is necessary for the heat losses that occur when heating the building. The overall resistance is the resistance of the parts of the envelope and their attachment to each other. Diverse levels of insulation, penetrations of the envelope and gaps in the insulation can lead to thermal bridges, which can negatively influence the energy efficiency. The prevention of thermal bridges can be a significant addition to the cost of an insulation project. The decision to insulate the whole building envelope should is a difficult one as it changes the characteristics and significance of the building [140]. Only upgrading parts of the envelope or take similar measures, such as preventing infiltration, might be better alternatives.

Wall [D3.1]

Depending on the wall and building external, internal or cavity insulation is applicable. Before adding any extra insulation the construction, condition and thermal performance of the wall must be understood [140]. Many older buildings have different types of walls, due to alterations over time [140]. The U-value of a wall depends on the thermal conductivity of the materials. However, there is some discussion on the relationship between the calculated and measured value [141]. A claim often made is that the measured value is higher than the calculated value. However, this is not always the case [142]. Also, to the uncertain U-value, it is important to consider the moister balance. Historic walls often are permeable and have a continuous exchange of moister; there must be an in-depth understanding of this system before insulation materials can be selected that match [140].

Other considerations are the type of wall, which influences the type of insulation possible. In the case of a cavity wall, cavity insulation is a possibility. Cavity insulation is the process of filling up the space in between the inner and outer wall with an insulating material. In other cases, there is a choice between insulation on the outside or the inside of the building, respectively external or internal insulation. Advantages of insulating the outside are that there is enough space, the disadvantage is that it often changes the characteristics of the building. Internal insulation has limited space available, and the insulation takes space away from the occupants. There are many types of insulation with variating U-values and characteristics. Considering historical walls aerogel and PIR board have shown good results [141]. Especially aerogel as it is effective in a low thickness [141], also, it is an up and coming insulation material in passive houses [110].

Roof [D3.2]

For the roof, similar insulation materials are applicable as mentioned when considering insulating the walls. The application of insulation depends on the ceiling construction and the floors in the building. In churches, it is often possible to directly look at the underside of the roof, a second level, attic or loft is not present. Figure 23 shows examples of insulating a sloped roof, for flat roof similar schemes are available. Important to consider here, like insulating walls is the moister-balance of the building. Insulating the roof is often highly beneficial for reducing the energy load of a building. Depending on the placement of the insulation, for example, if there is a monumental ceiling it will be necessary to add insulation for outside. A combination of roof repair and placing insulation prevents extra costs.

Floor [D3.3]

Insulation of the floor might have less effect on the energy use, but has a significant impact on the indoor climate. However, when dealing with a floor heating system and insufficient insulation, energy use reductions could be substantial. If present the crawl space underneath the floor is a place for insulation materials. Another possibility is creating a crawl space or adding materials in spaces available in between floorboards. Finally, there is the possibility to add insulation on top of the existing floor. This last option is expensive as it requires adjustments, such as the height of the doors.

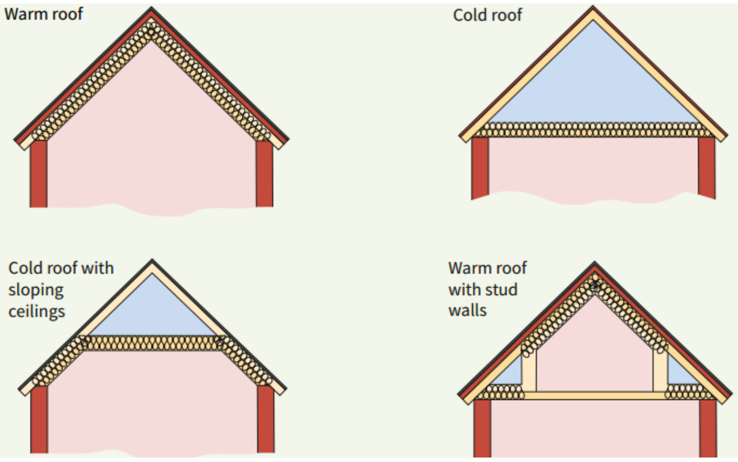


Figure 23 Warm and cold roofs depending on the placement of the insulation. [143]

Glazing [D3.4]

Before replacing the windows, it is important to know what is the state of the window frames, to combined work. Figure 24 and Table 33 offer U-value of several types of glazing and the effect of covers or other additions. The variations stem from the fact data comes from various regions and buildings. In the Netherlands, the legislation sets the U-value after remodelling at 2.2. Reaching this value would be possible, even without replacing the windows. Important to consider is that the U-value covers, such as curtains and shutters, only applies when closed. Considering the building characteristics, the highest U-value is the best options, as price differences are marginal, while the benefits both on an economic and comfort level are significant.

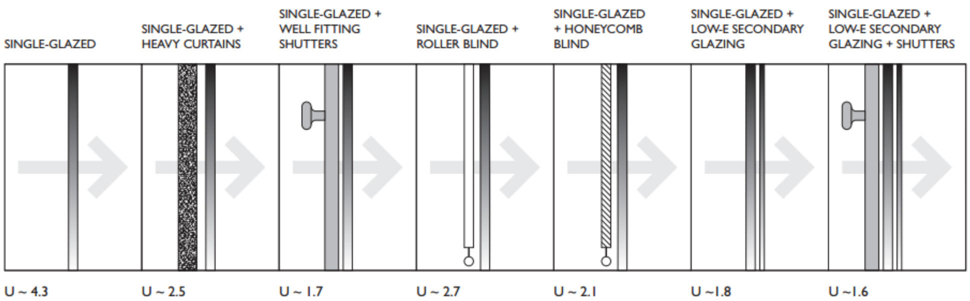


Figure 24 U-value of single glazing in historic buildings, and the U-value when a cover is added. [144]

In passive houses, several upcoming techniques are used for windows[109], such as aerogel glazing or vacuum glazing. These newer types of glazing reach a very low U-value, which could be beneficial for churches that have large window parties in the façade. An example is adding aerogel in the air space of the double-glazed window. Prototypes showed an U-value below 0.7 [145]. New techniques become available continuously, while it is not always the best choice, it is important to know what is possible and considered best at that moment.

Table 33 Different glazing types, additions, and their corresponding U-value. (W/m²K) [138], [146]

Options		U-value
Triple glazing		0.5 - 0.9
HR++		1.0 - 1.2
HR+		1.3 - 1.6
HR		1.7 - 2.0
Monument glazing		1.6 – 3.7
Secondary window + coating		1.8[3]
Double glazing		2.7
	Frame foil	2.0
	Reflecting window foil	2.1
	Insulating curtain	1.5
Secondary window		2.7[3]
Single glazing		5.8
	Frame foil	2.8
	Reflecting window foil	3.4
	Insulating curtain	2.1

Appendix B4 Improvement Energy Efficiency

Heating System [E1]

The are extensive studies on the heating systems of churches. For example, the effect of heating on the indoor climate and the preservation of cultural heritage [76], [77], [149], [150]. As well as the effects on preservation [126], [151], and studies into specific heating systems [92]. In the Netherlands, several publications on church heating are available, specific on sustainability [15], [16], in the direction of climate control [102]. Different heating systems considered for this study are warm air heating, floor heating, (infrared) radiant heating, radiator panel heating, convector heating, and local (pew) heating [76]. Not included are no heating, do-it-yourself heating, making use of independent systems that heat locally, or wall heating [77], because these systems are not common in the Netherlands.

Warm Air Heating [E1.1]

The main advantage of hot air heating is that it heats up the building very fast [76], [77], [102]; making it efficient. Inefficiency for warm air heating comes from the fact that it heats the whole building. Figure 25 shows the efficiency of a warm-air system, in which the green is the enjoyable heat, the red part is the heat that escapes aloft. Another general problem related to the quick heating of the building is the fluctuation of relative humidity (RH), Figure 26. This fluctuation is undesirable as it negatively affects the church building and its interior, damaging artworks, organs, and other building and interior elements. A general value for the RH is hard to define as it can depend on the historic RH surrounding the object [152] but should be as stable as possible [76], [77], [126], [149]. Stability could be created through the use of (de)humidifiers [76] or by a low basic temperature in the church [15], [16], [77].

[3] A secondary window in front of a single glazed window.

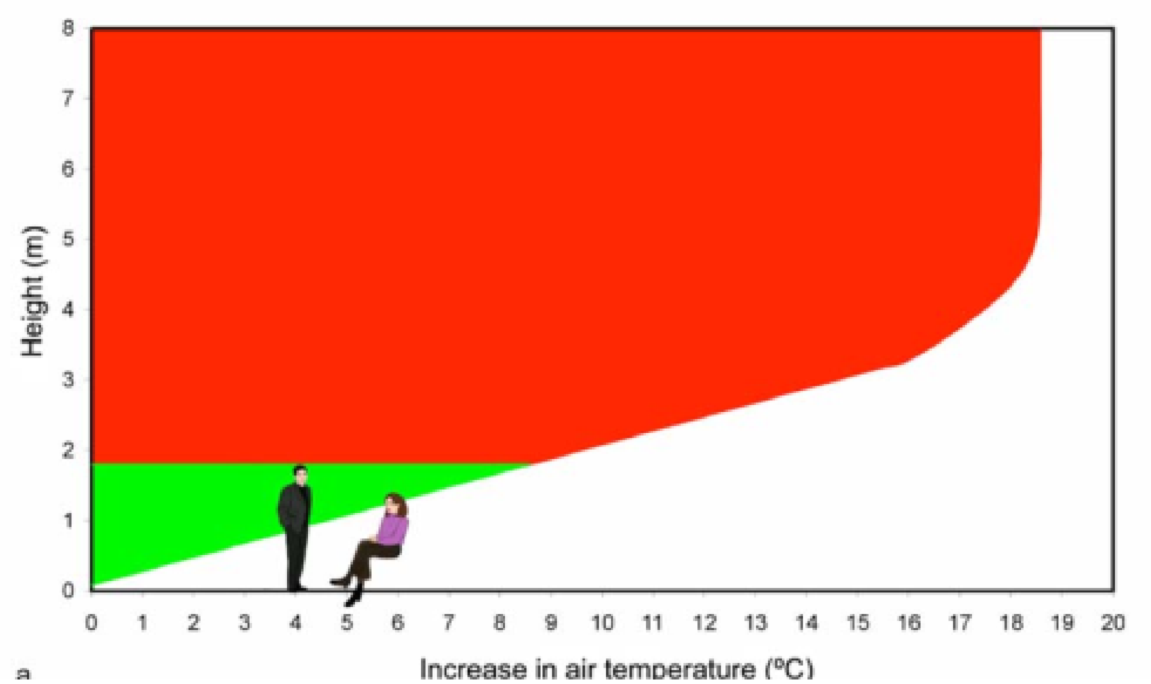


Figure 25 Efficiency (ratio between enjoyable heat (green) and total heat (red) of a warm-air system. [149]

Another factor is the distribution system most common is a centralised system with few air outlets; the alternative is many outlets distributed through the building. In a centralised system, there is a danger for stratification and dust circulation, as well as noise that comes from the air ducts. The downside of a decentralised system is the fact there are many air ducts, which depending on the design also need insulation. An advantage is a possibility of reaching a homogeneous temperature distribution. [76]. Outlets can be located on the floor, wall or as a separated system; this strongly influences the design [77]. Each design has specific risks and benefits, in addition to the general points mentioned in this section, making it necessary to judge each proposed design individually.

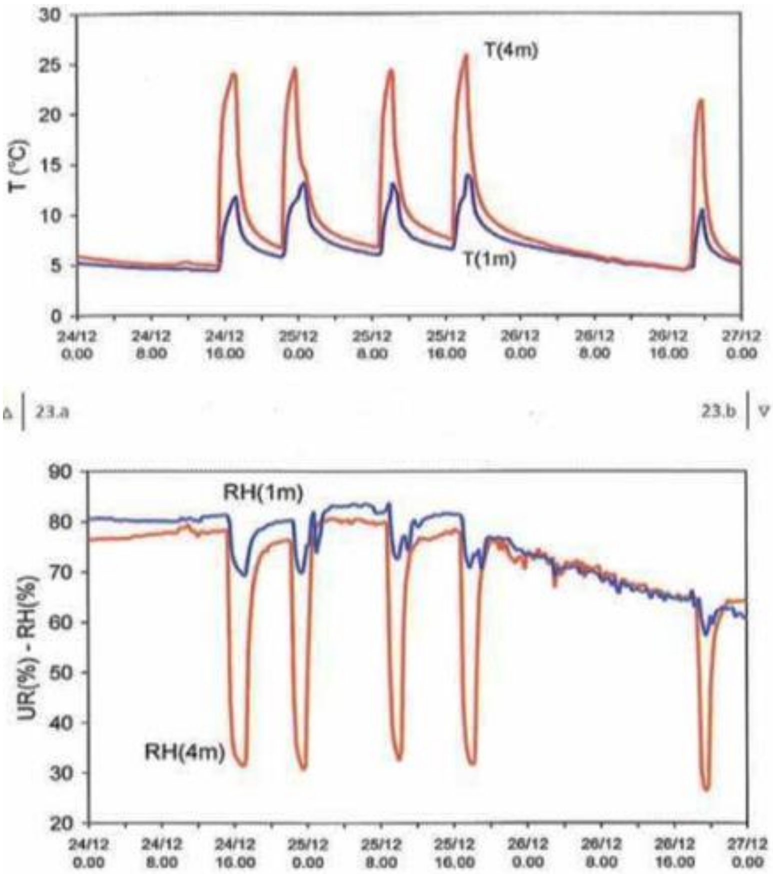


Figure 26 If the warm air heating is on, the T rise (top) causes RH to drop (bottom).[77]

Floor Heating [E1.2]

Floor heating has the potential to provide a balanced situation, as the heat is uniformly distributed [149]. However, in colder climates and the case of continued use the RH may become too low [16], [77], [149]. Also, the energy usage can be quite high, as the heating time may vary from hours to days [16], [76]. In older systems pipes are often uninsulated at the bottom, located deeper under the surface or part of a thick flooring layers, reducing the heating speed and causing heating losses [102]. Floor heating has the potential to offer elevated levels of thermal comfort if the settings are correct. For example, too high temperatures will cause discomfort, due to air flows [76], [102] and can lead to blackening of the walls and ceilings, damaging mural and ceiling paintings [16], [77]. The balance between comfort and conservation is hard to find and maintain and strongly depends on the local environment and the characteristics of the building and its interior [77].

The installation of a floor heating system is an invasive project, which will damage the floor, tombs, and possible archaeological remains underneath the building [76], [77], [102], [149]. In churches with a historically valuable floor or an undisrupted sub surface, floor heating is not a recommended system. A less invasive alternative is footboard heating underneath pews, Figure 27. However, in colder climates, this will not be sufficient to obtain a comfortable indoor climate, because of the small radiant surface and the general use of wood in the floorboards [77], [149]. Making it an unfit alternative for floor heating, especially considering the Dutch climate.

Figure 27 Example of heated floorboards as part of the benches/pews. [77]

Infrared Heating [E1.3]

Infrared heating is a variant of local heating [149], it comes from high-temperature emitters, either via direct fuel combustion or electricity [77], [102]. Infrared heating makes it possible to only heat parts of the church that is in use and has a short heating time. The downside is the fact that it only heats parts it directly reaches, in the case of heating from above that head in shoulders will be significantly warmer than other body parts [76], [77], [102], [149]. Figure 28, shows the profile of the mean radiant temperature of a person standing in the pew area of a church. Due to the high-temperature difference between head and toes, the person can feel uncomfortable.

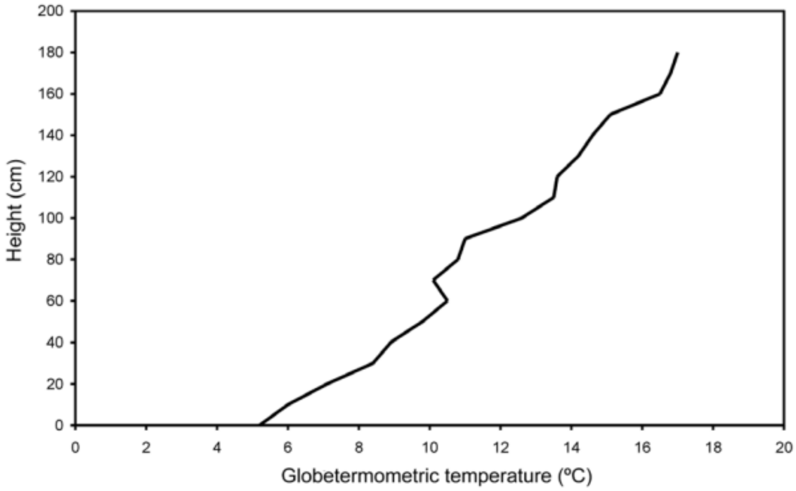


Figure 28 Profile of heating for a person standing in the pew area in a church heated with quartz halogen emitters. [149]

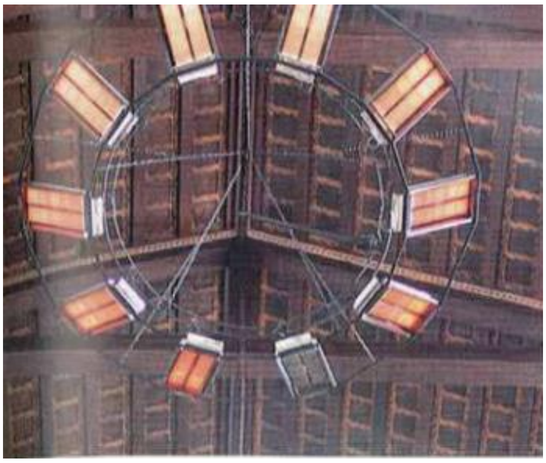


Figure 29 Example of an infrared fixture from direct gas combustion. [77]

Depending on the type of heaters selected several problems can occur. Emitters heated by gas combustion (Figure 29) could cause pollution of the indoor air. In the best-case scenario, there is complete combustion, and only emitting water vapour and CO_2, but if this is not the case other undesirable products such as NO_x, soot, deficiency of O_2, unburned hydrocarbons and possible CO could be emitted [77]. The water vapour and pollutants could do severe damage to the church and in high concentrations endanger the religious community. Another disadvantageous of gas supplied heaters is the significant noise pollution [76] and the invasive installation process of the gas supply. Electrical powered emitters do not cause pollution, they do cause visual discomfort [77]. As well as, possibly damage the building due to fast heating and the UV light that is emitted [76], [77], [149]. It could, if designed correctly, provide a flexible installation to heat (parts) of the church [77], taking into account that electricity grid in the church can cope with the additional demand [102].

Radiator and Convector Heating [E1.4]

Radiator heating is a direct form of heating and forms a combination of radiation and convection. Convector heating solely uses convection. Both systems can often easily be installed [76]. In the case of radiators people in the church benefit from warm air and some from direct heat [77]. It does take quite some time to reach a comfortable temperature, making it a weak system for a big church [76], [77]. Radiators tend to be larger than convectors, thus, having a bigger impact on the appearance of the building. Convectors, however, need a bigger air flow, making dust flows and disposition on walls and ceilings a significant risk [77].

Local (Pew) Heating [E1.5]

Pew or bench heating is a form of local heating extensively studied in the Friendly Heating project [104]. Figure 30, on the left, shows the tested elements, especially optimising conservation and thermal comfort. Figure 31 present other pew heating systems, the friendly heating system is an optimisation of these or similar systems. The general advantage of local heating is that it does not, or limits, the impact on the indoor climate, making it the best option for conservation [76], [77], [102], [149], as well as lower the energy usage [76]. The Friendly Heating project improved the reachable thermal comfort levels [77], [92], still in colder climates additional heating will be required [92], as a cold spot could cause damage due to humidity and condensation.

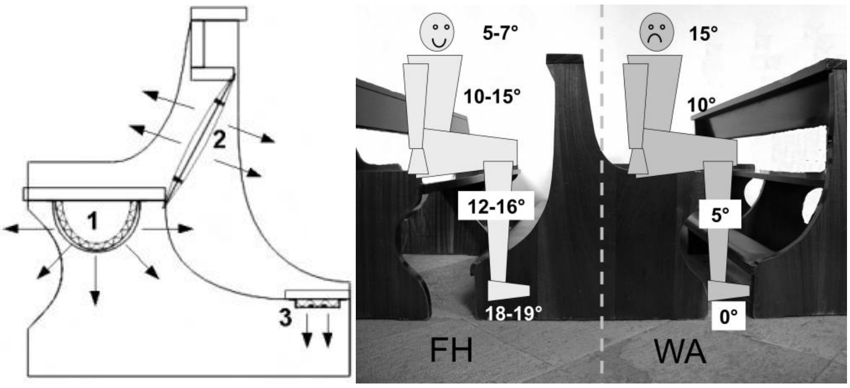


Figure 30 Left: Heating elements tested in the climate room set-up [92] Right: the effective temperature at different body parts for the Friendly Heating (FH) and warm air (WA) heating systems. [126]

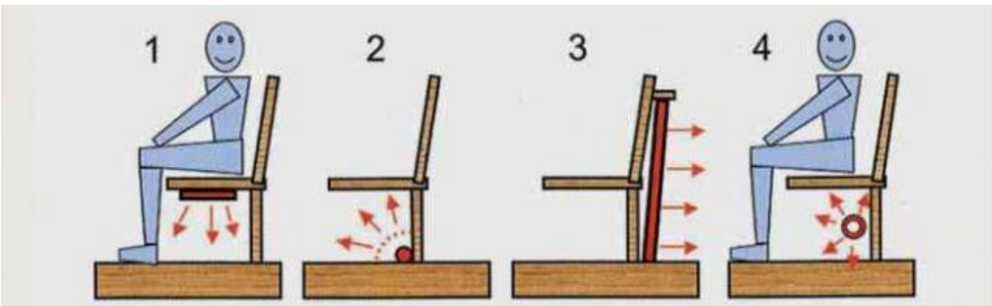


Figure 31 Pew heating: 1) panel electrical; 2) tubular electrical; 3) panel electrical; 4) hot water heating pipe. [77]

Balance Between Parameters

The heating systems all have good and bad points, which strongly depends on building and occupancy characteristics. The use of the system, for example, continuously, intermitted, or mixed heating also influence the impact and performance of the specific heating system. Table 34 presents a hierarchy based on the energy use of the system, the required capacity, the thermal comfort, influence of the heating system on the conservation of the church building, influence of the heating system on the cultural, historic character and the installation cost. Other researchers made a similar list and presented in Appendix B5. The first table (Table 34) presents results from Dutch case studies [76] and mostly corresponds with the hierarchy presented in the table below. The second table (Table 35) provides more information about the impact use has on the effects of the heating system [77].

Which system is the best depends on the requirements that come from the building and the religious community. When there is a clear focus on comfort, a floor heating system or an air heating would be best. If there is a favourable indoor and outdoor climate, pew heating can be enough to offer thermal comfort for the religious community. For conservation, local heating systems have a better performance. Finding a balance between energy use, conservation and comfort in the church building are difficult. When sustainability and conservation are considered significant, churchgoers might have to make some sacrifices and accept a low-temperature environment [149].

Table 34 Hierarchy of heating systems, based on energy use, capacity, thermal comfort, conservation of interior and building, and installation cost, according to the Groene Kerken. [100]

Local (pew) heating system;
Air heating system; non-distributed;
Air heating system; well-distributed;
Infrared heating system;
(Under)floor heating system;
Radiator heating system;
Convector heating system.

Current Heating System [E2]

A new heating system will require an investment, that will, from a cost point of view, only be beneficial if the current heating system is not functioning optimally. In some cases, it will be sufficient to optimise the existing system instead of a total replacement. Optimisations or renewals depend on the current scheme and the budget that is available. Small measures can be radiator foil, thermostatic radiator valves, and insulating pipes. Bigger measures are replacing equipment for high-efficiency equipment. Other measures are more management related and are part of energy management. Important is to have insight into the current state of the installations and optimise them as much as possible. A decision based on the investments required for optimising the existing system compared to the investment needed for renewal. Also, considering the thermal comfort, conservation, and sustainability of the options.

Other Energy Use [E3]

The main energy use in a church building is for heating. Other important uses are lighting and equipment, depending on its presence. The occupancy of the church is the primary characteristic that influences the effect of measures. For example, replacing infrequently used lamps will have a lower effect than a lamp more frequently used. Energy efficient emergency lighting will have a big effect, as the usage is continuous.

Lighting Fixtures [E3.1]

Considerations when replacing light fixtures are the investment cost, the operational cost, and the life expectancy. Another consideration is the period in which light fixtures need replacement.

Efficiency of Equipment [E3.2]

There should be an overview of all the energy using equipment in the building. The first selection has the use as a basis. Plugging out devices infrequently used and sell or dispose of unused equipment. Unplugging limits the standby time from equipment. However, it should not damage the specific device. Finally, but not least, there is the efficiency or energy label of equipment. When replacing appliances or equipment, the energy label of the product is essential. A higher label will have a higher investment, but lower energy costs. Buying a new device should go together with research into different options and comparing them, thus buying best choice for the religious community.

Appendix B5 Heating Systems

Table 35 Qualification of heating systems. [76]

		Heating systems						
		Warm air		Floor	Infrared	Radiator	Convector	Pew
		Few inlets	Distrib. inlets					
Energy use	Heating rate	++	++	--	++	0	0	++
	Local heating	--	--	--	+	0	-	++
Heating capacity	Needed	0	0	+	+	-	--	++
	Producible	++	++	-	+	--	-	-
Thermal comfort	Generated airflows	-	+	0	-	-	0	-
	Radiant temperature	-	-	+	++	+	-	+
	Radiant asymmetry	0	0	+	-	0	0	+
	Floor temperature	0[4]	0[4]	++	+	0[4]	0[4]	++
	Stratification	+[5] or -[6]	+	+	+	+	+	+
Preservation	Contamination	+[7] or -[8]	+[7] or -[8]	--	-[9]	-[9]	-[9]	++
	Changing RH	+[10]	+[10]	+	--[11]	-	-	+
	Condensation [12]	+	+	++	--[13]	+	+	++
Monumental impact	Construction work	+	--	--	0	0	-	0
	Esthetical impact	+	0	++[14]	--	--	0	0
Costs	Installation	+	--	--	++	0	0	0

Table 36 Adapted summary of the pros and cons of the heating systems. [77]

Heating system		Infrared			Convective			Pew				
	Warm air	Direct Gas Comb.	Quartz Tube	Quartz Halogen Radiant	Hot water radiators	Gilled tubes	Floor	High T	Low T	Warm air emission	Coanda effect	Friendly Heating
Typical use	I	I	I	I	C/I	C/I	C	I	I	I	I	I
T[15]	C[16]: 0 I[17]: - M[18]: 0/-	+/-	+/-	+/-	C: + I: - M:0	C: + I: - M:0	C: + I: - M: 0	+/-	+	0	0	+
RH[19]	C: -- I: - M: 0/-	-	+/0	+/0	C: - I: - M:0	C: - I: - M:0	C: -- I: - M: 0	+/0	+	0/-	0/-	+
Condense[20]	C: -- I: - M: --/-	0/-	0	0	C: + I: - M:0	C: + I: - M: 0	C: + I: 0/- M: +/0	-	-	-	-	0/+
Deposition	C: -- I: - M: --/-	0/-	0	0	C: -- I: - M: --/-	C: -- I: - M: --/-	C: - I: 0 M: 0/-	0/-	+/0	0/-	-	+/0
Pollution	D[21]	Ch[22], W[23]	No	G[24], UV	No	D	No	No	No	D	D	No
Comfort	C: 0 I: - M: 0/-	0/-	0/-	-/--	C: +/0 I: 0/- M:0	C: +/0 I: 0/- M: 0	C: ++ I: 0 M: +/0	0/-	0/-	0/-	0/-	0/+
Visibility[25]	-	0/-	0/-	-/--	-	+/-	++	0/+	0/+	0	0/-	0/+
Invasivity[26]	--	-	+	+	-	0/+	--	-/+	-/+	-/+	0/+	_+

[4] In case of a wooden floor
[5] In case of a low Archimedes number
[6] In case of a low Archimedes number
[7] In case of air infiltration
[8] Near the air extraction grilles
[9] Above the heater
[10] For low heating rates
[11] For directly heated objects
[12] ++ Low condensation risk
[13] Without air extraction
[14] If the monumental floor is not disturbed
[15] Risk for sudden temperature changes
[16] **C**: Continuous heating
[17] **I**: Intermittent heating
[18] **M**: Mixed heating
[19] Risk for sudden RH changes or too low levels
[20] Risk for condensation
[21] **D**: Resuspension of floor dust
[22] **Ch**: Chemical pollutants
[23] **W**: Water vapour
[24] **G**: Luminous glare
[25] Visual impact of the heating system
[26] Degree of invasion and damage to the structure

Appendix B6 Sustainable Energy Supply

Sustainable or renewable energy is energy from a theoretically inexhaustible source, that has a negligible impact on the environment. Power sources such as solar, hydroelectric and wind power, environment heat, aerothermal and hydrothermal energy, geothermal energy, and biomass, are renewable. Table 37 provides an overview of available sources in the Netherlands and their similar technologies, as well as categories from Marszal et al. [154] on the place of generation.

Sustainable Procurement [R1]

Becoming 100% carbon free does not have to be a difficult or expensive task. Many energy suppliers provide a 100% carbon dioxide free choice. Changing energy supplier, often done online, will not result in a significant increase in costs. An alternative is joining a collective; there are at least two collectives available specifically for churches: EVK [155] and Kerkstroom [156]. Both offer 100% green energy and try to negotiate the best contract. Another way would be to consider local initiatives or a contract with an energy supplier that has a green offer.

Table 37 Renewable energy sources and similar technologies, categories form [154] (adapted from [157]).

Source	Technology	Cat.
Wind	Wind turbines;	II, IV
Sun	Photovoltaic system (solar cells);	I, II, IV
	Thermic systems (solar boilers);	I, II
Hydroelectric power	Hydroelectric power plant;	IV
Tides	Tidal power plant;	IV
Waves	Golf power plant;	IV
Salinity gradient	Osmotic energy recovery;	IV
geothermal soil energy	Geothermal installation; Geothermal heating; Heat pump;	I, II
Aerothermal (air)	Heat pump;	I
Hydrothermal (surface water)	Heat pump;	I, II
Biomass	Thermal conversion: combustion, gasification, pyrolysis; Biochemical conversion: fermentation.	II, III

Sustainable Energy On-site [R2]

Generate energy on-site can bring long-term benefits, it also requires an investment. Power generation within the building envelope or on-site is possible with the aid of an energy supplier or independent. The building does need a connection to the grid, to be able to deliver unused energy back and if the local production is not sufficient to take up energy. In Table 37 presents several options; the next sections discuss these options.

(small) Wind Turbines [R2.1]

A Small wind turbine is placeable on top of the building if the structure allows. Alternatively, on an independent pole close to the building. A converter makes the generated energy useable and allows for supply to the grid. A wind turbine has potential, but this potential depends on many factors and is uncertain [158]. An extensive permit procedure is required, possible sound pollution, and the payback period uncertain [100]. Making the large investment risky and difficult to justify. Figure 32 presents several types of turbines; application depends on the placement and the local environment. A wind turbine is a last resort; they are only an option if there is a lack of alternatives and enough proof to expect success.

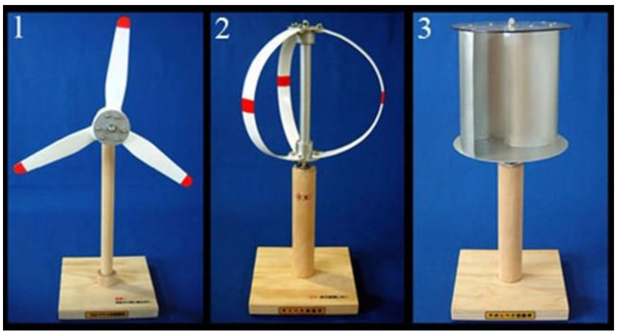


Figure 32 Different types of turbines: 1) Horizontal; 2) Vertical (Darrieus); 3) Vertical (Savonius). [138]

Photovoltaic Panels [R2.2]

PV-panels are becoming increasingly common. As the wind turbine, it is a visible sustainable measure, showing the church is trying to reduce their impact on the environment setting an example for others. The placement of solar panels is easy, depending on the roof construction, orientation, and the monumental status of the building. The panels do not require a permit, although there are some exceptions, for example, the protected status of the building. The payback period of PV-panels can be significant because of energy tax benefits of churches and the lower compensation for delivering to the grid depending on the size of the connection [100].

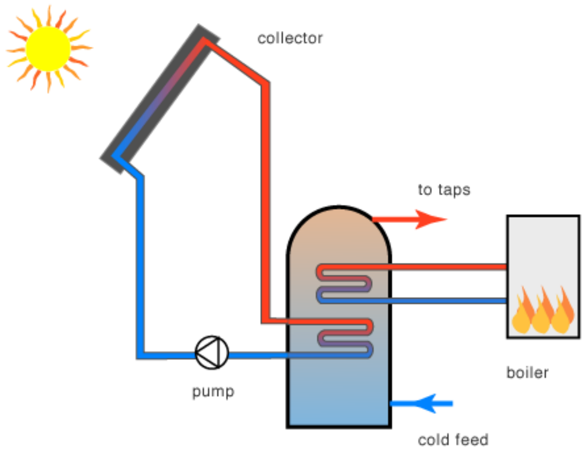


Figure 33 Possible design of a system with solar collectors. [159]

Solar Collectors [R2.3]

A solar collector collects heat by absorbing sunlight, most often the collectors placed on the roof. The system can combine with a conventional (gas) boiler that provides extra heat. However, not all boilers are suitable for this combination. The system (Figure 33) becomes quite complex as the installation must be compatible with the existing equipment. Also, the placement of all the parts can have a significant impact on the cultural, historical value of the building.

Heat Pump [R2.4]

Heat pumps offer many varieties, heat sources, reversibility, and combinations of systems can differ per specific type or system. Sources can be geothermal, either vertical or horizontal, hydrothermal, either from ground water, surface water or another water source, aerothermal, for outdoor air or ventilation air. The chosen source strongly influences the investment cost. The investment for a geothermal horizontal heat pump will be higher than an air based heat pump. Air to water heat pumps require lower capital costs, are easy to install, and need little space. The dimensioning is quite complex, in cold periods the system is often under dimensioned and not delivering sufficient heat, while if the system would cope with these extreme circumstances, it is over-dimensioned for the rest of the year [160]. Over dimensioning subsequently leads to higher investment cost [160], [161].

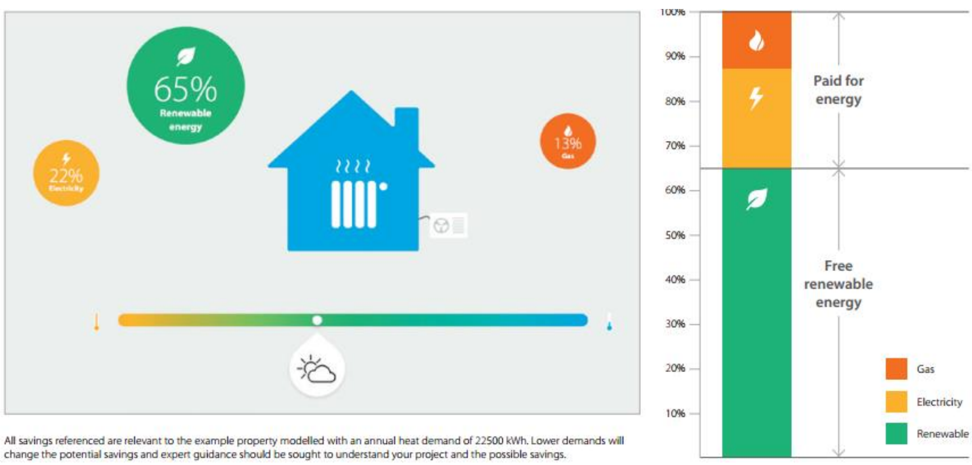


Figure 34 Example of a hybrid heating system and the composition of energy. [162]

Hybrid Heat Pump [R2.5]

An alternative would be a hybrid system, also called bivalent heat pump systems, combines a gas boiler with a heat pump. This hybrid model partly electrifies the heating system, but can apply heating from gas if the temperatures are extreme, Figure 34 offers an example of the balance between the heat pump and the conventional boiler. It allows for a smaller, less expensive, heat pump, and continued use of the existing system. The adjustment to the building, the outdoor and indoor temperature, and the heating system present influence the efficiency. The system functions best when low-temperature heating is present [138]. Higher insulation values also improve the performance of the combination, reducing the requirement of additional gas heating [160]. A factor that is important to consider is the electricity use of the heat pump, which should be part of cost-benefit calculations. Application in residential buildings shows that the gas reduction is greater than the additional electricity use [138]. However, the occupancy of a church building is quite different, making it an uncertain factor.

Thermal Conversion [R2.6]

Through the combustion of biomass, wood-pallets, -briquets, or dry wood. The system works similarly to a regular gas boiler. The initial investment is higher than in a regular system. The operational phase could be less expensive if the use is frequent, often not corresponding with the use of churches [100]. Also, the biomass source is important is and influences the sustainability. The impact of incomplete combustion and possible burning smell are not neglectable and affect the permit procedures.

Figure 35 Profile section of a pallet stove system. [163]

Micro Combined Power and Heat (CPH) [R2.7]

In this system, the central heat system provides heat as well as electrical energy. Instead of 20% losses, the CPH converts 15% of these losses into electrical energy. Figure 36 shows the schematics. The efficiency of the electricity production improves with continuous running time [164]. The use in church buildings is often not sufficient to earn back the investment [100]. Depending on the use the payback period is greater than the lifespan of the unit, making it an unwise choice.

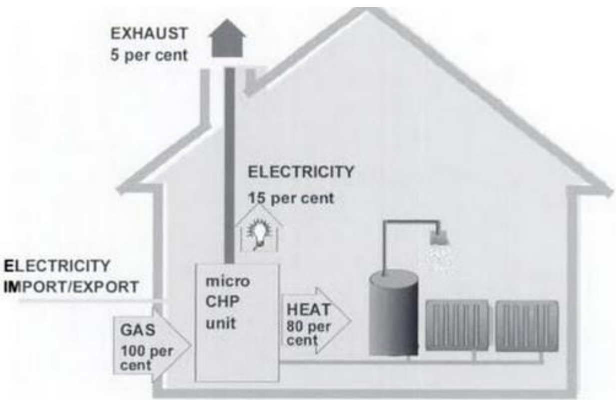


Figure 36 Micro-CPH schematic energy flows. [164]

Combination and Optimisation [R3]

In the sections above reviewed some of the main heating systems. Within these options, several types of equipment and system designs are possible, as well as combinations of systems. The amount of energy generated on-site can depend on the specific objective or strategy. It is also important to keep in mind that measures on the demand site will change the payback period of measures. Some actions have a negative effect on the payback period, while others are beneficial. Continuous monitoring of effects and adjustment of plans could limit the risk of measures that will have more costs than benefits.

Appendix B7 Multi-Criteria Analysis

Description of Indicators & Scores

This appendix presents an elaborate description of the indicators presented in section 2.2.1.1 and Table 15. The rating scales and scores related to the indicators follow the description.

Investment Costs

The capital costs of a measure are the amount of capital required to implement the measure successfully. Part of the investment costs is the capital needed for preparation, purchase, and installation of the measure. It is an estimation and relative to other actions, as the exact cost will depend on the building characteristics and the specific design. Table 38 present that rating scales for the investment costs. In the highest score (5), the cost is null or extremely low, while in highest (1), the cost is extremely high, for example, due to substantial structural work.

Table 38 Estimated investment costs rating scales.

	Score
Extremely low to null	5
Low	4
Medium	3
High	2
Extremely high	1

Energy Costs Reduction

The decrease in the energy costs is the financial benefit of the measure. Cost reduction either takes place due to a decline in demand or by generating energy on-site. In the case of power generation on-site the energy costs can even be below null by selling the surplus of energy back to the grid. The exact energy costs reduction will depend on the measure and implementation, but also on the occupancy of the building. Future adaptations can also influence the overall effect a measure has, positively and adversely. The score of a measure depends on its effect on a common situation. Table 39 presents the rating scales for the energy costs reduction. The highest score (5) means, that the energy cost reduction is close to being maximal, which means close to null or negative. The lowest score (1) is if a measure does not affect the energy cost or only marginally.

Table 39 Estimated energy costs reduction rating scales.

	Score
Extremely low to null	1
Low	2
Medium	3
High	4
Extremely high	5

GHG Emission Savings

GHG emission savings can be the result of a reduction in energy use, but also due to the use of sustainable energy. Changing energy sources can reduce the energy costs, but increase the amount of GHG. The rating expresses the potential of a measure for reducing the emission of the building compared to the situation before implementation. Similar measures require comparing them, coming to a relative score. Table 40 presents the potential GHG emission savings. The highest score (5) means the amount of GHG emission coming from the building becomes close to null. The lowest score (1) indicates there is no change or even more emissions than before.

Table 40 Potential GHG emission savings rating scales.

	Score
Extremely low to null	1
Low	2
Medium	3
High	4
Extremely high	5

Monumental Value Impact

This indicator expresses the impact the measure has on the building characteristics such as the invasiveness and the visibility of the measure. Also important here is the reversibility. If the measure is visible but reversible and the monumental factor not permanently damaged it scores higher. However, the measure must be easily reversible and leave no marks after removal. Table 41 present the rating scales of the impact a measure can have on the monumental value.

Table 41 Monumental value impact rating scales.

	Score
Extremely low	5
Low	4
Medium	3
High	2
Extremely high	1

Preservation

The preservation refers to the risks of a measure of the stability of the indoor climate, such as temperature fluctuations and changes in RH. As well as the risks of condensation or disposition of smoke and particles. Depending on the building, and the presence of specific artworks and organs, indoor climate characteristics influence the preservation factor. Rating of the measures uses an average Dutch situation, as well as a general stability of the indoor climate. If the specific church building has historically or culturally important pieces that need conservation, a more in-depth analysis should be made to make sure the measure does not have an adverse effect. Table 42 presents the rating scales of the preservation factor. A measure can have a positive effect, no effect, or a harmful effect. The highest score (2) means that improves the stability of the indoor climate and reduces the risk of factors that negatively influence the conservation. The lowest score (-2) such a significant risk of negative influences on the preservation.

Table 42 Preservation factor rating scales.

	Score
Extremely good	2
Good	1
Not good/not bad	0
Bad	-1
Extremely bad	-2

Thermal Comfort

The thermal comfort depends on many factors that make it difficult to estimate the improvement. However, from research including the thermal comfort, there are some generalisations. These generalisations make it possible to predict the effect of changes in the indoor climate on the comfort level. The airtightness of the building, the capacity of the heating system, the heat distribution are all factors that influence the comfort levels. Measuring or simulating the comfort level before implementing measures is advisable.

Table 43 Change in the thermal comfort rating scales.

	Score
More Comfortable	2
Slightly more comfortable	1
No change	0
Slightly more uncomfortable	-1
More Uncomfortable	-2

Aggregation & Results

Table 44 offers an overview of the performance of the measures on the criteria, based on the rating scales presented above. A higher score means a better score. The scores were normalised using Equation 1, the values between [*0.00*] and [*1.00*] (Table 44). (1) Presents a hierarchy based on the total list; (2) presents a hierarchical score within the categories. Applying weights did not solve the co-relation between measures and categories, even though within some categories it did offer insight. The SAW method shows some potential, but more knowledge should be available on church buildings, all their characteristics, and how this affects the effectiveness of measures.

Table 44 Rating scores and normalised scores [] for the different measures.

No	Investment		Reduction		Savings		Impact		Preservation		Comfort		(1)	(2)
1	6	[1.00]	0	[0.00]	0	[0.00]	6	[1.00]	0	[0.50]	0	[0.50]	3.00	3.00
M2	6	[1.00]	0	[0.00]	0	[0.00]	6	[1.00]	0	[0.50]	0	[0.50]	3.00	3.00
M3	6	[1.00]	0	[0.00]	0	[0.00]	6	[1.00]	0	[0.50]	0	[0.50]	3.00	3.00
M4														
.1	4	[0.60]	2	[0.33]	2	[0.40]	6	[1.00]	1	[0.75]	2	[1.00]	4.08	4.08
.2	6	[1.00]	2	[0.33]	2	[0.40]	5	[0.80]	1	[0.75]	0	[0.50]	3.78	3.78
.3	6	[1.00]	2	[0.33]	2	[0.40]	6	[1.00]	1	[0.75]	1	[0.75]	4.23	4.23
M5	6	[1.00]	2	[0.33]	2	[0.40]	6	[1.00]	1	[0.75]	0	[0.50]	3.98	3.98
D1	1	[0.00]	3	[0.50]	2	[0.40]	1	[0.00]	2	[1.00]	1	[0.75]	2.65	2.65
D2	4	[0.60]	3	[0.50]	3	[0.60]	4	[0.60]	1	[0.75]	2	[1.00]	4.05	4.05
D3														
.1	2	[0.20]	3	[0.50]	3	[0.60]	2	[0.20]	1	[0.75]	1	[0.75]	3.00	3.00
.2	3	[0.40]	4	[0.67]	4	[0.80]	3	[0.40]	1	[0.75]	1	[0.75]	3.77	3.77
.3	2	[0.20]	3	[0.50]	3	[0.60]	3	[0.40]	1	[0.75]	2	[1.00]	3.45	3.45
.4	3	[0.40]	4	[0.67]	4	[0.80]	3	[0.40]	1	[0.75]	2	[1.00]	4.02	4.02
E1														
.1	4	[0.60]	3	[0.50]	3	[0.60]	4	[0.60]	-1	[0.25]	-1	[0.25]	2.80	2.80
.2	1	[0.00]	1	[0.17]	3	[0.60]	3	[0.40]	1	[0.75]	2	[1.00]	2.92	2.92
.3	5	[0.80]	5	[0.83]	4	[0.80]	5	[0.80]	-2	[0.00]	-2	[0.00]	3.23	3.23
.4	3	[0.40]	2	[0.33]	1	[0.20]	1	[0.00]	-1	[0.25]	1	[0.75]	1.93	1.93
.5	5	[0.80]	5	[0.83]	4	[0.80]	5	[0.80]	2	[1.00]	2	[1.00]	5.23	5.23
E2	4	[0.60]	3	[0.50]	3	[0.60]	5	[0.80]	1	[0.75]	2	[1.00]	4.25	4.25
E3														
.1	3	[0.40]	3	[0.50]	3	[0.60]	3	[0.40]	2	[1.00]	0	[0.50]	3.40	3.40
.2	2	[0.20]	3	[0.50]	3	[0.60]	6	[1.00]	0	[0.50]	0	[0.50]	3.30	3.30
R1	6	[1.00]	0	[0.00]	5	[1.00]	6	[1.00]	0	[0.50]	0	[0.50]	4.00	4.00
R2														
.1	1	[0.00]	1	[0.17]	2	[0.40]	2	[0.20]	0	[0.50]	0	[0.50]	1.77	1.77
.2	3	[0.40]	6	[1.00]	4	[0.80]	3	[0.40]	1	[0.75]	1	[0.75]	4.10	4.10
.3	2	[0.20]	3	[0.50]	3	[0.60]	2	[0.20]	1	[0.75]	1	[0.75]	3.00	3.00
.4	2	[0.20]	2	[0.33]	4	[0.80]	3	[0.40]	1	[0.75]	1	[0.75]	3.23	3.23
.5	3	[0.40]	4	[0.67]	3	[0.60]	3	[0.40]	1	[0.75]	1	[0.75]	3.57	3.57
.6	2	[0.20]	1	[0.17]	3	[0.60]	2	[0.20]	-2	[0.00]	0	[0.50]	1.67	1.67
.7	1	[0.00]	1	[0.17]	1	[0.20]	4	[0.60]	0	[0.50]	0	[0.50]	1.97	1.97
R3	2	[0.20]	4	[0.67]	4	[0.80]	4	[0.60]	0	[0.50]	1	[0.75]	3.52	3.52

Appendix B8 Levels of Maturity

Table 16 presented the six formulated maturity levels, including a short description. This appendix contains a further explanation on the different levels.

Level 0: Starting Point

Level 0 is the lowest level; the religious community is not actively working on their sustainability performance. There are no plans to improve the performance or start creating awareness concerning the topic. This situation is unlikely, as most religious communities are at least considering their energy use. However, moving to the first level is only possible if there are actions towards reducing the energy use of a building. Including consciously made steps, and not an added benefit of other measures.

Level 1: Initiated

The religious community is starting to become aware of the sustainability performance of their building. Active awareness of the religious community, especially considering small measures. Also, the church must start monitoring and registering the energy use. The measures in this level are necessary for the other levels. However, minor the effects on the actual energy usage, this level forms the foundation for a structured approach to the following levels. Even if a religious community has already surpassed this point of planning; it is advisable to return to this point. Returning to this point and formulating a status quo allows for evaluation of measures implemented and planned.

Level 2: Managed

In this level, it is important that plans become defined. The religious community must decide on a goal, define the corresponding objectives and strategies. Multiple objectives over time will keep the religious community involved and aware of the project. It also allows for adjustment of plans, depending on the results of previously implemented measures. Equally important is the appointment of a person responsible for keeping track of the progress and signals when things are going wrong. The second level plans the steps to further levels and requires continuously review on progress and results of the implemented measures. To pass to the next stage goals and objectives must be clear, the strategies, however, can be less detailed, to prevent unnecessary work, due to the adjustments later.

Level 3: Defined

The previous levels target mostly the preparation of the project and creating the awareness within the religious community to optimise support for implementation and behavioural change. In this level, the implementation of measures starts. The measures do not need a significant investment Optimising the control and operation of the system, as well as making small improvements to the building and use of the building, are actions. The actions will give extra insight into the characteristics of the building, which can serve as preparation for the implementation of bigger measures. Finally, it is also important to look at the possibility of procuring sustainable energy. In the third level, most important are the active implementation of measures. Exploring all actions makes weighting of high and low investment measures possible. Comparing measures could cause some overlap between the actual implementation of measures in level three and planning of level four.

Level 4: Institutionalised

In this level, investments improve the sustainability performance of the church building further. Examples are improving the thermal conductivity of building envelope or generating energy on-site. Another exploration area is the delivery mode of the heating system, keeping in mind the building characteristics, occupancy characteristics and the state of the current installations. Formulated plans consider the interrelation measures have. The end of the project approaches, there are detailed plans and significant implementations steps.

Level 5: Optimised

In this level sustainability is part of every action undertaken. Continued monitoring is essential to ensure the system performance as best as it can. Possibly there are some additional measures to reach the final goal. Maintenance will be necessary as well as continued awareness within the religious community. Level 5 is the final level, the goals and objectives reached. In this level, it is important to keep up-to-date with possible new methods. The religious community stays focussed on sustainability, it does not become stagnant, but it keeps moving forward through optimisation and renewal of the system.

Appendix B9 Statements including eleborations (Dutch)

1	**Het energiegebruik wordt gemonitord.**
	Er is inzicht in het energiegebruik omdat het regelmatig bekeken wordt. Er is een dusdanige kennis dat grote afwijking vastgesteld worden.
2	**Het energiegebruik wordt minimaal maandelijks geregistreerd.**
	Het energiegebruik wordt niet alleen bekeken, maar ook geregistreerd. Dit maakt het gebruik inzichtelijk en het wordt makkelijker te zien wanneer er afwijkingen zijn. Er zijn lijsten beschikbaar waarin data nagegaan kan worden. De frequentie is minimaal maandelijks, maar een hogere frequentie zou aan te raden zijn.
3	**Er is terugkerende aandacht voor duurzaamheid binnen de geloofsgemeenschap.**
	In de communicatie met de geloofsgemeenschap is er aandacht voor duurzaamheid. Dit kan aandacht betekenen tijdens diensten of vieringen, maar ook in het kerkblad, op de website of tijdens themabijeenkomsten. Hierbij gaat het specifiek om aandacht voor de duurzaamheid van het kerkgebouw.
4	**Er is aandacht in het gebouw zelf voor het duurzame gebruik.**
	In het gebouw zelf is aandacht voor duurzaamheid, bijvoorbeeld door mensen eraan te herinneren lichten en verwarming uit te doen en ramen te sluiten. In sommige gebouwen lijkt dit overbodig, bijvoorbeeld als er een koster aanwezig is. Het is echter wel een laagdrempelige manier om bewustwording te creëren over het gebruik van energie.
5	**De geloofsgemeenschap wordt geënthousiasmeerd voor het verduurzamingsproject.**
	In de vormgeving van het verduurzamingsproject wordt de geloofsgemeenschap betrokken. Het is belangrijk de gemeenschap vroegtijdige bij het project te betrekken om zo goed in beeld te krijgen wat hun eisen en wensen zijn.
6	**Betrokkenheid van leden is gestimuleerd.**
	Door leden actief te betrekken bij de planvorming of uitvoering worden ze geënthousiasmeerd. Een bijkomend voordeel is dat er in een geloofsgemeenschap vaak een verscheidenheid aan kennis en vaardigheden beschikbaar is. Door hiervan gebruik te maken, kun de plannen beter vorm krijgen.
7	**Er is een duidelijke missie, in het bijzonder voor het gebouw.**
	Een missie geeft iets aan over hoe een organisatie zichzelf ziet, wat ze doet en wat ze wil bereiken. Voor een kerk heeft de missie al zeer duidelijke contouren, maar details, zeker omtrent het gebouw, zullen uitgewerkt moeten worden. Een voorbeeld is de functie van het kerkgebouw, is deze zuiver religieus of er een functie als wijkcentrum.
8	**Er is een visie geformuleerd voor de toekomst en voor het verduurzamen van het gebouw.**
	De visie geeft aan wat de plannen zijn voor het gebouw en hangt vaak sterk samen met de missie. Het toekomstbeeld en ambities voor het gebouw komen hierin samen. Het is belangrijk deze goed te formuleren, omdat het gebruik sterk beïnvloed welke maatregelen het duurzaamst zijn.
9	**Aan de hand van missie en visie zijn doelen geformuleerd.**
	Met de missie en visie worden doelen voor duurzaamheid geformuleerd. De doelen mogen breed en algemeen zijn, zoals het verminderen van de impact op het milieu door gebruik van het gebouw.
10	**Aan de doelen zijn doelstellingen verbonden die, specifiek, meetbaar, acceptabel, realistisch en tijdsgebonden zijn.**
	Bij het formuleren van doelstellingen worden de doelen concreet gemaakt. Hiervoor kan de SMART methode worden gebruikt, waarbij de doelen uiteindelijke Specifiek, Meetbaar, Acceptabel, Realistisch en Tijdsgebonden zijn. Een voorbeeld van een doelstelling kan zijn: “Geen CO_2-uitstoot van het verwarmingssysteem in de kerkzaal in januari 2025.”
11	**Er zijn doelstellingen opgesteld voor een kortere termijn (<jaar).**
	Door het formuleren van meerdere doelstellingen op verschillende termijn blijft er beweging in het project. Het behalen van (deel)doelstellingen werkt motiverend en stimuleert inzet voor het vervolg van het project.
12	**Er zijn doelstellingen opgesteld voor een langere termijn (>jaar).**
	Langere termijn doelstelling zijn belangrijk, omdat ze het project vormgegeven. De langere termijn doelstellingen liggen het dichts bij de feitelijke doelen en vormen een ijkpunt voor het eindresultaat voor het project.
13	**Er is een plan van aanpak om de doelstelling te behalen.**
	Het plan van aanpak beschrijft de methodes waarmee de doelstellingen bereikt kunnen worden. Over het algemeen zijn er verschillende methodes of combinaties van methodes mogelijk om een doel te bereiken. Verschillende methodes zullen moeten worden verkend, waarna de beste wordt geselecteerd.
14	**Er zijn evaluatiemomenten ingepland om de voortgang te meten.**
	Tijdens de evaluatiemomenten wordt gekeken naar de effecten van de al uitgevoerde maatregelen ten opzichte van de beginsituatie of vergeleken met voorgaand evaluatiemoment. Evaluatiemomenten kunnen worden gebruikt om plannen te heroverwegen of kleine aanpassingen te doen.
15	**Er is een energiebeheerder aangesteld die toezicht houdt op het verloop van de plannen.**
	De energiebeheerder is verantwoordelijk voor het soepel verloop van het project en heeft een centrale rol bij de evaluatie. Deze persoon heeft inzicht in alle plannen en heeft toegang tot de verzamelde energiegegevens. De beheerder zal alarm slaan als er iets mis dreigt te gaan of als de effecten tegen lijken te vallen.

16	**De huidige onderhoudstoestand van het verwarmingssysteem is bekend.**
Het verwarmingssysteem in zijn geheel in kaart gebracht en in het bijzonder de onderhoudstoestand. Belangrijk is dat het gehele systeem meegenomen wordt van de bron tot aan de verspreiding van de warmte.	
17	**Er is een inventarisatie gemaakt van de mogelijkheden om het systeem te verbeteren.**
Aan de hand van de onderhoudstoestand en algehele toestand van het verwarmingssysteem wordt gekeken naar hoe de efficiëntie van het systeem verbeterd kan worden. Verbeteringen kunnen zijn het schoonmaken van het systeem, maar ook het vervangen van bijvoorbeeld de ketel.	
18	**De instellingen van het energiesysteem zijn geoptimaliseerd om de efficiëntie te verbeteren.**
Hierbij kan worden gedacht aan automatische regelingen, zodat de verwarming niet onnodig aanstaat. Of de temperatuur van de warmtetoevoer, zoals het toepassen van lage temperatuur verwarming.	
19	**De optie van zonering van het systeem is verkend.**
Afhankelijk van het gebouw kunnen er (verwarmings)zones worden ingesteld. Dit maakt het mogelijk de temperatuur van ruimtes onafhankelijk in te stellen en afstemmen op individueel gebruik. Wel is er per zone een thermostaat nodig.	
20	**Zonering is ingevoerd, zones zijn afzonderlijk instelbaar en regelbaar.**
Indien mogelijk, zijn er zones gecreëerd en worden deze afzonderlijk geregeld. Over het algemeen heeft een kerkgebouw meerdere ruimtes, waarbij het kan helpen een aparte regeling te creëren. Mocht het niet mogelijk zijn om fysiek zones te creëren, terwijl hier wel behoefte aan is, zou er gewerkt kunnen worden met tijdelijke of beweegbare scheidingswanden.	
21	**Het temperatuurverloop in de kerk(zaal) is gemeten met een interval van minimaal 5 minuten voor een periode van minimaal 3 weken.**
Deze periode van intensieve metingen wordt gebruikt om aanpassingen te doen aan de ingestelde temperatuur in de kerk. Het is een idee om in deze studie ook de relatieve luchtvochtigheid mee te nemen, om deze naast de fluctuaties in de temperatuur zichtbaar te maken.	
22	**Het gebruik van het gebouw is in kaart gebracht.**
Het in kaart brengen van het gebruik van het gebouw is belangrijk voor het energiegebruik. Vaste diensten, koren die repeteren, vergadering etc. Allemaal gebruiksmomenten, waar eventueel verwarmd moet worden.	
23	**Afhankelijk van de meetresultaten en gebruik is de basis temperatuur geoptimaliseerd.**
Afhankelijk van de temperatuurverschillen, relatieve luchtvochtigheid en het aantal graaddagen kan de basis temperatuur verlaagd worden, wat kan leiden tot energiebesparingen.	
24	**Gebruik van het gebouw is zoveel mogelijk gepland rondom om het vaste gebruik, zoals erediensten.**
Door het combineren van activiteiten op aansluitende dagen, hoeft het gebouw niet iedere keer van de basis temperatuur omhoog te worden gebracht. Bijvoorbeeld koorrepetities op maandag zodat de restwarmte van de dienst van zondag benut kan worden.	
25	**Bij aanvullend gebruik dat geen direct onderdeel is van de missie, wordt een afweging gemaakt inclusief tussen inkomsten, kosten en milieu-impact.**
Als het gebouw anders gaat worden gebruikt dan volgens de missie is vastgesteld, dan moet er een afweging gemaakt worden tussen de eventuele inkomsten, kosten en milieu-impact die dat heeft. Er moet een duidelijke schatting zijn wat het gebruik van het gebouw kost voor het specifieke gebruik, wat vervolgens meegenomen kan worden in de prijs. Milieukosten zijn moeilijker mee te nemen, maar dit zou zeker moeten als het gebouw nog niet verbeterd is.	
26	**Luchtdichtheid van het gebouw is geanalyseerd.**
De luchtdichtheid van het gebouw is belangrijk voor het energiegebruik, maar ook voor het thermisch comfort in het gebouw. Er moet worden gekeken waar infiltratie plaatsvindt en hoe dit voorkomen zou kunnen worden. Vaak zijn het kleine handelingen, die geen grote investering vergen. In het geval dat er grotere maatregelen op de agenda staan, kan er voor gekozen worden te wachten met het uitvoeren van deze kleinere maatregelen. Bij voorkeur is er een blowerdoortest uitgevoerd.	
27	**Kieren, voeg tussen bewegende en vaste deel, van ramen en deuren zijn dicht.**
De ruimte tussen de kozijnen en raam of deur dicht gemaakt met bijvoorbeeld tochtbanden of -strips.	
28	**Naden, voeg tussen vaste delen, bij de aansluiting van kozijnen op gevels zijn dicht.**
Bij de aansluiting van kozijnen op andere bouwonderdelen kan ruimte overblijven, vaak zijn deze al afgedekt met een houten lat. Nog steeds zullen de effecten van de dichten van deze naden er zeker zijn. Kleinere naden kunnen dicht gekit worden, in het geval van grotere naden kan bijvoorbeeld purschuim gebruikt worden.	
29	**Naden tussen de gevel en het dak en de muren zijn dicht.**
Ruimte tussen de bouwonderdelen is gesloten, bijvoorbeeld met kit of schuim.	
30	**Naden tussen de gevels en de ondergrond zijn dicht.**
Afhankelijk van de ondergrond kan een vulmiddel gekozen worden.	
31	**Daknokken zijn geïsoleerd.**
Aanbrengen van isolatie en zorgen dat de (aanwezig) isolatie goed aansluit.	

32	**Penetraties van bouwschil zijn geïsoleerd.**
Allerlei soorten isolatiemateriaal kan worden gebruikt voor het isoleren van doorvoeren in de bouwschil. Afhankelijk van het materiaal kan dit, net als de bovenstaande materialen, gewoon in de bouwwinkel gekocht worden.	
33	**De brievenbus is luchtdicht of staat los van het gebouw.**
Het dicht maken de brievenbus kan op twee manieren, enerzijds door een tochtborstel. Anderzijds is het sluiten van de brievenbus en een aparte bus neer zetten.	
34	**Er is een inventarisatie van de aanwezige energie gebruikende apparaten.**
Op deze lijst staan alle energie gebruikende apparaten aanwezig in het gebouw. Er moet ook worden aangegeven of ze aangesloten zijn, hoe vaak ze worden gebruikt en hoe veel ze gebruiken als dit bekend is.	
35	**Er is een plan geformuleerd om dit energiegebruik te optimaliseren.**
Het energiegebruik van apparaten wordt verbeterd door in eerste instantie een selectie te maken tussen gebruikte en niet-gebruikte apparaten. Een andere maatregel zou het verminderen van de stand-by time kunnen zijn. Uiteindelijk zal er een plan moeten liggen, waarbij over tijd minder efficiënte apparatuur verdwijnt of wordt vervangen door apparaten met een beter energielabel.	
36	**Er is gekeken naar het inkopen van duurzame energie.**
Het inkopen van duurzame energie zorgt ervoor dat het effect van het energiegebruik meteen gemitigeerd wordt. Dit betekent niet dat het verminderen van het gebruik niet meer belangrijk is. De hoeveelheid duurzame energie die opgewekt wordt, is niet eindeloos, dus moet er spaarzaam mee omgegaan worden. Bij het verkennen van de mogelijkheden voor het inkopen van energie, moeten de langere termijn doelstellingen meegenomen worden over groene energie en het zelf opwekken van energie.	
37	**Er is duurzame energie ingekocht of dit gaat op zeer korte termijn gebeuren.**
Het traject tot een duurzaam kerkgebouw kan lang duren. Met kleine en grotere stappen worden de doelen uiteindelijk wel bereikt. Door het inkopen van duurzame energie kan het effect op het milieu meteen worden gereduceerd.	
38	**Er wordt aandacht besteed aan de plannen en reeds geïmplementeerde maatregelen.**
Er is blijvende aandacht binnen de geloofsgemeenschap voor de al uitgevoerde plannen en plannen die nog op de agenda staan. Er wordt aandacht besteed aan het bereiken van tussendoelen en dit wordt ook gedeeld met de geloofsgemeenschap.	
39	**Het gemiddelde isolatieniveau van de bouwschil is bekend.**
Het gemiddelde isolatieniveau van de bouwschil wordt bepaald door de isolatiewaarde van de verschillende onderdelen. Het niveau van de verschillende onderdelen zoals de muur, dak, vloer en ramen en kozijnen kan interessant zijn om te weten. De waardes kunnen berekend worden door gebruik te maken van de materiaaleigenschappen en -dikte. Een alternatief is warmtebeelden, waarbij de luchttemperatuur binnen en buiten en de temperatuur aan de oppervlakte gebruikt wordt.	
40	**Er is een doelstelling opgesteld voor het te behalen isolatieniveau.**
Het toevoegen van isolatie kan zorgen voor energiebesparingen en een prettiger binnenklimaat. Het is echter ook een complex proces dat een significant investering nodig kan hebben. Daarnaast kunnen er negatieve effecten zijn op de cultureel historische waarde. Het is dus belangrijk om met de bekende waardes een realistische doelstelling te formuleren over het nieuwe isolatieniveau.	
41	**Er is een plan van aanpak opgesteld om de gestelde isolatieniveau te behalen.**
Afhankelijk van de doelstelling kan een plan van aanpak geformuleerd worden, dit kan uiteenlopen van het construeren van een dubbel gevelsysteem, tot het ophangen van gordijnen. Belangrijk is dat er rekening wordt gehouden met de kwaliteit van het binnenklimaat en de cultureel historische waarde van het gebouw.	
42	**Er is gekeken naar de mogelijkheid van een alternatief verwarmingssysteem.**
Er zijn uitgebreide onderzoeken gedaan naar verwarmingssystemen voor kerken. In deze onderzoeken worden verschillende afwegingen gemaakt, voornamelijk tussen comfort en conservatie. Maar andere aspecten worden zeker meegenomen. Een ander of aanvullend verwarmingssysteem zou een goede manier zijn om naast het verminderen van het energiegebruik ook het comfortniveau te verhogen. Het systeem moet uiteraard wel afgestemd zijn om het gebouw en het specifieke gebruik.	
43	**Er is een vergelijking gemaakt tussen het alternatief en het huidige systeem.**
De aanpassingen aan het bestaande systeem zullen vergeleken moeten worden met de plaatsing van een nieuw systeem. In het geval er grote investeringen gedaan moeten worden aan het huidige systeem wordt het overwegen van een nieuw systeem aantrekkelijker.	
44	**Er is een plan van aanpak voor het verwarmingssysteem gebaseerd op de vergelijking.**
Het aanpakken van het verwarmingssysteem kan een grote stap zijn in de richting van een duurzaam kerkgebouw. Maar het kan ook ingrijpende veranderingen met zich meebrengen. Als er plannen zijn voor het zelf opwekken van energie, kan het belangrijk zijn dit mee te nemen in het plan van aanpak voor een verwarmingssysteem.	

45	**Niet zuinige apparatuur is vervangen.**
Naar aanleiding van de inventarisatie en plan van aanpak wordt er aan de slag gegaan met het vervangen van apparatuur en bijvoorbeeld lampen. Hierbij kan vervangen plaatsvinden aan het einde van de levensduur van een apparaat, maar er kan ook gekozen worden voor actieve vervangen als iets veel gebruikt wordt. Zoals bijvoorbeeld de noodverlichting.	
46	**Mogelijkheden tot het zelf opwekken van energie zijn verkend.**
Het opwekken van energie biedt verschillende mogelijkheden en kan op verschillende manieren aangepakt worden. Het is belangrijk te verkennen wat de mogelijkheden zijn, maar ook wat de doelstelling is van het zelf energie opwekken. Als het uiteindelijke doel zelfvoorzienend zijn is, dan moeten er andere keuzes gemaakt worden, dan als dat geen doel op zich is.	
47	**In het selecteren van maatregelen is rekening gehouden met reeds genomen en geplande maatregelen.**
Zoals eerder al is aangegeven hebben de maatregelen vaak een relatie en kunnen ze elkaar versterken of verzwakken. Als men bijvoorbeeld kiest voor een warmtepomp, is het wijs dit te combineren met lage temperatuurverwarming, zoals vloerverwarming. Een warmtepomp heeft ook baat bij een beter geïsoleerd gebouw. Zo grijpen maatregelen op elkaar in en zeker bij de grotere maatregelen is het belangrijk dit op elkaar af te stemmen.	
48	**‘Best practice’ is meegenomen in de selectie van maatregelen**
Bij de selectie van maatregelen is het belangrijk te kijken naar de eigen situatie maar het is ook wijs om te kijken naar wat op dat moment de best mogelijke maatregel is. ‘Best practice’ kan technisch zijn, maar ook economisch of sociaal. Het is belangrijk dat de lijst met maatregelen up-to-date is zodat er niet bij voorbaat een veroudering ontstaat en dat steeds de best mogelijk maatregel gekozen wordt binnen de middelen en corresponderend met de doelstellingen.	
49	**Duurzaamheid wordt altijd meegenomen als er een beslissing moet worden genomen.**
Duurzaamheid is niet een apart agendapunt, het is volwaardig deel van de bedrijfsvoering van de geloofsgemeenschap. Bij iedere beslissing of activiteit wordt rekening gehouden met de duurzaamheid van deze activiteit.	
50	**De combinatie van maatregelen zorgen voor een ‘optimaal’ systeem.**
Het nieuwe systeem is zo samengesteld en ingesteld dat het een zo goed mogelijk systeem vormt, het is zo efficiënt als mogelijk, maar ook recht doet aan de andere condities zoals comfort, behoud en beheer. Als er duidelijke verbeteringen mogelijk zijn worden deze opgepakt en wordt gekeken wat het verwachte effect is in het systeem.	
51	**Er is continue aandacht voor verdere verbeteringen.**
De performance van het systeem wordt constant gemonitord en er wordt actief gekeken naar de mogelijkheid tot verbetering. Aanpassingen worden doorgevoerd waar mogelijk om zo tot een steeds beter systeem te komen.	
52	**De gestelde doelstellingen zijn voor een groot deel bereikt.**
De doelstellingen gesteld in eerdere stappen zijn grotendeels bereikt of er zijn gedetailleerde plannen beschikbaar om deze alsnog te bereiken. Doelstellingen die nog niet zijn bereikt en waarvan lijkt dat deze niet bereikt worden, kunnen op dit punt aangepast worden. Een andere optie kan zijn het formuleren van aanvullende deeldoelstellingen, waardoor stapsgewijs het uiteindelijke doel alsnog bereikt kan worden.	
53	**Er zijn concrete plannen voor de nog openstaande doelstellingen.**
Zoals eerder aangegeven moeten er duidelijke plannen zijn voor de nog openstaande doelstellingen. Als het niet mogelijk is een toepasbaar plan van aanpak te formuleren voor de openstaande doelstellingen, zullen de doelstellingen heroverwogen moeten worden. Dit kan zijn door het aanpassen van de doelstellingen, maar ook door het toevoegen van tussenstappen.	
54	**‘Best practice’ is toegepast in het gebouw.**
Alle maatregelen individueel vormen samen vormen een ‘best practice’ voorbeeld voor andere geloofsgemeenschappen en hun gebouwen. Het systeem is niet geoptimaliseerd op de eisen, maar daarboven. De gebruikte maatregelen zijn de best mogelijke maatregelen op het moment.	
55	**Er is sprake van een constante evaluatie van maatregelen, combinaties en efficiency van het systeem.**
Energiegebruik wordt constant gemonitord en beoordeeld. Constant wordt er gekeken of het systeem nog presteert zoals het zou moeten. Verslechteringen worden niet geaccepteerd en er is een actief beleid om steeds verder te verbeteren. Belangrijk is dat er geen achteruitgang plaatsvindt, er in ieder geval sprake is van stilstand en eigenlijk een vooruitstrevende bewegingen met de veranderende normen van duurzaamheid.	

Appendix B10 Statements English

1	There is monitoring of the energy use.
2	There is at least a monthly registration of the energy use.
3	There is recurring attention towards sustainability within the religious community.
4	There is attention to sustainability within the church building.
5	There is enthusiasm creation for the sustainability project within the religious community.
6	There is encouragement of members to participate in the project.
7	The is a clear mission, especially regarding the building.
8	There is a sharp vision for the future and the improvement of the sustainability of the building.
9	The mission and vision form the basis to formulate goals.
10	The objectives are specific, measurable, acceptable, realistic, and time-bound.
11	There are short-term goals (<year).
12	There are long-term goals (>year).
13	There are strategies related to the objectives.
14	There are scheduled evaluation moments to measure progress.
15	Appointment of an energy manager to supervise the progress of the plans.
16	The status of maintenance of the heating system is known.
17	There is an inventory containing the possible improvements of the system.
18	The settings of the energy system are optimal to improve the efficiency.
19	There is an exploratory study of the possibility of zoning the system.
20	Implemented zoning allows for independently controlled zones.
21	There is a study of the temperature progression of the church (hall); with measurements in a minimal interval of five minutes for a period of minimal three weeks.
22	The occupancy of the building is known.
23	There is an optimised basis temperature, depending on the measuring results and the use of the building.
24	There is a scheduling policy of planning activities around fixed user moment, such as religious services.
25	Considering added use, not directly part of the mission, includes the revenue, costs, and environmental impact.
26	There is an analysis of the air tightness of the building.
27	Closed cracks (a joint between rotating and fixed part) of windows and doors.
28	Closed seams (a joint between fixed part) at the junction of window frames on the facades.
29	Closed seams at the connection of the facades and roof to the building walls.
30	Closed seams at the connection of the facades on the ground floor.
31	There are insulated roof ridges.
32	There is insulation of the penetrations in the building envelope.
33	The mailbox is airtight or separated from the building.
34	There is an inventory of the energy using devices in the building.
35	There is a plan to optimise this energy use.
36	There is an exploratory study on the procurement of sustainable energy.
37	Procurement of sustainable energy or on a short-term.
38	There is attention to plans and implemented measures.
39	The average insulation of the building envelope is known.
40	The is an objective for the insulation level.
41	There is a strategy to reach the set insulation level.
42	There is an exploratory study into alternative heating systems.
43	There is a comparison between the alternatives and the existing system.
44	There is a strategy based on the comparison.
45	There is active replacement of non-energy efficient equipment.
46	There is an exploratory study into the possibility of generating energy on-site.
47	The previously implemented and planned measures are part of the selection of new measures.
48	'Best practice' is part of the process when selecting measures.
49	Sustainability is part of every decision.
50	The combination of measures becomes an 'optimal' system.
51	There is a continuous attention for improvements.
52	There is a fulfilment of most of the set objectives.
53	There are concrete strategies for the remaining objectives.
54	'Best practice' is part of the building.
55	There is a constant evaluation of measures, combinations, and efficiency of the system.

Appendix C.

Appendix C1 Elaborate case description

Onze Lieve Vrouwe ten Hemelopnemingkerk

Figure 37 Top left corner: organ; middle: picture in the period 1950-60; top right corner; entrance at the hoofdstraat; bottom left: view from the stationsstraat; bottom right: interior with a view of the altar. [165], [166]

The ‘Onze Lieve Vrouwe ten Hemelopnemingkerk’ (Our Lady Assumption Church; O.L.V.) is in downtown Apeldoorn. It is the only Roman Catholic (RC) still in use by the Emmaus Parish, which came to be, because of a merging of seven city parishes in Apeldoorn in January 2005 [167]. In 2012, there was a decision to use one place of worship, as the cost of maintenance became too high. It became the O.L.V. because of the age and the location of the building.

The O.L.V. is the oldest and was for a long time, just like now, the only RC church in Apeldoorn. J.W. Boerbooms (1849-1899), who started construction in 1895. Following his death architects, J. Cuypers (1861 – 1946) and J. Stuyt (1886 – 1934) completed the building. They designed the choir and transept, for which construction started in 1901. Plans for a western tower were never implemented, because of a lack of funds [167]. The church is primarily as a place of worship; regular services are Saturday evening and Sunday morning, as well as several moments during the week. Incidental used for concerts. However, these always need to have a religious touch to it. There is warm air heating with several furnaces. The system is under revision. Initially, the choice was to keep the same system. However, the finding of asbestos offered extra time to consider alternatives.

Open Hofkerk

Figure 38 Top left corner: photo from 1966-67; Bottom left corner: façade & entrance; middle: stained glass window; right: the organ. [168]–[170]

The 'Open Hofkerk' (OHK) is in the area Kerschoten a neighbourhood in the residential area Apeldoorn North. Kerschoten was designed by David Zuiderhoek (1911-1993) and appointed as one of the thirty sectors that are exemplary for the post war period by the RCE [171]. This means that the area should be appreciated and treated with regard for the historical value. The national government does, however, support local governments and residents in the formulation of plans to improve while preserving the characteristics of the area. The OHK was also designed by David Zuiderhoek, except for the original window, which comes from his daughter Hanneke Zuiderhoek [169], [171].

Figure 38 gives an impression of the church, the current organ was placed 1974, but has parts that originate from 1850 [170]. The building is the place of worship of a small PKN community, with an average age 65+; primarily used during the Sunday morning service. Additional use primarily takes place in the side buildings. The church has floor heating and additional radiators to improve the temperature. There are four separate meters, corresponding with four high-efficiency boilers. There is an uninsulated floor heating system. There are plans for insulating the floor and presented to the College of Church Stewards (College van Kerkrentmeesters; CvK). The CvK formally owns the building and decides on the financial aspects of the plans. Considering much smaller, and bigger measures; such as solar panels and changing the use of the building. Priority, however, was the insulation of the floor.

At the start of this project, it was clear that the OHK had some significant problems and there was pressure to come to a solution. Now nearing the end, the project, the church board had to decide to close the building. A negative decision on the requested funding forces the community to explore alternative options such as merging with another community or multifunctional use of the building.

Jachtlaankerk


Figure 39 Top left: postcard image; bottom left: 'Reil' organ, in-use since 2003; top right: Church with extension and new entrance; bottom right: church hall viewed from the altar [172]

The 'Jachtlaankerk' (JLK) is in Sprengenbos, an area that is part of 'De Sprengen', which is a neighbourhood in the residential area of Apeldoorn West. During summer (June, July, and August) the chapel in Hoog Soeren, 5 kilometres west of Apeldoorn, provides bi-weekly housing. The JLK was constructed in 1952 by architect Schuring and officially opened in '53. In 2000 saw the completion of an extension, and more recently there was an analysis of the energy use of the building. After which a project followed to improve the sustainability performance of the building. The project that follwed is in the finishing stages.

The JLK is, in contrast to the other two cases, a multifunctionally used church. Expect for Saturdays there is daily use of the church building. The use ratio is 20%-80%, respectively for religious use and additional use. For the future, there are plans regarding solar panels. As the building itself is not suitable, an alternitave is a collaboration with schools.

Appendix C2 Questionnaire Results

Table 45 Response OLV.

1	JA	11	NEE	21	NEE	31	NEE	41	NEE	51	JA
2	NEE	12	NEE	22	JA	32	NEE	42	JA	52	NEE
3	JA	13	NEE	23	JA	33	NEE	43	JA	53	NEE
4	JA	14	NEE	24	JA	34	NEE	44	NEE	54	NEE
5	JA	15	NEE	25	NEE	35	NEE	45	NEE	55	NEE
6	NEE	16	JA	26	NEE	36	NEE	46	JA		
7	JA	17	JA	27	NEE	37	NEE	47	JA		
8	JA	18	JA	28	NEE	38	NEE	48	JA		
9	NEE	19	JA	29	NEE	39	NEE	49	NEE		
10	NEE	20	NEE	30	NEE	40	NEE	50	NEE		

Table 46 Response OHK

1	JA	11	JA	21	JA	31	NEE	41	JA	51	JA
2	JA	12	JA	22	JA	32	NEE	42	JA	52	NEE
3	JA	13	JA	23	JA	33	JA	43	JA	53	JA
4	NEE	14	JA	24	NEE	34	JA	44	JA	54	NEE
5	NEE	15	JA	25	JA	35	JA	45	NEE	55	NEE
6	JA	16	JA	26	JA	36	JA	46	JA		
7	JA	17	JA	27	JA	37	NEE	47	JA		
8	JA	18	JA	28	NEE	38	JA	48	NEE		
9	JA	19	JA	29	JA	39	JA	49	JA		
10	JA	20	JA	30	NEE	40	JA	50	NEE		

Table 47 Response JLK

1	JA	11	JA	21	JA	31	JA	41	JA	51	JA
2	JA	12	JA	22	JA	32	JA	42	JA	52	JA
3	JA	13	JA	23	JA	33	JA	43	JA	53	JA
4	JA	14	JA	24	NEE	34	JA	44	JA	54	JA
5	JA	15	JA	25	JA	35	JA	45	JA	55	JA
6	JA	16	JA	26	JA	36	JA	46	JA		
7	JA	17	JA	27	JA	37	JA	47	JA		
8	JA	18	JA	28	JA	38	JA	48	JA		
9	JA	19	JA	29	JA	39	JA	49	JA		
10	JA	20	JA	30	JA	40	JA	50	JA		

Appendix C3 Mandatory Requirements

Table 48 List of required and optional requirements & explanation.

Nr.	Type	Explanation
1	M	Required for the planning of the project.
2	M	Required to provide data and compare results.
3 4 5 6	1 out of 4	Similar measures all in the direction of creating awareness within the religious community.
7	M	Required for the formulation of the vision.
8	M	Required to formulate goals.
9	M	Required and important for shaping the project.
10	M	Required to plan the project and keep it manageable.
11 12	1 out of 2	Indicates there is attention to time management.
13	M	Required action plans to start and structure the project.
14	M	Required to keep track of the progress and adjust the actions plans if needed.
15	M	Plays a key role in planning and managing the project.
16	O	Could be done as a preparation for the next level.
17	M	Required to get insight into the heating system and what the alternatives are.
18	M	Required to gain insight into the (possible) performance of the current system.
19	M	Required to set up a zoning system and get insight into the requirements per zone.
20	M	Required to manage the system and better adjust it to the occupancies needs.
21	O	Specific data collection from the church hall, especially important if (parts of) the interior is (are) fragile and susceptible.
22 23 24 25	3 out of 4	Getting an insight in the use of the building and develop a critical view on the matter.
26 27 28 29 30 31 32 33	5 out of 8	Awareness of the airtightness of the church building and concrete actions to reduce the infiltration losses.
34	M	Better knowledge about the energy using equipment, required to make an action plan for replacement.
35	O	An action plan is formulated to reduce the energy usage by equipment
36	M	A thorough exploration of options of buying renewable energy
37	O	There is a sustainable energy contract (within a short term).
38	O	There is continued attention for the project within the religious community.
39	M	Gain insight into the building characteristics, needed for the next level.
40	M	Required for formulating an action plan, considering the current insulation level.
41	M	There is a plan of action.
42	O	Preparation steps for the improvement of the heating system
43	O	
44	M	There is a plan of action for the renewal of the heating system
45	M	The implementation of the action plan.
46	M	Important to know what is possible, could influence other measures.
47	M	Required to prevent redundant actions and deterioration of the improved situation.
48	M	Required to create an overall good performing system.
49	M	Required to obtain an overall sustainable system.
50	O	There is continued attention to the performance of the system.
51	O	
52	M	Provides insight into the development of the church.
53	M	Action plans for remain goals show the steps the church is still going to take.
54	M	The building must be an example for other religious communities.
55	M	Required to stay on top of new developments and improvements.

Appendix C4 Improved Statements & Elaborations (Dutch)

<table>
<tr><td>M</td><td>1</td><td>Het energiegebruik wordt minimaal maandelijks geregistreerd.</td></tr>
<tr><td colspan="3">Het energiegebruik wordt niet alleen bekeken, maar ook geregistreerd. Dit maakt het gebruik inzichtelijk en het wordt makkelijker te zien wanneer er afwijkingen zijn. Er zijn lijsten beschikbaar waarin data nagegaan kan worden. De frequentie is minimaal maandelijks, maar een hogere frequentie zou aan te raden zijn.</td></tr>
<tr><td>PM</td><td>2</td><td>Er is terugkerende aandacht voor duurzaamheid binnen de geloofsgemeenschap.</td></tr>
<tr><td colspan="3">In de communicatie met de geloofsgemeenschap is er aandacht voor duurzaamheid. Dit kan aandacht betekenen tijdens diensten of vieringen, maar ook in het kerkblad, op de website of tijdens themabijeenkomsten. Hierbij gaat het specifiek om aandacht voor de duurzaamheid van het kerkgebouw.</td></tr>
<tr><td>PM</td><td>3</td><td>Er is aandacht in het gebouw zelf voor het duurzame gebruik.</td></tr>
<tr><td colspan="3">In het gebouw zelf is aandacht voor duurzaamheid, bijvoorbeeld door mensen eraan te herinneren lichten en verwarming uit te doen en ramen te sluiten. In sommige gebouwen lijkt dit overbodig, bijvoorbeeld als er een koster aanwezig is. Het is echter wel een laagdrempelige manier om bewustwording te creëren over het gebruik van energie.</td></tr>
<tr><td>PM</td><td>4</td><td>De geloofsgemeenschap wordt geënthousiasmeerd voor het verduurzamingsproject.</td></tr>
<tr><td colspan="3">In de vormgeving van het verduurzamingsproject wordt de geloofsgemeenschap betrokken. Het is belangrijk de gemeenschap vroegtijdige bij het project te betrekken om zo goed in beeld te krijgen wat hun eisen en wensen zijn. Bijvoorbeeld door leden te vragen actief mee te doen bij de uitvoering.</td></tr>
<tr><td>M</td><td>5</td><td>Er is beleid voor het gebruik van het gebouw.</td></tr>
<tr><td colspan="3">Naast het religieusgebruik kunnen er nog andere gebruiksmomenten zijn van het kerkgebouw. Direct gerelateerd aan het religieus gebruik is bijvoorbeeld gebruik door het kerkkoor. Andere voorbeelden zijn vergaderingen of gebruik door derde. Het is belangrijk dat de geloofsgemeenschap beleid formuleert waarin wordt opgenomen welk gebouwgebruik bij de kerntaken (taken die als essentieel onderdeel van de geloofsgemeenschap worden gezien) hoort en welk gebruik daarbuiten valt.</td></tr>
<tr><td>M</td><td>6</td><td>Er is een visie geformuleerd voor de toekomst en voor het verduurzamen van het gebouw.</td></tr>
<tr><td colspan="3">De visie geeft aan wat de plannen zijn voor het gebouw en moet samenhangen met het gebruiksbeleid. Het toekomstbeeld en de ambities voor het gebouw komen hierin samen. Het is belangrijk deze goed te formuleren, omdat het gebruik sterk beïnvloed welke maatregelen het duurzaamst zijn.</td></tr>
<tr><td>M</td><td>7</td><td>Er zijn doelstellingen geformuleerd die, specifiek, meetbaar, acceptabel, realistisch en tijdsgebonden zijn.</td></tr>
<tr><td colspan="3">Bij het formuleren van doelstellingen worden de visie concreet gemaakt in stappen. Hiervoor kan de SMART-methode worden gebruikt, waarbij de doelen uiteindelijke Specifiek, Meetbaar, Acceptabel, Realistisch en Tijdsgebonden zijn. Een voorbeeld van een doelstelling kan zijn: “Geen CO_2-uitstoot van het verwarmingssysteem in de kerkzaal in januari 2025.”</td></tr>
<tr><td>PM</td><td>8</td><td>Er zijn doelstellingen opgesteld voor een kortere termijn (<jaar).</td></tr>
<tr><td colspan="3">Deze kortetermijndoelstellingen hebben een tijdsstap van een jaar of minder. Deze (deel)doelstellingen zorgen ervoor dat er structuur wordt aangebracht in de plannen. Het geeft ook een bereikbaar doel om naar toe te werken naast het einddoel. Het behalen van (deel)doelstellingen werkt motiverend en stimuleert inzet voor vervolgstappen.</td></tr>
<tr><td>PM</td><td>9</td><td>Er zijn doelstellingen opgesteld voor een langere termijn (>jaar).</td></tr>
<tr><td colspan="3">De langere termijn doelstelling zijn doelstellingen die een tijdstap hebben van een jaar of langer. Hierbij kan gedacht worden aan 5 jaar, maar ook 10 of 20. Deze doelstellingen zijn vormgevend het project voor de verduurzaming van het kerkgebouw. De langere termijn doelstellingen vormen een ijkpunt voor het gewenste eindresultaat en kunnen ondersteuning bieden als er keuzes gemaakt moeten worden voor de korte termijn (deel)doelstellingen.</td></tr>
<tr><td>M</td><td>10</td><td>Er is een plan van aanpak om de doelstellingen te behalen.</td></tr>
<tr><td colspan="3">Het plan van aanpak beschrijft de methodes waarmee de doelstellingen bereikt kunnen worden. Tijdens het opstellen van het plan van aanpak is het belangrijk verschillende opties te verkennen en de beste te selecteren. Hierbij is het belangrijk de economische, ecologische en sociale factoren mee te nemen en rekening te houden met de andere doelstellingen.</td></tr>
<tr><td>M</td><td>11</td><td>Er zijn evaluatiemomenten ingepland om de voortgang te meten.</td></tr>
<tr><td colspan="3">Tijdens de evaluatiemomenten wordt gekeken naar de effecten van de al uitgevoerde maatregelen ten opzichte van de beginsituatie of vergeleken met voorgaand evaluatiemoment. Evaluatiemomenten kunnen worden gebruikt om plannen te heroverwegen of kleine aanpassingen te doen.</td></tr>
<tr><td>M</td><td>12</td><td>Er is een energiebeheerder aangesteld die toezicht houdt op het verloop van de plannen.</td></tr>
<tr><td colspan="3">De energiebeheerder is verantwoordelijk voor het soepel verloop van het project en heeft een centrale rol bij de evaluatie. Deze persoon heeft inzicht in alle plannen en heeft toegang tot de verzamelde energiegegevens. De beheerder zal alarm slaan als er iets mis dreigt te gaan of als de effecten tegen lijken te vallen.</td></tr>
</table>

M	13	**Er is een inventarisatie gemaakt van de mogelijkheden om het verwarmingssysteem te verbeteren.**
Het verwarmingssysteem in zijn geheel in kaart gebracht en in het bijzonder de onderhoudstoestand. Belangrijk is dat het gehele systeem meegenomen wordt van de bron tot aan de verspreiding van de warmte. Hierbij is het belangrijk dat er ook gekeken wordt naar hoe het systeem verbeterd kan worden. Bijvoorbeeld door schoonmaken, het vervangen van de ketel etc.		
M	14	**De instellingen van het energiesysteem zijn geoptimaliseerd om de efficiëntie te verbeteren.**
Hierbij kan worden gedacht aan automatische regelingen, zodat de verwarming niet onnodig aanstaat. Of de temperatuur van de warmtetoevoer, zoals het toepassen van lage temperatuur verwarming.		
M	15	**De optie van zonering van het systeem is verkend.**
Afhankelijk van het gebouw kunnen er (verwarmings)zones worden ingesteld. Dit maakt het mogelijk de temperatuur van ruimtes onafhankelijk in te stellen en afstemmen op individueel gebruik. Wel is er per zone een thermostaat nodig.		
M	16	**Zonering is ingevoerd, zones zijn afzonderlijk instelbaar en regelbaar.**
Indien mogelijk, zijn er zones gecreëerd en worden deze afzonderlijk geregeld. Over het algemeen heeft een kerkgebouw meerdere ruimtes, waarbij het kan helpen een aparte regeling te creëren. Mocht het niet mogelijk zijn om fysiek zones te creëren, terwijl hier wel behoefte aan is, zou er gewerkt kunnen worden met tijdelijke of beweegbare scheidingswanden.		
O	17	**Het temperatuurverloop in de kerk(zaal) is gemeten met een interval van minimaal 5 minuten voor een periode van minimaal 3 weken.**
Deze periode van intensieve metingen wordt gebruikt om aanpassingen te doen aan de ingestelde temperatuur in de kerk. De **KMS-methode** is ontwikkeld door de Werkgroep Kerk, Milieu en Samenleving in Bennekom speciaal voor kerkgebouwen. Het is een idee om gelijktijdige ook de relatieve luchtvochtigheid mee te nemen, om deze naast de fluctuaties in de temperatuur zichtbaar te maken.		
PM	18	**Het gebruik van het gebouw is in kaart gebracht.**
Het in kaart brengen van het gebruik van het gebouw is belangrijk voor het energiegebruik. Vaste diensten, koren die repeteren, vergadering etc. Allemaal gebruiksmomenten, waar eventueel verwarmd moet worden.		
PM	19	**Afhankelijk van de meetresultaten en gebruik is de basistemperatuur geoptimaliseerd.**
Afhankelijk van de temperatuurverschillen, relatieve luchtvochtigheid en het aantal graaddagen kan de basistemperatuur aangepast worden, wat kan leiden tot energiebesparingen.		
PM	20	**Gebruik van het gebouw is zoveel mogelijk gepland op aan één gesloten dagen.**
Door het combineren van activiteiten op aansluitende dagen, hoeft het gebouw niet iedere keer van de basistemperatuur omhoog te worden gebracht. *Bijvoorbeeld koorrepetities op maandag zodat de restwarmte van de dienst van zondag benut kan worden*.		
PM	21	**Bij aanvullend gebruik dat geen direct onderdeel is van de kerntaken, wordt een afweging gemaakt inclusief tussen inkomsten en kosten.**
Extra gebruik buiten de *kerntaken* zou niet meer mogen kosten dan het inbrengt. Het is dus belangrijk te weten wat het kost om het gebouw te gebruiken en dit door te berekenen in de prijs. In de kosten zouden effecten op het milieu meegenomen kunnen worden. Milieukosten zijn moeilijker mee te nemen, maar dit zou zeker moeten als het gebouw nog niet verbeterd is. *Voor de berekening van de milieukosten zou bijvoorbeeld de toegevoegde hoeveelheid broeikasgassen kunnen worden gebruikt*.		
PM	22	**Luchtdichtheid van het gebouw is geanalyseerd.**
De luchtdichtheid van het gebouw is belangrijk voor het energiegebruik, maar ook voor het thermisch comfort in het gebouw. Er moet worden gekeken waar infiltratie plaatsvindt en hoe dit voorkomen zou kunnen worden. Vaak zijn het kleine handelingen, die geen grote investering vergen. In het geval dat er grotere maatregelen op de agenda staan, kan er voor gekozen worden te wachten met het uitvoeren van deze kleinere maatregelen. Bij voorkeur is er een blowerdoortest uitgevoerd.		
PM	23	**Kieren, voeg tussen bewegende en vaste delen, van ramen en deuren zijn gedicht.**
De ruimte tussen de kozijnen en raam of deur dicht gemaakt met bijvoorbeeld tochtbanden of -strips.		
PM	24	**Naden, voeg tussen vaste delen, bij de aansluiting van kozijnen op gevels zijn gedicht.**
Bij de aansluiting van kozijnen op andere bouwonderdelen kan ruimte overblijven, vaak zijn deze al afgedekt met een houten lat. Nog steeds zullen de effecten van de dichten van deze naden er zeker zijn. Kleinere naden kunnen dicht gekit worden, in het geval van grotere naden kan bijvoorbeeld purschuim gebruikt worden.		
PM	25	**Naden tussen de gevel en het dak en de muren zijn gedicht.**
Ruimte tussen de bouwonderdelen is gesloten, bijvoorbeeld met kit of schuim.		
PM	26	**Naden tussen de gevels en de ondergrond zijn gedicht.**
Afhankelijk van de ondergrond kan een vulmiddel gekozen worden.		
PM	27	**Daknokken zijn geïsoleerd.**
Aanbrengen van isolatie en zorgen dat de (aanwezig) isolatie goed aansluit.		

<table>
<tr><td>PM</td><td>28</td><td>Penetraties van bouwschil zijn geïsoleerd.</td></tr>
<tr><td colspan="3">Penetraties van de bouwschil zijn openingen in de bouwschil waar bijvoorbeeld leidingen het gebouw binnen komen. Allerlei soorten isolatiemateriaal kan worden gebruikt voor het isoleren van doorvoeren in de bouwschil. Afhankelijk van het materiaal kan dit, net als de bovenstaande materialen, gewoon in de bouwwinkel gekocht worden.</td></tr>
<tr><td>PM</td><td>29</td><td>De brievenbus is luchtdicht of staat los van het gebouw.</td></tr>
<tr><td colspan="3">Het dicht maken de brievenbus kan op twee manieren, enerzijds door een tochtborstel. Anderzijds is het sluiten van de brievenbus en een aparte bus neer zetten.</td></tr>
<tr><td>M</td><td>30</td><td>Er is een inventarisatie van de aanwezige energie gebruikende apparaten.</td></tr>
<tr><td colspan="3">Op deze lijst staan alle energie gebruikende apparaten aanwezig in het gebouw. Er moet ook worden aangegeven of ze aangesloten zijn, hoe vaak ze worden gebruikt en hoe veel ze gebruiken als dit bekend is.</td></tr>
<tr><td>O</td><td>31</td><td>Er is een plan geformuleerd om dit energiegebruik te optimaliseren.</td></tr>
<tr><td colspan="3">Het energiegebruik van apparaten wordt verbeterd door in eerste instantie een selectie te maken tussen gebruikte en niet-gebruikte apparaten. Een andere maatregel zou het verminderen van de stand-by time kunnen zijn. Uiteindelijk zal er een plan moeten liggen, waarbij over tijd minder efficiënte apparatuur verdwijnt of wordt vervangen door apparaten met een beter energielabel.</td></tr>
<tr><td>M</td><td>32</td><td>Er is duurzame energie ingekocht of dit gaat op zeer korte termijn gebeuren.</td></tr>
<tr><td colspan="3">Het traject tot een duurzaam kerkgebouw kan lang duren. Met kleine en grotere stappen worden de doelen uiteindelijk wel bereikt. Door het inkopen van duurzame energie kan het effect op het milieu meteen worden gereduceerd.</td></tr>
<tr><td>O</td><td>33</td><td>Er wordt aandacht besteed aan de plannen en reeds geïmplementeerde maatregelen.</td></tr>
<tr><td colspan="3">Er is blijvende aandacht binnen de geloofsgemeenschap voor de al uitgevoerde plannen en plannen die nog op de agenda staan. Er wordt aandacht besteed aan het bereiken van tussendoelen en dit wordt ook gedeeld met de geloofsgemeenschap.</td></tr>
<tr><td>M</td><td>34</td><td>Het gemiddelde isolatieniveau van de bouwschil is bekend.</td></tr>
<tr><td colspan="3">Het gemiddelde isolatieniveau van de bouwschil wordt bepaald door de isolatiewaarde van de verschillende onderdelen. Het niveau van de verschillende onderdelen zoals de muur, dak, vloer en ramen en kozijnen kan interessant zijn om te weten. De waardes kunnen worden berekend door gebruik te maken van de materiaaleigenschappen en -dikte. Een alternatief is warmtebeelden, waarbij de luchttemperatuur binnen en buiten en de temperatuur aan de oppervlakte gebruikt wordt.</td></tr>
<tr><td>M</td><td>35</td><td>Er is een plan van aanpak opgesteld om het gestelde isolatieniveau te behalen.</td></tr>
<tr><td colspan="3">Afhankelijk van de doelstelling kan een plan van aanpak geformuleerd worden, dit kan uiteenlopen van het construeren van een dubbel gevelsysteem, tot het ophangen van gordijnen. Belangrijk is dat er rekening wordt gehouden met de kwaliteit van het binnenklimaat en de cultureel historische waarde van het gebouw.</td></tr>
<tr><td>O</td><td>36</td><td>Er is een vergelijking gemaakt tussen alternatieve verwarmingssystemen en het huidige systeem.</td></tr>
<tr><td colspan="3">Er zijn uitgebreide onderzoeken naar verwarmingssystemen voor kerken. In deze onderzoeken worden verschillende afwegingen gemaakt, voornamelijk tussen comfort en conservatie. Een ander of aanvullend verwarmingssysteem kan het energiegebruik verminderen en het comfortniveau verhogen. Dit hangt af van het gebouw en het specifieke gebruik, maar ook van het huidige systeem. Aanpassingen aan het bestaande systeem moeten worden vergeleken met de plaatsing van een nieuw system. In het geval er grote investeringen moeten worden gedaan aan het huidige systeem wordt het overwegen van een nieuw systeem aantrekkelijker.</td></tr>
<tr><td>M</td><td>37</td><td>Er is een plan van aanpak voor het verwarmingssysteem gebaseerd op de vergelijking.</td></tr>
<tr><td colspan="3">Het aanpakken van het verwarmingssysteem kan een grote stap zijn in de richting van een duurzaam kerkgebouw. Maar het kan ook ingrijpende veranderingen met zich meebrengen. Als er plannen zijn voor het zelf opwekken van energie, kan het belangrijk zijn dit mee te nemen in het plan van aanpak voor een verwarmingssysteem.</td></tr>
<tr><td>M</td><td>38</td><td>Niet zuinige apparatuur is vervangen.</td></tr>
<tr><td colspan="3">Naar aanleiding van de inventarisatie en plan van aanpak wordt er aan de slag gegaan met het vervangen van apparatuur en bijvoorbeeld lampen. Hierbij kan vervangen plaatsvinden aan het einde van de levensduur van een apparaat, maar er kan ook gekozen worden voor actieve vervangen als iets veel gebruikt wordt. Zoals bijvoorbeeld de noodverlichting.</td></tr>
<tr><td>M</td><td>39</td><td>Mogelijkheden tot het zelf opwekken van energie zijn verkend.</td></tr>
<tr><td colspan="3">Het opwekken van energie biedt verschillende mogelijkheden en kan op verschillende manieren aangepakt worden. Het is belangrijk te verkennen wat de mogelijkheden zijn, maar ook wat de doelstelling is van het zelf energie opwekken. Als het uiteindelijke doel zelfvoorzienend zijn is, dan moeten er andere keuzes gemaakt worden, dan als dat geen doel op zich is.</td></tr>
<tr><td>M</td><td>40</td><td>In het selecteren van maatregelen is rekening gehouden met reeds genomen en geplande maatregelen.</td></tr>
<tr><td colspan="3">Zoals eerder al is aangegeven hebben de maatregelen vaak een relatie en kunnen ze elkaar versterken of verzwakken. Als men bijvoorbeeld kiest voor een warmtepomp, is het wijs dit te combineren met lage temperatuurverwarming, zoals vloerverwarming. Een warmtepomp heeft ook baat bij een beter geïsoleerd gebouw. Zo grijpen maatregelen op elkaar in en zeker bij de grotere maatregelen is het belangrijk dit op elkaar af te stemmen.</td></tr>
</table>

M	41	**'Best practice' is meegenomen in de selectie van maatregelen**
Bij de selectie van maatregelen is het belangrijk te kijken naar de eigen situatie maar het is ook wijs om te kijken naar wat op dat moment de best mogelijke maatregel is. '*Best practice' kan technisch zijn, maar ook economisch of sociaal. Het is belangrijk dat de lijst met maatregelen up-to-date is zodat er niet bij voorbaat een veroudering ontstaat en dat steeds de best mogelijk maatregel gekozen wordt binnen de middelen en corresponderend met de doelstellingen*.		
M	42	**Duurzaamheid wordt altijd meegenomen als er een beslissing moet worden genomen.**
Duurzaamheid is volwaardig deel van de bedrijfsvoering van de geloofsgemeenschap. Bij iedere beslissing of activiteit wordt rekening gehouden met de duurzaamheid van deze activiteit.		
O	43	**De combinatie van maatregelen zorgen voor een zo goed mogelijk systeem.**
Het nieuwe systeem is zo samengesteld en ingesteld dat het een zo goed mogelijk systeem vormt, het is zo efficiënt als mogelijk, maar ook recht doet aan de andere condities zoals comfort, behoud en beheer. Als er duidelijke verbeteringen mogelijk zijn worden deze opgepakt en wordt gekeken wat het verwachte effect is in het systeem.		
M	44	**De gestelde doelstellingen zijn voor een groot deel bereikt.**
De doelstellingen gesteld in eerdere stappen zijn grotendeels bereikt of er zijn gedetailleerde plannen beschikbaar om deze alsnog te bereiken. Doelstellingen die nog niet zijn bereikt en waarvan lijkt dat deze niet bereikt worden, kunnen op dit punt aangepast worden. Een andere optie kan zijn het formuleren van aanvullende deeldoelstellingen, waardoor stapsgewijs het uiteindelijke doel alsnog bereikt kan worden.		
M	45	**Er zijn concrete plannen voor de nog openstaande doelstellingen.**
Zoals eerder aangegeven moeten er duidelijke plannen zijn voor de nog openstaande doelstellingen. Als het niet mogelijk is een toepasbaar plan van aanpak te formuleren voor de openstaande doelstellingen, zullen de doelstellingen heroverwogen moeten worden. Dit kan zijn door het aanpassen van de doelstellingen, maar ook door het toevoegen van tussenstappen.		
M	46	**'Best practice' is toegepast in het gebouw.**
Alle maatregelen individueel vormen samen een 'best practice' voorbeeld voor andere geloofsgemeenschappen en hun gebouwen. Het systeem is niet geoptimaliseerd op de eisen, maar daarboven. De gebruikte maatregelen zijn de best mogelijke maatregelen op het moment.		
M	47	**Er is sprake van een constante evaluatie van maatregelen, combinaties en efficiëntie van het systeem.**
Energiegebruik wordt constant gemonitord en beoordeeld. Constant wordt er gekeken of het systeem nog presteert zoals gewenst. Verslechteringen worden niet geaccepteerd en er is een actief beleid om steeds verder te verbeteren. Belangrijk is dat er geen achteruitgang plaatsvindt, er in ieder geval sprake is van stilstand en eigenlijk een vooruitstrevende bewegingen met de veranderende normen van duurzaamheid.		

Appendix C5 Improved Statements English

1	There is at least a monthly registration of the energy use.
2	There is recurring attention towards sustainability within the religious community.
3	There is attention to sustainability within the church building.
4	There is enthusiasm creation for the sustainability project within the religious community.
5	The is a policy for the use of the building.
6	There is a vision for the future and the improvement of the sustainability of the building.
7	The objectives are specific, measurable, acceptable, realistic, and time-bound.
8	There are short-term goals (<year).
9	There are long-term goals (>year).
10	There is a plan of action to reach the objectives.
11	There are scheduled evaluation moments to measure progress.
12	Appointment of an energy manager to supervise the progress of the plans.
13	There is an inventory containing the possible improvements of the heating system.
14	The settings of the energy system are optimised to improve the efficiency.
15	There is an exploratory study of the possibility of zoning the system.
16	Implemented zoning allows for independently controlled zones.
17	There is a study of the temperature progression of the church (hall); with measurements in a minimal interval of five minutes for a period of minimal three weeks.
18	The occupancy of the building is known.
19	There is an optimised basis temperature, depending on the measuring results and the use of the building.
20	There is a scheduling policy of planning activities in consecutive days.
21	Considering added use, not directly part of the policy includes considerations on the revenue and costs.
22	There is an analysis of the air tightness of the building.
23	Closed cracks (a joint between rotating and fixed part) of windows and doors.
24	Closed seams (a joint between fixed part) at the junction of window frames on the facades.
25	Closed seams at the connection of the facades and roof to the building walls.
26	Closed seams at the connection of the facades on the ground floor.
27	There are insulated roof ridges.
28	There is insulation of the penetrations in the building envelope.
29	The mailbox is airtight or separated from the building.
30	There is an inventory of the energy using devices in the building.
31	There is a plan to optimise this energy use.
32	Procurement of sustainable energy or on a short-term.
33	There is attention to plans and implemented measures.
34	The average insulation of the building envelope is known.
35	There is a strategy to reach the set insulation level.
36	There is a comparison between the alternatives and the existing system.
37	There is a strategy based on the comparison.
38	There is active replacement of non-energy efficient equipment.
39	There is an exploratory study into the possibility of generating energy on-site.
40	The previously implemented and planned measures are part of the selection of new measures.
41	‘Best practice’ is part of the process when selecting measures.
42	Sustainability is part of every decision.
43	The combination of measures becomes an 'optimal' system.
44	There is a fulfilment of most of the set objectives.
45	There are concrete strategies for the remaining objectives.
46	‘Best practice’ is part of the building.
47	There is a constant evaluation of measures, combinations, and efficiency of the system.