THE SUSTAINABLE REFURBISHMENT OF BK CITY

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Abstract

Climate change - and particularly its long term-implications - has become the greatest challenge that scientists and politicians have to face. The building sector worldwide and, more specifically, the existing building stock, have been identified as major contributors to both global energy consumption and environmental damage.

This study aims at investigating the most appropriate measures for the refurbishment of the Architecture building of TU Delft (BK City) that, currently, lacks sufficient energy conservation measures and is characterized by its obsolete fabric and outdated building services systems. Moreover, the final proposals take into account the historical value of the building, along with its most essential features.

The first part of the study is a theoretical approach to the problem that starts by defining the content of the terms 'sustainability', 'refurbishment' and 'historic buildings'. Next, a framework of the 'sustainable refurbishment of historic buildings' in terms of legal, ethical and procedural aspects, is outlined, as well as the range of possible refurbishment measures that can be applied within this framework. After having analyzed the extent and severity of the problem with specific reference to Europe, this section ends by highlighting the potential of refurbishment and by providing a brief summary of the current status of well-known refurbishment policies in four European countries.

The second part of the study is an investigation of the case-study building. Necessary information concerning the context of BK City is presented, ranging from climatic and geographical data, to specific information on the building, its history and its performance in terms of building physics. Here, the distinguishing features of the building are identified, as well as the permissible interventions. With regards to building physics, it is pointed out that the weaknesses of the building are, mainly, the out-dated exterior envelope and mechanical equipment, which result in a poor indoor climate, despite the excessively high energy consumption. The information in this section is essential for the development of the refurbishment strategies.

Before elaborating on the refurbishment alternatives, an investigation is carried out to cluster all possible measures in 8 categories and cite relevant showcases and good practice examples of previously refurbished buildings. The most appropriate of these measures form the three proposed refurbishment Strategies of this Thesis, that range from basic interventions, such as cavity wall insulation, to more sophisticated solutions, as is the use of fuel cells. Advantages and disadvantages, application guidelines and market availability for each measure are provided.

The objective of the last section is to evaluate the impact of a selection of the aforementioned measures. For this purpose, a model is provided that allows the static calculation of the heating and cooling demands that will keep the indoor climate of the building at comfort levels. The results of these calculations are further analyzed and discussed. The conclusions suggest that the existing building is wasteful in its use of energy resources and, thus, huge possibilities lie in its refurbishment, even if only moderate measures are applied.

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1 Introduction

Climate change has become the greatest challenge that scientists and politicians have to face and, in particular, its long term-implications. Countries all around the world are striving to reduce greenhouse emissions in whatever way possible. In this context the Kyoto Protocol that was adopted in Kyoto, Japan, on 11 December 1997, 'sets binding targets for 37 industrialized countries and the European community for reducing greenhouse gas emissions. These amount to an average of five per cent against 1990 levels over the five-year period 2008-2012' (1).

Humanity is called upon to take immediate actions against a threat whose consequences are still not fully apparent. This threat is growing around two main points ('twin threat'). On the one hand, the inadequacy of energy supplies, along with the increasing difficulty of accessing them and, on the other hand, the environmental damage caused by the relentless exploitation of existing energy resources.

Statistics and figures demonstrate the significant contribution of the building sector to global energy consumption – the first component of the 'twin threat'. According to the U.S. Energy Information Administration (EIA), the residential sector accounted for about 15% of world energy consumption in 2006. The ratio increases in developed countries where building energy consumption is estimated at 20-40% of the total final energy consumption. In the EU, the final energy consumption for 2009 in the *Household, Services and Agriculture* sector totalled 483,9Mtoe (corresponding to a 41,1% share of the total EU-27 final energy use), the largest consumers being Germany, France and the UK (the Netherlands rank 8th in this category) (2), (3), (4).

As far as the environmental damage is concerned (the second component of the 'twin threat'), the building sector (residential and services) worldwide is expected to contribute to the global CO_2 emissions during 2010 by 3.573Mt, i.e. 12% of the total amount. According to the predictions[1], this amount will increase to 4.298Mt by the year 2030. In the EU, according to figures provided by *Eurostat*, in 2006 the building sector was accountable for more than 13% of the total CO_2 emissions. The impact of the building sector becomes even more evident when taking into account that the construction and operation of buildings worldwide is responsible for 25% of all virgin wood use and 16% of total water withdrawals, apart from waste generation, the rural land occupation and many more harmful environmental impacts (4), (5), (6).

The magnitude of the existing building stock and the very low replacement rate of existing buildings, along with the strong correlation between the age of a building and its energy performance (and, consequently, its environmental impact) have led researchers to agree that energy-driven refurbishment has enormous potential and is the most appropriate way to achieve a sustainable building stock and, thus, contribute to the battle against climate change (7), (8), (9), (10), (11), (12).

This feeling, i.e. that the existing building stock will be the main challenge for the building sector in the coming decades, led me to choose a Thesis topic in this field. Exploring the balance between the urge to refurbish and the need to preserve historic buildings was a further challenge. The current project of the refurbishment of the TU Delft Architecture building on Julianalaan (*BK-City*[2] *slim*) seemed to perfectly fit the purpose. In this context I was more than pleased to accept the proposal that my tutors made to adopt as a Thesis topic the 'SUSTAINABLE REFURBISHMENT OF BK-CITY'.

The analysis of the problem and the development of the solutions are carried out in two main parts, as seen in the following diagram. Part I is a more general research on the refurbishment of existing buildings, while Part II focuses on the case-study building.

[1] These predictions take into account the government policies and measures that were enacted by mid-2006
[2] '*The name Bouwkunde City refers to both the collection of complex, multifunctional public-private spaces and the diverse population of students, professors, researchers, staff and many, many visitors*' (203).

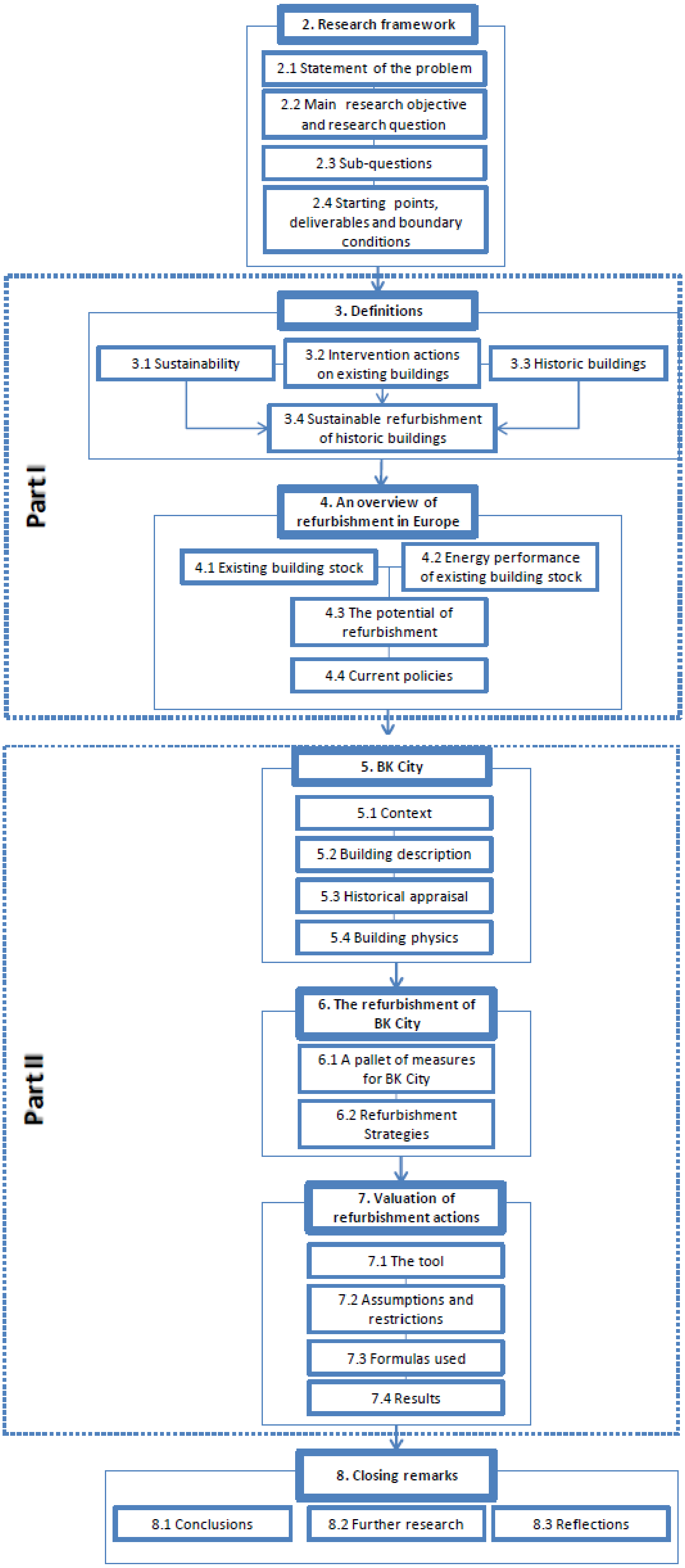

Figure 1 Structure of Thesis

Chapter 2 briefly describes briefly the Thesis topic itself (§2.1), determining the main objective (§2.2) and the partial goals (§2.3) while setting the overall framework of the research (§2.4).

Chapter 3 is a theoretical approach to the problem, as it provides a further explanation of the Thesis topic. It defines the themes of sustainability (§3.1), refurbishment (§3.2), historic buildings (§3.3), and how these are linked (§3.4).

Chapter 4 focuses on European countries and presents some figures on the problem under consideration, analyzing its extent and severity (§4.1 and 4.2), briefly describing the proposed solution (§4.3) and the status quo in four leading European countries (§4.4).

Chapter 5 is an investigation of the case study building. The required information is derived from literature research, historical archives, prior projects on the building, data from weather stations, interviews with conservation architects and municipality representatives, field investigations and on site measurements. In this part, information is provided about the general context (§5.1) but also the building itself (§5.2). Following, it is explained why BK City is considered historically important and to what extent this applies (§5.3) and, finally, I clarify what the needs of the building are (in terms of energy consumption and building physics) and how these needs are fulfilled at the moment (§5.4).

Chapter 6 deals with the refurbishment alternatives. After having gathered together all the possible and suitable measures (§6.1), a selection of these is integrated in refurbishment strategies specified for BK City (§6.2). Three strategies are elaborated ranging from basic interventions to more sophisticated solutions, each one of which contains implementation guidelines.

Chapter 7 explores the impact of the refurbishment actions on BK City on a practical level. A simple modeling procedure is followed (§7.1, 7.2, 7.3) to provide indications on the effectiveness of the measures in terms of energy usage (§7.4).

Finally, in **Chapter 8**, the main points of the research are highlighted (§8.1), suggestions are made for future research (§8.2) and a more personal remark is made (§8.3).

2 Research framework

2.1 Statement of the problem

The building sector worldwide and, more specifically, the existing building stock make a major impact on both the destruction of the natural environment but also the depletion of energy resources. In this context, the refurbishment of old buildings offers great opportunities.

The historic building that houses the Faculty of Architecture of TU Delft, though prominent for its historical value, lacks sufficient energy conservation measures. Its obsolete fabric, along with the outdated building services systems, where these exist, result in substantial thermal losses and poor indoor climate conditions. Alternatives should be investigated in order to minimize energy demands and energy consumption but also to make maximum use of renewable energy resources. These alternatives should compromise between the dual challenge of a sustainable building and the need to protect its monumental character.

2.2 Main research objective and research question

It follows from the above that the main objective of this research is to propose a package of refurbishment measures applicable to the Architecture building of TU Delft on Julianalaan (BK city). These measures should comply with the restrictions created by the fact that the building is a listed monument, and at the same time, fulfill the sustainability-related targets set by the research itself.

This leads us to the main research question:

'What are the most appropriate solutions available for converting the existing building on Julianalaan into a low energy building, without altering its character?'.

2.3 Sub-questions

There is a set of sub-questions that need to be answered in order to attain the main objective of this Thesis. These 'partial Thesis topics' are presented in the next table, along with indications of the answers sought:

Sub-question	Information required
What is the exact meaning of *sustainable refurbishment of a historic building* and how does that relate to BK City?	*Explicit definitions of the terms used in the Thesis title*
What is the framework in which historical buildings can be improved energy wise?	*Review of literature and prior research on historical buildings, their refurbishment and the related hindrances*
What is the general context of the case study building?	*Location, topography, weather & climatic data, current ownership and use*
What are the building's essential features?	*Layout, materials, structural issues*
What is it that makes this building historically significant and how does this restrict the refurbishment possibilities?	*Historical background, architectural style, monumental significance, other special building interest, national legislation, listing act*
What is the current state of the building?	*Building fabric, installations and building services, climate provisions, energy profile*
What are the main identified weaknesses?	*Building physics, indoor climate and comfort issues, thermal losses, functional issues*
What is the range of the refurbishment measures?	*Clustering of applicable measures in packages*
How can these be applied in BK City?	*Development of scenarios, implementation guidelines*
What energy retrofitting scenario fulfills best the set targets?	*Setting up of a model, assessment of measures, energy consumption figures*

Table 1 Set of sub-questions

2.4 Starting points, deliverables and boundary conditions

The wide range of issues set out above, along with the complex nature of the research topic, dictates the necessity of imposing boundary conditions and defining an overall research framework.

The initial concerns of this project are a) inefficient energy performance and b) the resulting environmental impact of BK city. Along with these concerns, however, follows c) the challenge of converting the said building into a landmark of sustainability. In this quest, the first step has already been made, i.e. putting into use an existing building; this, however, is not enough.

The focus of the research is on the intervention possibilities, rather than the historic value of BK city, which is taken into account mainly as a restriction parameter. Thus, one should not expect an exhaustive argumentation on the significance or otherwise of the building in terms of architecture and aesthetics.

The aim is to elaborate and assess a number of retrofitting measures, after having defined the governing criteria. The final deliverable of the project will be distinct and self-contained refurbishment Strategies that include both realistic and ambitious variants. At the end of the project, a simple model will be presented that provides energy consumption figures, related to the Strategies.

It should be pointed out that the refurbishment proposals are specific to the case-study building, but may also act as an inspiration for other refurbishment projects of historic buildings.

The limited amount of time for carrying out this Thesis, together with the large number of intervention actions resulted in certain constraints/boundary conditions:

- Financial issues are not treated, though they are taken into account.
- Time restrictions haven't been imposed. In this sense back-casting is the process that has been followed: the desirable result is set out and subsequently the policies to achieve it are determined.
- Guidelines on function and space extension issues are approached as a 'by-product' of the analysis.
- While applicability is a major concern, the design of the measures is limited to what is considered essential.
- The energy consumption figures are treated as decision-making tools rather than precise calculations.

Apart from the above, it is obvious that not all existing measures can be examined in great detail. A selection has been made, leaving the excluded possibilities for future investigation. In this respect, the focus is on technical measures such as energy generation and storage systems (ground, water etc.), heating distribution, ventilation alternatives etc. Additionally, cutting-edge technology and any innovative measures appropriate for such a building are investigated. An equal treatment of traditional measures (e.g. insulation, glazing replacement) has been included, although their efficiency is established and well known. Besides, it is expected that in a few years time the trend in refurbishment policies will be the implementation of newer technology that, at the moment, might not be affordable financially.

Finally, it is important to define the evaluation criteria of the proposed measures. The general objectives mentioned previously should be narrowed down to specific requirements:

- Energy savings
- Maximum use of sustainable or environment-friendly energy resources
- Minimization of the environmental impact
- Reduction of operational costs
- Reduction in thermal losses

- Improved indoor comfort conditions
- Extension of building service-life beyond original life span
- Creating a paradigm in sustainable refurbishment

Considering all the above, the *ultimate* target of the interventions will be set at the highest standard: in this case, exploring the preconditions for converting BK city into a highly efficient building; the course of this project will show whether this target is realistic.

Part I

3 Definitions

This section explores the concepts of 'sustainability' and 'refurbishment'. Furthermore, background information is sought on 'historic buildings', along with the possibilities of and obstacles in the way of the renovating process.

3.1 Sustainability

'Sustainability' is a vague term with wide usage and numerous interpretations, which till now has no widely accepted measurement tool. The main idea behind it is '*to maintain the longevity of the global ecosystem safeguarding humanity's further development or even survival*' (13).

In tracing the origins of this idea one comes across the work of Dr. John Augustus Voelcker (1854–1937), a chemical agricultural scientist who was one of the first to spot that natural systems have limits. When appointed by the British government in India, with the task of proposing ways to improve indigenous agriculture, his report took his superiors by surprise: '*I do not share the opinions which have been expressed as to Indian agriculture being as a whole primitive and backward, but I believe that in many parts there is little or nothing that can be improved. . . . I make bold to say that it is a much easier task to propose improvements in English agriculture than to make really valuable suggestions for that of India*' (14).

It took several years for the concept of sustainability to come into use again. In the '70s, it was mainly used to refer to products that withstand the test of time (15). However, the collapse of numerous natural systems, ozone layer depletion, global warming, the deterioration of natural resources and many other factors resulted in the formation of the World Commission on Environment and Development (WCED) in 1983. The term 'sustainable development' was then defined by the commission as '*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*' (16). It seems that what seems sustainable to an engineer may not be sustainable for an expert in economics and vice versa.

Sobotka et al. see the content of sustainable development in the following terms (17):

- Aiming at economical and rational use of the environment
- Using up renewable resources
- Minimising environmental destruction and risk in relation to human health
- Attaining economic development by securing the growth of economic standards now and for future generations

When it comes to sustainable buildings researchers agree that each building should be considered as an object-product, with attention paid to its whole life cycle, i.e. from the selection of the raw materials till the phase of demolition (17), (18), (19). In this context the *Environmental Preference Method*, developed in The Netherlands by Woon/Energie[3] in 1991, sets the main criteria for the sustainable building assessment (19):

- Shortage of raw materials
- Ecological damage caused by extraction of raw materials
- Energy consumption at all stages (including transport)
- Water consumption
- Noise and odour pollution
- Harmful emissions
- Global warming and acid rain
- Health aspects
- Risk of disasters

[3] *http://www.woonenergie.nl/*

- Repairability
- Reusability
- Waste

The Cradle-to-Cradle (C2C) – as opposed to Cradle-to-Grave – theory took a step further. Its implementation in the building sector suggests a more holistic approach with the creation of entirely autonomous systems and closed cycles (except for the continuous flow of sustainable energy resources). Among others, common characteristics of C2C buildings will be the:

- Emphasis on the design that takes into account the elements of nature (orientation, topography etc.)
- Flexible layout that allows for adaptive reuse
- Use of natural, locally-available materials that ensure the well-being of the occupants
- Demountability of the construction
- On-site use of renewable resources (solar energy, windpower, rainwater harvesting etc.)
- Treatment and recycling of waste (solid or liquid)

The last point has been extensively considered. According to the C2C model, the best way to minimize waste is to ensure that everything can be broken down into technical or biological nutrition that can be reused (20), (21), (22), (23).

3.2 Intervention actions on existing buildings

A wide range of building intervention measures exist, the variety of which makes it hard to come up with universally applicable definitions and classification systems. The traditionally used terms sometimes describe something similar while at other times they are used as synonyms. Overlapping of meanings also occurs in many cases.

Reasons for this lack of clarity are the varying degrees of change imposed, compared to the retained building fabric, the varying starting points and purpose (aesthetic, technical, functional etc.) for each intervention and, finally, the ongoing misuse of terms that does not match the actual measures proposed (24).

This paragraph examines some of these terms and their relevance while it is acknowledged that many more exist.

3.2.1 Conservation

'Conservation is the action taken to prevent decay and manage change dynamically. It embraces all acts that prolong the life of our cultural and natural heritage' (25).

Conservation is thought of, by some, as more generic than refurbishment (26), (25), while for others it is often the result of refurbishment (27). The main reason behind conservation actions is the wish to safeguard for future generations the artistic and human messages that a building might possess. As these actions usually entail the loss, to some extent, of the original value they should comply with a certain conservation philosophy and ethics framework. The main pillars of this philosophy are:

a) Minimum possible degree of intervention
b) Reversibility of actions
c) Future interventions should not be hindered

3.2.2 Reconstruction

'Reconstruction is the act or process of depicting by means of new construction the form, features and detailing of a non-surviving site, landscape, building, structure, or object for the purpose of replicating its appearance at a specific period of time and in its historic location' (28).

Rebuilding a structure is the most extreme form of intervention and some even consider it as '*falsification of history*' (28). Accordingly, reasons that justify such an action are major disasters (wars, earthquake, fire etc.) or extreme decay; in all cases, action should be based on accurate documentation.

3.2.3 Rehabilitation

'Rehabilitation is defined as the act or process of making possible a compatible use for a property through repair, alterations, and additions while preserving those portions or features which convey its historical, cultural, or architectural values' (28).

Rehabilitation might involve modernization along with a change in use (adaptive reuse) but keeping the original function should be preferred, if possible. It is considered the '*best way of preserving buildings'* (25). Rehabilitation is sometimes used in the same context as the term refurbishment (29), (30).

3.2.4 Restoration

'*Restoration is the act or process of accurately depicting the form, features, and character of a property as it appeared at a particular period in time by means of removal of features from other periods in its history and reconstruction of missing features from the restoration period. The limited and sensitive upgrading of mechanical, electrical, and plumbing systems and other code-required work to make properties functional is appropriate within a restoration project'* (31).

Restoration ('*finishing an incomplete structure'* (24)) is thought to be very close to reconstruction, the difference lying in the fact that in the latter no original building elements are available. The aim of restoration actions is to preserve, reveal, revive and exhibit the value of the building (monumental, aesthetic, historic etc).

A sensitive restoration should respect the original material and take into account all evidence and documentation on the original building. Interventions from later periods should be kept as long as they are considered as 'historic documents' and if not they may be altered or removed. Replacement of missing or decayed parts should be made with care in order to be harmonically incorporated in the whole but at the same time they should be recognizable as such and must bear a contemporary stamp.

Restoration works might involve the cleaning of the interior/exterior of a building, the replacement of decorative elements, repair of outworn materials or the rebuilding of a part of a building (24), (25), (26), (32).

3.2.5 Renovation

'*Renovation or renewal is described as the work that involves the removal of substantial parts of the original fabric and their replacement on an extensive basis*' (26).

Capturing the meaning of renovation in one phrase is not as easy as it may seem. Literature sources offer more clues on what is *not* considered renovation or what specific measures could be included in a renovation project, rather than provide a definition of the term itself. Contradictory descriptions are also given.

While renovation '*does not add anything new to the existing stock, nor does it replace old with new, it maintains the value and function of the existing building through competent upkeep*' (24).

Renovation possibilities may entail the simple replacement of fixtures and fittings, the removal, restitution and renewal of several elements that are no longer viable or even stripping a building from top to bottom. Compared to restoration, renovation does not involve so much structural work.

Possible reasons for initiating the renovation of a building may be its poor physical condition, unsuitable previous use or even its redundancy (e.g. a structurally robust industrial building but with spaces that are too large) (33).

3.2.6 Refurbishment

'*Refurbishment is the extensive renewal or modification of secondary elements of a building that may be required to adapt the structure to a new purpose'* (26).

Refurbishing has always been regarded as the alternative to demolishing. While in the beginning of the 20th century demolition was the dominant practice, the '60s marked a turn of the tables with refurbishment gaining more and more popularity.

The term is sometimes wrongfully used as a synonym of conservation. However, while the latter has an emotional significance attached to it, refurbishment is triggered by economic reasons. Though refurbishment might (rarely) serve a 'cosmetic preservation' cause, most of the time it is driven by the need to house a new function in an old building. Thus, its scope is much wider than that of conservation.

When compared to maintenance, refurbishment also includes undamaged but obsolete elements or surfaces. In other words, maintenance is part of the refurbishment project. However, refurbishment does not include major changes to the load-bearing structure or the interior layout, thus it is a step before conversion (24), (26), (27).

The main concerns of refurbishment are (29):

- Conserving and preserving the heritage
- Dealing with the physical and functional building elements
- Introduction of up-to-date building services
- Dealing with energy use, fire protection, noise control, thermal performance, air quality, waste reduction and spatial comfort

As the range of the above actions is extremely wide, we can distinguish three degrees of refurbishment (24):

1) Partial refurbishment, that concerns only a component or a part of the building (one wing, one floor, the facade etc)
2) 'Normal' refurbishment, that concerns the entire building, or a part of it that can be considered as separate and independent
3) Total refurbishment, that includes demolition actions, the replacement of infrastructure and the upgrading of all building components

BREEAM[4] defines a '*major refurbishment project*' as '*a project that results in the provision, extension or alteration of thermal elements and/or building services and fittings'* (34), i.e. their upgrading to a better condition. By thermal elements in this case we refer to the walls, roofs and floors. Windows and doors are part of the fittings, while building services include the lighting, heating, cooling and mechanical ventilation provisions.

[4] *http://www.breeam.org/*

3.2.7 Relevance to Thesis topic

The title of this research is 'The Sustainable Refurbishment of BK City'. The idea of sustainability has been defined previously; however, its exact significance and scope in this context will be analyzed in the following paragraphs.

What seems to be more debatable is the use of the term 'refurbishment'. When examining the previously mentioned terms, three of them seem appropriate, at one level, for this project: rehabilitation, renovation and refurbishment.

The concept of rehabilitation is closely related to the '*compatible use*' or the '*adaptive reuse*' of an existing building, actions that have been performed already on the Julianalaan building, just after the outbreak of fire at the old Architecture Building in May 2008.

Renovation, on the other hand, seems an ill-defined term, the only clear aspect of it being that it does not involve structural work. A renovation project aims more at preserving the value and functionality of a building that is no longer viable, whereas in our case the standard is set much higher than that. We are dealing with a building that in a conventional sense functions properly, but what is lacking is a further upgrade and improvement of its performance to the highest possible level.

In this sense, refurbishment seems to fit the purpose better. It is wider in content, it includes more extensive work (while again no structural elements are to be altered) and its main concerns are, indeed, the introduction of modern building services, energy consumption issues, thermal performance, and so on, which are all aspects of this Thesis. Moreover, the distinction between different degrees of refurbishment work provides a more flexible use of the word. Finally, the definition that BREEAM gives (see §*3.2.6 Refurbishment*) appears to be tailor-made for the proposed interventions at BK city.

3.3 Historic Buildings

According to one author, a historic building '*is one that gives us a sense of wonder and makes us want to know more about the people and culture that produced it*' (25). While initially there was only an aesthetic value attached to old buildings, the term embraces much more than that: historic, documentary, economic, social, political, religious or spiritual values.

It wasn't until the beginning of the 20th century (at a time when the modernization of European cities demanded the extensive demolition of old buildings) that the first attempts were made to protect monumental buildings under a legislative framework. Indeed, it was Alois Riegl, an art historian and the first Conservator General of Monuments in the Austro-Hungarian Empire, who expressed the romantic view[5] on monuments in a statutory context.

Despite his fruitless efforts, Riegl was vindicated some years later. As we speak, there is a number of charters and declarations by which monumental buildings are sanctioned and protected. Below a list of the most significant ones is given:

Declaration	Issuing authority	Date
Manifesto for the Society for the Protection of Ancient Buildings	Society for the Protection of Ancient Buildings	1877
The Athens Charter	First International Congress of Architects and Technicians of Historic Monuments	1931

[5]The romantics, like François-René de Chateaubriand, were the first to express their adoration of old buildings. The signs of age were considered as evidence of the past, thus they should be treasured (36).

The Venice Charter	Second International Congress of Architects and Technicians of Historic Monuments	1964
Charter for the Conservation of Historic Towns	ICOMOS General Assembly in Washington, DC	1987
The Nara Document on Authenticity	Nara Conference on Authenticity in Relation to the World Heritage Convention	1994
The Eindhoven Statement	DOCOMOMO First International Conference	1990

Table 2 Declarations for historic buildings

On a national level, historic buildings can be listed as means of control on intervention actions that affect their character. The object of listing is to '*define the quality of buildings and to avoid their thoughtless destruction*' (35). In the UK, listed buildings appear on the statutory List of Buildings of Special Architectural or Historic Interest. Their relative value is determined by a grading system (Grade I buildings being those of 'exceptional interest').

Apart from listed buildings, a number of other edifices are in need of protection such as buildings located in conservation areas, national parks and World Heritage sites or buildings referred to in local authorities' monuments' list (25), (28), (36).

3.4 Sustainable Refurbishment of Historic Buildings

Historic buildings add, beyond doubt, to the aesthetic value of modern cities and towns. For various reasons, the possibilities lying in their refurbishment have been underestimated. In particular, the hesitation or ignorance of owners of historically significant buildings has led to numerous missed chances in this field.

The issue to be tackled here is achieving a right balance between modernisation and conservation of the heritage, as '*the task of retrofitting the oldest homes to adequate energy performance standards in a visually unobtrusive way [is] particularly demanding*' (37). The restrictions, however, may sometimes mask the true possibilities of refurbishment in an energy-efficient way.

The reversal of the trend is now been acknowledged by numerous experts. According to Prof. Dr. Anke van Hal (from Nyenrode's Centre for Sustainability and TU Delft), '*our feeling is that the subject of sustainability in relation to buildings of historic and visual significance has long been unjustly ignored. The scales are now starting to turn. We can now use examples to show that it is definitely possible to make sustainable modifications to buildings of this type. It is becoming a hot topic.*' (38). Furthermore, senior researcher ir. Birgit Dulski claims that in order to achieve the environmental targets '*every opportunity has to be utilised, so the monuments and buildings of historic and visual significance also have to be dealt with'* (38).

Stronger feelings have been expressed by other parties. The *Environmental Change Institute* at Oxford University favours a more radical approach: '*Heritage conservation needs to be balanced against climate change mitigation — more interventions should be possible in heritage/conservation buildings than are currently allowed. Re-creation of original features (e.g. cornicing on top of internal wall insulation) should be seen as desirable, not rejected because of the intransigent position of conservation bodies, which argues that no original features should ever be lost*' (37). *Heritage Link*[6] suggests that while innovative energy efficiency solutions should respect the character of existing buildings, '*older buildings themselves are not the problem. Changing people's behaviour is just as important as improving energy performance*' adding that people '*may have to be prepared for visually intrusive measures on much loved buildings*' (37), (39).

[6] *http://www.heritagelink.org.uk/*

The 4th annual US/ICOMOS Symposium[7] agreed with the above statements, declaring that '*conservation has always been much related to sustainability, because of its mainly support in traditional technologies, allowing repair and reuse, instead of the constant and common wasteful cycles of destruction and rebuilding*' (40).

3.4.1 Legal and ethical aspects

The legal procedures for the refurbishment of an old building are similar to those required for a completely new construction. A refurbishment project will have to comply with the national building acts and other forms of legislation that cover heritage care issues. For example, in the UK the following need to be taken into account:

- Town and Country Planning Act, 1971
- Listed Building and Conservation Area legislation, provisions under Act 1971
- Building Regulations
- Factories Act, 1961
- Offices, Shops and Railway Premises Act, 1963
- Fire Precaution Act, 1971
- Rules of the Fire Offices Committee

However, apart from the above, which have a significant effect on the feasibility of refurbishment plans, there are other issues that need equal consideration, even though they depend largely on the good will of the parties involved. These so called 'ethics of conservation' entail the following (25):

- The condition of the building must be recorded before any intervention
- Historic evidence must not be destroyed, falsified or removed
- Any intervention must be the minimum necessary
- Any intervention must be governed by unswerving respect for the aesthetic, historical and physical integrity of cultural property
- All methods and materials used during treatment must be fully documented

In addition, the professionals themselves who are entrusted with a conservation task should fulfill certain requirements. These have been specified by ICOMOS[8]:

- Read a monument, ensemble or site and identify its emotional, cultural and use significance
- Understand the history and technology of monuments, ensembles or sites in order to define their identity, plan for their conservation, and interpret the results of this research
- Understand the setting of a monument, ensemble or site, their contents and surroundings, in relation to other buildings, gardens or landscapes
- Find and absorb all available sources of information relevant to the monument, ensemble or site being studied
- Understand and analyse the behaviour of monuments, ensembles and sites as complex systems
- Diagnose intrinsic and extrinsic causes of decay as a basis for appropriate action
- Inspect and make reports intelligible to non-specialist readers of monuments, ensembles or sites, illustrated by graphic means such as sketches and photographs
- Know, understand and apply UNESCO conventions and recommendations, and ICOMOS and other recognised Charters, regulations and guidelines

(25), (33), (41).

[7] Philadelphia, 2001
[8] ICOMOS Guidelines, para. 5 (Colombo, 1993)

3.4.2 The refurbishment scheme

3.4.2.1 Planning

A refurbishment project requires the close cooperation of the parties involved who usually specialise in a wide range of disciplines. Participants typically are:

- owner or the owner's representative
- the State's representative
- contractor and subcontractors
- architects expert in conservation
- development architect
- landscape architect
- engineers (structural, mechanical, electrical)
- art conservator
- historian
- quantity surveyors
- health officer
- urban planner
- development economist

A variety of tasks and challenges awaits the multi-disciplinary refurbishment team. These are listed below (24):

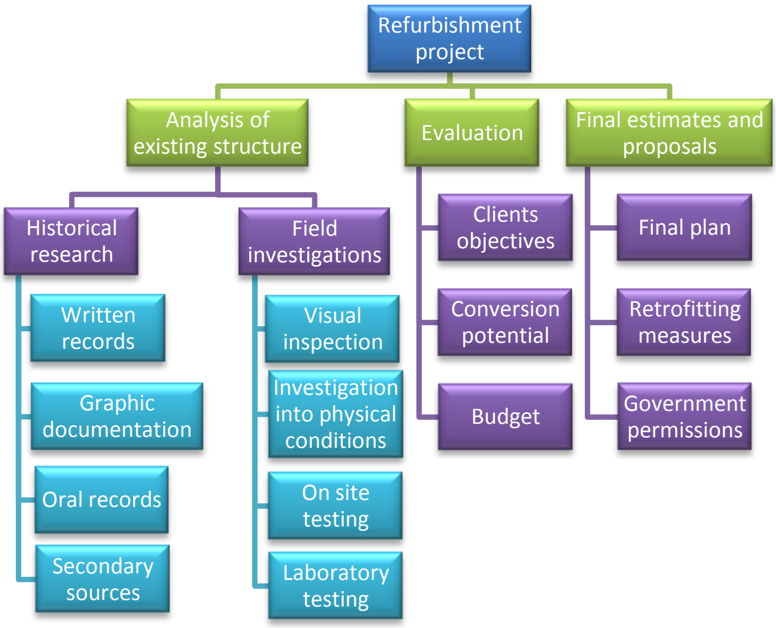

Figure 2 Planning of a refurbishment project

3.4.2.2 Assessment

As discussed previously, a historic building, along with its setting, is considered to be a work of art. In order to be able to read it as a 'whole', the architect or the conservation specialist should be able to recognize and prioritize the messages that it carries. This task, however simple it may seem, is rather complex. Researchers at the *Katholieke Universiteit Leuven* proposed an assessment scheme based on the Nara Document on Authenticity (Nara, Japan 1994) (42). This is presented below:

Aspects	Dimensions of heritage			
	Artistic	Historic	Social	Scientific
Form and design				
Materials and substance				
Use and function				
Tradition, techniques and workmanship				
Location and setting				
Spirit and feeling				

Table 3 Nara-grid

The grid can be complemented with more dimensions such as spiritual, economic, educational, use value and more. Filling in the above grid will help in determining the importance of the historic building, which will guide the intervention process.

Another useful characterization grid is proposed by *Appelbaum B.*, who emphasizes the equal importance of the four following fields-quadrants (43):

	Material aspects	Non-material aspects
Object specific information	• Current physical state	• Past and current values • Building's history
Non-object specific information	• Properties & physical behaviour • History of technology • Construction method	• General historic information • Historic attitudes towards the building

Table 4 Characterization grid

In The Netherlands, an interesting tool is provided by the DuMo calculation model for sustainable heritage refurbishment. According to this, there are four categories of buildings (or building parts), depending on their monumental value and the permitted degree of intervention. The second part of this model assesses the sustainability scenarios, thus providing an index for the entire building (44).

Finally, it is important to mention that the assessment procedure should not be considered as a momentary one. On the contrary, it should be regarded as continuous throughout the whole refurbishment progress and it should be supported by appropriate documentation.

3.4.2.3 Understanding how the building works

In every refurbishment of an old building special care needs to be taken to prevent the implementation of inappropriate adaptations as the building philosophy of the previous century (-ies) needs to be balanced with the technological knowledge and advancements of today. Alterations and interventions during the life cycle of the building should also be identified.

The properties of the materials (permeable, soft or thick materials such as brick and stone masonry, lime plasters, paints etc.) used in a traditional building dictate a response to moisture, air or structural displacements different from what is expected from modern impervious and hard materials. For instance, cementitious mixes for plasters might prove incompatible in permeability and porosity and cause salt migration and damage.

Ventilation and air-tightness issues are often troublesome. The design philosophy of historic buildings is to allow the fabric to breathe so moisture will evaporate internally. Thus, applying a vapor barrier – just like in modern construction – will hinder this process. We shouldn't forget that a significant amount of fresh air used to be provided in the original building through loosely fitting doors, windows and openings, which will now be carefully sealed. To avoid the formation of mould and the high levels of moisture (which are expected to increase due to the better heating provisions), increased ventilation rates will be required in a refurbished building (a rule of thumb used by some designers is 'twice as much').

Improving the thermal performance of the building also requires special care. Adding too much insulation, or inserting it in the wrong place might introduce new problems, such as thermal bridging, interstitial condensation etc (45), (46).

The above are some examples of how modern building techniques differ from older ones and how these differences, if disregarded, might worsen the performance of the refurbished building.

3.4.3 Range of refurbishment measures

The range of the applicable measures for the sustainable refurbishment of a building is fairly wide. In the case of a historic building, however, it is somewhat restricted. In this paragraph, an effort is made to cluster all measures that are applicable to historic buildings. Thus, this is on a practical level – the question being what is *possible* to apply. At a next stage the discussion and the sorting out will concern the *desirable* measures.

A clustering scheme needed to be found. For this, the 'Trias Energetica' principal seems to fit the purpose. 'Trias Energetica' is the main pillar on which the sustainable refurbishment of German buildings designed and constructed in the 1950s, '60s and especially during the post war period (with significant weaknesses in energy efficiency) lies. This approach focuses on three distinct points:

- Minimizing energy demands
- Applying sustainable energy sources and
- Efficient and intelligent use of fossil fuels

While some researchers believe that, in order to reach the desirable goal of a sustainable building stock, improving the 'Trias Energetica' application is enough (47), others have noted its deficiency (48), (49), (50), (51). The small degree of renewable energy sources penetration, focusing too much on the third principle, inefficiency, the slow delivery of results, 'Trias Energetica's' mere technical nature and repeatedly bad applications, have led researchers to alternative paths ('Penta Energetica', 'REAP', 'Trias Hylica', 'Trias Hydrica', 'Trias Toponoma' and others).

Among these, the 'REAP' (Rotterdam Energy Approach and Planning) model points out the importance of waste reuse, inspired by the cradle-to-cradle approach. The 'Penta Energetica' method indicates that without changing today's lifestyle into a low CO_2 emission way of living not much can be expected. In other words design should take into account human behavior. Important to note, 'Penta Energetica' stresses the use of cogeneration technology to compensate for example the fluctuations of solar or wind power.

All the above have been taken into account in order to form the packages of measures shown below. These are further categorized according to the degree of innovation that they introduce (*standard/traditional* versus *technical/innovative* approach) and the extent to which the building is affected (*local approach* versus *larger context).*

The *standard/traditional* approach refers to measures that have been extensively used in the past with well established results. Most of these can be realized with relatively simple means and in most of the cases require a small amount of initial investment. On the other hand, measures have been labelled as *technical/innovative* when their implementation requires the use of advanced technology and a more sophisticated design approach.

A measure *locally* carried out is one that might concern only a part (a wing, a floor, spaces with special function etc) or an element of the building (the front facade, the roof etc) and that does not require the redesign of the whole. On the other hand, there are measures that in order to be effective need to be applied on a *larger scale (context)*, which usually results in high initial investment.

It is possible, of course, that some measures might apply in two categories (for example, the fuel policy might entail the use of natural gas, i.e. a *traditional approach*, but also the use of fuel cells which is an *innovative* concept).

	Standard / Traditional approach		Technical / Innovative solutions	
	Local approach	**Larger context**	**Local approach**	**Larger context**
Reducing energy requirements	• Distinct element/area insulation • Tree shading, overhangs, shutters • Making use of building's thermal mass	• Building wrap up with insulation • Window & door replacement • Airtightness • Duct and hot pipe insulation	• Local fresh air provision • Secondary windows (window box) • Local heating (furniture) • PCM materials • Use of solar tubes	• Heat recovery • Multiple layer glazing • Energy efficient appliances • Intelligent shading technology • Surface heating
Waste flows treatment policy	• Rainwater harvesting	• Building refuse recycling • Rainwater harvesting	• Use of batteries, capacitors, etc. • Drainwater heat recovery	• Waste heat recovery • Waste water recycling • Waste incineration • Rainwater reuse • Composting • Material reuse • Energy storage in water/PCMs etc
Application of sustainable energy resources	• Natural daylight enhancement • Natural ventilation	• Solar water heating • Green surfaces & vegetation	• Green roofs • Glasshouse roofs	• Microgeneration (solar, wind, hydro etc) • Acquisition of green energy • Earth energy • Energy storage in water/PCMs etc. • PVC electricity generation • Solar absorption cooling • Biomass
Intelligent solutions for fossil fuel energy		• Replace outdated radiators • High efficiency boilers • Fuel policy		• Cogeneration station • Fuel policy
Focus on user and lifestyle	• Occupants' adaptive opportunities • Stand by killers	• Energy saving fixtures • Energy saving appliances • Raise user awareness	• Occupancy sensing control • CO_2, moisture sensors etc	• Intelligent control systems • Individual metering • Building Energy Management Systems

Table 5 Range of refurbishment measures

4 An overview of refurbishment in Europe

This chapter investigates the extent of the problem under consideration for European countries. The magnitude of the existing building stock, along with the inevitable deficiencies this brings about, demands a competent solution. The potentialities of refurbishment as the proposed solution are presented in figures, and lastly, there follows a review of current developments in four leading European countries.

4.1 Existing building stock

It is necessary to examine the existing building stock in Europe and its breakdown by construction age – the importance of which relates to the strong correlation between the energy performance of a building and its age (52). This relationship (building age and energy performance) is further analysed in the next paragraph (§ *4.2 Energy performance of existing building stock*).

The following sections provide data on the entire European building stock and specific data on three distinct European countries that all have a renowned policy on Heritage Care (The Netherlands, Germany and Great Britain). The Netherlands were chosen since the case study of this research is a Dutch listed building. The German and British building profiles will provide a useful comparison to the Dutch situation.

As the breakdown of the building stock provided by the available literature differentiates between *residential* and *non-residential* stock, the same distinction will be adopted here.

4.1.1 Residential building stock

As far as *residential* function is concerned, amongst 28 European countries[9] in a total of about 196 million dwellings an average of 28,8% have been built prior to 1945, 34,8% were built in the years 1945-1970 while an average of only 8.2% were built after 1990 (53) – *see chart 1*.

Dwellings dating before WWII constitute a significant proportion in all European countries varying from 20% to 40% (Finland is the only exception with a 10,4% pre-War percentage). At the same time, the estimated replacement ratio (ratio of annual demolition rate to the size of existing stock) for dwellings in Europe is approximately 0,07% (8).

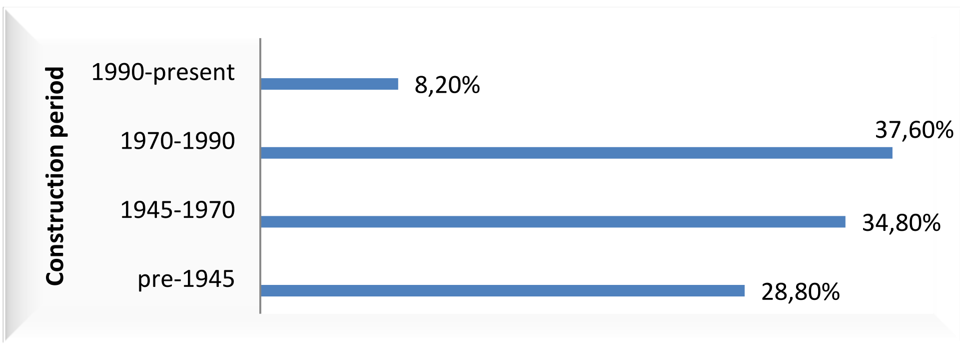

Chart 1 Age of European residential building stock

Chart 2 compares the building profiles of The Netherlands, the UK and Germany (7).

[9] The study takes into account the 25 EU members by 2004 plus Bulgaria, Romania and Turkey (applicants for EU membership in 2004)

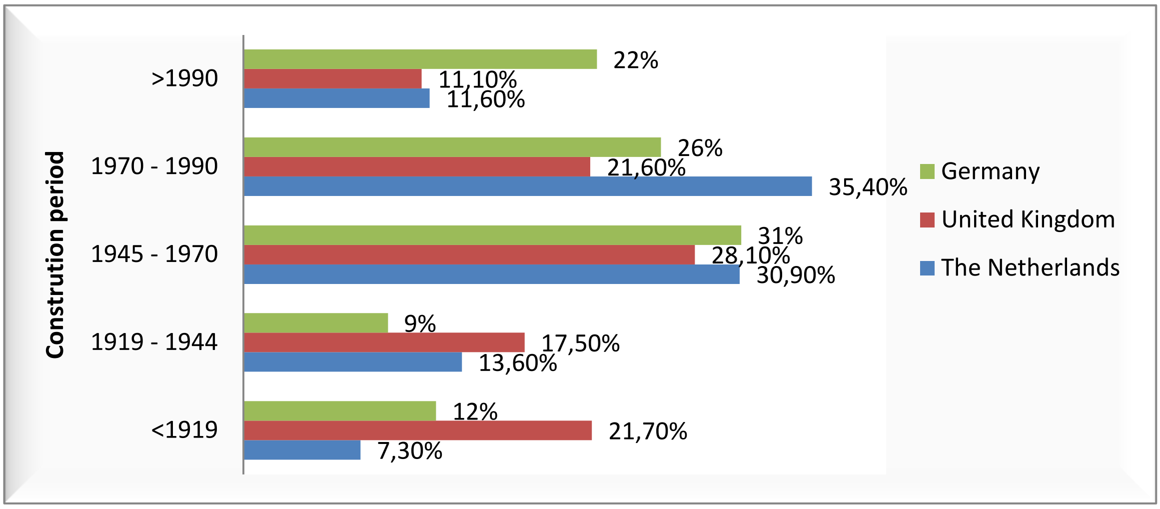

Chart 2 Building stock profile (residential buildings) of Germany, the UK and The Netherlands

The figures demonstrate clearly the magnitude and so the importance of the older stock in the UK – one in five homes[10] is more than 90 years old. The complexity of the issue is underlined by the fact that 94% of the pre-1919 dwellings in the UK are privately owned which hinders the implementation of binding refurbishment policies (54). However, the particularity of the English stock lies in the plethora of listed buildings – today, they account for up to 370.000 buildings. At the same time, a total of 1.000.000 non-listed buildings are to be found on the UK's conservation areas (52). All of these, while prominent either for their high aesthetical standards or their historical significance, tend to be the least efficient in terms of energy.

Germany and The Netherlands, on the other hand, have relatively small pre-WWII residential stock (21% and 20,9% respectively, compared to a 28,8% mean for the EU). In The Netherlands, the construction sector seems to have had a boost after the oil crisis in the '70s, while the most 'productive' time in Germany was during the '90s. The only period where we observe comparable trends for all three countries is after WW-II (1945-1970).

4.1.2 Non-residential building stock

For *non residential* European buildings the following breakdown is given (9)[11]:

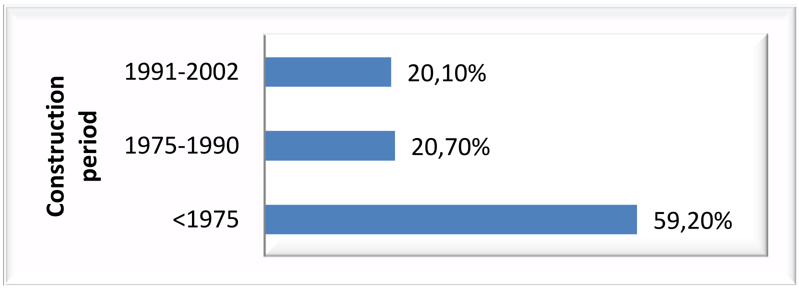

Chart 3 Age of European non-residential building stock

The ageing nature of the non residential stock becomes evident from the chart above, as the vast majority (60%) of buildings are at least 35 years old. A comparison between the two building sectors demonstrates that while the non-residential stock is made up of a larger newly-built (post 1990) part, 20% compared to 8,2%, the 1970's and 1980's seem to have favoured the construction of dwellings.

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[10] The British stock comprises of 21.5-24 million dwellings (197), (54)

[11] Data includes all countries from the three climatic regions appertaining to the EU in 2002

The following chart presents the building profile of Dutch non-residential stock (no comparable data was found for Germany or the UK) (7).

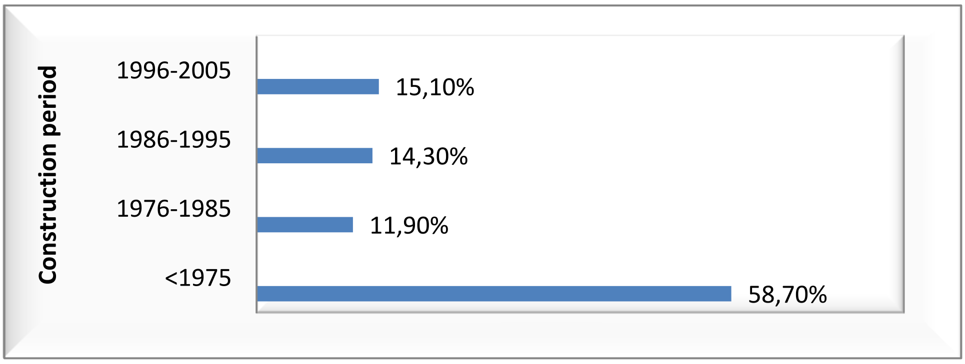


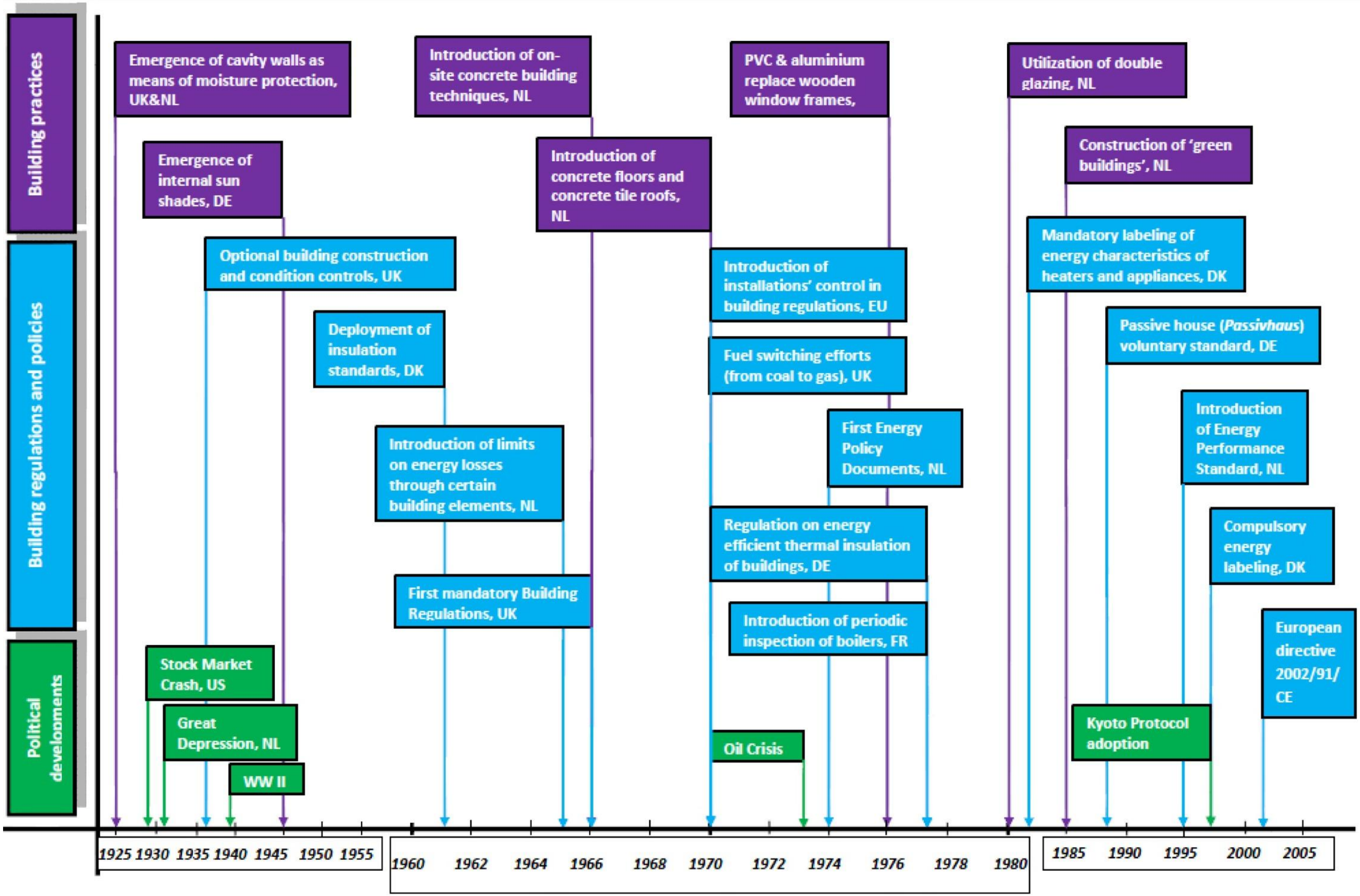
Chart 4 Age of Dutch non-residential building stock

The percentage of non-residential Dutch buildings built prior to 1975 corresponds to the equivalent European (58,7% and 59,2% respectively). An interesting piece of information, relating to the topic of this Thesis, is revealed when we examine the figures for the non-residential stock: nearly 30% of the Dutch *educational* buildings are already at least 50 years old, while only 8% was built after 1996 (7).

4.2 Energy performance of existing building stock

As a general rule, contemporary edifices are more energy efficient compared to older ones. Before the energy crisis of the '70s, few people had reasons to care about energy losses and it wasn't until the '90s that people started to be aware of climate change and its consequences. This means that not much effort had been put into constructing energy-efficient buildings. The increasing awareness and knowledge of the energy performance of buildings means that through time regulations and standards for newly built structures have become stricter. These, in turn, have affected the quality and amount of insulation, the condition and efficiency of climate installations, the air tightness measures and many more parameters. At the same time, modern building design develops and takes more into account the new lifestyle trends, as many studies have shown the relation between everyday routines and energy consumption (55).

Crucial facts and landmarks have been placed in order in the following timeline, to help the reader visualise the evolution of building regulations and practices in Europe since the beginning of the 20th century in relation to political developments (7), (12), (37), (47), (56), (57), (58), (59), (60), (61), (62).



Building practices
Building regulations and policies
Political developments
Emergence of cavity walls as means of moisture protection, UK&NL
Introduction of on-site concrete building techniques, NL
PVC & aluminium replace wooden window frames,
Utilization of double glazing, NL
Emergence of internal sun shades, DE
Introduction of concrete floors and concrete tile roofs, NL
Construction of 'green buildings', NL
Optional building construction and condition controls, UK
Introduction of installations' control in building regulations, EU
Mandatory labeling of energy characteristics of heaters and appliances, DK
Deployment of insulation standards, DK
Fuel switching efforts (from coal to gas), UK
Passive house (Passivhaus) voluntary standard, DE
First Energy Policy Documents, NL
Introduction of Energy Performance Standard, NL
Introduction of limits on energy losses through certain building elements, NL
Regulation on energy efficient thermal insulation of buildings, DE
Compulsory energy labeling, DK
First mandatory Building Regulations, UK
Introduction of periodic inspection of boilers, FR
European directive 2002/91/CE
Stock Market Crash, US
Great Depression, NL
WW II
Oil Crisis
Kyoto Protocol adoption
1925 1930 1935 1940 1945 1950 1955
1960 1962 1964 1966 1968 1970 1972 1974 1976 1978 1980
1985 1990 1995 2000 2005

As the chart shows, there was a concentration of regulations and policies initiated in the period 1960-'80, the main triggering factor being the oil crisis of 1973.

A common characteristic of these policies is the improvement of the required insulation values. In the EURIMA project[12] it was estimated that the average U value of a roof in the moderate climatic zone[13] had decreased from 1,5W/m^2K (roof constructed prior to 1975) to 0,23W/m^2K for a new building in 2006. The equivalent values for a facade are 1,5W/m^2K (prior to 1975) and 0,38W/m^2K (2006) (9). Indicative of the development of energy efficiency standards is the following chart that summarises the development of the permissible elemental U values in the British Building Regulations (57), (63), (64). It should be mentioned that parallel to the stringency of the U values building regulations have also become more detailed (providing prescriptions for an increased number of building elements).

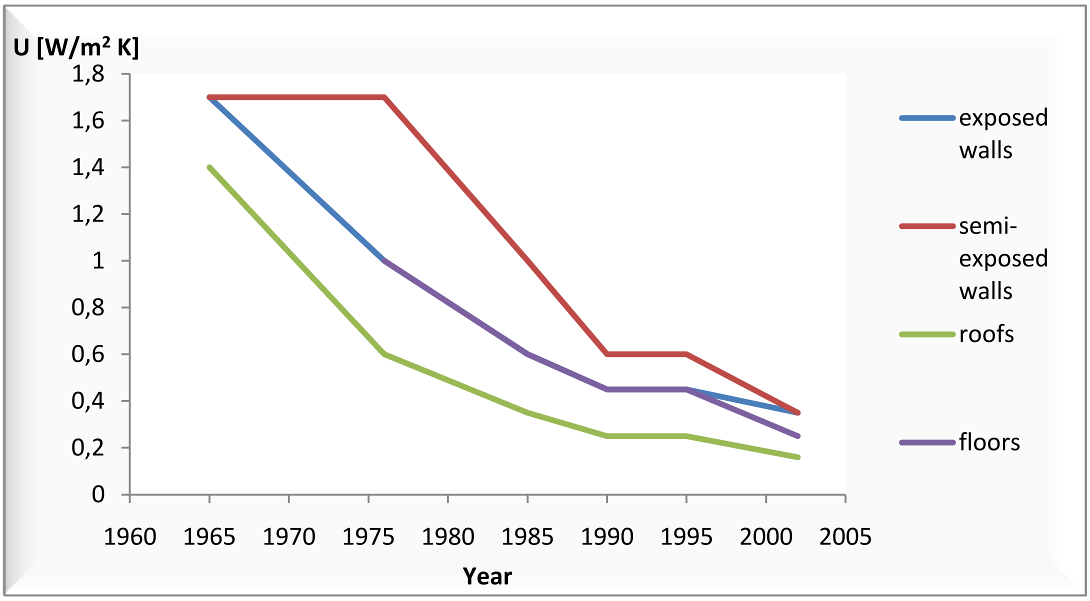


Chart 5 Development of U values, UK

However, most of these strategies have not included the treatment of the already existing stock and as a result a 72,5% of British cavity wall dwellings in 2000 had no cavity wall insulation while in the Netherlands the equivalent percentage was 41% - data from 2002. The same sources indicate that in 2000, 30% of all British houses had no loft insulation (7), (65).

The period after the oil crisis and the embargo imposed by the *Organization of Arab Petroleum Exporting Countries* (OPEC) was also marked by a change in fuel policy. As a result, while in 1970 only 31% of homes in Britain (5,6 million homes) had central heating by 2000 this percentage had risen to 90% (21,7 million homes) most of which was based on natural gas (65), (66).

Apart from the existence or otherwise of regulations, an old or obsolete building will anyway show a decline in its performance. *Lowe* gives an estimation of the physical lifetime of various building elements (67):

[12] The study entitled 'Cost-Effective Climate Protection in the EU Building Stock' that was conducted by Ecofys for EURIMA, examines the economics of suitable measures for the building sector. *www.eurima.org*

[13] Countries belonging to the moderate climatic zone are Austria, Belgium, Denmark, France, Germany, Great Britain, Ireland, Luxembourg and the Netherlands.

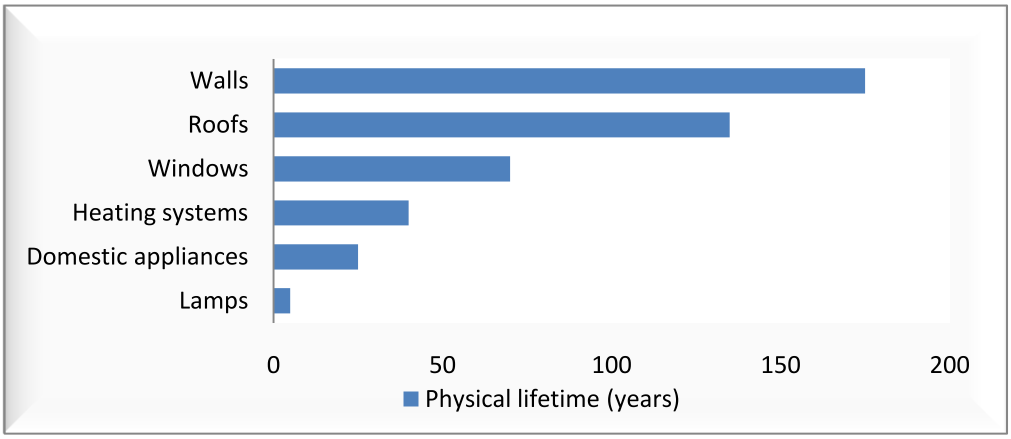


Chart 6 Physical lifetime of building elements

Notable is the short lifetime expectancy of heating systems. The importance of this factor is even more appreciated if we take into account that it was only in 1977 that France became one of the first European countries[14] to implement a compulsory periodic inspection of boilers. Other countries introduced such measures much later (Spain in 1998, Austria in 2000, Greece in 2002). At the same time, only Greece (2002) and the UK (2002) have introduced measures related to efficient lighting (59).

It becomes apparent that an old property will tend to have a low energy performance. Estimations show that a building in France, built prior to 1980 consumes more than 250KWh/m^2/year while the equivalent for a 2005 new building is less than 100KWh/m^2/year (68).

In support of the above statement, the next chart provides information on the profile of energy performance of the existing dwelling stock (data from 2004) in the UK. It shows clearly the significant change in the energy efficiency of the stock, especially after 1990, when the energy efficiency standards were raised by the Building Regulations (Part L). For example, 42% of British buildings built prior to 1919 have a SAP[15] index lower than 40, while for post 1990 buildings this percentage is only 2% (52).

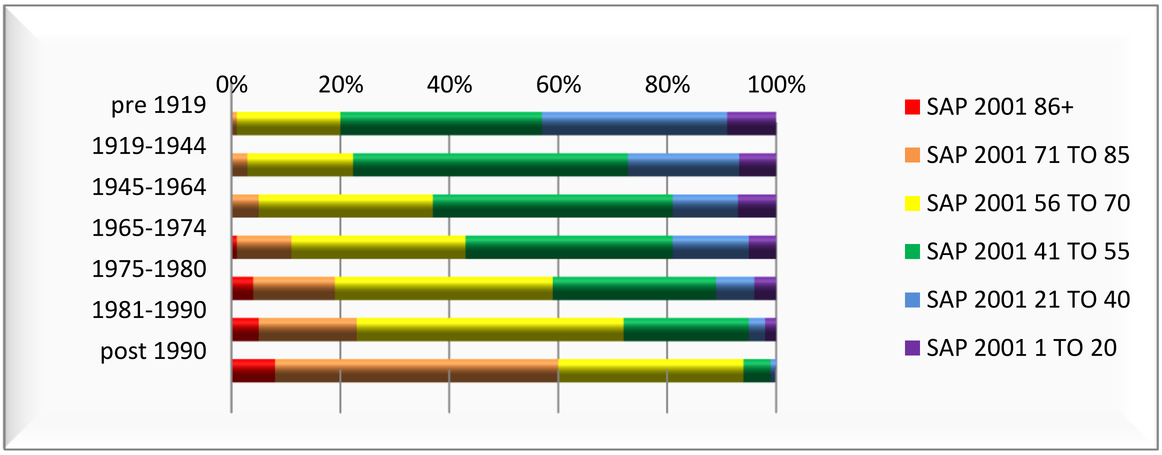


Chart 7 Energy Performance of Existing Dwelling Stock, UK

[14] The study included Austria, Belgium, Denmark, Finland, France, Greece, Ireland, Norway, Spain, Switzerland and the United Kingdom

[15] Standard Assessment Procedure (SAP) is an index of the energy performance of buildings. It measures the fuel efficiency of heating systems and the heat retention of the building fabric. The index is expressed on a scale of 1 (highly energy inefficient) to 120 (highly energy efficient).

The above data were meant to demonstrate how the date of construction of a building relates to its energy performance. The evolution of building practices, policies and legislation in European countries implies that the older the building, the more it will lack in sufficient energy-saving design and measures.

4.3 The potential of refurbishment

The major role of the building sector in the quest for lower energy consumption and a milder environmental impact has been acknowledged by the International Energy Agency (IEA). When the IEA was invited by the G8[16] leaders to provide advice on alternative energy strategies it responded with the formation of the *Alternative Policy Scenario*. According to this, the residential and services[17] sector can offer savings of up to 40% of the total anticipated savings in final consumption. Special reference is made to the possible electricity savings (68% of electricity savings will be achieved through the residential and services sector) as buildings are by far the largest electricity users (53% of total electricity demand) (5).

Similar principles were adopted by the European Union, as the EU Directive on Energy Performance of Buildings (EPBD) indicates. The EPBD makes extensive reference to the refurbishment of old buildings. According to this, if all proposed retrofit measures were realized, the overall emission savings would amount to 82Mt/a, while an additional 69Mt/a could be achieved, if the measures included all multi-family houses and all non-residential buildings (9).

In the following table, examples of findings of studies show the effectiveness of some energy saving retrofit measures:

Source	Measures proposed	Country	Effectiveness
(12)	cavity wall insulation filling	across Europe	20% energy savings
(37)	cavity wall insulation filling	UK	2,62MtC[18] emissions savings
(69)	solid walled (without cavities) insulation installation	UK	4,19MtC emissions savings
(37)	replacement of all glazing with energy efficient windows	UK	5MtC emissions savings
(37)	insulation of cavity walls, lofts and hot water tanks, improvements to heating (better controls, thermostatic radiator valves and high-efficiency condensing boilers) and more efficient lighting	UK	20% carbon emissions savings by 2050
(69)	100% cavity wall fill, major program of solid wall insulation, 100% loft insulation at 300mm, 100% high performance windows, air tightness, mechanical ventilation	UK	60% carbon emissions savings by 2050
(70)	interior insulation of historical buildings	Germany	75-90% heating energy savings
(59)	boilers retrofit/replacement	Austria	10-30% of heating energy savings
(59)	HVAC inspection	Austria	3-10% of heating energy savings
(59)	energy efficient lighting	UK	26% of lighting energy savings

Table 6 Potential savings from energy-saving measures

[16] Canada, France, Germany, Italy, Japan, Russia, United Kingdom, United States
[17] The service sector covers all commercial and public buildings (schools, restaurants, hotels, hospitals, museums, etc.)
[18] Million Tonnes Carbon

The above, though indicative, make it clear that the refurbishment of the existing and ageing building stock offers great opportunities in terms of energy efficiency, accompanied at the same time by economic and social benefits

In conclusion, we should remember that the pursuit of a sustainable future is closely linked to the idea of maximum use of the existing resources. In this sense, renovating an old building is perhaps the most sustainable means of construction as most of the necessary materials are already present in the existing buildings. Given the potential in the field of refurbishment, some researchers have even suggested that we should stop expanding the building stock and simply limit ourselves to improving the existing one (71).

4.4 Current policies

While almost all European countries have integrated major refurbishment programs and measures into their policies, some have made a better start in the race for energy savings originating from the building sector – the most prominent being Germany, Great Britain, Denmark, and The Netherlands (7), (53), (72).

The opposing view, however, claims that there is still much to be done, as the existing building stock offers even greater potential for energy savings. The non-binding nature of the proposed refurbishment measures along with the continuing focus on newly built edifices (as far as technology application and financing are concerned) are put forward as arguments in support of the above statement (7), (59). Additionally, it is argued that simply providing financial incentives for refurbishment is not enough, as people take decisions taking into account other factors as well – such as social comparison, convenience, time use etc (55).

4.4.1 Germany

Germany is a world leader in refurbishment projects with an advanced refurbishment infrastructure and a generous state subsidy policy (53), (37), (72). Suggestive of this is the answer that Professor Anne Power[19] gave when she was asked what the British Government's priority should be as far as the energy performance of the existing stock is concerned: '*Copy Germany'* (37).

The principle of the 'Trias Energetica' is the main pillar on which the sustainable future of buildings designed and constructed in the 1950s, '60s and especially during the post war period (with significant weaknesses in energy efficiency (73)) lies. This approach focuses on three distinct points:

- Minimizing energy demands
- Applying sustainable energy sources and
- Efficient and intelligent use of fossil fuels

While in The Netherlands the efforts revolve mainly around the generation of sustainable energy (solar, wind, nuclear, biomass etc.) in Germany this is handled after having treated the energy requirements (72).

The first of the aforementioned targets is, mostly, achieved by means of extensive insulation and prevention of leakage through the building envelope. Thick insulation materials are used (up to even 40cm for roof constructions) along with double and triple glazed insulated windows. Energy demand is further cut down with the application of nearly perfect heat recovery systems. The second constituent of the 'Trias Energetica' principle is addressed with the use of various sustainable technologies for heat and power generation (heat generation with wooden pellets, heat pumps, thermal solar collectors, PV panels etc). Finally, additional energy demands are provided by high efficiency fossil fuels installations (72), (73).

[19] Professor of Social Policy, London School of Economics and Political Science

4.4.2 United Kingdom

In the UK, although recently introduced policies mainly refer to new buildings, significant refurbishment programs have also been launched especially with regards to social housing. While investments in refurbishment have been reported much bigger than the ones in new construction, the main barrier still remains the high cost that private house owners have to pay (e.g. for microgeneration) (7), (53), (37).

Finally, as far as historical buildings are concerned, there is currently an intense discussion on whether the rating system for new houses (SAP) is also suitable for the older stock, the main argument being that thick solid walls with permeable materials (as is the case of most Victorian and Edwardian buildings) should be considered in a different manner than the cavity wall buildings.

4.4.3 Denmark

Denmark is considered to be a frontrunner in the field of energy refurbishment, implementing an effective energy policy on buildings (resulting, for example, in stable electricity consumption during the past decades). The energy labeling scheme for buildings introduced in the EU in 2006 has been largely influenced by the equivalent Danish one, established much earlier, in 1997 (8), (55), (74).

4.4.4 The Netherlands

The Netherlands have fallen behind partly due to the particular architectural traditions but also due to the lack of a wise financial encouragement (no tenant contribution in the renovated building). This demonstrates how important the 'return on the investment' can be, considering the continuous increases in the price of fossil fuels.

However, a change in policies has been noticed since the VROM[20] decided to shift the focal point from the 'environmental efficiency of buildings' to the renovation of the existing stock. The will to change the status quo in The Netherlands has been demonstrated in various ways (central government aiming at 100% sustainable procurement[21] by 2010, Dutch authorities aspiring to strong CO_2 emissions reduction etc). As a result, the UK has taken The Netherlands as a 'case study' when discussing its energy efficiency program (75), (76), (77), (78).

The same determination is also visible at municipal level. The local authorities in Amsterdam have set a goal of 40% CO_2 emissions reduction by 2025, in relation to the 1990 levels, while the municipality of Delft has launched the 3E (effective energy consumption) Climate Plan (38), (78).

In this so-called 'Delft interpretation of the Kyoto Convention', the Sustainability Sector foregrounds the significance of sustainable refurbishment in the pursuit of the environmental ambitions. Even from the early '90s the Delft Municipality performed energy saving scans and applied the appropriate measures in existing municipal buildings and monuments. Actions taken in this cadre involve, among others, the programmed refurbishment of two buildings, technical innovations in all municipal buildings and the energy consumption management in all existing municipal facilities (78).

Important steps have been taken in the field of the sustainable refurbishment of monuments. Notably, the Dutch government has ordered that '*purchasers of buildings listed as national monuments no longer have to pay transfer tax*', in order to encourage the energy refurbishment of buildings with historical value (38). Nowadays, historical buildings are protected by the 'Monuments Act' of 1988. On October 15, 2007, the Minister of Culture, Ronald Plasterk, announced the monument protection shield over one hundred buildings built in the period 1940 - '58. In addition, the year 2010 was marked by the launching of a *National Conversion* ('*Herbestemming*') program

[20] Ministry of Housing, Spatial Planning and the Environment - *http://www.vrom.nl/*

[21] 100% sustainable procurement is understood to mean that all purchases meet the minimum requirements that have been set for the relevant product groups at the time of purchase

aiming at encouraging the restoration of churches, factories, offices, farms and other historical buildings that have been left vacant for years, while 23 million euros per year were the subsidies announced for such restorations. Finally, in favour of Dutch conservation policies are the numerous long-standing Dutch firms specialising in the monument preservation business (79), (80).

4.5 In a nutshell

In the previous paragraphs an effort has been made to present Europe-wide environmental and energy problems in relation to the building sector. This link is enhanced by the magnitude of the ageing building stock, as old buildings comprising of an obsolete fabric exhibit significantly low performance in terms of energy use and CO_2 emissions.

One of the proposed solutions is, apparently, the refurbishment of a large part of these outdated buildings, the predictions for such strategies being very promising. As a result, most European countries are striving to implement efficient refurbishment policies, but still lack impressive outcomes.

Part II

5 BK City
5.1 Context

5.1.1 Location, topography and climate

Bouwkunde City (BK City) is located on the north edge of the TU Delft campus in south east Delft. Delft is a 13th century city located in the province of Zuid-Holland, in the western part of The Netherlands.

The country, including the west part, is made up of mainly low and flat lands, a large part (a quarter) of which is below mean sea level. The average elevation of Delft in particular is -2m, which has resulted in numerous floods over the years (81).

The Dutch climate is described as a temperate marine climate, characteristic of which are the cool summers and mild winters. The climate patterns in The Netherlands are strongly influenced by the prevailing winds, especially those originating from the sea. As a result, the coastal areas tend to have cooler summers than the mainland but also milder winters.

The average temperature throughout the year in The Netherlands is about 10°C, while the average annual rainfall is about 790mm (March being the driest month, August the wettest). Limited sunshine is one of the main characteristics of the Dutch climate, as average sunlight hours range from 1,3hours/day in December to a peak of 7,4hours/day in June (82), (83) .

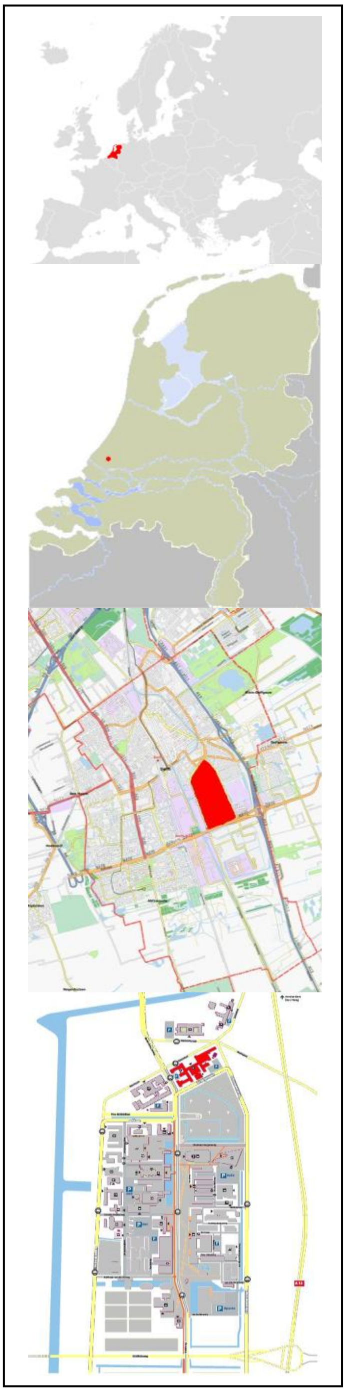
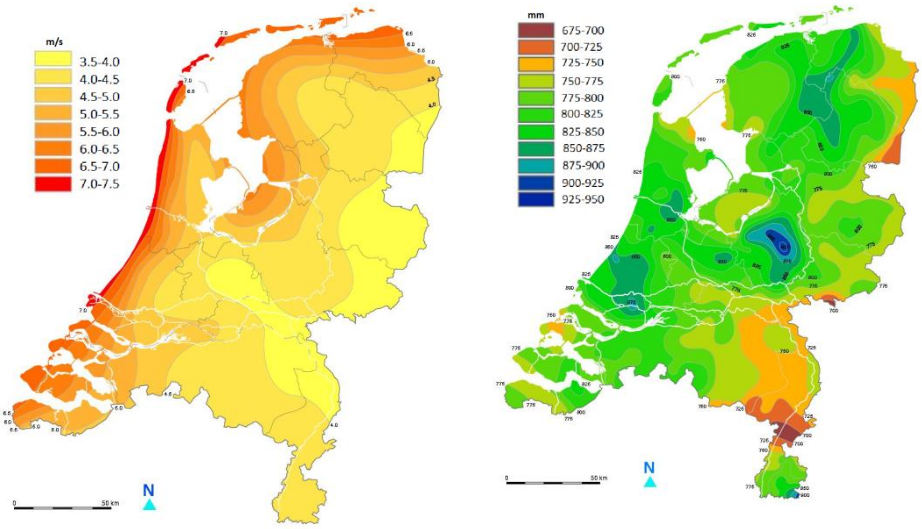


Figure 3 Locating BK City. Europe, The Netherlands, Delft, TUD campus (from top to bottom)



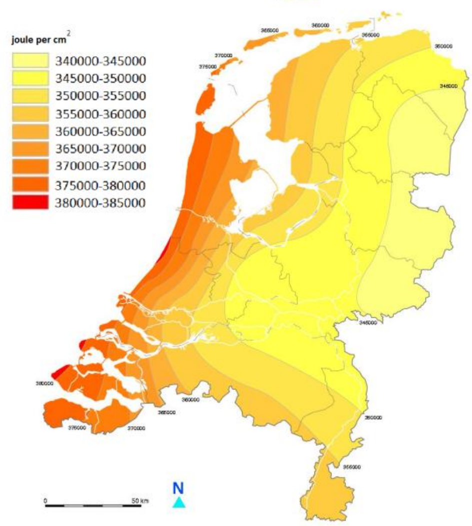


Figure 4 The Netherlands: average wind speeds (top left), total yearly amount of precipitation (top right) and total yearly global solar radiation (bottom left)

For specific climatic information in the area of *Delft* the weather station of *Zestienhoven* provides the data shown in table 7 (82). For the area of Delft see also chart 8.

Area of Delft weather data			
	Data period	Average values	
temperature [°]	1957-2010	mean	10,04
		maximum	22,23
		minimum	-1,09
relative humidity [%]	1956-2010		83,19
annual precipitation [mm]	1957-2010		834,50
daily global radiation [J/cm^2]	1988-2010		1006,14
wind speed [m/s]	1959-2010		4,69

Table 7 Area of Delft weather data (weather station 344 Zestienhoven) (82)

Average maximum temperatures in Delft, around 22°C, usually occur at the end of July and beginning of August, while during the coldest period (from December till February) the temperature drops to around -1°C. Relative humidity fluctuates around an average of 83%. The total amount of precipitation for a whole year amounts to an average of 834mm (higher than the national average of 790mm), November having the largest amount of rainfall (as opposed to August for the entire country). The amount of global radiation has its peak in June – July and its lowest point in December – January, with a daily average of 1006J/cm^2. Finally, the predominant winds are southwestly, including those with the highest speeds.

The aforementioned should, however, be supplemented with the scenarios for prospective climate change. The *Royal Netherlands Meteorological Institute* predicts that as global warming continues, mild winters and dry hot summers will become increasingly common, as well as the occurrence of extreme rainfall (winters, thus, become wetter) (82).

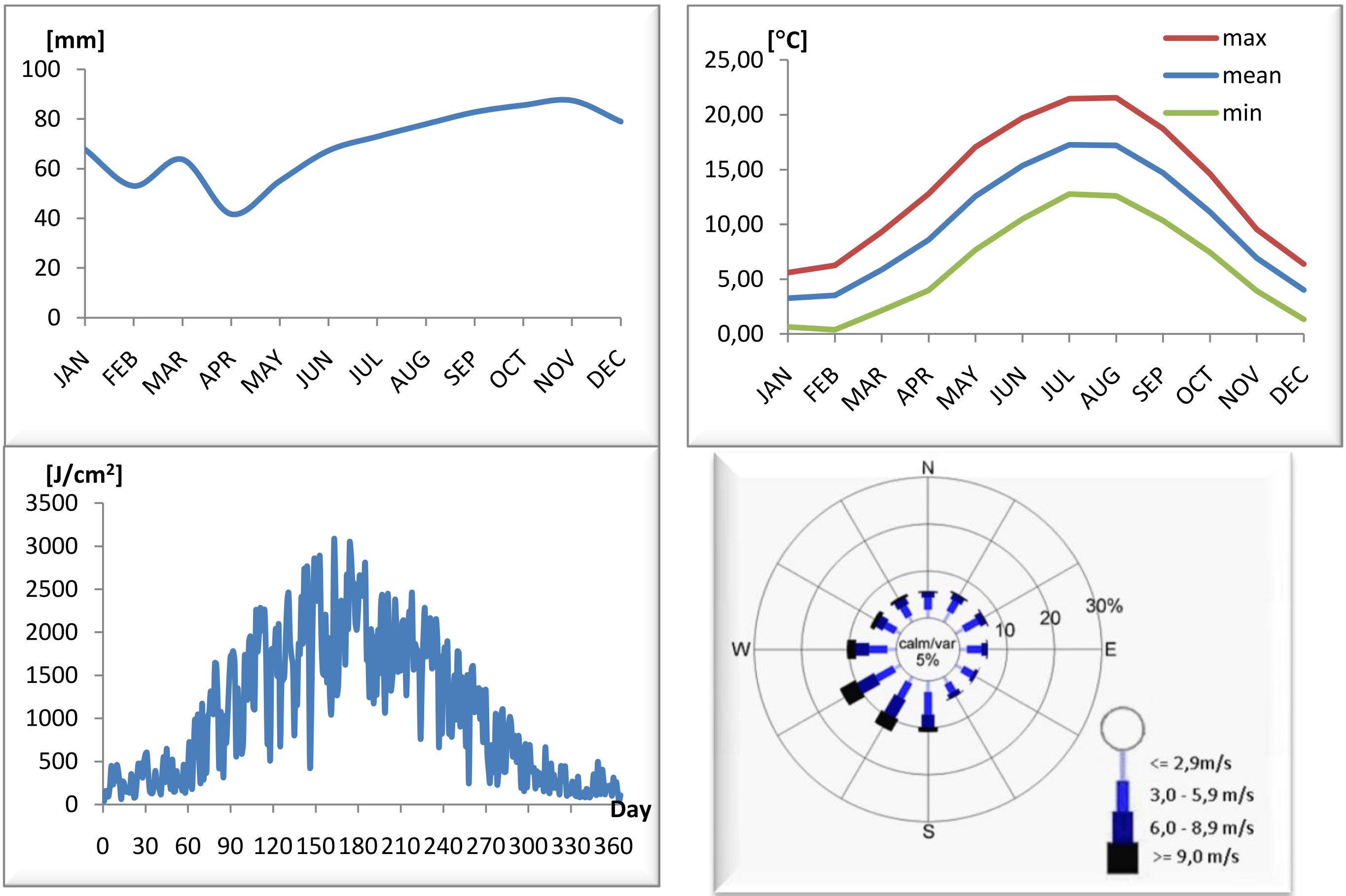


Chart 8 Weather data in the area of Delft (82). From top to bottom: monthly average temperature, monthly average amount of precipitation, daily global radiation for year 2009 and wind frequencies distribution (right).

The weather data presented in this paragraph was meant to give to the reader an idea of the climate situation in The Netherlands and, more specifically, in Delft where the case-study building is located. This information will be used, later on, for the development of the refurbishment Strategies (see §*6.2 Refurbishment Strategies for BK City*).

5.1.2 The history of BK City

The Julianalaan building, that was chosen to house the Faculty of Architecture in 2008, dates back to the beginning of the 20th century. Its turbulent history has been marked by frequent changes in ownership and numerous changes in its function.

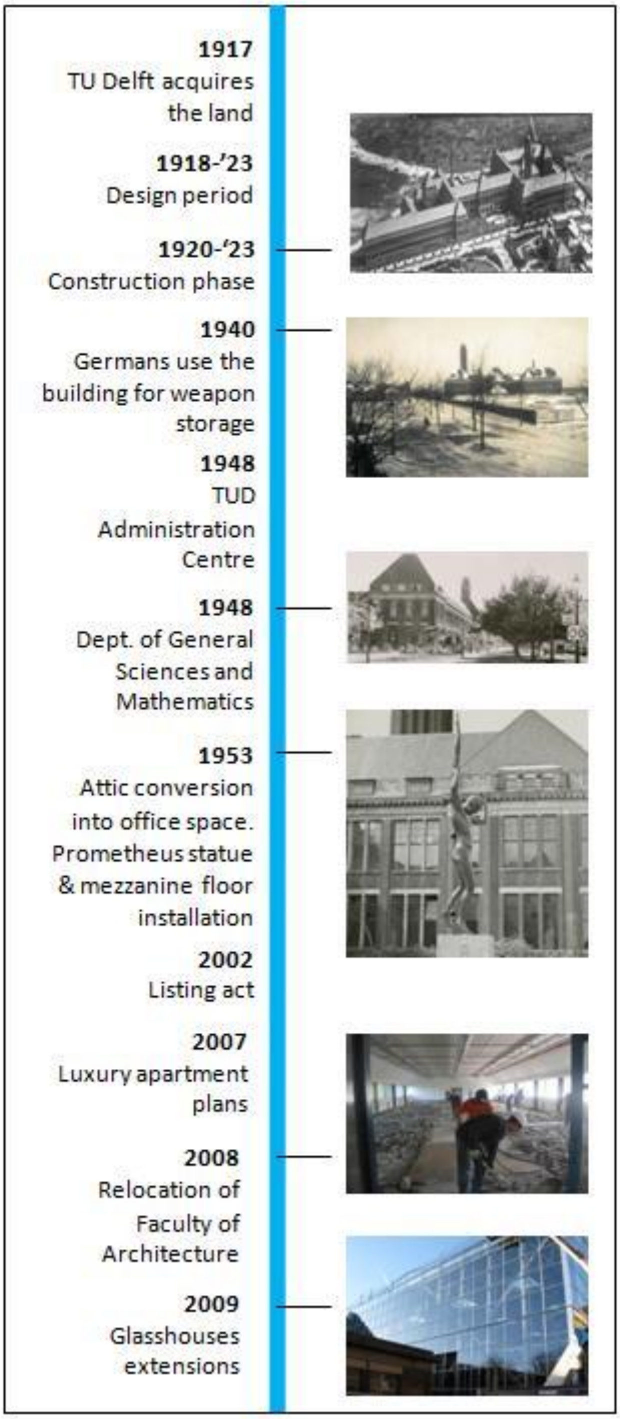


Figure 5 History of BK City – the milestones

It was in 1917 when the University authorities decided that the Chemical Engineering building (on Westvest Street) could no longer serve its designated purpose. The growing number of students, along with its obsolete structure, demanded immediate action.

During the 1918-1923 period, architect G. Van Drecht designed the new Chemistry building (the '*Rode Scheikunde*', i.e. '*Red Chemistry*') in a '*traditionalist style with influences from the Amsterdam School*' (84). At the time, the building was one of the largest in the entire country. However, the construction phase coincided with the financial recession of the 1920's, during which the Dutch Government decided to drastically cut down salaries and subsidies. By then, the erection of walls and roof had been completed, but the air/water tightness of the building had yet to be done (85).

The lack of ceilings and floors did not prevent the youngsters of Delft from occupying the building and putting it 'into use' as a playground. Significant damage was recorded during this period, including all original timber elements. In subsequent years, the building would attract several prospective owners, amongst them *Rijksverzekeringsbank* (State Insurance Bank) and *Philips*. In the meantime, the Dutch government used it to store some thousand kilos of straw and the Department of Justice to store the furniture it did not need. In 1939, the building was once again used for storage purposes, this time for two hundred crates of uranium oxide (yellowcake) (85).

The attack on The Netherlands during World War II, in 1940, cancelled any plans for a possible rehabilitation of the '*Rode Scheikunde*' and allowed the Germans to use it as a weapons storehouse. Surprisingly, at the same time many Dutch people would use some of its abandoned wings as a refuge.

After the War, the building housed some departments of the TNO (Netherlands Organization for Applied Scientific Research), the Departments of Applied Physics and Aerospace Engineering, and ultimately, in 1948, the University Administration Centre, along with the Department of General Sciences.

In 2007, the Dutch Bank Fortis in cooperation with the architectural firm Braaksma & Roos, made plans for converting the building into 170 luxury apartments under the name of 'Villa Academica'. This new adventure for Red Chemistry would offer, according to the sales brochure, '*many residential benefits to a broad target group, treating them to the joys of premium residency for years to come*' (86). The halt to these plans, due to the little demand for apartments, coincided with the fire in the TU Delft Faculty of Architecture on May 13th 2008. As the University was in urgent need of a new Faculty building to accommodate its 3.000 students and 1.000 staff members, the Julianalaan building seemed to fit the purpose in the best way.

5.1.3 The making of BK City

The events following the fire at the former Architecture Faculty building on May 2008 are a lesson in good planning, team work and willingness to achieve the impossible.

The first thing that needed to be done was the selection of the most appropriate alternative to house the Faculty. The initial five options (two existing University buildings, two existing off-campus buildings and the possibility of erecting a new building from scratch) were quickly narrowed down to two, the Julianalaan building and a new campus village. The selection process didn't last long, as the Julianalaan building fulfilled the criteria better (87):

- Location in relation to TU Delft campus
- Suitability for use – qualitatively and quantitatively
- Contribution to the Faculty's image
- Availability on September 1, 2008
- Costs (initial investment and annual costs)
- Possibilities for future extensions and alterations
- Technical condition and required improvements
- Accessibility
- Procedures and process risks

From this point onwards a remarkable effort took place to relocate the Faculty. In only three months, i.e. by early September 2008, the multi-disciplinary project team, consisting of academics, professionals and support staff *indeed* managed to plan and execute the renovation of this '*monumental labyrinthine*' building (87).

However, due to time and financial restrictions, and as the initial intention was the use of BK City for a 5 year period, the works were limited to the bare essentials. Amongst others, these involved (88):

- The installation of a sprinkler system
- The removal of any asbestos elements
- The maintenance of all windows and frames
- The rough finishing of the interior
- Minimum investment in climate systems
- Minimum investment in mechanical ventilation system (only input of fresh air, no extraction)

- The maintenance of the existing heating system
- High quality furniture at a reduced price
- Cabling works
- Installation of the necessary lighting fixtures

Further works were planned to improve the performance of the building. These included (85):

- Measures to control the artificial lighting
- Installation of equipment for indoor temperature control
- Repair and maintenance of blinds
- Installation of new blinds and curtains where necessary
- Mounting of acoustic panels

However, from the first months of the operation of the building it became apparent that it demanded much more work and radical measures for it to achieve sustainability.

5.2 Building description

This neo-classical building is mainly developed on the horizontal plane in a semi-symmetrical layout. It consists of one central wing with the main entrance, an E-shaped wing on the west and an L-shaped wing on the east, the total surface area amounting to 30.000m^2. Each wing consists of two floors 6m high – this height was necessary for the Chemistry laboratories.

On May 2009, BK City was expanded with the addition of two glasshouses, one on the south and the other on the east side. The main reason behind this was the desire to create some extra space for the students (the building lacks approximately 10.000m^2 to fulfill its needs).

BK City Identity

- Location: Delft, The Netherlands
- Owner: TU Delft
- Year of construction: 1918-1923
- Total area [m^2]: 32.000
- South glasshouse [m^2]: 2.240
- East glasshouse [m^2]: 1.200
- Restaurant Ketelhuis [m^2]: 1.100
- Main storeys: 3
- Other storeys: 2 mezzanines, basement and attic
- Working hours: Monday to Thursday: 07.00 - 22.00, Friday: 07.00 - 19.00
- Students / staff: 3.000 / 1.000

Figure 6 BK City

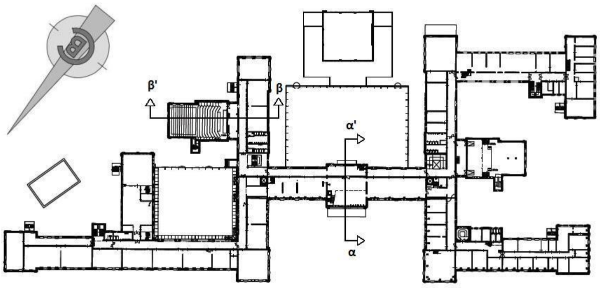


Figure 7 BK City floor plan

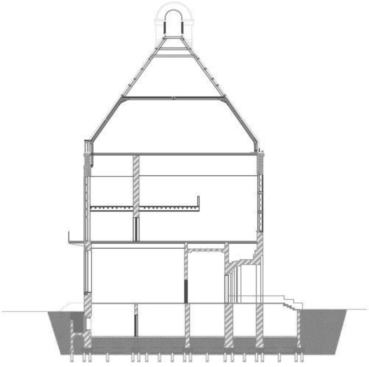


Figure 9 Cross section α-α΄

Figure 8 Cross section β-β'

Apart from the main building the complex includes another two annex buildings, both of which were designed at the same period as the main building. On the south of the main entrance is the former boiler house, *Ketelhuis*, which was converted in 1953 in a transformer house (*transformatorhuis*). This detached building, which today houses the Faculty Restaurant and various meeting rooms, is one storey high, half sunk in the ground, and its structure is mainly made of concrete and brick. On the southeast side, one finds the *Tempel* (i.e. the temple) a one-storey building with a simple rectangular floor plan. This building has been converted into a meeting place for students and staff, the *Bouwpub* (84), (88).

The three buildings have been developed in an area around numerous courtyards. This has allowed the creation of multiple parking spaces both for cars (270 spaces) and bicycles (1100).

The complex has been divided into 12 wings, as shown in figure 10. Table 8 shows the surface areas of each wing.

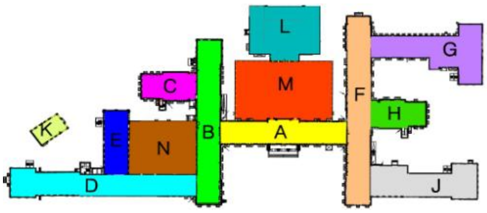


Figure 10 BK City, the 12 wings

Surface areas [m²]							
Wing	Floor	Façade			Roof		
		brick wall	openings	openings (timber frame)	oblique	flat	skylights
A	3819,3	1352	514	116	1035,1	167,4	0
B	5246,1	1902,3	534,3	206,4	1317	349	0
C	1270,81	998	202,4	0	464	60	0
D	4908,7	2089,2	644,8	227,4	1424	378	0
E	2530,4	796	293,7	106	463	123	0
F	5358,8	1906,4	594,8	207,78	1195	319	0
G	4767,3	1546,6	444,1	168,8	922	246	0
H	1348,8	998	202,4	0	464	60	0
J	3698,21	1243	472,4	147	785	210	0
L	922,7	428	115,8	0	0	1008	0
M	2402,01	0	1606	0	0	1488	181,35
N	1180,7	0	479	0	0	891	218,48
Total	**37453,83**	**13259,50**	**6103,70**	**1179,38**	**8069,10**	**5299,40**	**399,83**

Table 8 Surface areas of each wing

As far as functions are concerned, the basement of the main building is mainly used for building services as well as a storage area for the various departments of the Faculty. Additionally, it houses the multimedia lab, the logistic point, a few office spaces, a photography studio, the waste area and other minor functions. The ground floor, apart from the student and staff areas, also houses the restaurant, a canteen, the central information area, working and meeting spaces, printer rooms, pantries and many other functions. Characteristic of the first floor is the Faculty library, while the second floor is taken up by bachelor students' studios. In between the elevations, at some locations, there are mezzanine floors, mainly occupied by the University staff. Finally, at the top of the building, there is an attic that till now has never been used.


Figure 11 Interior of the unused attic. Image retrieved from (88)

Structurally, the loads are transferred from the floors to the ground via the load bearing walls. The roof is supported by an iron truss, which in turn is supported by the exterior walls. The lower part of the iron truss is still visible in the upper floor.

With regards to the materials used, the choice was significant. This is reflected in a clear way in the original name of the Faculty, *Rode Scheikunde* i.e. Red Chemistry, which is derived from the red bricks of the exterior walls. Apart from the extensive use of bricks, the building also has numerous details of natural stone (around the openings, the cornice and the main entrance) and others made of masonry or brick. Lastly, the roof is covered with stone slates (*maasdekking*).

The sophisticated and eclectic use of materials was rather controversial when the *Rode Scheikunde* was first built, indicative of which is the article that appeared in the Delft Courant on June 23, 1926: '*...Indeed, the tax payer would certainly be surprised if he knew the truth about this abandoned monument to wastefulness.[...]. The chimneystack cost more than a royal villa, the tower is built of the most expensive, handcrafted stone that exists, and there are expensive carvings at the top of the building, which can be seen with a spy-glass [...]. The exterior is sumptuous and enormous in size...* (86)'.

5.3 Historical appraisal

5.3.1 Listing act

Rode Scheikunde was declared a National Monument (*Rijksmonument*) in year 2002. The listing act justifies the public interest in protecting the building for the following reasons (89):

1. Historic value due to its function as a University building and, furthermore, its significance in the history of the Delft University of Technology
2. Outstanding architectural value, with regards to shape, materials, detailing and integrity, but also due to the place it has in the works of the architect G. van Drecht
3. Monumental value due to its important location in the urban setting of Delft but also in the TU Delft campus
4. Functional and visual relationship with the surrounding buildings of TU Delft
5. Finally, the building is valuable for its rarity as one of the largest pre-war academic buildings

The listing act also refers to the necessity of preserving the *Ketelhuis*, the former boiler house. Its value lies in the following (89):

1. Its function as a boiler house and its historic value as a part of the TU Delft
2. Characteristic shape, applied style, materials and detailing which make it an integral part of the *Rode Scheikunde*
3. Its important position at the rear of the main building and the spatial/visual relationship with it

Finally, the detached building on the southeast, the *Tempel*, is significant for (89):

1. Its role as a historical-functional component of the complex
2. Distinctive use of materials and detailing in a Traditionalist style
3. Its location on the southeast side of the main building and the spatial/visual relationship with it
4. Its location as a border of the former course of the road/street

As noted previously, the building has not always been as appreciated as it is today. It has been discredited as a '*broken millionaire's dream*' and, as we have seen, a '*monument to wastefulness*' by the Delft Courant newspaper, 1926 (86). Even today, one of the principal architects involved in the renovation works, ir. Job Roos, has criticized it on the basis of it having '*so much heritage, that it becomes boring*'. He also describes it, disparagingly, as '*very horizontal*' and '*very vast*' (90).

5.3.2 Elements of special significance

Period	Features	Photo
<1950	• Manufacturer Crittall • Slim steel profile (30mm) • Poor condition	
1953-1967	• Manufacturer Alta • Thick steel profile (60mm) • Reasonable condition	
Unknown period	• Thick & slim steel profiles • No window sill for rainwater protection	
1958	• Timber frame windows	
1966	• Blocking of openings	
1975	• Slim steel profiles • (Possible) Manufacturer Crittall	

Table 9 Main window types by installation date

The particularity of BK City lies in elements that have been kept from the original building, some of which were especially designed to serve its initial purpose as a Chemistry Faculty.

Amongst these, the most outstanding feature of BK City is probably the 40m high water tower that interrupts the horizontality of the layout. Today considered the hallmark of the building, it was originally placed there as a water reservoir in case of fire. Till today, it has remained inaccessible.

Though the decorated brick façade itself is entirely authentic, the same doesn't apply to the windows and openings, where we can distinguish different types, according to the installation period (91) (*see table 9*). During the lifetime of the building, many were the cases when existing windows were replaced or maintained. For instance, in 1966, new windows were installed in some lecture halls while various openings were filled with brick, in 1975, changes were made by adding slim profiled windows, and in 1992 many windows on the ground floor and first floor were replaced. Other examples are the addition of shutters or blinds to improve the building physics performance or the conversion of some window openings into emergency escape doors. The windows of the last floor are of particular interest. In 1958, when the space was converted into an office area, the architects decided to replace the dormer windows existing at the time with a continuous strip of wooden frame windows, which are still present today.

As we will see below, today, the existence of many authentic openings is causing various indoor-climate-related issues. For example, whether a window can open or not is determined by its original purpose. The Urbanism section nowadays suffers from this as the same space was used as a data center with expensive equipment that required strict security measures (91).

Steel frames, 1967, inside glazing with wooden battens
Steel frames, 1967, with flat glass rods
Steel frames, before 1950, inside glazing
Steel frames, 19??, wide sections without window sill
Steel frames, 1957, exterior glazing
Steel frames, 1992
Timber frames, 1958

Figure 12 The variety of windows on the front and back facade

Figure 13 The 40m high water tower of BK City

The exterior walls are significant for one more reason. On them are embedded numerous decorative metal projections that served as camouflage for the ventilation outlets. These were necessary in the original building for extracting air from the Chemistry laboratories, but were never actually used (*see figure 14*).

In the interior, various elements are also considered as historically important, such as some granite staircases, the stained glass details by Daan Wildschut or the staircase inside the water tower.

Finally, the Prometheus statue, made by Dutch sculptor Ludwig Oswald Wenckebach, dates from the works carried out in 1953 (91).

Figure 14 Characteristic decorative projections of the façade, intended to serve as camouflage for ventilation outlets

5.3.3 Permissible interventions

It is obvious that the original elements of the building cannot be altered, removed or destroyed without the prior consent of the respective authorities.

When plans were made for converting the building into apartments it was clearly stated that intervention actions would be permitted as long as they did not alter the image of the building. For example, the construction of loggias was allowed, behind the existing openings. The current window layout should be preserved as much as possible, but some modifications were allowed (*see figure 15*). The timber framed openings of the last floor are a special case as they were added at a late stage (*see §5.3.2*) and their replacement is '*discussable*', according to ir. Ilse Rijneveld from the Monuments' Department of Gemeente Delft (*see figure 16*).

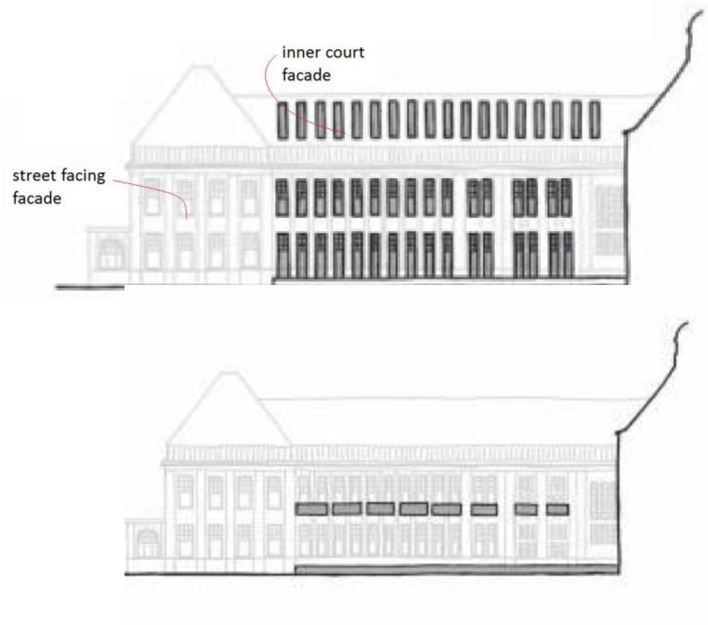


Figure 15 'The current window layout should be preserved as much as possible, but some modifications were allowed'

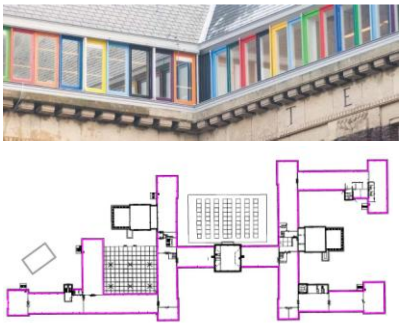


Figure 16 The timber framed windows at the 2nd floor of BK City. The purple line indicates their location

With regards to the interior, permission was given to demolish the mezzanine floors (added during 1953-'58). The same does not apply to the interior walls for which it is only possible to make openings e.g. for light penetration.

The stone slate roof of BK City is considered to be an essential element of the appearance of the building. Those parts of it facing the main street cannot be altered in any visually obstructive way and any interventions should be restricted to those parts facing the inside courts (*see figure 17*).

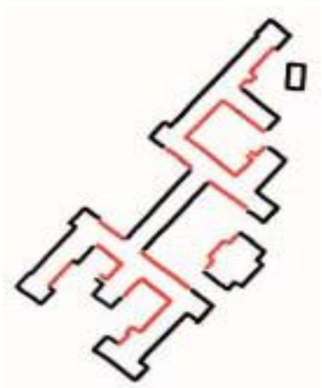


Figure 17 Sections of the roof that can be subject to interventions (red line)

Finally, the shape of the building should also be preserved as much as possible. This means, for example, that the heights of the elevations should be kept as they are. Demolishing certain wings of the building was allowed for the apartment plans, while any new constructions should 'complete' the original shape (*see figure 18*).

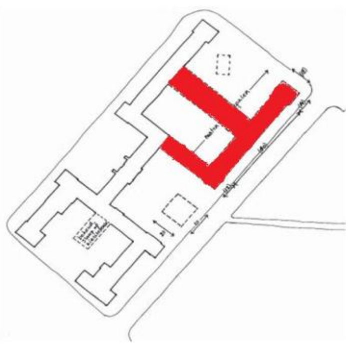


Figure 18 Wings that could be demolished (dotted lines), and the allowed new constructions for the apartment plans (in red)

5.4 Building Physics

5.4.1 Heat transfer through the building envelope

The exterior fabric is in general out-dated with regards to its insulation and air tightness characteristics. The external wall, consisting of two brick skins separated by a cavity, has no insulation and the same is true of the concrete floor structures. The windows are single glazed in steel and timber frames. In the attic, the condition of the roof is so bad that even below zero temperatures are expected during winter. The following table indicates the U values of the various elements of the building envelope. A more detailed table is presented in Appendix II.

#	Description	U [W/m²K]
1	Brick façade	1,17
2	Natural stone façade	1,16
3	Basement floor	3,59
4	Ground floor	2,46
5	Glasshouse floor	0,63
6	Second floor roof	0,64
7	Attic roof	3,11
8	Glasshouse roof - steel part	0,70
9	Steel frame windows	5,90
10	Timber frame windows	3,5
11	Glasshouse façade	1,10
12	Glasshouse roof	1,10

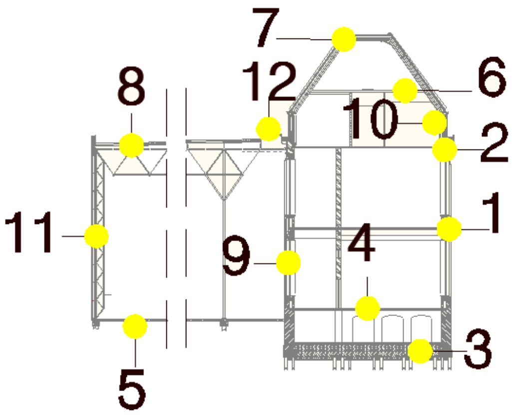
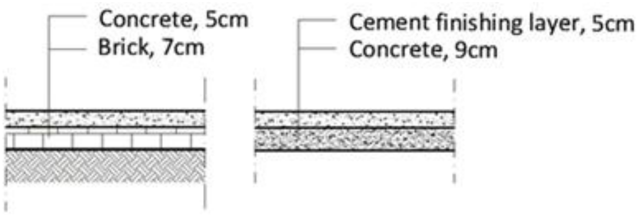


Table 10 Calculation of U values



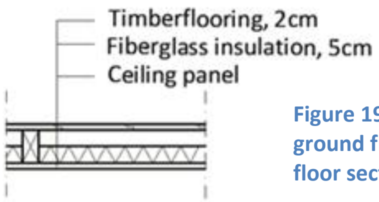


Figure 19 Basement (top left), ground floor (top right) and attic floor sections

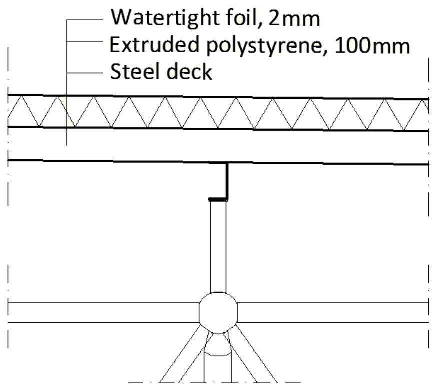
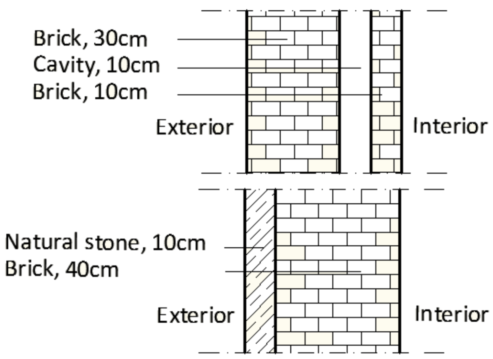


Figure 20 Glasshouse roof section



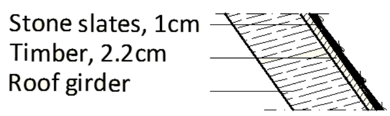


Figure 21 Roof section

Figure 22 Exterior wall sections

When analyzing the thermal performance of an existing building, it is common to use infra-red thermography as a support tool. Infra-red thermography is a technique based on detection of the emitted radiation by surfaces that serves, among other things, the monitoring of buildings.

The Municipality of Delft provides infra-red thermographic images of the city. BK City and its surrounding area are depicted in the following figure (92).

Figure 23 Infrared thermographic images of Delft and BK City

As can be seen, BK City is currently a landmark of inefficiency in terms of thermal losses. The roof of the building, compared to the rest of the city, appears to have very high thermal losses. The obvious explanation for this is the complete absence of thermal insulation.

For the needs of this project, thermographic pictures were taken from the building surfaces, during a winter day with very low temperature (below 0°C).

From the set of photos (*see figure 24*) we conclude that:

- Exterior walls compared to interior ones have significantly lower inside temperature. This shows the low thermal resistance of the facade
- One of the weakest points of the envelope are the single glazed openings, that show even smaller resistance to heat transfer
- The timber frame windows (double glass) perform better than the steel ones (single glass)
- The glasshouses perform much better than the old part of the building

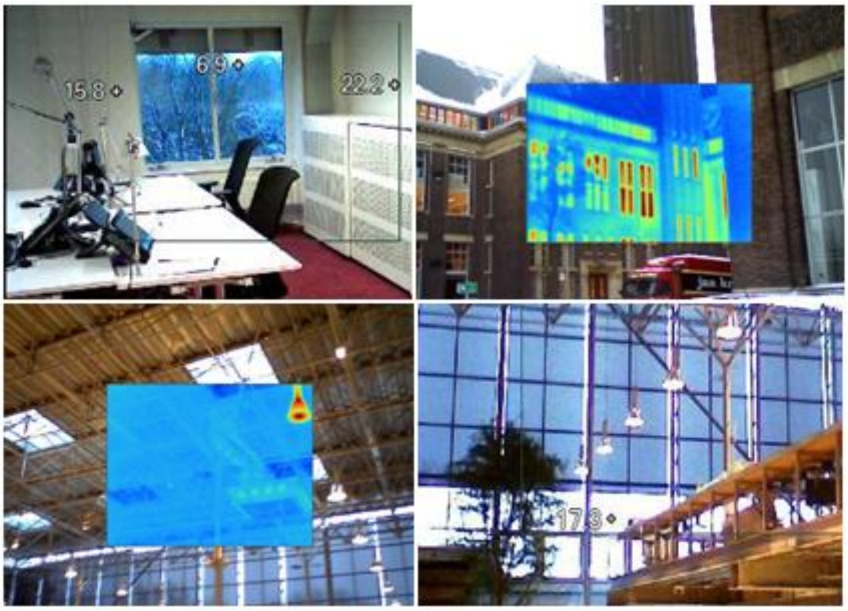


Figure 24 Infrared thermographic images of BK City

5.4.2 Mechanical Equipment

5.4.2.1 Ventilation

Prior to the works during the summer of 2008, the building had no means of ventilation, apart from some small fan coil units. The renovation scheme included the installation of a new mechanical ventilation system, which provides fresh air mechanically in some parts of the building, whereas air extraction relies on window openings or infiltration from the building envelope. In the rest of the building (with no mechanical ventilation equipment) window openings and infiltration fulfill the need for both fresh air input and output. The only parts of the building that have mechanical air extraction are the two glasshouses which is, however, not sufficient.

The ventilation system is not meant to regulate the temperature, though it is coupled to air handling units. There, the incoming air is pre-heated to a constant of 20°C, which cannot be adjusted to the actual room temperature. The air flow rate has been designated according to the prescriptions of the National Building Regulations that demand an amount of 35m^3/person/hour – the number of users is calculated according to the floor area. The entire system is controlled centrally – the controls are situated in the basement.

	air input	air extraction	temperature regulation
(white)	mechanical	window opening/infiltration	no
(green)	window opening/infiltration	window opening/infiltration	no
(cyan)	mechanical	mechanical, not sufficient	no
(orange)	mechanical, not sufficient	window opening/infiltration	no
(dark blue)	infiltration	infiltration	no

Figure 25 Ventilation zones

As seen in the above figure, the main concern has been to provide the 5 large lecture halls (B and D on the ground floor, A, C and F on the first floor) with independent air conditioning as they are frequently occupied by a large number of students and, thus, large ventilation rates are necessary. In room A, apart from mechanical supply, there is also mechanical exhaust of the circulating air. The intermediate floors have been excluded from the mechanical ventilation system.

The main problems occur in spaces where fresh air provisions depend exclusively on natural ventilation, such as:

- Opening a window becomes complicated in areas with a large number of people – who will take the initiative?
- Not all windows can be opened – this depends on the previous functions of the building
- The users of mezzanine floors can operate the windows only from the floor below

As we will see further on, these spaces suffer from low indoor air quality.

5.4.2.2 Heating

Apart from the pre-heated air coming from the ventilation ducts, the building is equipped with radiators. Some of these existed in the building before the renovation took place (not older than 20 years) while the very old radiators were replaced with new ones. The necessary hot water that circulates in the radiators is provided by the central plant of the University Campus.

It is not clear yet how the temperature of the radiators is controlled. The building is divided into zones which, however, do not have uniform temperatures. Some radiators do have thermostats – not those located in the corridor. As the thermostat-controlled radiators are located in large spaces, shared by large numbers of people, frequently nobody feels responsible for adjusting the temperature to the desired levels. On the other hand, the temperature in the corridors might get very high, resulting in uncomfortable conditions.

Frequently the users of the building are not aware of how the radiators work and, as a result, they set the radiators at either the maximum or the minimum power when they feel cold or warm respectively. It is most probable, however, that a more balanced and stable operation of the radiators would provide better thermal conditions while the fuel consumption would also be less (85).

The glasshouses are autonomous as both of them have floor heating systems that meet the heating requirements.

Finally, the needs for hot water are met by small electrical boilers (for example in the restaurant).

5.4.2.3 Cooling

Contrary to the heating provisions, no cooling is supplied through the air handling units. The lack of active cooling installations is compensated for by the mass of the building elements that are assumed to keep the indoor temperature at low levels. The opening of the windows assists this function, while the sun-blinds offer protection from solar radiation. In locations where the thermal mass of the building is not enough, overheating problems have been reported (for example on the second floor or for south facing spaces).

5.4.2.4 Lighting

During the day, the design of the building (size, position and number of openings) is such that abundant natural daylight is provided in most of the spaces. This effect is enhanced by the light coloured surfaces of the walls, the furniture and the floor carpets. Protection from glare is provided by a variety of blinds – exterior, interior, automatically or manually controlled. Initially, the irregular function of the automatically controlled blinds caused some frustration which was resolved by providing additional manual controls for most of the blinds. Sun shading devices in the glasshouses are operated by the service desk.

When sunlight is not available, numerous lighting fixtures have been appropriately placed. As the main concern of the renovation in 2008 was the rapid completion of the works, little attention was given to the light provisions – so common energy-saving light armatures were opted for. Initially, lighting control relied solely upon movement sensors but, later on, manual switches were added (except for the 2nd floor which has exclusively movement sensors). Problems persist however as, even today (at the time when this research was being written), users express their complaints about the difficulty they have encountered switching off the lights manually. As a consequence, the energy needed for the lighting of the building is excessively high. Finally, at closing times a central timer switch ensures that all lights are turned off.

5.4.3 Indoor climate and comfort

The indoor climate conditions of BK City were investigated by a group of TU Delft students in 2009. They performed measurements on air quality, temperature, acoustics and lighting in specific areas of the building and also conducted a survey among students and staff to detect the shortcomings in terms of comfort (85).

With regards to **air quality** the following were found:

- In general, air quality was characterized as 'poor'
- Measurements in some spaces showed high levels of CO_2 concentration
- Some lecture halls suffer from very dry climate, creating unpleasant working conditions, while relative humidity in other spaces was above accepted levels
- Ventilation rates were found insufficient in numerous lecture halls
- The temperature of the incoming air was occasionally found to be unreasonably high for winter conditions (up to 23°C)
- Incoming air creates a draft that is sensed by the spaces' occupants

Measurements on **indoor temperature** showed:

- Generally, unstable temperatures (high rates of fluctuation) indicating bad adjustment to the presence of people, outside temperature etc.
- On sunny days various parts of the building suffer from overheating
- Some college rooms were found 'very cold', forcing the users to wear their coats while seated
- The temperature in small rooms with a lot of equipment (CPUs, printers etc) is influenced significantly by the high internal load
- The mass of the building was found to be effective in terms of cooling down the temperature

The third measured parameter of interest is **lighting**:

- In general the levels of illumination are 'very good'
- The shape of the building and the wise design of the openings favour the penetration of natural daylight. This results in a low demand for artificial lighting
- The required illumination levels for exams were easily achieved in all measured rooms
- The needs for presentations (dark room) were adequately fulfilled in rooms with appropriate shading devices
- In various locations the operation of the lighting fixtures does not allow for the necessary distinct control (for example fixtures in front of windows or close to projection screens)

The conclusions of the survey amongst students and staff of the faculty on **comfort** issues were:

- The overall feeling is of a 'pleasant' building
- Users of computer rooms with increased internal loads were reported as 'very unhappy'
- Staff of the Urbanism space on the ground floor expressed their discontent with regards to bad air quality
- Complaints of headaches were expressed in connection to bad air quality (hot and stale atmosphere)
- Though the possibility of opening the windows was always welcome, people found it difficult to come to an agreement with other colleagues
- People had little knowledge of *whether* and *how* they could adjust the indoor temperature

The report also identified the main reasons that would explain some of the aforementioned shortcomings. A common weakness is the lack of appropriate means of control on the climate regulation equipment. For example, the ventilation rate could be better adapted to the use of each room (according to people present, time of the day, season etc). Spaces that rely solely on natural ventilation suffer from either the impossibility to open windows, or the unwillingness of people to take the necessary initiative. Suggestive of the natural ventilation inadequacy is the occasional removal of window handles, presumably for reasons of security. The suggested solution for the radiator-related problems (intense in large spaces with many users) was the installation of central thermostats. Overheating and the glare effect were usually a result of the improper or completely absent sunray protection measures.

Apart from the above, however, other inherent building features also affect the performance of the building. These include:

- the absence of insulation on the building envelope
- the deteriorating state of the flat roofs
- the single glazing that allows significant thermal losses
- the low levels of air tightness
- the obsolete condition of the radiators

It should be mentioned however that this survey was conducted when renovation works were still in progress, so the building was not at its final operational state. Additional measures and maintenance works had already been scheduled at the time. In any case, it does take some considerable time for the facilities of a recently renovated building to be adjusted to its users and reach optimum performance. Besides, the (re)design of the building and consequently the planned budget, were executed according to the initial intention of using the building for a 5 year period.

5.4.4 Energy use profile

The Faculty of Architecture currently gets its energy from the cogeneration plant of TU Delft – a 79MW power plant with two cogeneration units and three gas boilers for peak demand[22]. A cogeneration plant (Combined Heat and Power, CHP) captures the emitted heat from the electricity generation, thus allowing the simultaneous production of electricity and heat.

The following table shows the breakdown of the energy consumption for electricity and heating for the year 2009. Though the figures for the winter period are a rough estimation, due to the non-full occupancy of the building, the required energy of BK City is still comparable to the respective figures for an average academic institution in The Netherlands – *see table 11*. These figures, rather than a

[22] Annual gas consumption for the whole University is estimated at $11*10^6$ m^3 which result in a 21605 tons production of CO_2. The distribution temperature ratio is 130°C-supply/80°C-return (143).

reason for being complacent about the situation at BK City, should be treated as a cause for concern for the average academic Dutch institution, with regards to its wasteful use of resources.

Primary energy consumption per m^2 per year[23] (88)				
	MJ_{prim}		kg CO_2	
	BK City	Universities, HBO and MBO[24]	BK City	Universities, HBO and MBO
Electricity	478,50	486,00	33,41	33,08
Heating	413,51	451,00	23,20	25,30
Total	**892,01**	**937,00**	**56,61**	**58,38**

Table 11 Energy consumption and CO_2 emissions for BK City, 2009, compared to the equivalent average for academic institutions in The Netherlands (88)

Chart 9 shows the energy consumption breakdown per month for the case-study building (year 2009).

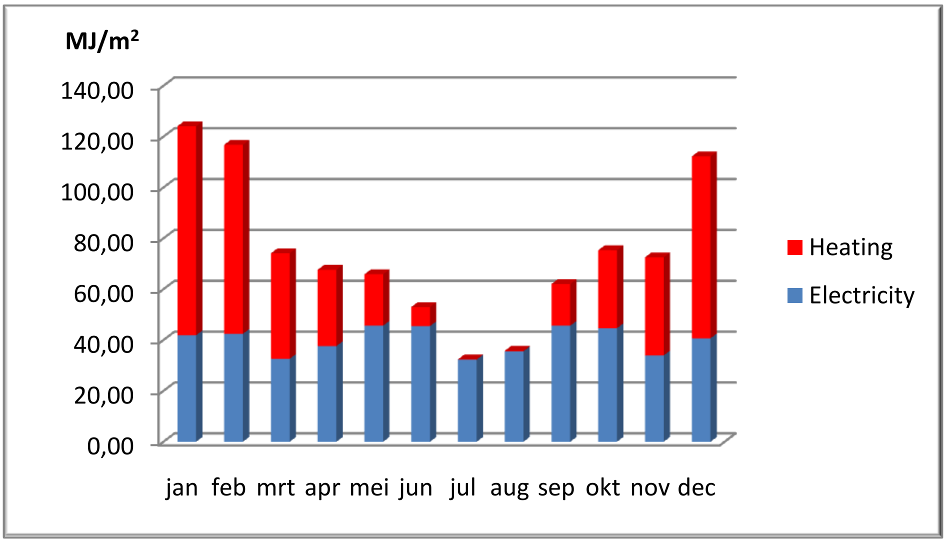


Chart 9 Energy consumption in BK City for year 2009, breakdown per month. Since May 2009 the two glasshouse extensions were added to the building

Finally, with current energy prices, the electricity bill for the year 2009 came to around € 320.000 while keeping the building warm cost another € 360.000

[23] The assumptions for the conversions are: 1KWh electricity = 8,55MJ_{prim} , corresponding to 0,582kg CO_2 , while for heating, 1MWh = 3600 MJ_{prim} , corresponding to 0,0561kg CO_2

[24] HBO stands for *Hoger beroepsonderwijs* i.e. 'higher applied education' while MBO stands for *Middelbaar beroepsonderwijs* i.e. 'middle-level applied education'

6 The refurbishment of BK City

6.1 A pallet of measures for BK City

In this section, a number of *selected* interventions applicable to BK City and other listed buildings will be discussed. This overview of generic measures is accompanied by case studies, along with the most important advantages and disadvantages of each one. The proposed measures range from traditional and widely used to more sophisticated ones, involving cutting-edge technology.

6.1.1 Basic building improvements

6.1.1.1 Post - insulation

Enhancing the insulation of a building can be applied to the exterior walls, the floor structure and/or the roof.

With regards to the *exterior walls* there are three possibilities:

- External wall insulation
- Internal wall insulation and
- Cavity wall insulation

The first option is not a possibility for BK City, so it will not be discussed. Table 12 summarizes the main advantages and disadvantages of the two other options (*see figure 26*).

	Internal wall insulation	Cavity wall insulation
Moisture/ condensation	Eliminates surface condensation Cold bridging at junctions (floor-walls) Interstitial condensation risk Condensation risk between insulation and wall Rainwater can enter through porous bricks Rising damp and rain water cannot dry easily	Increased risk for damp penetration Gaps in insulation favour condensation and mould
Temperature	Low temperatures within wall Thermal mass is isolated from internal gains (heat absorption & release will not take place)	Internal wall surface temperature is kept high
Air movement	Reduced infiltration Air flow behind internal insulation	Reduced infiltration
Applicability	Can be applied selectively to various parts of the building Practical limitations on thickness Difficult to apply around doors, windows and internal fittings	Imperfections and obstructions (wall ties, debris etc.) hinder the complete filling of the cavity
Aesthetics	Masks existing interior wall finishes	No effect
Cost	Cheaper than external	Relatively cheap
Maintenance	Easy access to treated surface	Very difficult
Other	Unaffected by weather Existing wall is not protected (from external environment)	Insulation might sink and settle under its own weight (compaction of fibres) Additional internal or external insulation might be needed The low temperature within the cavity might affect iron/steel ties

Table 12 Advantages and disadvantages of internal wall insulation and cavity wall insulation

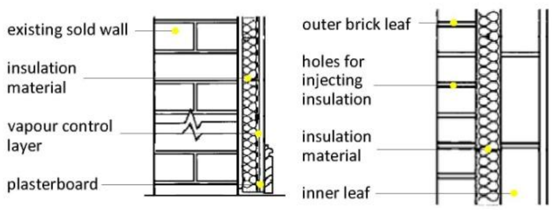


Figure 26 Internal (left) and cavity wall insulation (right)

Insulating the *floor structure* can be done in two ways, either on the underside (underfloor insulation) or on top of the existing structure (overfloor insulation) (*see figure 27*). The two possibilities are compared in table 13.

	Underfloor insulation	Overfloor insulation
Advantages	• Separate insulation in distinct rooms is possible • Appropriate for south facing rooms • Limited occurrence of overheating • Makes use of the thermal mass of the floor	• Floor heating can be applied • Immediate warming up/cooling down of the room
Disadvantages	• Thermal bridging risk • Excavating floor will be required • Basement ceiling will be a problem	• Thermal bridging (internal walls) • Current floor no longer in sight • Problems with doors

Table 13 Advantages and disadvantages of underfloor and overfloor insulation

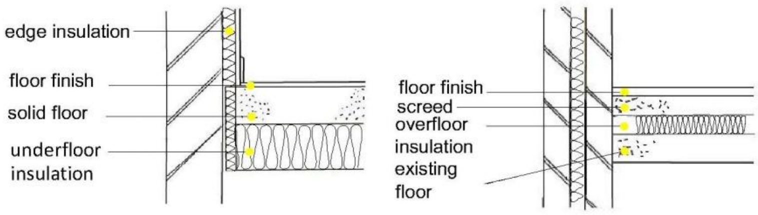


Figure 27 Underfloor (left) and overfloor insulation (right)

Finally, there are three types of *roof insulation*:

- between the rafters
- between and below rafters
- between and above rafters

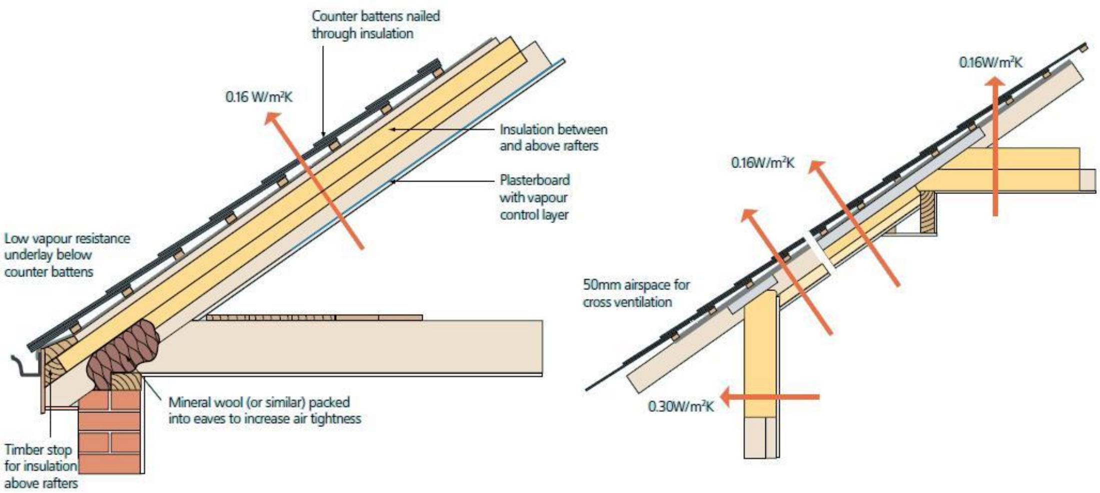


Figure 28 Between-and-above-rafters insulation and between-and-below-rafters insulation, as suggested by the Energy Saving Trust (123). Best practice U values are also shown

In the first case (between rafter insulation), the depth of the rafters might have to increase in order to accommodate thick insulation materials. It is the simplest way of insulating the roof, but entails a high cold bridge formation risk. This can be solved by applying the insulation material below the rafters too. However, in the case of an attic, this option might be restricted due to the (non)available height and the possible obstruction to door and window openings. Another constraint is the problematic installation of light fixtures on the ceiling. The last option (between and above rafters) requires the re-covering of the roof and is, thus, the most expensive, laborious and time consuming of all, however, it solves effectively all the above mentioned problems.

One of the most successful approaches towards energy refurbishment through the enhancement of the building envelope's insulation properties is the German so-called FAKTOR10 concept. FAKTOR10 stands for an up to 90% reduction in fuel consumption. The following table demonstrates the measures applied along with the savings achieved (93):

Level	Measures				
	Insulation			Glass	Ventilation
	Exterior wall	Basement	Roof		
EnEv[25]	12 cm	8 cm	16 cm	2-pane insulating glass	Without heat recovery
EnEv-30%[26]	16 cm	12 cm	20 cm	3-pane insulating glass	With heat recovery
EnEv-50%	20 cm	14 cm	30 cm	3-pane insulating glass	With heat recovery

Table 14 FAKTOR10 concept achievable results

There are many case studies where the FAKTOR10 methods have been applied. One that is relevant to the Thesis is the following German building, dating from 1885. By applying the EnEv-30% measures impressive results were achieved – *see table 15* (94).

Typology	Gründerzeit ('the Founder Epoch')	
Characteristics	sandstone facade with decorative elements	
Country	Germany	
Construction year	1885	
Volume	2.873m³	
Storeys	5	
	Prior to refurbishment	**After refurbishment**
Component	U value [W/m²K]	
Ext. wall	1,8	0,53
Ceiling	0,83	0,17
Ground floor	1,39	0,20
Windows	2,80	1,00
Savings	[kWh/(m²a)]	[kWh/(m²a)]
Annual heating requirement	164,5	29,2
Hot water	17,0	17,0
Yearly primary energy demand	254,1	53,1

Figure 29 The case study building

Table 15 Energy savings through insulation increase for a 1885 German building

In The Netherlands, a very interesting project is the refurbishment of the listed as a National Monument '*Latijnse School*' in Middelburg. This complex of buildings comprises of three parts dating

[25] The Energieeinsparverordnung (EnEV), or Energy Conservation Regulations, is Germany's energy efficiency building code. One of the most stringent codes in the world, the EnEV sets standards for insulation, fenestration, envelope, and HVAC.

[26] EnEV 30% corresponds to an annual primary energy and a transmission heat loss 30% under EnEV.

from the 14th century, 1879 and 1922. As the National Monument Committee imposed serious restrictions concerning the original elements (façade, part of the roof, the chimney, several openings etc.) the refurbishment measures were applied on the two more recent parts of the complex. The total energy consumption reduction, however, remains impressive.

The target set was to convert this monumental complex into a passive house (heating energy ≤15 kWh/m^2, total energy ≤ 120 kWh/m^2 per year) with mostly passive measures. The viability of the building relies today upon the airtightness and the high insulation values of the envelope, the function of the thermal mass, solar shading and night ventilation, while solar and internal gains are efficiently controlled.
Table 16 mentions the main measures taken for the '*Latijnse School*' complex refurbishment.

Component	Measure	Remarks
Garden side walls	240mm inside wooden frame insulation (hsb elements)	The gap between the original wall and the new frame is filled with mineral wool
Street facing facade	Outside surface insulation, 300mm polystyrene	The inside surface is covered with valuable tiles and had to remain intact
Windows	Inside window installation with triple glazing	Original windows are single glazed. In the cavity, between the new and the old frame, blinds are placed
Roof	Steel and hsb insulated elements	Some visible interventions were allowed, while the original (1879) zinc finished roof had to remain intact.
Chimney	Ceiling around the chimney is covered with 360mm glass wool	Chimney remains a cold bridge
Adjacent outdoor space	Creation of a sheltered/covered entrance to the building	

Table 16 '*Latijnse School*' complex in Middelburg refurbishment

These measures along with others (geothermal and solar energy) have resulted in highly energy efficient results (heating demands = 1.5 m^3 gas equivalents per m^2 per year = 13kWh/m^2/year) (95), (96), (97), (98), (99).

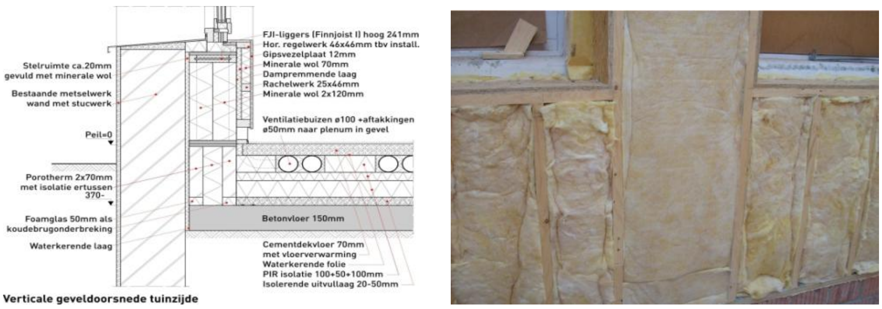


Figure 30 Details of the wooden framed inside wall insulation, '*Latijnse School*'

Figure 31 The steel structure for the roof support and the insulation elements, '*Latijnse School*'

Interesting innovative insulation practices are those used in the 'bio-ecological conversion' of buildings. When the one-century-old farmhouse '*Ferme du Bois-le-Comte*' in Antwerp, Belgium, was turned into the *Oost West Centrum*[27] it was decided that nature-inspired insulation materials would be used. In this context, the building was insulated with woodwool (shavings of timber) most commonly used in packaging and expanded clay granules (generally known as LECA) used in horticulture (100). Similarly, paper flakes and oriented strand board (OSB) for roof insulation, cork and paper flakes for wall insulation and recycled paper and flax straw for acoustic insulation were used in the renovation of a townhouse in Bruges, Belgium (101).

6.1.1.2 Window replacement

Insulating the envelope of the building involves, apart from the roof, the walls and the floor, dealing with the windows, too. The following diagram shows the possible alternatives for a listed building:

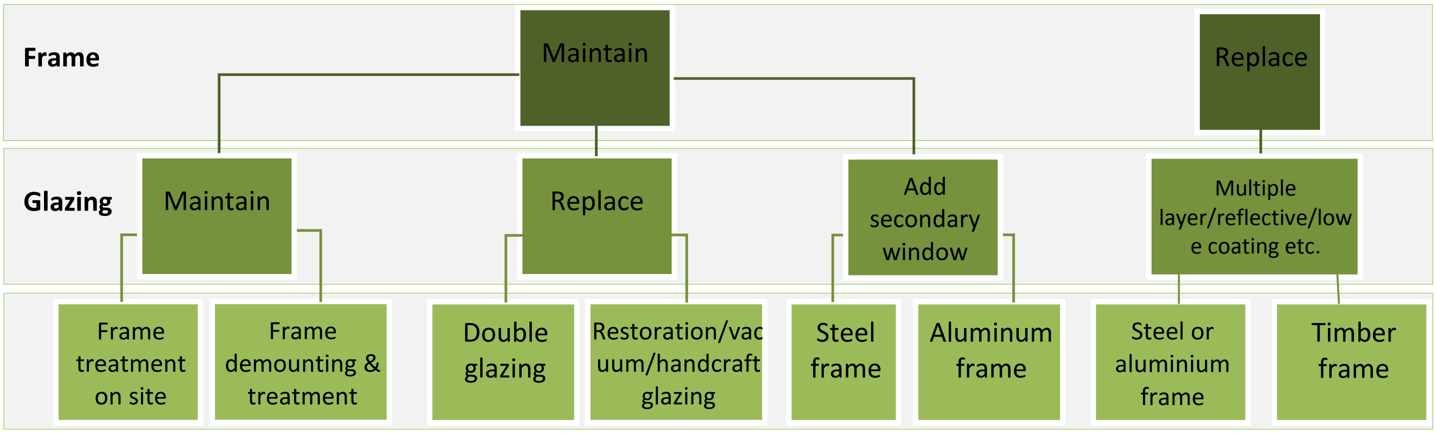
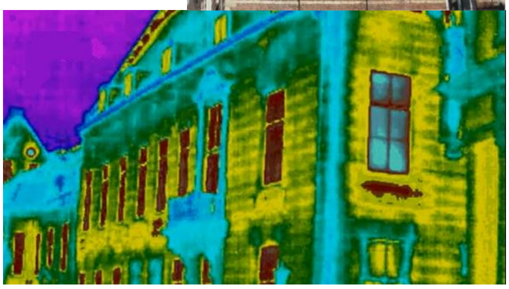


Figure 32 Alternatives for the treatment of windows in a listed building

Maintaining the window frames in a listed building will fulfill the aesthetic and historic considerations, but this will have an effect on issues such as energy performance, moisture resistance, security, acoustic performance etc. In addition, maintaining the glazing is, also, considered a sustainable choice as the existing material is not thrown away. In this case, treating the frame on the spot will be cheaper but not as efficient. On the other hand, replacing the glass with double/triple glazing might be hindered in case the frame profile is too narrow – there are however products for such situations, too (e.g. *Conforglace* by GRONA). Finally, adding a secondary window will cause some problems with the opening of existing pivot windows, while there is high risk of condensation for the exterior frames.

Figure 33 The elegance of the *Paushuize* in Utrecht is evident (left) and so is the deficiency of its thermal envelope (below)



If possible, the first choice should be to replace the old frames. In this way the standards of newly built structures can be met and the maintenance costs will be minimized. Steel frames are aesthetically superior and perform better in terms of fire safety, burglary and durability, they are however more expensive than aluminum ones.

Dealing with the windows in sustainable restoration is a very common task. The architects involved in the restoration of the '*Paushuize*' (literally the Pope's house, built in 1517), in Utrecht, had to overcome difficulties posed both by the monumental nature of

[27] The *Oost West Centrum* is an educational organization for '*natural living and transformation*'.

the building and various technical issues (*see figure 33*). The entire building had single glazed windows, whereas certain oak frames were equipped with 'safety glass', which is tempered glass that doesn't provide, however, any thermal protection.

On elevations where the existing frames could not be replaced and, thus, double glazing was not an option due to the narrow profile, the architects chose to install secondary windows (achterzetbeglazing). In this way, the achieved performance is similar to the double glass. In other areas, special restoration glass will be used, which, of course, is less efficient than the double glazing, but maintains the original visual impression of the façade. The cost for this type of glass proved to be relatively high due to specific color requirements.

Figure 34 The narrow profiled existing windows favor the option of installing secondary windows (above). When that is not possible (below), the plan is to use thick curtains to minimize heat losses. '*Paushuize*', Utrecht

The restoration architects were also concerned to equip the building with thick insulating curtains (also for acoustic reasons) and shutters. Shutters that were original were kept after some maintenance work. Finally, in order to attain the best results special attention was paid to the airtightness measures as the frames were provided with special removable strips. At some points cracks were left unsealed to enhance the natural ventilation of the spaces.

By applying a number of other energy saving measures, the '*Paushuize*' reached a DuMo index of 342, while the environmental costs were also significantly reduced (102), (103), (104).

6.1.2 Building services equipment upgrade/modernization

Upgrading outdated building services is the main pillar in most refurbishment projects. This might involve choosing an HVAC system between all-air, all-water systems or air-water systems. Some of these systems require centralized equipment, whereas others consist of local equipment.

Deploying modern heating technology is possible through choosing modern heat *supply* means. Low temperature equipment should be favored as it demands significantly smaller amounts of energy to adjust the indoor climate. This could entail replacing the existing radiators with a floor heating system or cooling ceiling panels etc. Surface heating systems are briefly examined in Table 17:

	Advantages	Disadvantages
Floor/wall/ceiling heating	• well combined with heat pumps • low temperature heating • cheaper to run than central heating using radiators (for 24hr use) • no visual impact • ideal for use with high efficiency condensing boilers	• lifting floor boards is required (floor heating) • clash with existing doors (floor heating) • require a large application surface • not suitable for rooms with great heights • efficiency depends on level of insulation • risk of thermally driven airflows (near cold walls, single glazed windows) • difficult to repair and maintain • floor covering might reduce its efficiency (slow response time)

Table 17 Advantages and disadvantages that surface heating systems offer

There exists, of course, a huge variety of heat supply systems, a mixture of which can be opted for an existing building. For example, in spaces with a need for local heat supply, as in study rooms, furniture heating can be used which is also ideal for areas with irregular use as it provides immediate comfort (*see case study at the end of the paragraph*).

Mechanical ventilation is also a consideration that offers certain advantages over natural means of fresh air provision (*see table 18*):

	Advantages	Disadvantages
Mechanical VS natural ventilation	• Better overall control • Heat recovery possible • Minimal ventilation heat losses • Security • Lower street noise levels	• Limited individual control • Higher initial cost • Higher running costs • Higher maintenance cost • Plant noise • Environmental impact

Table 18 Advantages and disadvantages of mechanical ventilation

Ventilation supply units should also be a field of investigation. In case of space unavailability smaller devices can be installed:

- Units that can be integrated into suspended ceilings or a double façade
- Units that can be integrated into the wall or into the wall insulation
- Units that can be integrated into the windows system
- Integrated devices into prefabricated roof construction

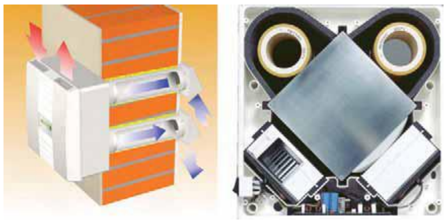


Figure 35 Section of decentralized ventilation units with heat recovery

An innovative application in the field of ventilation units is the so-called *breathing window* that has been developed by prof. Jon Kristinsson (*see figure 36*). This decentralized system provides preheated, through a heat exchanger, fresh air (50m^3 per hour for one unit) while polluted air is drawn out. The main advantage of the system is the ability to individually monitor each space where it is applied.

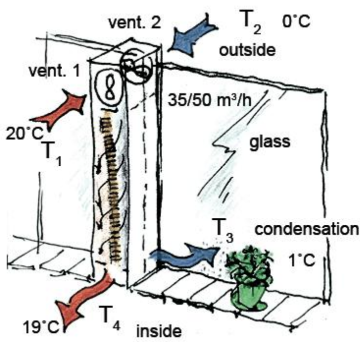


Figure 36 The breathing window which can be integrated in the building skin

Upgrading the HVAC installations of an old building is a complex task so alternative strategies can be sought. In Mannheim-Gartenstadt, Germany, a block of flats built in 1930 was refurbished in 2004 in order to transform it into a '3-litre house[28]' (105). The heated living area totals 1.150m^2 while the gross volume is 6.560m^3.

Figure 37 The '3 liter house' in Mannheim

The concept for the modernization of the building services was to deploy five different scenarios for the ventilation and heating of the flats, in order to compare the final results in terms of comfort and energy requirements. For the energy generation, a CHP unit was chosen that is connected to the grid and a storage tank for the excess heat produced, while a gas condensing boiler provides additional power to cover peak load needs.

The five different scenarios are briefly described below. The common characteristic in all of them is that fresh air is provided

[28] A '3-litre house' indicates an annual primary energy requirement for heating of 34 kWh/m² p.a., which is equivalent to 3 liters of heating oil/m^2/year

by a central unit placed at the top floor that allows for heat recovery, and a radiator placed in the bathroom.

	Heat & ventilation	Fresh air volume regulation	Temperature regulation	Temperature control	Performance
Variant 1	central unit	uniform in all levels	air heating	VTC	Overheating in upper floors, during heating period Long warm up time
Variant 2	central unit	uniform in all levels	air heating	distinct control in each level, through separate reheaters	Overheating in upper floors, during heating period Long warm up time
Variant 3	central unit	individual in each room	air heating	individual control in each room	High air quality
Variant 4	central unit	individual in each room	air heating + complementary room heating system	individual control in each room	High air quality
Variant 5	central unit	individual in each room	air heating + capillary tube mats, cooling also possible	individual control in each room	High air quality Lower temperatures achieved

Table 19 The five scenarios deployed in the '3 liter house'

A very useful outcome of this project was the importance of the user's practices. This was demonstrated clearly during summer when some flats without cooling equipment achieved indoor temperatures lower than the ones in flats with capillary tubes for cooling. Night ventilation along with the effective use of solar shades and the use of extraction fans helped reduce the overheating in the said flats. Automating these functions could be the solution for the entire building.

The cost for the HVAC technology was estimated at €370/m^2, while the capillary tube mats were covered by '*special technology subsidies*'. All of the refurbishment measures resulted in an impressive reduction of the source energy for heating and hot water from 389kWh/m^{2}a to 34kWh/m^{2}a.

Local heating systems and their use has been investigated in monumental buildings, such as the 15th century '*Rocca Pietore*' Gothic church in North Italy, the Amsterdam School '*Julianakerk*' in Dordrecht, The Netherlands, and others. A common feature of these buildings are the numerous sensitive items, often of very high value, that should be protected from excess moisture, shrinking, swelling, cracking etc. Examples of such items are wooden altars, mural paintings, sculptures, church organs and others. Additionally, these buildings usually require instantaneous warming when crowds enter, while, for the rest of the day, they have hardly any heating needs. This rapid heating might cause abrupt variations in the temperature and the relative humidity in the interior with condensation issues commonly arising. The proposed local heating system is mounted on pews and benches and it comprises of three radiant heating elements, one

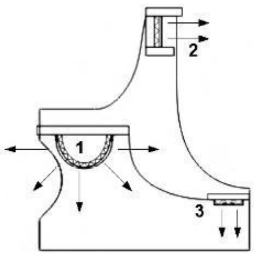


Figure 38 Seat heating element (1), hand heating element (2) and kneeler pad element (3) (left) and the '*Julianakerk*' bench heating system (right).

underneath the seat, one on the back of the seat (hand heater) and one below the kneeling pads (*see figure 38*). Instead of providing heat for the whole indoor area, this system radiates heat only where necessary and for much shorter periods of time, resulting in significant energy savings (106), (107), (108).

6.1.3 Redesigning

Redesigning an existing building as part of its refurbishment means:

- Changing its function
- Optimizing space use
- Altering the layout
- Creating climate zones
- Adding new spaces
- Creating buffer zones
- Demolishing existing wings of the building
- Adding/demolishing existing floors of the building etc.

Reasons for redesigning an existing building may vary. What is of interest here is when it serves the reduction of the energy use and the amelioration of indoor climate conditions.

Examples of such actions is the placing of secondary uses on northern sides, minimizing the heated surface area, managing the distribution of the internal heat loads, reusing blocked windows, reactivating lift shafts, gathering utility installations, minimizing transport heat losses through careful duct and pipe placement, adding an atrium to cover an open air space and so on.

In The Netherlands, the large number of historic churches, abandoned industrial buildings, castles and water towers makes the need for redesign very big.

A widely acclaimed project, along these lines, is the refurbishment of the '*Bussumse Watertoren*', a water tower in Bussum. The refurbishing team claims that this building is now the most sustainable in The Netherlands (due to the use of materials, the energy and water consumption). The '*Bussumse Watertoren'* complex (3.500m^2) consists of the water tower, dating from 1897, and an attached office pavilion. Through a diversity of measures (CHP, windmills, PVs, biomass heating, ground heat storage, making use of the thermal mass for cooling, using fry oil as a secondary fuel) the building obtains all of its energy in a CO_2 free way (109), (110).

Figure 39 The water tower and the newly built attachment, Bussum, The Netherlands

Another interesting reuse of space, that, also, demanded division into climate zones, is the '*Hermitage Amsterdam'* building. This historic building (17.000m^2) dates from 1683 and has gone through numerous conversions throughout its history. In 1979, it was turned into a nursing home until 2007 when it was re-transformed into a modern museum. The particularities of the said building that had to be taken into account during its refurbishment were the following (111), (112):

- The museum houses art collections that are brought from Russia. The exhibits are renewed every six years; flexibility is thus sought, both in terms of space usage but also of the conditions required (indoor temperature and relative humidity) for the preservation of the works.
- Comfort for the numerous visitors had to be ensured.
- As a museum, the security demands are very high.

- The low floor heights exclude the possibility of lowered ceilings and special floors had to be applied to maximize the elevation. As a result, climate installations can only be placed in the attic, while the distribution systems have to pass through thickened walls and beams

These parameters influenced significantly the decisions for the climate installations which at the same time had to contribute to the limitation of the energy consumption. The initial concept of displacement ventilation in combination with floor heating was rejected due to:

Figure 40 The *Hermitage museum*, Amsterdam, The Netherlands

- Height restrictions but, also, to protect the floor decking material.
- Calculations showed that such a heating system would cause the formation of cracks.
- The presence of people would create a 'pollution bubble' that would have to be extracted at the top part of the rooms. This is undesirable for the preservation of artwork that is placed at a high level on the walls.
- In order to avoid complaints by the visitors, the incoming air temperature could not be too low. The preservation of the art objects, however, demands a relatively low extraction temperature. This would result in a very small difference between supply and exhaust air with low cooling capability, requiring, thus, high ventilation rates and the resizing of the installation equipment.

After careful consideration and the appropriate simulations and test measurements, the design team opted for an induction ventilation system. Furthermore, as the building is divided into several spaces, according to their function, the requirement for low energy consumption and low operation costs implied the creation of climate zones. Three zones were defined, office rooms, exhibition halls and circulation areas with a high visitor concentration. A part of the air supply is re-circulated while the exhibition halls are equipped with filters (dust, chemical and electrostatic filters). The division is realized through the overpressure principle, doors with automatic door closers, and laminar air curtains. Finally, humidity and temperature controls are accomplished through a monitoring system and CO_2, temperature and moisture development detectors.

Creating an atrium in an existing building will add valuable usable floor space and, at the same time, will act as a buffer zone for the rest of the building. The '*Droogbak*', in Amsterdam, built in 1884 was declared a national monument in 2001. The conversion of this 10.000m^2 building into a modern office building had to fulfil all necessary indoor climate requirements while preserving its essential characteristics. As part of this plan the existing courtyard was covered with a glass roof in order to shelter a library, traffic areas and a waiting room. In this way all the offices facing the courtyard benefit from the abundant daylight, as the two sided laminated glass of the atrium is solar controlled. Underneath the courtyard a car park was built. In their attempt to preserve the existing infrastructure, the refurbishment designers decided to use the steam pipes and the old ducts for the new installations (air ducts, exhaust systems, cabling etc.) (113).

Figure 41 *The Droogbak*: the addition of the atrium has been done in such a way that the intervention is not visible from the main street.

6.1.4 Reducing electricity and energy consumption

Reducing electricity consumption can be done in various ways:

- Use of stand-by killers
- Replacement of equipment with energy efficient appliances
- Replacement of electrical equipment with alternative appliances
- Opting for energy efficient equipment
- Efficient lighting (optimizing daylight admission, maximizing internal light distribution, energy efficient artificial lighting). This will also decrease the internal loads.

For more rational energy and electricity consumption a good management and control system is also required. This can involve, among many other options:

- Building Energy Management System (BEMS)
- Automated control systems (thermostats programmed according to time, day, room etc.)
- Presence detectors (temperature, lighting, ventilation)
- Time programming (temperature, lighting, ventilation)
- Humidity sensors (temperature, ventilation)
- CO_2 sensors (temperature, ventilation)
- Air quality sensors (ventilation)
- Daylight sensors (lighting control)

The case study for this set of measures is the '*Jülich research laboratory*' in Jülich, Westfalen, Germany. The building, constructed in 1967 and refurbished in 2003, suffered from very high energy consumption, as is the case with many laboratory buildings (high ventilation rates needed and high consumption equipment). The refurbishment measures included the following:

- Optimized daylight use (light diverting louvers, daylight openings in corridor doors, skylights, interior color scheme, demolition of emergency exit balconies)
- Energy saving bulbs
- Demand oriented control (presence detectors, daylight sensors)
- Night ventilation (cooling demand reduction)
- Variable volume flow controllers in each room
- Time dependant ventilation (rate decrease during weekends)
- Presence detection for activating the ventilation system
- Energy saving speed controlled fans
- Air quality sensors in spaces with variable people presence

Figure 42 The Jülich research laboratory, Germany

The above measures resulted in more than 50% primary energy reduction. After the refurbishment the building consumed (primary energy) 39kW/m^{2}a for electricity, 29kW/m^{2}a for heating and 146kW/m^{2}a for cooling (114).

6.1.5 Other passive measures

The already mentioned post-insulation of a building, the window replacement and its redesign are all passive measures. In addition to these, one can distinguish a set of alterative measures that minimize the need for a traditional heating or cooling system:

- Natural ventilation (cross/stack ventilation, wind catchers, ground-coupled air systems, ceiling fans, exploitation of sun and wind pressure, shower towers)
- Evaporative cooling
- Night ventilation for passive cooling (in combination with thermal mass)

- Air tightness measures
- High efficiency glazing to optimize solar gain
- The use of trees for solar/wind protection
- Use of solar tubes
- Roof solutions (greenhouse roofs, living roofs)

The apparent advantages of passive measures are the low to zero costs (capital, running and maintenance costs) and the very low environmental impact.

Figure 44 Main façade of the renovated school, Sachsen, Germany

In Sachsen, Germany, during the sustainable refurbishment of an old school building (dating from 1928) there was an effort to provide fresh air with only natural means (115). Originally, the building relied for its ventilation needs on windows and exhaust air ducts integrated on the masonry facade, which were blocked during past renovation works.

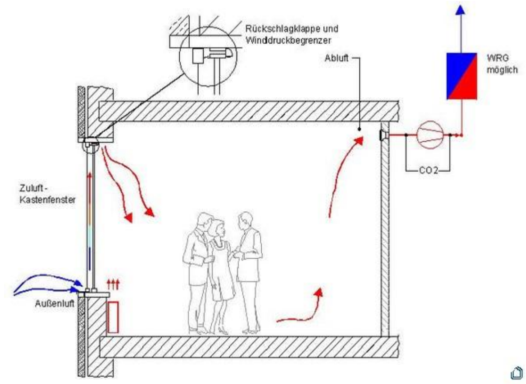


Figure 43 The natural ventilation principle, Sachsen, Germany

This inspired the new ventilation scheme. New double glazed windows were installed with thermal insulation glazing. Natural uplift with the help of fans drives the fresh air through an opening at the bottom part of the frame into the cavity between the glass panes, where it is naturally heated and then enters the space, through the top window frame. The height at which the air enters minimizes the risk of draught while wind pressure reducers prevent the undesired air currents. Additionally, temperature monitoring allows the increase of the incoming air volume by the opening of skylights in the inner panes. The old air ducts were also reactivated so that air is sucked out through natural uplift. In support of this, CO_2 sensors activate exhaust fans in case of large concentration of students. Sanitary spaces were the only ones where conventional exhaust air systems were installed with presence control. To avoid overheating during summer, night cooling is deployed in combination with the thermal mass of the building. The ventilation energy requirements were reduced by 83% after the refurbishment.

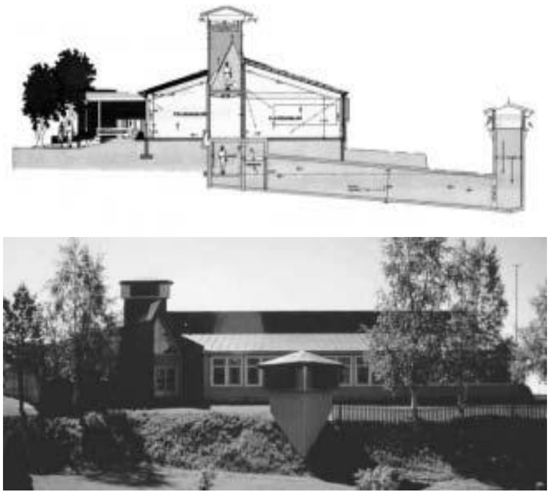


Figure 45 The natural ventilation principle (above) and the inlet and exhaust tower (below) in Mediå primary school, Norway

Another interesting concept for fresh air provision through natural means is demonstrated by the Mediå primary school in Grong, Norway (116). This one storey building is new (1997), but its system can be incorporated, with the necessary adjustments, in a refurbished building. Fans installed at the air inlets and outlets along with natural forces (buoyancy) conduct the air flow in a controlled manner.

An inlet tower is located a few meters away from the building. An underground air duct leads the fresh air to a distribution chamber which is located under the main spine of the building. From there, air is directed to the various school spaces. The air suppliers are embedded either in the walls on in the floor. The contaminated air leaves the building after being warmed up by the internal loads and is driven to an exhaust chamber and finally exits the building through the exhaust tower. Sound attenuators, CO_2 and temperature sensors, dampers, climate data systems, filters and mosquito nets complete this impressive ventilation scheme.

6.1.6 Water treatment strategy

A number of measures can be applied to the treatment of water, either waste water from the building, or rainwater treatment. These are summed up in the following list:

- Rainwater collection, recycling or infiltration
- Ecological water treatment through vegetation and microorganisms for non-potable uses
- Reuse of grey water
- Water consumption saving measures (water saving facilities)
- Solar collectors for heating the water and insulated hot water pipes

Rainwater harvesting requires the installation of suitable drains, special filters and tanks for the storage. Common uses of such water are toilet flushing, washing machines, cleaning, gardening etc. Dealing with rainwater can be an opportunity to improve the surrounding environment and biological diversity (increasing green surfaces, implementing green roofs etc.). Some key water saving measures can include:

- Use of water efficient fittings (flow regulation)
- Use of water efficient appliances (dishwashers, washing machines etc.)
- Individual metering of water consumption
- Raising user awareness

The water tower in Bussum, The Netherlands, is a good display case of water treatment. In the pursuit of 'extreme durability' the refurbishment engineers chose to purify the waste water through a 'constructed wetland'. The latter imitates the features of a natural wetland that removes sediments and pollutants from water in a natural way. The said building has no traditional sewage system, as a combination of plants, reeds and bacteria act as filters for the water cleaning, which is stored in a reservoir from which it is led back to the building for reuse (toilet flushing). In this way the claimed savings have reached an 80% reduction of drinking water consumption, while a connection to the main sewage system has also been avoided (along with the costs for such a connection). This system had never been applied on such a large scale prior to this project (109), (110).

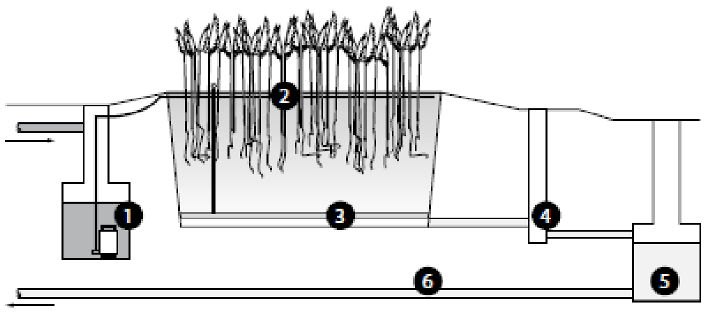


Figure 46 The principle of the constructed wetland, Bussum, Netherlands. Building wastewater (1), substrate filter (2), drainage pipes (3), control well, (4), water tank (5), return pipe (6)

6.1.7 Microgeneration[29]

The following table shows the main advantages and disadvantages of some selected forms of microgeneration.

	Environmental impact	Reliability	Installation	Operation	Maintenance	Space requirements	Publicity
Solar energy (PVs and Solar thermal collectors)	Pollution free	Weather dependant	High initial capital	Low operating costs	Low requirements	High	High public acceptance
Small wind turbines	Pollution free	Weather dependant	High initial capital	Low operating costs	Costly	Relatively small	Uncertain
Heat pumps	Low emissions	Constant Back-up heating system typically required	High initial capital	Requires electrical energy	Laborious & costly	Unobtrusive Storage tanks required	Limited market potential (invisible)
Biomass boilers	High NO_X, CO_2 emissions	Depends on fuel availability	High initial cost	Wood more expensive than gas	Frequent	Large storage areas required	High public acceptance
Gas turbine CHP	CO_2 emissions Pollutants during fuel cycle	Heating & electricity demand must coincide	High initial cost	High fuel cost	Costly	Small plant size	Unknown
High efficiency gas fired boilers	Greenhouse emissions	Efficiencies up to 95% are possible	High initial cost	High fuel cost	Higher costs compared to tr. Boilers	Relatively small	Moderate
Piezo-electricity	Pollution free	Dependant on human presence & kinetic energy	High initial cost	Low operating costs	Frequent	High	High public acceptance

Table 20 Comparison of selected microgeneration alternatives

Apart from the above technologies, innovation in energy generation has brought about applications such as energy generating revolving door, energy generating floors, thermo-ionic generators etc.

Figure 47 *The Renewable Energy House*, Brussels, Belgium

An impressive showcase of integrating sustainable energy resources in refurbishment is the '*Renewable Energy House*' in Brussels (117). Built in 1870, this listed office building houses the Headquarters of the European renewable energy sector, with a total surface area of 2.800m^2. The target set for the refurbishment scheme was to minimize the energy consumption for heating, ventilation and air conditioning while covering the energy needs of the entire building by, mostly, renewable resources. For achieving this target, the building was equipped with the following:

- Biomass boilers
- Solar thermal collectors (evacuated tube and flat plate collectors)
- A geothermal heating and cooling system (loops, 115 m deep, exploited by a ground source heat pump)
- A thermally-driven absorption cooling machine
- A cooling tower
- Electricity production with PV

[29] Microgeneration is the term used to describe the small-scale heat and power generation in an environmentally friendly manner. Typically it includes solar thermal heating, photovoltaic cells, wind turbines, micro-hydro, micro-combined heat and power (CHP), heat pumps, biomass boilers and fuel cells.

The following diagram shows the summer cooling and the winter heating circuit:

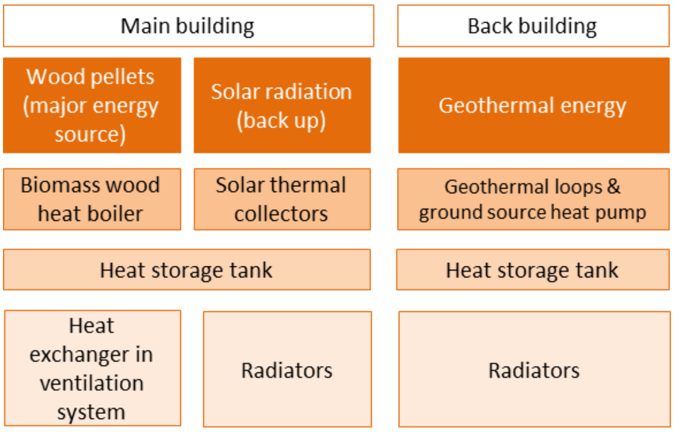


Figure 49 The heating system of the Renewable Energy House

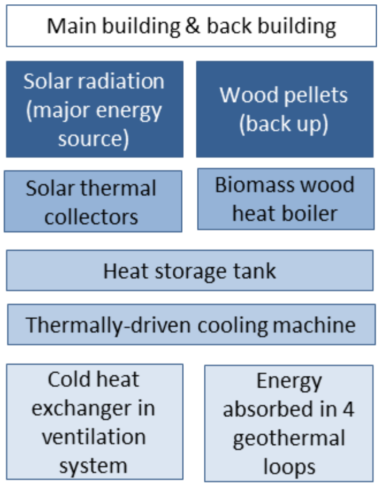


Figure 48 The cooling system of the Renewable Energy House

To supplement the above, the building met all of its electricity needs by buying renewable energy from external plants in Belgium (a mix of wind, bioenergy, CHP and small hydro plants). The results were encouraging. The building reduced its energy requirements impressively, while 100% of them are met by sustainable resources.

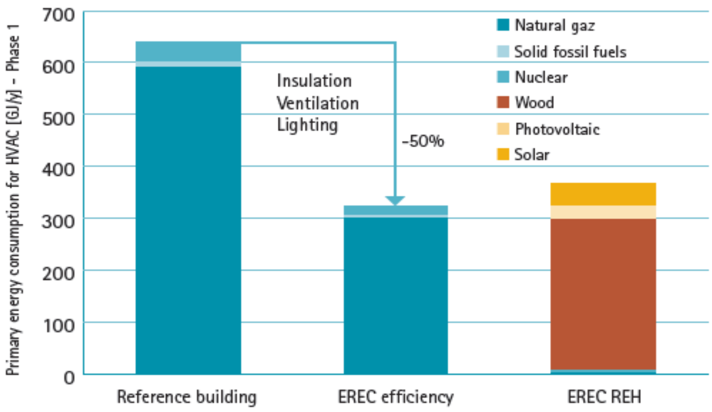


Figure 51 The efficiency of the 'Renewable Energy House' and the breakdown of its energy resources

Figure 50 Solar Thermal collectors front façade, 'Renewable Energy House', Brussels

6.1.8 Energy storage/reuse energy flows

Reuse of waste energy flows is a concept that is gradually gaining publicity and acceptance. Buildings generate energy that is simply dumped in the environment, whereas it could be more effectively used. Ways to do this in an existing building are:

- Energy storage (thermal, electrical, electrochemical, chemical, thermal mass)
- Heat recovery systems
- Combining functions and energy systems in a large building (heat and cold exchange)
- Smart building energy interconnection

Figure 52 The ‘Stopera’ building (118)

Figure 53 The warm and cold wells of the ‘Stopera’

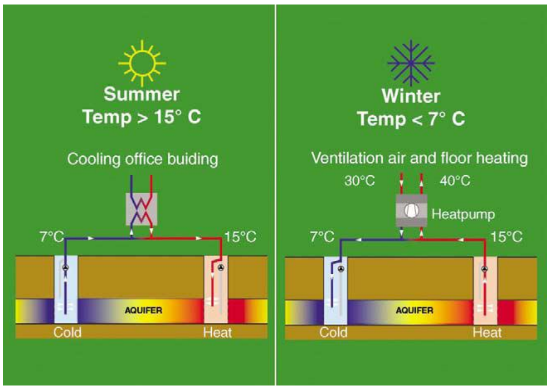


Figure 54 The principle of the Aquifer Thermal Energy Storage (ATES),TUE, Netherlands (119)

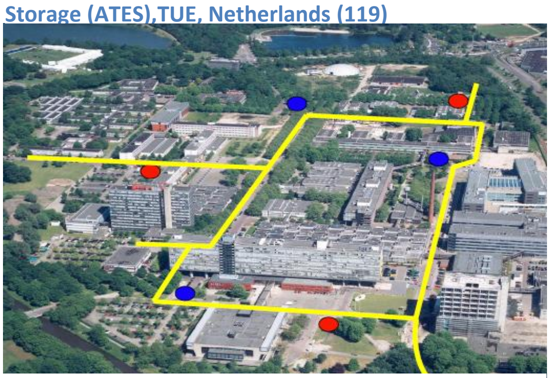


Figure 55 Heat and cold transport piping at the TUE campus, the Netherlands

Figure 56 Climate plaster on capillary mat tube, Office Building, Berlin

The barriers to the above mentioned concepts and technologies are usually the high costs and the long payback times, as well as various practical hindrances for listed buildings.

The ‘*Stopera*’, in Amsterdam, is an example of how an existing building (completed in 1986) can be retrofitted with a thermal energy storage system. Indeed, in 2002, an aquifer system was put into use in order to provide the building with cooling. During the winter months the aquifer retains the cold water which is extracted during the cooling period. The cold water, after circulating inside the building (so it becomes warm) is re-injected back into the ground (the system serves only the cold storage) (118).

An entire University campus in The Netherlands was equipped in 1998 with a highly energy efficient heat storage system. The old buildings of the Technological University of Eindhoven proved to be excessive gas consumers while the faculties were expanding at great rates in terms of number of students. This huge heat and cold storage system consists of 32 wells (16 cold, 16 warm, at 25-80m below ground level) and provides 15GWh heating/year and 13,5GWh cooling/year and has resulted in a 59% primary energy consumption saving (electricity annual savings 2.600MWh and $1{,}2*10^6 m^3$ natural gas) while CO_2 emissions have been reduced by 2.800 tones (119), (120).

The scheme of the aquifer function is shown in figure 54. In the first place, heat is extracted from the buildings during summer months and is then stored in the aquifers. In the winter period this heat is re-used to provide the necessary heating for the campus and is then directed to the cold aquifers.

Finally, the use of Phase Change Materials in building refurbishment was tested in a 1921 office building in Berlin, Germany. Microencapsulated PCM was integrated in the ceiling structure along with the plastering layer which covers the cooling capillary tube mats. After monitoring the spaces with the 4cm thick ‘climate plaster’ it was found that 2°C lower temperatures were achieved during summer periods compared to spaces with conventional ceiling gypsum plaster (121).

6.2 Refurbishment Strategies for BK City

6.2.1 Strategy I: Basic but Cheap

This package of interventions includes actions that are considered as *basic* in a refurbishment scheme, i.e. are commonly applied, have well established efficiency, do not require huge capital investment and are highly reversible, while the disturbance level is kept very low. In general, they constitute a necessary set of interventions, that bear the minimum risk but no extreme results should be expected.

6.2.1.1 Thermal skin

In order to reduce the heated space, the basement will be placed outside the thermal skin. Basement rooms that are frequently used should be insulated separately. Additionally, and to keep the amount of works at a low level (Strategy I includes only the essential interventions), the attic will stay as it is, i.e. non-insulated. In this case it can serve as a storage room or, alternatively, it can house the climate installations. Naturally, the second floor ceiling will have to be carefully insulated with new material in order to reduce the huge heat losses.

6.2.1.2 Insulation of exterior façade, ground floor and roof

The need to maintain the original exterior facade of the building excludes the possibility of applying external insulation on the walls. In this way, the building keeps its original appearance, the use of the materials is still visible and the numerous decorations are not hidden.

Figure 57 The cavity wall of BK City.

Insulating the cavity walls seems to be the most appropriate option. In locations where cavity wall insulation is not sufficient, internal wall insulation should be sought as an alternative or a combination of the two. Careful investigation of the conditions of the exterior walls should be carried out prior to any work. On both the external and internal leaf, cracks should be carefully inspected and sealed. The cavity itself should be continuous; if, for example, bricks have been used as wall ties, or stones and debris are keeping the cavity unclear, the wall won't be appropriate for filling.

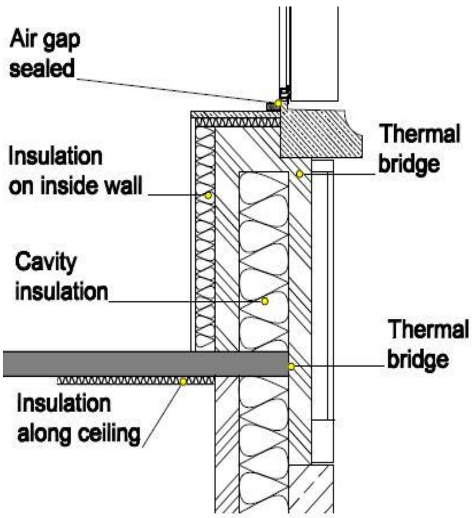


Figure 58 Occurrence of thermal bridges and ways to deal with them

A variety of materials exist (blown mineral wool, beads and granules, Urea-formaldehyde (UF) foam, polyurethane foam, polystyrene etc.) each of which has its own specifications and installation technique. In our case, blown mineral wool (λ=0,035W/m*K) is chosen that is suitable for walls up to 12 meters high (122). Mineral wool is relatively cheap, but, it should be carefully examined whether the walls are watertight or not. Walls highly exposed to wind driven rain are susceptible to mould formation due to the penetrating rain water from the outer leaf, which will gradually lead to the obsolescence of the insulation.

The width of the cavity has been estimated at 10cm which should allow the achievement of a U value of 0,50W/m^{2}K, which is close to the best practice target set by the 'Energy Saving Trust' (123). When the cavity filling has been completed it should be checked that the quantity used was comparable to that previously estimated. To this extent, infrared thermography will help in detecting possible gaps, as will visual inspection.

As mentioned previously, the basement is excluded from the thermal skin, so it should be insulated. As no floor heating system is chosen in this variant, the basement ceiling will be insulated from the underside. In this case, it should be verified that the reduced basement floor height does not obstruct its function – vacuum insulation panels (λ=0,01 W/m*K, d=2cm) provide a solution to such a problem. This way we also make use of the thermal mass of the floor, while the basement areas will be instantaneously warmed up.

Finally, the attic floor will have to be reinsulated in locations where the currently existing (assumed) rock wool insulation is obsolete (*see figure 59*). The part of the stone slate roof covering the second floor has been assumed to be insulated (between the rafters) so the only improvement would be to eliminate the thermal bridges. To achieve that, a continuous layer of phenolic foam (PF) insulation will be set extending across the underside of the rafters. To minimize the risk of condensation, a ventilation gap must be left above the insulation material and below the stone slates (*figure 60)*. Table 21 shows the U values prior and after the refurbishment.

Figure 59 The existing rock wool insulation of the attic floor

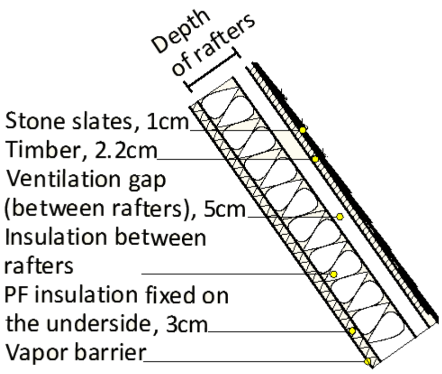


Figure 60 Suggested between-and-below-rafter insulation of the roof

element	U value [W/m^2*K] prior to refurbishment	after the refurbishment
facade	1,17	0,28
ground floor	2,46	1,02
2nd floor ceiling (attic floor)	0,64 (obsolete material)	0,64
2nd floor slate roof	1,06 (thermal bridges)	0,41

Table 21 U values before and after the insulation measures

6.2.1.3 Window strategy and airtightness

The prime concern, when dealing with the openings in the facade, is to preserve the current window layout as much as possible. Steel framed windows add to the style and elegance of BK City and their application is becoming rarer as years go by. Maintaining them also fits with the 'minimum investment' that Strategy I aims at.

Excluding the possibility of replacing the frames, leaves us with three alternative actions. Maintaining the single glazing, which does not fulfill any requirements (thermal losses, security and sound insulation), replacing the single glass with a double one which is not possible due to the slim profile and the large size of the glass surfaces, and, finally, installing a secondary window (achterzetbeglazing). The secondary window will insulate the window area as a whole (frame and glass) so the existing frames do not need extra treatment.

Compared to the other alternatives the latter seems to be the most suitable. However, condensation problems might occur on the glass surfaces and cleaning will become a troublesome issue. The suggested solutions for minimizing the condensation risk are discussed in the next paragraphs.

The first possibility would be to allow *indoor air* to enter the cavity between the existing window and the secondary window. However, this would introduce warm and moist air (internal loads, people etc.) and, as a result, condensation would form on the colder single glass. This would, also, cause significant heat losses to the outdoor environment.

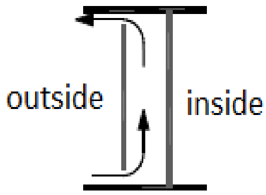


Figure 61 Proposed ventilation in order to eliminate the condensation risk on the outside glass

The alternative configuration is to allow *outside air* penetrate the cavity (*see figure 61*). In this way, the outside air is warmed up inside the cavity and the relative humidity will drop. As a consequence, the secondary glass will be cooled down and condensation might occur, this time on the inner glass surface (if the glass temperature falls below the dew point), as the incoming air, at the bottom of the cavity, has the same temperature as outside air. The chances, however, for this are as high as for a normal single glazing, so the success of the proposed measure depends on the type of glass used for the secondary window – in this case double glass.

In cases where secondary windows obstruct the opening of pivot windows and therefore cannot be installed, thick curtains can be applied to act as a thermal barrier (in this case removing and repairing the frames is advised). The curtains will, mainly, block the draughts, so they will act as a supplement to the sealing of the frames, but they should, under no circumstances, block radiators. The degree of insulation provided by the curtains depends on the achieved level of air entrapment between the window and the curtain. The Chartered Institution of Building Services Engineers (CIBSE) proposes the following correction of the thermal transmittance of a window for the effect of curtains or blinds (124):

$U_{wb}' = [(1/U_w) + R_{bi}]^{-1}$,

where U_{wb}' [W/m^{2}K] is the thermal transmittance of the window corrected for an internal blind or curtain, U_w [W/m^{2}K] is the thermal transmittance of the window and R_{bi} is the thermal resistance of the internal blind or wall [m^{2}K/W] (*see table 22*).

Description	Thermal resistance [m^{2}K/W]
conventional roller blind, curtain or venetian blind	0,05
closely fitting curtain with pelmet	0,07
roller blind	
- **bottom only sealed**	0,09
- **fully sealed**	0,18

Table 22 Thermal resistance of blinds and curtains (124)

The main argument against the use of curtains is the resulting blocking of natural daylight. However, the curtains will have an important impact, even if they are used exclusively during afternoon and night hours – raising the awareness of users becomes very important here. Alternatively, the use of internal shutters could be investigated, e.g. shutters that allow sunlight to enter from the top part, but block the rest of the opening.

Figure 62 The existing double glass timber framed windows

The timber framed windows (*figure 62*), as we have seen, are a different case as there is much bigger flexibility in their replacement. From a variety of available materials for the new frames, a combination of aluminium and timber is opted for, in order to combine the strengths of both materials (wood, a natural renewable resource, offers a high thermal performance but lacks durability). Composite aluminium-clad softwood cores are a relatively new development, with an expected lifetime over 40 years and a high level performance. The options for high performance glass are numerous (double, triple, low emissivity, micro-double-glazing etc). The choice for Strategy I is a low-e glass that can reach a U value of 1,5W/m^2*K (125).

Table 23 shows the U values achieved after the refurbishment.

element	U value [W/m²*K] prior to refurbishment	after the refurbishment
steel frame windows with secondary window	5,9	3,0 (124)
steel frame windows with curtain	5,9	4,5 (124)
timber frame windows	3,5	1,8

Table 23 U values before and after the insulation measures – the effect of the frames has been taken into account

All the above measures should be followed by a serious effort to seal the leaky elements, as the infiltration rate in the existing building is very high. The efficiency of the heating and ventilating strategy depends, to a large extent, on the airtightness of the building - *'Build tight - ventilate right'*. The attained level should be comparable to that of a new building, i.e. $0,25h^{-1}$ from $1h^{-1}$ which is the assumption for the current situation. The key points that need special attention are (126):

- Joints around components, e.g. doors and windows
- Voids between elements, e.g. wall to floor boundary
- Installations and services passing through the building elements
- Building materials that are permeable (lightweight blockwork)

Common materials used for refurbishment applications are (127):

- Gun applied sealants, including mastics, polyurethane and silicone sealants
- Expanding foam sealants
- Gaskets for movement joints
- Draught stripping
- Sealing fibre and
- Membranes/films.

6.2.1.4 Existing CHP plant for energy generation

Currently TU Delft generates its energy from a central cogeneration plant. In 2008, due to the ageing of the engines and as part of the national Long-term Universities Agreement (MJA 2), it was decided to replace them with new ones, '*ideally dimensioned*', that will provide a higher electrical output. As the gas CHP plant is expected to last at least for the next twenty years, it is sensible to keep it as the main energy supplier for BK City too (128).

6.2.1.5 Heating and cooling

One of the most common measures, in refurbishment schemes, is the installation of a floor heating system. In BK City, such an installation is hindered by various factors. Firstly, by keeping the radiator heating system we achieve maximum use of the existing material and infrastructure, which is in accordance with the sustainability statement that this project aims at. Where outdated, new efficient radiators should be installed. Second, the efficiency of such systems (underfloor heating) is questionable when applied in spaces with large heights, as are most spaces of the faculty. Furthermore, the installation of a floor heating system will require the placement of the insulation on the top side of the floor, to achieve maximum effectiveness. It becomes obvious that the increased floor thickness will have an impact on the levels in stairwell areas and the internal door head heights. Finally, we should take into consideration that the simultaneous placement of insulation and floor heating will be a highly disruptive process, and it is doubtful whether the University can accommodate it – BK City is not used for only 1-2 months per year, which means that students and staff might have to de-camp for a certain period of time.

With this proposal, the radiators can receive the necessary hot water from the CHP unit.

As for cooling, it is advisable to try and avoid mechanical cooling. Besides, the measurements carried out till now have shown that heating is mostly needed, while cooling is compensated for by the mass of the building. The effectiveness of the thermal mass of floors and walls, in compensating for overheating, presupposes that all surfaces are exposed. Improving the cooling of the building during summer can be achieved through night ventilation.

6.2.1.6 Ventilation concept

Currently, the building has a mechanical ventilation system for most of its spaces. Considering the numerous complaints, with regards to air quality and the problematic opening of windows, Strategy I includes:

- Control of incoming air temperature
- Mechanical exhaust
- The use of waste heat to preheat the incoming air (heat recovery) via heat exchangers
- Admitting cool night air into the building, to purge daytime heat

With the above measures it is expected that the indoor climate level will rise. Firstly, by adjusting the air temperature (currently constant supply at 20°C), overheating and unnecessary expenses will be reduced. Mechanical air extraction will ensure that air is constantly renewed, while the combination with a heat recovery system is indispensable due to the airtightness measures. Besides, the efficiency of an MVHR unit can be as high as 95%.

Overheating has been identified as a frequent annoyance. By including a night ventilation scheme and activating the existing building mass during summer, the temperature of the building is expected to drop considerably, by as much as 3-4°C (129). Despite the large volume of the building, the relatively low equipment gains (an upper limit of 40W/m^2 is, usually, considered for effective night time ventilation), the low occupancy levels during the warm months and the expected working patterns render night cooling a very good solution. The monumental character of the building, along with security reasons, do not allow the operation of windows or grills to serve the night cooling strategy, so air will be drawn inside the building and exhausted, using the ducts for mechanical ventilation. In support of these, the glasshouses can be incorporated into the system by leaving the roof openings open at night. If natural forces are not considered adequate, the effect of night cooling can be enhanced by switching on the air extraction fans to increase the ventilation rate. Finally, a controlling system should be foreseen that will be connected to sensors and a weather station.

The above are expected to increase the electricity consumption, but in this way mechanical cooling during the day will be avoided.

6.2.1.7 Energy saving through electric equipment

Energy efficient lighting and appliances should always form part of a refurbishment package, as they affect not only the electricity consumption but, also, the internal gains, resulting in lower cooling needs. The simplicity and efficiency of this measure is an additional benefit.

For the artificial lighting in BK City the following suggestions are made:

- Careful design of the artificial light policy (e.g. providing separate control for fixtures close to windows and projection screens, low level background wall light for office spaces, directing light where it is needed, etc.)
- Use of LED lamps[30]

[30] LED lamps contain no contaminants such as mercury or phosphor (as opposed to compact fluorescent lamps) and can be safely disposed of or recycled. Their high initial cost is counterbalanced by their long lifetime (around 50.000 hours) compared to CFLs (10.000hrs) and halogens (3.000hrs) (146)

- Maximum use of dedicated fittings[31]
- For the exterior lighting, energy efficient lamps (efficacy greater than 40lm/W) with daylight sensors or timers should be used

The savings from this policy can be very high. For example, the mere replacement of an incandescent lamp of 120W with a CFL one of 23W will result in a €12 annual saving (130).

Apart from the luminaires, the same attention is required for the selection of appliances, such as printers, fax machines, copiers, scanners, screens, audio/video etc. There are several organizations that provide a labeling scheme for the energy efficiency of products and also recommend products with proven efficiency (for example the Energy Saving Trust in the UK or the Energy Star international standard in the USA). The savings potential can be increased by encouraging users to adapt their behavior and by enabling automatic power management (i.e. whereby an unattended appliance turns itself off). For example the potential saving of one single computer that is turned off at night and is accordingly configured will amount 91KWh per year (131).

6.2.1.8 Controls

In addition to the above, the installation of a building energy management system will prevent both unnecessary expenditures but will also reduce the environmental impact of the building. The proposed monitoring and controlling systems are:

- Artificial and natural light
  - Photocells dimming controls (artificial lighting is turned off or dimmed according to daylight levels). Several sensors, carefully located will ensure the optimum correspondence to natural light levels. Time delays should be incorporated to avoid excessive switching.
  - Infra red *absence* detectors. This approach relies on manual switching-on whereas turning-off is automatic when no occupants are detected for a certain period. Time delays should be incorporated to avoid excessive switching.
  - Shading control when solar radiation exceeds an upper threshold (e.g. 125W/m^2).
- Radiators
  - Thermostatic controls in spaces shared by a large number of people and centrally controlled thermostats for the corridors.
- Mechanical ventilation
  - Air quality sensors in lecture rooms with variable use during the day.

The use of IC technology and telemonitoring will guarantee the smooth operation of the system. The regularity in the occupancy patterns of BK City allows the integration of a time program, so that during the night (after 22:00), weekends and university vacations, all lights are turned off, ventilation rates are at low levels and the temperature set point can fall.

It is extremely important to ensure that the users of the building are informed about the controlling strategy and that manual overriding is always available. For this reason, the manual controls should be located at a visible spot and be simple to use. *Local* overrides of the time programming should also be available to allow work outside usual office hours. In this way, the numerous complaints regarding the control of the temperature, shading and artificial lighting operation will be tackled.

6.2.1.9 Water saving measures

Only the essential measures will be included in Strategy I for the water policy, which, in this case, are the installation of water efficient fittings with flow regulation for the restrooms and water efficient

[31] Dedicated fittings (luminaires) are those that will only take low energy lamps. Building regulations in parts of the UK now require a minimum number of dedicated fittings to be installed (123)

equipment for the kitchen of the faculty restaurant. Additionally, point-of-use hot water should be provided. Savings from this action should be expected during holidays when demand is significantly lower and hot water demand is restricted to cleaning purposes. Low power (e.g. 3KW) electric heaters should be placed above or below the sinks and access to them should be provided only to the cleaning staff and the building janitor.

An additional action, simple and cheap, is a water-saving campaign to increase awareness among students and staff.

6.2.1.10 Synopsis

An overview of Strategy I and the proposed measures is provided in the following image. The measures have been classified as in *§6.1 A pallet of measures for BK City*.

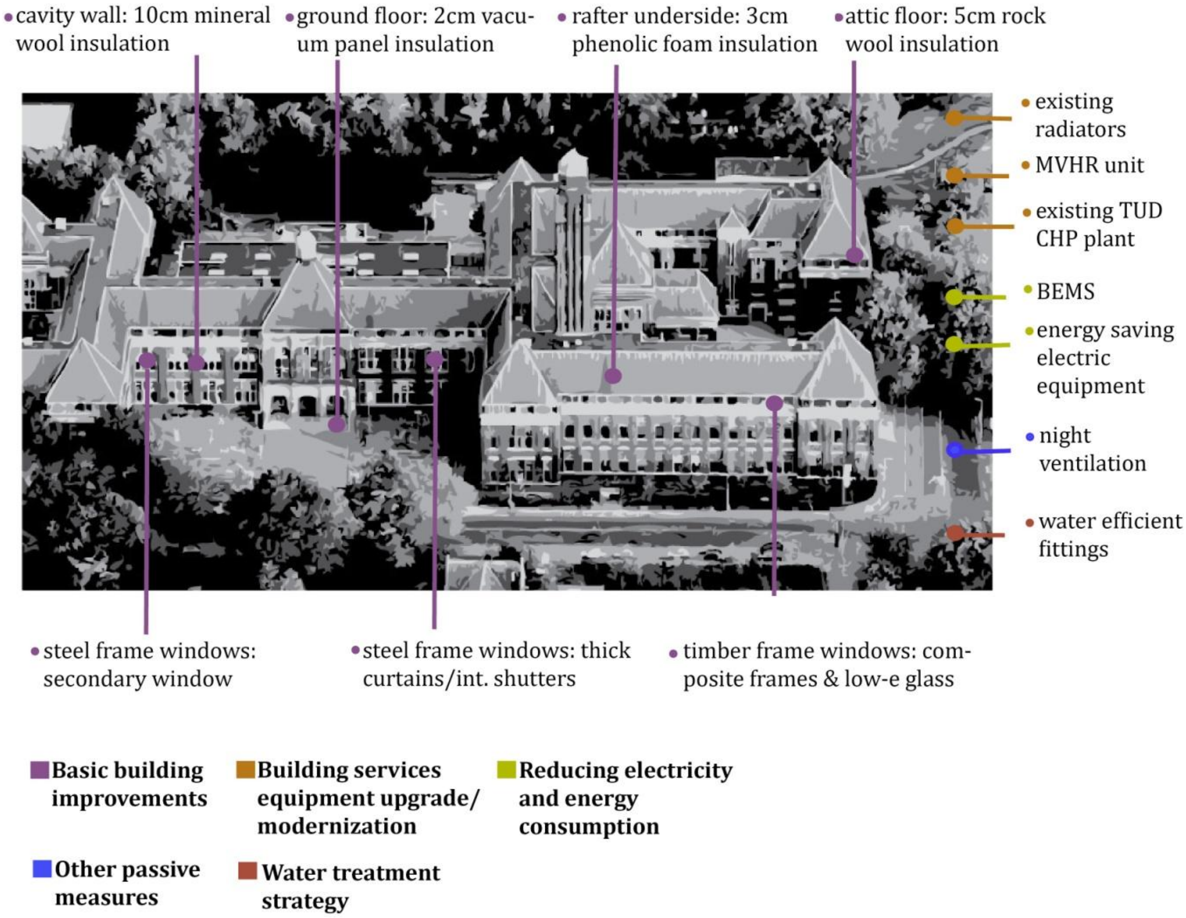


Figure 63 Overview of Strategy I

6.2.2 Strategy II: Ambitious but feasible

Compared to Strategy I, this package of measures includes somewhat more complex solutions. The required expenses, workmanship and installation time are greater, but the anticipated outcome is more ambitious, as are the risks involved. However, an effort has been made to keep all proposals to a realistic and accomplishable level.

6.2.2.1 Converting the attic into a student area

In addition to the proposals of Strategy I, Strategy II takes into account the need for extra floor space that the Faculty currently lacks, around 10.000m^2. The attic seems to offer an excellent alternative for providing this space, as it covers in total an area of 6.500m^2. In light of this opportunity, bachelor student workspaces could be located here, as well as silent study rooms and meeting areas.

The conversion of a 'cold roof'[32] into a 'warm' one requires careful planning. It is, amongst other things, most probable that planning permits, electrical, plumbing and mechanical permits as well as listed building approvals will have to be obtained.

In order to meet the building regulations' specifications for a living space certain requirements need to be fulfilled:

- Structural issues (can the floor carry the additional live and dead loads?)
- Adding new windows may require additional structural actions to ensure that wind loads are resisted
- The floor height must be above a lower limit, at least for a percentage of the total floor area (for example 2m in the US (dictated by regulations) or 2.3m in the UK (as a recommendation) for at least half of the floor area). In The Netherlands, the usable area (*gebruiksoppervlakte*) has to be at least 1.5m high, whereas living areas (*verblijfsgebied*) requirements are 2.6m floor height. Additional requirements may be valid for the attic height at the edge of stairs for fire safety reasons (in the UK this is 1.8m).
- More requirements might involve stair specifications (tread width, riser height etc.), door sizes (emergency doors), window dimensions etc.

Currently the attic of BK has no means of ventilation or access to daylight. For this reason, and after the approval of the Municipality authorities, the attic will be provided with skylights.

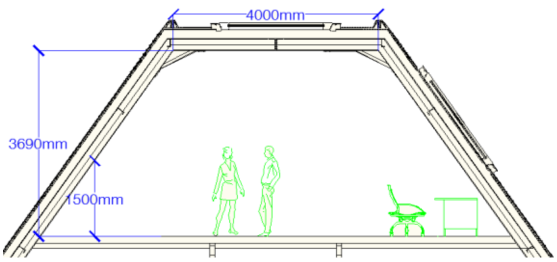


Figure 64 The interior of the attic as is today (left) and the space configuration for the conversion (below)

The creation of a warm space in the attic entails its appropriate insulation, without compromising the conservation of the stone slate roof covering that is of historic interest. When internal space is at a premium, it is not advisable to insulate below the rafters. Above rafter insulation ('sarking insulation') will not only save space but guarantees as well the optimum thermal performance, minimizing thermal bridges – by applying a compound insulation board – and also protecting the timber roof structure from condensation. The

[32] The term 'cold roof' is used to describe the unheated pitched roof area when the insulation is placed at the ceiling of the top-most floor

main drawbacks of this choice are, first, the higher costs for re-roofing and providing the necessary scaffolding and, second, the raising of the roof line by a few centimeters.

From the two possibilities that were examined, the first was to lay non-structural beams over the existing structure to create a rafter system (up to 300-400mm insulation can be incorporated). This was rejected due to the excessive overall roof height.

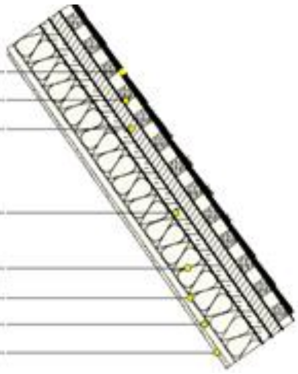


Figure 65 Suggested between-and-above-rafter insulation of the roof

The alternative to this is placing insulation boards between and above the rafters (*as seen in figure 65*). The *'Pavatex'* board is a sustainable non-toxic material, made of wood fibers pulped and mixed with water resulting in a very good λ value of 0.04 W/m*K (132). Sheep wool insulation has an even better thermal performance, λ value 0.039 W/m*K (133), and is a natural and renewable, not toxic material. Both materials are 'breathing' in the sense that they absorb and release moisture freely (vapor permeable), without jeopardizing the insulating performance. In this way, vapor control is not necessary and a mere airtight layer will suffice. This quality of the roof structure is in accordance with the spirit of the original design of the roof that allowed the abundant ventilation in order to keep the moisture levels of the timber low.

element	U value [W/m^2*K] prior to refurbishment	after the refurbishment
slate roof	3,11	0,35

Table 24 U value for the stone slate roof before and after Strategy II

In any case, a point that will need careful attention is the eave and the link between the cavity wall insulation and the roof insulation so that no thermal bridges occur that cancel the function of the insulation.

6.2.2.2 Window strategy and airtightness

Strategy II examines a different scenario for the windows. The steel frames will be maintained as in Strategy I but this time the single glazing will be replaced with a more energy efficient solution. Due to the small profiles of the existing frames the examined alternatives were restricted (*see table 25*).

The choice made from the various alternatives is the vacuum insulating glass that performs very well in terms of thermal insulation and sound insulation (U=1,4W/m^{2}K, RW=30 dB). The thermal performance of the total window surface depends largely on the frames which, according to this Strategy, will not be replaced. After so many years of exposure, however, the frames have deteriorated and are in need of serious treatment. In terms of longevity and durability disassembling and treating the frames at the factory is the wiser option, even though this will cost much more than treating

glass brand name	thickness [mm]	U-value [W/m^2*K]
Van Ruysdael insulating+ (134)	3,8	3,7
Van Ruysdael insulating+ sun reflective (134)	5,8	4,1
Van Ruysdael HPI (vaccum) (134)	6,2	1,4
Van Ruysdael insulating++ ultra thin (134)	5,8	3,5
Van Ruysdael handcraft (extra distortions) (134)	6,9	3,4
Allwin Glassique (135)	4	3,8
Allwin vacuum (135)	6,2	1,4
Stolker Monuglas (136)	9	3,1
Slimlite Double Glazed Units (137)	10	2,1
Conforglace built-in elements (138)	15	2
Spacia (vaccum) (139)	6,2	1,4
Dörr (140)	10	1,9

Table 25 The examined glass alternatives for the steel frames, Strategy II

the affected parts on site – besides, the lower future maintenance costs will in time compensate for this higher initial expense. Repairs typically include cleaning, roughening and recoating the surface, replacing the lower sill, replacing the hinges and the latches, filling scratches with special paints etc.

element	U value [W/m²*K] prior to refurbishment	after the refurbishment
steel frame windows	5,9	2,5 (91)
timber frame windows	3,5	1,5

Table 26 U values for the windows after the refurbishment, Strategy II – the effect of the frames has been taken in account

As in Strategy I, the timber frames will be entirely replaced by composite aluminium-timber frames, with the additional installation of high efficiency glass, such as the Pilkington Activ™ with an argon filled cavity that can reach a U value of 1,2W/m^{2}K (141).

6.2.2.3 Ground source heat pumps and biomass boilers

The main energy source for both the heating and cooling needs of BK City will be earth energy, i.e. solar energy that is stored in the ground. Among the various types of earth connection systems, the selected variant here is a ground-coupled heat pump (GCHP) that will use soil as a heat source and sink, with the use of horizontal ground heat exchangers (GHXs).

Some inherent characteristics of BK City make the use of a GCHP system a more attractive choice compared to conventional heating/cooling systems:

- The requirement for both heating and cooling that would need two separate conventional systems, whereas a GHCP can serve both purposes
- The all year round operation of the system, that will result in high energy savings, compared for example to an air conditioning unit solely used for the cooling season and a gas boiler for the heating season
- The use of the attic as a studio area will take up a large space, so conventional plants could not be installed there, whereas a heat pump needs significantly less floor area
- BK City as a leading educational institution will welcome an innovative scheme even if it requires a longer pay back time

The alternatives for an earth connection system were either a vertical borehole system or a horizontal arrangement of heat exchangers. Geothermal energy, i.e. energy from great depths, has been the object of investigation for the TU Delft area, initiated by Delft University students. The results, still at a research level, show that, at a depth of ca. 2300m, water can be produced of around 75-80°C (142), (143). Despite the promising investigations, Strategy II aims at a more realistic plan that can be directly implemented. In this sense, the horizontal configuration was chosen which in addition is cheaper, though it requires a larger surface area. To minimize the surface area needed, 'slinky coils[33]' will be used. These are a variation of common horizontal loops, as they consist of overlapping circular heat exchangers in order to save volume and surface area.

The size of BK City favors the use of *multiple heat pump units,* located around the building. This configuration is favorable, as it simplifies the local control of the indoor climate but, also, allows the simultaneous heating and cooling of separate zones. For example, separate heat pumps can be placed on each orientation in order to deal with the solar radiation variations.

The heat pump system is electrically driven, which is its only environmental impact. During winter, fluid (an antifreeze solution as temperatures often fall below 0°C) that has been warmed up due to the soil is transferred to the evaporator, which functions as a heat exchanger. The evaporator contains a cooler refrigerant that absorbs the heat and consequently evaporates. The refrigerant is subsequently driven into a compressor that raises the pressure of the gas and, so, its temperature

[33] 'Slinky' or 'spiral' is the term used instead of the scientific term 'curtate cycloid'.

and pushes it to the condenser (heat exchanger) where the warm and high pressure refrigerant vapor gives off its heat to the water (water-to-water heat pump) and becomes liquid again. This water will then be used to warm up the building – a floor heating system is elaborated in §*6.2.2.5 Underfloor heating and cooling*. Meanwhile, the refrigerant continues towards the expansion valve that causes a sudden fall in pressure and, consequently, in temperature. The cool liquid refrigerant is driven to the evaporator to repeat the cycle once again (closed loop). Typically, heat pumps will deliver an output temperature of maximum 50/55°C (144), but to keep the efficiency high the delivered temperature should be kept as low as possible – in this case 40-45°C.

The slinky coils have to be placed in trenches around 1,5-3m deep where the temperature is stable all year round (9°C for The Netherlands). The depth depends on the soil characteristics (temperature difference between circulating fluid and ground, soil thermal properties and moisture, possible water movement at the site) and the design of the system. The minimum distance between adjacent trenches is 3m (144), (145).

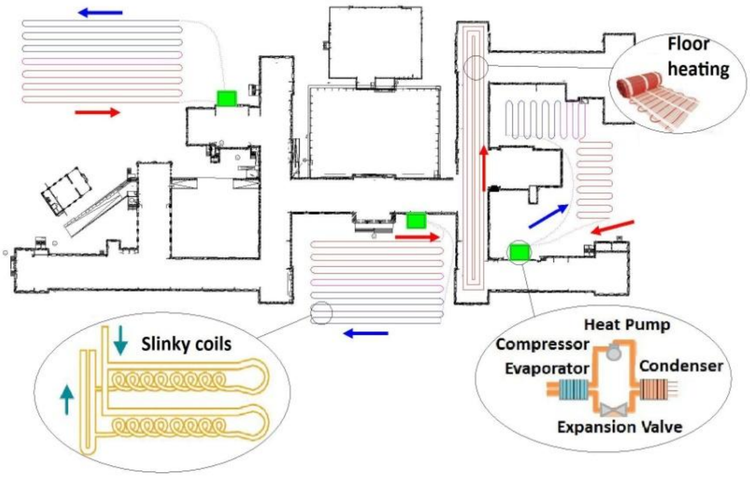


Figure 66 The ground-source heat pump system scheme (in the figure the heating mode is shown).

The horizontal loop system will be sized according to the maximum heating capacity and not the cooling one – which is substantially larger –, in order to decrease the total investment cost of the earth connection, which amounts to 30-50% of the total system costs (144). The dimensioning of the coil lengths requires complex calculations (special software exists), but the British National Green Specification (GreenSpec) gives an estimation of 1kW of heating load per 10m long trench laid slinky coil (146). A rough calculation shows that, with a full exploitation of the free courts of BK City, a heat load of around 450kW can be provided.

The total heating demands of BK City are (currently) around 3.800MWh. This results, roughly, in an hourly demand of 880kW (180 heating days). Consequently, the ground pump will not be sufficient, under current circumstances, and additional means have to be sought (also for covering peak heating loads). For this reason, a biomass[34] burner will be used, that will operate complementary to the soil heating. Biomass burning is considered a 'carbon neutral'[35] fuel, though one has to take into account the impact during the production cycle (fertilizers, pesticides etc.), the collection and, most of all, the transportation of the harvested fuel. However, it provides a good means for establishing waste streams (domestic and municipal waste, agricultural waste etc.) and has a relatively small payback time (3-5 years for Europe (147)).

The main issues that have to be dealt with in the application of biomass burning in BK City are:

- The low penetration of the biomass technology in the Dutch market (148)
- Large storage areas are required due to the large heating capacity of the boiler
- Locally produced appropriate fuel has to be sought

[34] '*Biomass refers to a fuel that is produced by* ***organic*** *means*.' (146)

[35] Provided the amount of biomass that is burnt equals the annual growth of the remaining biomass

The choice of the biomass fuel depends on various factors. Table 27 gives an idea of the biomass fuel availability in The Netherlands:

Type of biomass	Biomass Availability in The Netherlands Availability [Kton/year]	Energy content [GJ/ton]	Bio-energy content [PJ/year]	€/GJ supplied
wood blocks	500	10,2	5,1	1
wood chips	540	10,2	5,5	1,8
saw dust (fine wood particles)	270	15,6	4,2	0
wood pellets	100	17,5	1,8	5,2
cereal	0	17	-	7
grass hay	140	12,7	1,8	6
hemp, flax	5	11,3	-	0,5
vegetable oil	4	38	-	18,6
rape straw	15	13,6	-	3
peels	100	16,5	1,7	4,8
bio-oil, frying fat	60	38	2,3	5,3
bio-oil, fatty acid	60	38	2,3	2
residues from meat processing industry	50	22	1,1	0
animal fat	200	25	5	6
organic household waste (GFT)	2280	3,4	7,8	-9,1
rubbish/litter	6800	9	27,5	-12
chicken manure	1000	6,6	6,6	0
pig manure	15000	-	-	-
paper/plastic pellets	1400	18	18,9	0,6
paper sludge	1000	1,6	1,6	0

Table 27 Biomass availability in the Netherlands (205)

The most commonly used fuel is derived from wood (wood chips, wood pellets or logs). For BK City wood pellets can be used that are suitable for medium scale operations (10kW – 1000kW). However, the quality of the available pellets has to be considered, as the variations depending on the source can be significant (146). Although sources of wood pellets in The Netherlands are scarce (the production capacity for the whole country is 130.000tonnes (148)), a transportation distance of around 40km permits the fuel to be considered CO_2 neutral (147). The main producers of pellets can be found relatively close to Delft, *Energy Pellets BV* in Moerdijk and *Plospan Bioenergy BV* in Waardenburg.

An important factor to be taken into account is the need for large storage spaces for the pellets. The specifications for the pellet storage room are the following:

- Dry storage conditions throughout the year should be guaranteed
- The loads for the enclosing walls should be calculated for a density of ~650kg/m^3 (a 10cm concrete wall or 17.5cm brick wall is usually sufficient)
- Crumbling and abrasion of the walls should not occur, so that pellets rest uncontaminated
- Careful sealing of door and openings so that dust does not enter adjacent rooms
- Electrical installations should be removed from the room (switches, lights etc.) (149)

Figure 67 Configuration of the wood pellet storage room

Recommendations for the sizing of the storage area suggest that the room should be able to accommodate the annual pellet requirements. In BK City, such large spaces (0,9m^3 space per kW heating load[36]) are impossible to be found, except for the basement, in which case low moisture level conditions should be provided.

For the needs of BK City, large capacity boilers or a combination of small scale ones is appropriate. *Schmid AG* (Switzerland, Germany and France) provides for example the *Lignumat UTSL* (up to 150kW). Other major boiler exporters can be found in Austria, where an 80% of biomass boiler applications use wood pellets (146), (150).

It should be mentioned here, that there has been serious opposition to the use of wood pellets as, despite the (questionable) low CO_2 burden in the atmosphere, their burning makes inefficient use of the available exergy[37] and may also contribute to the increase of forest cutting. Currently, most Dutch companies, including *Energy Pellets BV*, produce their pellets from fresh wood[38] from Germany[39] – Germany is also one of the main final pellet destinations. However, this could be solved by using waste wood, the poor condition of which, or its contamination, might render the recovering process for other end-uses too expensive. In this way, valuable landfill space can also be preserved. Waste wood sources include wood waste from construction sites, demolition waste, wood processing residues (residential and commercial), park and orchard maintenance waste (tree stumps, branches etc.) and others. Even straw and grass residues have been identified by researchers as a promising energy generation basis in the Dutch market. Table 28 gives an overview of the available wood and green waste in The Netherlands (151), (152), (153), (154).

Material	Amount [*1000 ton/yr]	Heating value [GJ/ton]
demolition wood	200-275	16
palletwood	400	16
green waste	1.000	4,8
red wood dust/shavings	100	16
public garden waste	250	10-16
residual wood	45	16
bark[40]	50	16
grass residues	600	8
thinnings[41]	500	13-16

Table 28 Estimated availability of wood and green waste in the Netherlands (151)

The breakthrough made in the production of biofuels from waste wood by two TU Delft researchers is worth mentioning. *Frank Koopman* and *Nick Wierckx* discovered that the bacterium *Cupriavidus basilensis* can decompose the hazardous by-products of the wood being processed into biofuels. This will potentially reduce both the costs and the environmental impact of the treatment methods (155).

Alternatively, the use of bio-gas could be explored, sources of which can be food waste, sewage and farm waste. In the UK, *green gas* provided from the anaerobic digestion of food waste has already been explored and applied (156), (157). In any case, the use of the boiler should be limited to periods when it is absolutely necessary.

Finally, the cooling demand of the building will be covered by the heat pump that can reverse its function (the evaporator becomes the condenser and vice versa) and provide an underfloor system with the necessary cool water. A thermally driven cooling machine was also considered as a possibility, but was rejected, as it would require the constant operation of the biomass boiler.

[36] 1 m^3 pellets ≈ 650 kg Energy content ≈ 5 kWh/kg or 18 MJ/kg
[37] Exergy is the '*maximum work potential of energy*', and is an indicator of the energy quality (212)
[38] The raw material is not always 100% fresh wood (mixing with waste wood reduces the production cost)
[39] Sweden, Canada, Finland, as well as some Eastern European countries (Poland, Estonia and Lithuania), are the other key players in the pellet market
[40] Outer covering of a tree
[41] Seedlings, trees, or fruit which have been thinned out to improve the growth of those remaining

6.2.2.4 Converting the water tower in an energy storage tank

The difficult-to-predict and unregulated heat production by the heat pump and the biomass boiler requires a means of storage to balance the fluctuations in the heating/cooling demand and to top up peak load conditions. Available means for heat storage include:

- Water tanks
- Phase Change Energy storage devices
- Molten salt storage
- Ground storage
- Hot bricks

In BK City, the water tower, serving only decorative purposes at the moment, seems ideal for the purpose. The biomass boiler will heat the accumulator which will store heat for a certain period, till it is needed in the building. The inherent properties of water make it a very good storing medium, as it is cheap, abundant, non toxic and has a high specific heat capacity (4,187kJ/kg*K). Additionally, water is convenient both as a transfer medium and as a heating medium for underfloor heating (*see §6.2.2.5 Underfloor heating and cooling*).

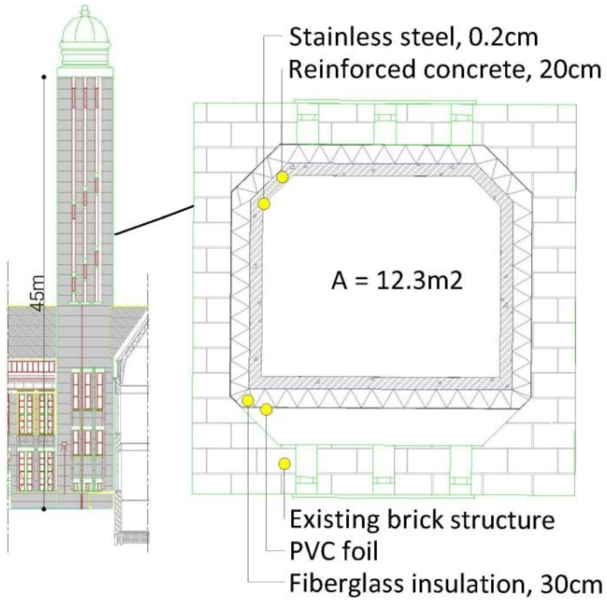


Figure 68 Elevation of the water tower as is today and a typical section showing the necessary interventions to transform it into a storage tank

Several interventions have to be made to transform the tower for energy storage purposes – figure 68 shows a proposed section of the water tower.

The heat storage unit will be designed as a reinforced concrete tank. The walls of the tank need to be insulated with 30cm insulation (i.e. fiber glass) on the outer side of the concrete wall, while the interior will be covered with stainless steel to prevent vapour diffusion through the concrete wall and ensure water tightness. Other proposed materials for the tank are high density concrete or glass fiber reinforced plastics (158).

Among other things, the tank will be equipped with heat exchangers, temperature regulators, temperature-pressure relief valves etc. In front of the tank, the necessary space is left empty to allow for maintenance and repair works.

It is preferable to locate the energy sources as close as possible to the water tower, to minimize pipework and transportation losses. Charging of heat will be done at the top while discharging at the bottom. A common problem of water tanks is the stratification within the tank during charging and discharging. To deal with this, first a CFD simulation has to be carried out and, if necessary, a third device between charge and discharge can be introduced to facilitate stratification, allow low temperature heat charging and also enable concurrent charging and discharging.

In order to calculate the density of energy we will use the formula:

$Q_D = c_P * \rho * \Delta T$, where c_P is the heat capacity of water, ρ is the density of water and ΔT is the temperature difference of the water at storage level and the final use temperature. With an average ΔT=40°C the energy density in the tank reaches 50-60kWh/m^3 (158), (159).

The storage capacity of the water tank is estimated at 33MWh (volume of the water tank $V=12{,}3m^2*45m=550m^3$) while the current energy demands for BK City are around 3.800MWh. Consequently, only a short term storage can be expected, e.g. per week, and not inter-seasonal.

6.2.2.5 Underfloor heating and cooling

The high operating temperatures of the existing radiators render them unsuitable for a low energy consumption refurbishment project and should, therefore, be replaced with an alternative distribution system. The following table shows the delivery temperatures of various heating systems (144).

Distribution System	Delivery temperature °C
underfloor heating	30-45
low temperature radiators	45-55
conventional radiators	60-90
air	30-50

Table 29 Typical delivery temperatures for various heating distribution systems

The importance of choosing a low temperature heating system is even bigger when considering the efficiency of the heat pumps: the lower the difference between source and delivery temperature the higher the coefficient of performance of the pumps. Additionally, such a system in combination with the high insulation level of the Faculty will result in a lower pay back time.

For Strategy II, underfloor heating/cooling is chosen. The operation of the underfloor heating is based on the distribution of warm/cold water in a network of pipes (plastic, composite plastic or aluminium, usually 15mm diameter) that is integrated into the floor structure. One of the main disadvantages of this system is the low response heating that it offers. Eliminating this delay can be accomplished by:

- Placing the floor insulation above the concrete slab
- Installing a floating floor above the heating loops instead of placing the pipes within a concrete screed
- Choosing large surface areas for applying the system
- Choosing large diameter pipes and placing them close to each other, in order to increase the heat emitting surface
- Carefully selecting the floor finishing (stone, tiles and slate transmit heat more effectively)
- Avoiding the use of carpets and rugs that obstruct the heat flow

Figure 69 The Intercell heating system

With regards to the above mentioned drawback of underfloor heating, an interesting development in such systems is the demountable *Intercell® Underfloor Heating (see figure 69).* This system allows the placement of the heating pipes between a cell structure, on top of which is a thin steel plate that functions as a radiator (various floor coverings are available). The manufacturers claim that this system reduces significantly the response time, while the high level of flexibility allows for future space use alterations (160).

The heat output [W/m^2] of the underfloor heating system can be calculated with the following formula (161):

$$\phi = 8{,}92(t_f - t_i)^{1,1}$$

where t_f the average floor temperature and t_i the room temperature. Table 30 shows the desired floor temperatures for various materials (barefoot occupants) (161). The limitations on desired surface temperatures lead to a maximum heat output of around 90W/m^2 – for a room temperature of 20°C (suspended timber floors have a maximum of 70W/m^2) .

Material	Surface temperature range [°C]
Textiles	21 – 28
Pine wood	21,5 – 28
Oakwood	24,5 – 28
Hard thermoplastic	24 – 28
Concrete	26 – 28

Table 30 Comfortable temperatures for barefoot occupants for typical floor structures

The same hydronic floor system will be used for cooling purposes, too. The limitations on cooling capacity are the following (162):

- to prevent condensation the floor temperature has to be kept in the range of 17°C - 20°C (for a RH~60-70%)

- comfort issues (acceptable vertical air temperature, floor temperature, radiant asymmetry) dictate a minimum floor temperature of 18.5°C
- international standards recommend a floor temperature interval of 18℃/19℃ to 29℃ (for seated and/or standing people wearing normal shoes)

Keeping in mind the above limitations, the maximum cooling capacity is less than 50W/m^2. For BK City, due to the large glazed surfaces that allow the solar radiation to reach the floor surface, higher values should be expected. The condensation risk can be reduced by using dehumidification which will allow the denser placing of the pipes. In any case, researchers recommend dimensioning the floor system according to the heating needs and then get the most possible cooling out of it (163).

In conclusion, figure 70 and table 31 show schematically the proposed interventions for Strategy II, with regards to the heating and cooling provisions for BK City.

	BK CITY heating and cooling circuit		
	Heating mode		Cooling mode
energy source	soil heat energy	biofuels	soil heat energy
conversion	slinky coils & ground source heat pumps (max. 450kW)	biomass boilers	slinky coils & ground source heat pumps (max. 450kW)
storage	water tower (33MWh capacity)		
use	floor heating (max. output 90W/m^2)		floor cooling (max. Output 50W/m^2)

Table 31 Heating and cooling circuit in BK City

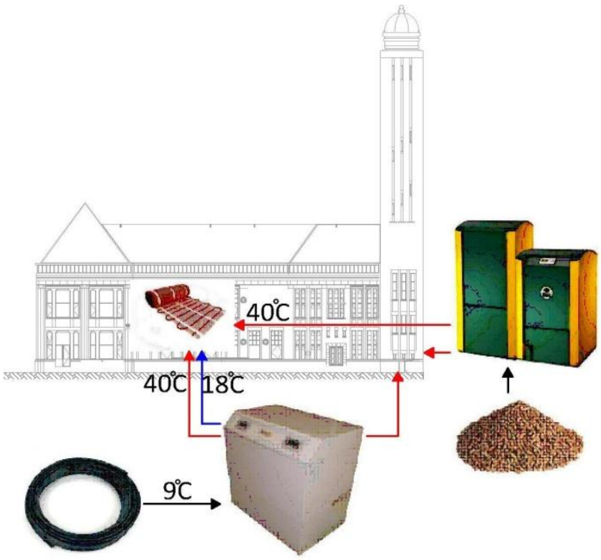


Figure 70 Energy generation, conversion and distribution in BK City

6.2.2.6 Opportunities for adaptive temperature limits

Installing the underfloor heating system is an opportunity to alter the set temperatures and adapt them to the time of the year, day of the week, hour of the day, provided the new setting doesn't significantly affect the indoor comfort. For example, enforcing a night setback, with a set temperature of 16°C, will pause the operation of the heat pumps and the boiler and result in significant savings. The same can be done during weekends and university holidays.

Similar actions should, also, be considered during normal working hours of the Faculty. Research in The Netherlands has clearly demonstrated the significance of the adaptive user behaviour in the desired and tolerable indoor temperature. Higher operative temperatures are accepted when the outdoor temperature is also high, resulting in a more flexible range of (perceived as) comfortable temperatures (164), (165).

In this respect, the British *Chartered Institution of Building Services Engineers* suggests a comfort temperature range of 19 – 21°C and 21 – 23°C for lecture halls, computers rooms, teaching spaces etc., during winter and summer respectively[42]. For office buildings, these figures are even higher, while summer peak temperatures are allowed to exceed a certain threshold for 1% annual occupied hours (28°C for offices). However, when taking into account the mean outdoor temperature, the bands of acceptable temperatures are much more flexible (*see figure 71*) (124).

Among others, crucial factors, for enabling an adaptive temperature range, are:

- users' ability to control the indoor climate (convenient control over windows, climate equipment, solar shading etc.)
- relaxation of formal office dress
- flexible working hours
- availability of local climate control equipment (e.g. fans)
- gradual drifts from comfort conditions

To confirm the above, recent measurements in BK City showed that, for warm days, indoor temperatures up to 28-30°C will be accepted. Besides, according to the same measurements, overheating occurred only in late afternoon hours when most users have already left the faculty (166).

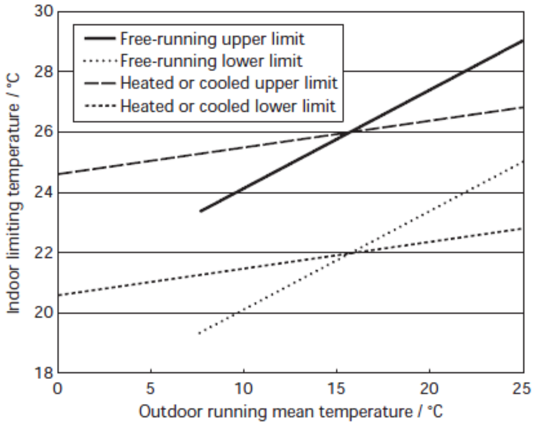


Figure 71 Bands of comfort temperatures in offices related to the running mean of the outdoor temperature. Figure retrieved from (124)

6.2.2.7 Photovoltaic modules for electricity generation

Strategy II includes the installation of photovoltaic modules to provide electricity. PV technology includes a variety of application types, some of which are mentioned in table 32 (147).

Due to the monumental character of the building, integrating PV in BK City can be done only on the flat stone slate roof (crystalline silicon cells) and on the glasshouse roof (semi-transparent PV modules, replacing the glass surface that provide insulation apart from electricity). The flat roof surface is 3.244m^2 (including the Bouwpub and the Ketelhuis) while the east and south glasshouse roofs cover a 2.340m^2 surface. The electricity production of the installed modules depends on various factors such as:

- Shadowing from trees and neighbouring buildings (not applicable for BK City)
- Orientation of the elements (south is obviously the optimum)
- Panel inclination

However, for the needs of this project a simple rule of thumb will be used, i.e. 100kWh/year/m^2 of module surface area (167), which agrees with the figures provided by the European Solar Test Installation laboratory[43] (168) – see also the figures provided in §*5.1.1 Location, topography and climate*. With this assumption, the annual generation will be:

[42] The temperature ranges may be widened by approximately 1 °C at each end if a PMV of ±0.5 (i.e. PPD of 10%) is acceptable.

[43] For modules on a horizontal plane, with a 10% efficiency

E = 100*(3.244+2.340) = 560MWh per year

According to the energy bills, provided by the Facility Management of BK City, the electricity consumption for year 2009 (i.e. prior refurbishment) amounted to 1.979MWh. To cover this demand, a surface area of:

$A_{PV\text{-}cells}$ = 1.979.000/100= 19.790m^2 would be required.

Technology	Advantages	Disadvantages
crystalline silicon solar cells	• Cheap • Mature • Commercially available	• Limited crystalline resources • Energy intensive production • Temperature dependent efficiency
thin-film solar cells	• Flexible • Transparent • Attachable to conventional materials • Max. active area exposed to solar radiation per used silicon (m^3) • Low system cost per capacity (kW) • Low cost and energy production	• Moderate efficiency • Low kWp per m^2 of installed area
multijunction solar cells	• High efficiency	• Expensive
emerging solar cell technologies (dye-sensitized cells, organic cells, inorganic cells)	• Low cost and energy production • Environmentally friendly	• Low efficiency • Immature

Table 32 Photovoltaic technology

One could investigate whether solar electricity generation can cover the operation of the heat pump. The heating demands for year 2009 (i.e. prior to refurbishment) reached a total of 3.800MWh. If this demand is entirely provided by the heat pumps and the COP (coefficient of performance) is 4, then the electricity needed to drive the GCHPs will be 950MWh, much higher than the calculated PV generation. These figures, of course, represent the current situation of the Faculty.

Finally, in order to avoid the use of batteries, we can chose to connect the solar system of BK City to the local electricity grid, allowing the trade of power to the grid on sunny days and taking it back on overcast periods.

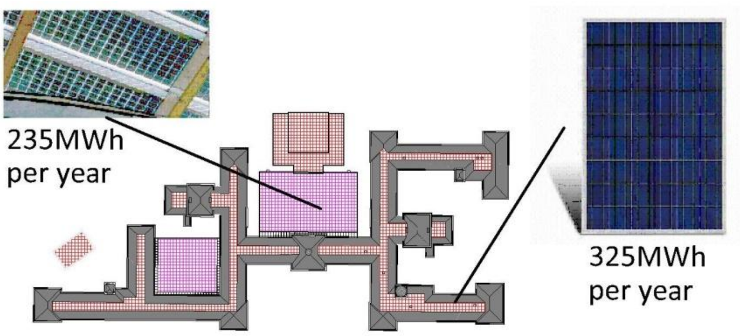


Figure 72 Electricity generation through PV cells for Strategy II

6.2.2.8 Synopsis

An overview of Strategy II and the proposed measures is provided in the following image. The measures have been classified as in *§6.1 A pallet of measures for BK City*.

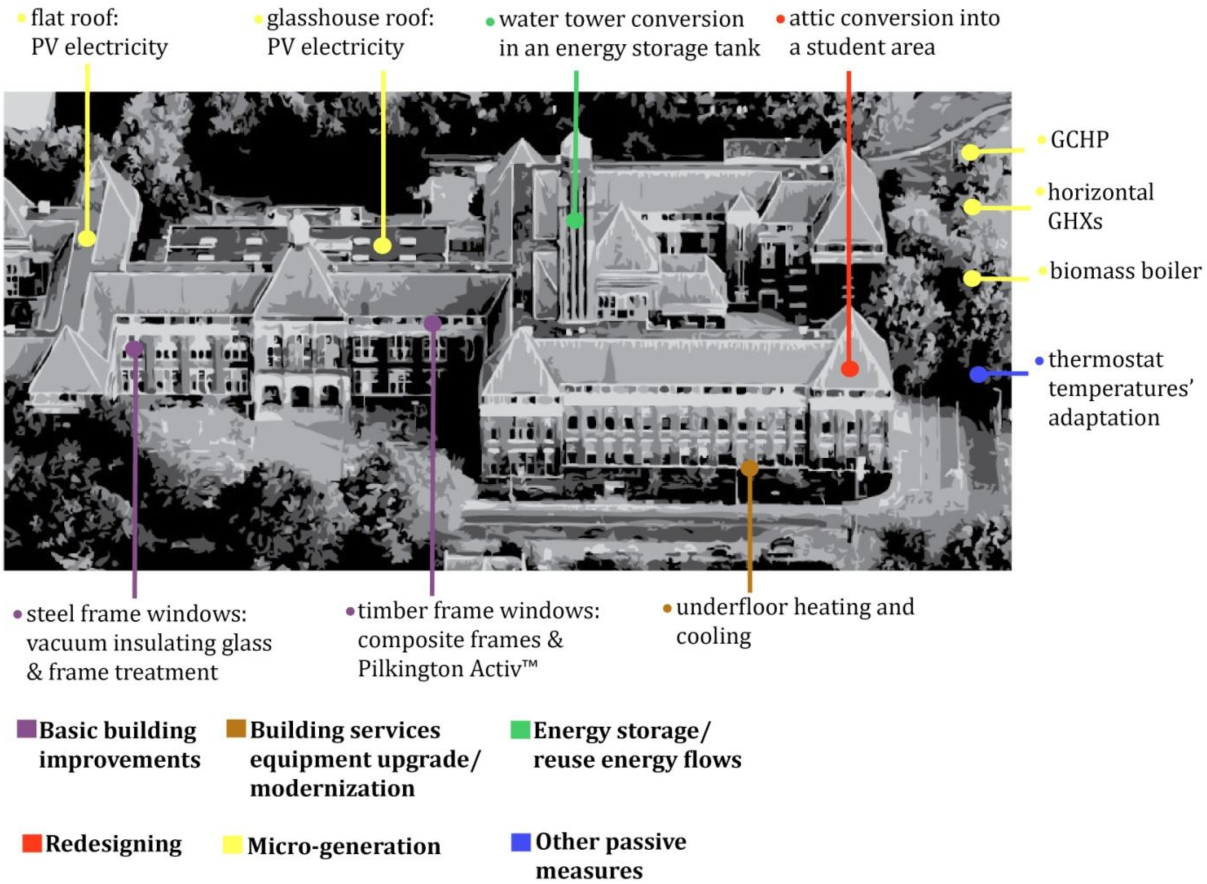


Figure 73 Overview of Strategy II

6.2.3 Strategy III: Innovative but risky

Strategy III is a further development of Strategy I and II. This scenario emphasizes the use of the latest technology applications that can, now or in the near future, be implemented at the Julianalaan building. Less attention is paid to the restrictions that follow from the character of the building which means that the difficulty of realizing the proposed interventions is higher compared to the previous Strategies. Additional deterring factors are the high investment costs and the doubtful effectiveness (i.e. not verified on a large scale) of the proposed actions.

6.2.3.1 Cavity wall dry lining and roof insulation

In addition to the blown mineral wool used in Strategy I & II, Strategy III aims at reaching a PassivHaus insulation standard, typically around 0.10-0.15W/m^2K by applying an internal dry lining. Suitable for use in cavity walls is the 'K17 Kingspan' insulated board, which consists of CFC free rigid phenolic insulation (λ=0,021W/m*K) and a plasterboard facing (λ=0,19W/m*K), in total around 7cm thickness (169).

Compared to other insulants (e.g. mineral fiber), rigid phenolic insulation is not vulnerable to water penetration, air movement or compression. Additionally, it performs very well in terms of fire resistance (class 0 - low risk fire rating) and also has a minimum impact on internal surface area dimensions. However, certain limitations exist, such as its non applicability in persistent damp conditions, or the clash with the existing wall fittings (sockets etc.). For existing wall-mounted fittings with considerable load, it is recommended that the load is applied on the supporting wall and not on the insulation board. Finally, mounting the rigid insulation on the existing surface can be done either with adhesive plaster methods or mechanical fixing or both (*see figure 74)*.

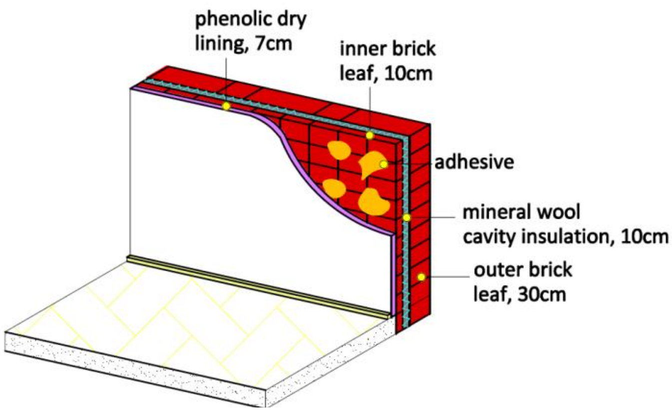


Figure 74 Application of dry lining on the exterior façade of BK City

Achieving PassivHaus standards is also a target for the roof insulation. As is explained further on, the attic will remain cold for Strategy III, so it is the flat ceiling of the second floor that has to be further insulated. On top of the existing ceiling structure, rigid boards will be laid, such as 'Kingspan Thermapitch'. This rigid board consists of polyisocyanurate (λ=0,023W/m*K) faced on both sides with low emissivity foil. By placing it on top of the existing insulation no condensation on the interface will occur as 'Kingspan Thermapitch' has a higher R-value. A thickness of 200mm will result in a total U-value of 0,10 W/m^2*K.

	BK exterior facade U value [W/m^2K]	BK ceiling U value [W/m^2K]
prior to refurbishment	**1,17**	**0,64 (obsolete material)**
Strategy I & II	**0,28**	**0,64**
Strategy III	**0,14**	**0,10**

Table 33 Thermal performance of the exterior façade and the flat roof for the three Strategies

The enhanced thermal performance of the cavity wall and the flat roof is calculated in table 33.

6.2.3.2 Window replacement

In the choice of the window strategy, energy efficiency, thermal performance, acoustic insulation and safety have been favored over monumental restrictions. The proposal of Strategy III is to replace the existing steel frames with new ones, fitted with high efficiency glazing. This option has previously been considered for the apartment plans, before the building was converted into the Faculty of Architecture. In this way, future performance is also guaranteed – fewer maintenance costs and higher life expectancy.

Naturally the choice of the frames needs careful thinking so as to minimize the visual impact on the façades. Insulated steel frames will be chosen as they are superior to aluminium profiles in terms of fire safety, durability and burglary prevention and, additionally, they are closer aesthetically to the existing profiles. According to the research done by the architects for the conversion of Julianalaan into an apartment block, it is, indeed, possible to approach the original appearance of the facades by ordering tailor-made 'renovation' frames (detailing, smoothness, width etc.) (*see figures 75 and 76*). Among other companies, manufactures dealing with renovation projects are *Schüco, Crittall, Rollecate* etc.

Figure 76 Right side test frame in black colour (left) and left side frame painted in same colour as test frame (right). The research was carried out by the *Braaksma & Roos Architectenbureau.*

Figure 75 Window sill detailing. Existing (left) and new frame (right) - *Braaksma & Roos Architectenbureau.*

Typical PassivHaus refurbishment requires the use of advanced technology for the openings and, so the accomplishment of very low U-values, in the range of 0,85-0,70W/m^2K (93). For this reason, a window system such as the *S 7000 IQ* can be chosen that, despite its narrow sash profile, reaches a U value of 0,7 W/m^2K for the glass only and 1,2W/m^2K for the frame-and-window combination (170).

For the timber frames, innovative heated glass technology will be used. This type of glass typically consists of a double unit, of which the inner pane has a thin metal oxide coating linked to a power source and the outer pane is a low-e glass surface (*see figure 77*). When turned on, the glass component radiates heat to the interior of the space, while turned off, it acts as regular insulating glass. In this way, the glass will act as an auxiliary heating resource reducing the need and size of other heating systems and eliminating at the same time the risk of condensation formation as well as dust accumulation. The required energy to heat the glass is expected to be counterbalanced by the significant increase of the indoor temperature. Radiant heating glass can be used as the exclusive heating resource, controlled by a thermostat[44], but, in that case, the power requirements are much higher. Providers of radiant glass products are *Groupe Prelco*, *IQ Glass* etc.

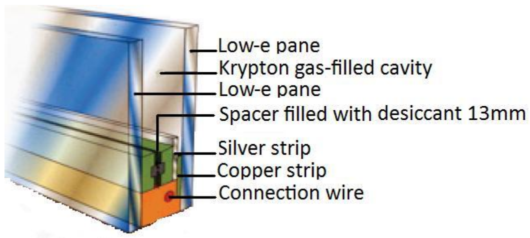


Figure 77 Schematic section of radiant glass

Table 34 compares the three Strategies and the achieved U-values for the windows of BK City, while table 35 gives some technical data on the performance of the radiant glass unit (171), (172).

[44] Air thermostat, glass surface temperature regulation, or a combination of an air thermostat and a glass surface temperature regulation are possible

Radiant glass technical data	
Glass thickness [mm]	21 – 25
U value, not heated [W/m^{2}K]	0,8 – 1,8
U value, heated [W/m^{2}K]	0,04
Light transmission	71
Delivered heat gain [W/m^2 glass surface]	50[45]
Electric power [W/m^2 glass surface]	50 – 200

Table 35 Technical data of radiant glass units

	Steel frames U-value [W/m^{2}K]	Timber frames U-value [W/m^{2}K]
prior to refurbishment	5,9	3,5
Strategy I	3,0	1,8
Strategy II	2,5	1,5
Strategy III	1,2	0,04

Table 34 Thermal performance of the windows for the three Strategies

With the data from table 35, a rough calculation shows that if radiant glass is used for all timber frame windows, a total of 100W/m^2*1180m^2 = 118kW would be needed to provide the necessary electricity. This can easily be covered by the PV modules placed on the roof (*see §6.2.3.4*).

6.2.3.3 Natural ventilation concept and the attic

Strategy III includes a hybrid[46] ventilation system based on buoyancy forces, assisted by intake and extraction fans, as wind-driven ventilation would not be reliable in the urban context of Delft.

The essential features of such a system are the following:

- Intake towers
- An earth duct network
- An air distribution chamber
- Exhaust channels and
- Exhaust towers

The concept, shown in the following figure, is described below.

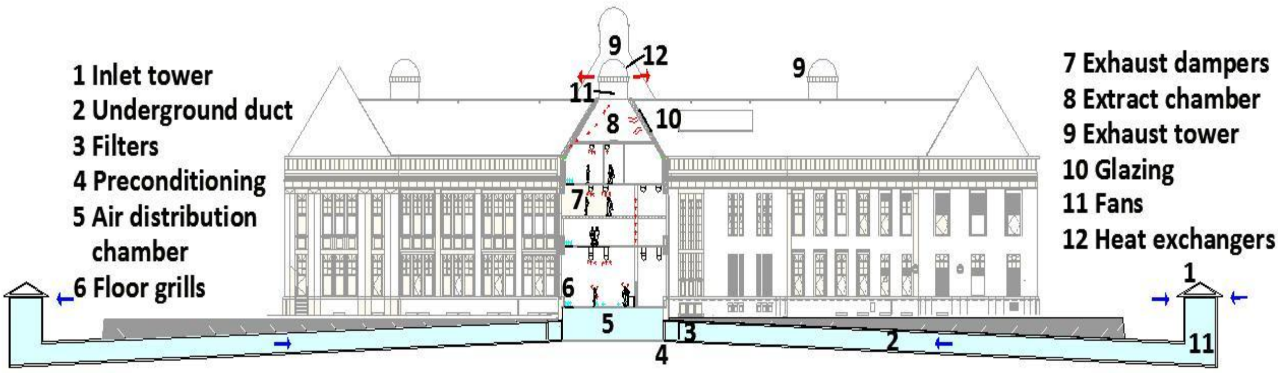


Figure 78 Ventilation concept of BK City

Fresh outdoor air enters the system through the inlet towers. These are located on the backside of the Faculty (southeast) in order to avoid the traffic of the Julianalaan avenue, which is a source of air pollution and noise, but also to keep them far from student and passer-by activities. The air is driven inside underground ducting that pre-conditions the air thanks to ground temperature – a depth of 10m will be required. These ducts lead to underground distribution chambers, located in the basement of the building. From there, and after the air temperature has been regulated (through heat recovery and auxiliary heating means), the air is supplied inside the building through floor-embedded grills at a low velocity (around 1m/s) so as not to cause draft. Alternatively, the supply could be passed through wall diffusers that can be used as benches or stands for the students (*figure 80*).

[45] For a glass temperature of 24°C and room temperature of 20°C
[46] By hybrid system is meant a fan assisted natural ventilation system

Now, it is the turn of the indoor heat sources to drive the process. As the air enters at floor level, convection flows are created that force the air to move upwards to the breathing height. Along with the air, odours and contaminants are also carried away and exit the space through dampers, to be thereafter led to exhaust ducts and from there to the attic space that acts as an extract chamber. At this point, use of the existing duct system can be made. Restrooms and the kitchen areas should be provided with separate local air exhaust.

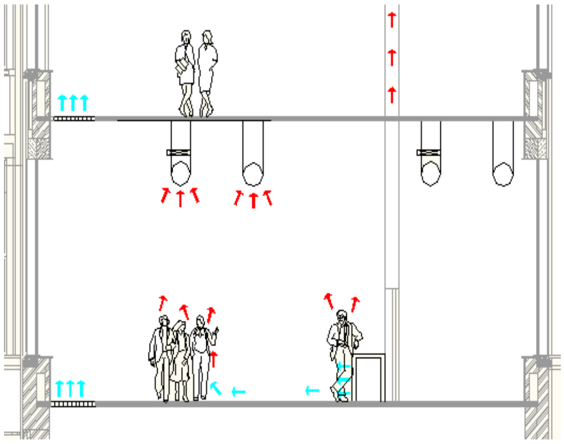


Figure 80 The natural ventilation concept of BK City at room level

The polluted air will exit the attic through appropriately designed exhaust towers (*figure 79*). In the middle of the attic, there is already a tower that, if adjusted, could possibly serve the extracting purpose. For fire safety reasons and the subsequent requirement for compartmentation, multiple exhaust chimneys should be placed that will also ease the flow of the air inside the building. Naturally, this design will require the authorities' permission for the alterations on the roof. In order to enhance the stack effect, the towers need to have a certain height. This height is calculated according to the necessary supply of fresh air and the temperature difference of incoming and exhaust air. For the same purpose, parts of the roof which look on the inner-court could be glazed to allow solar radiation to enter the attic and heat the air - the orientation of this roof (south and southeast) is ideal for this purpose. As is elaborated in the next paragraph, instead of conventional glass, PV glazing can be used to serve the electricity generation and at the same time allow solar radiation to enter the attic.

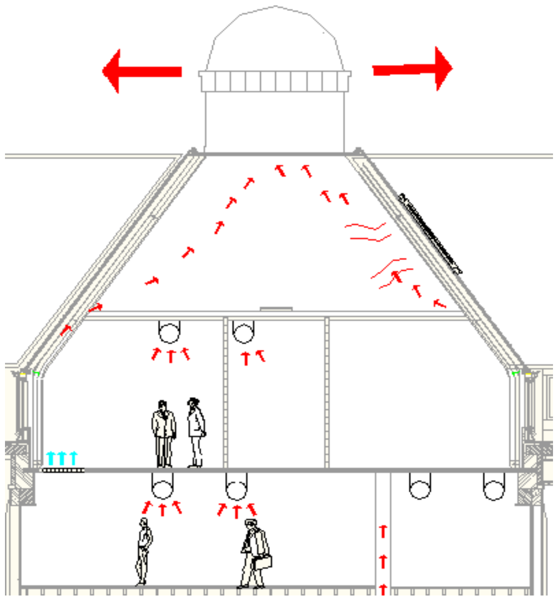


Figure 79 The attic as an exhaust chamber

As the exhaust towers will have to be located well above the roof, this might give rise to architectural concerns related to the need to maintain the visual effect of the building. A possible alternative would be to realize the exhaust of air through Venturi elements that are designed to increase the airflow velocity over the outlet and, thus, increase the underpressure. Such a mechanism has been designed for the GSW headquarters building in Berlin, where, according to the architects, mechanical ventilation is required only for 30% of the year (173), (174) (*see figure 81*). In any case, however, tests in wind tunnels and CFD calculations will have to be performed to investigate the performance of such a system.

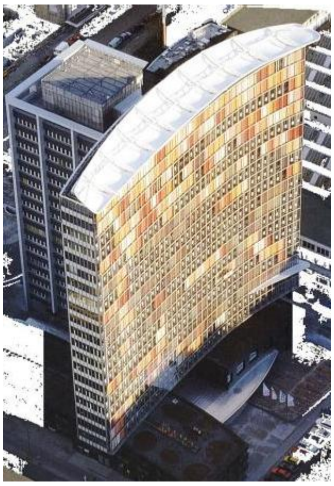


Figure 81 The GSW office block and the roof wing

In order to guarantee the air flow throughout the year, low pressure fans should be accommodated at the inlet and exhaust systems. These will operate in case of pressure drop or when increased air volumes are needed.

Figure 82 Example of a fine filter through which air will pass before entering the distribution chamber. The subsequent pressure loss could reach 50Pa

Secondary equipment will include CO_2 sensors to adjust the flow rate, filters to prevent dust from entering the building and sound attenuators to minimize the noise levels in the ducts. A weather station should, also, be installed in order to have an integrated building management system that gathers information on air temperature, wind direction, relative humidity levels etc.

It is also possible to incorporate a recovery system by which heat is captured at the exit chimneys and is then transported with the help of appropriate fluid to the distribution chambers in the basement. Relatively small efficiencies should be expected, i.e. around 50-60% judging from other case studies.

However, in a system like this, that relies to a large extent on natural forces, it is very important to minimize airflow resistance. Resistance is typically caused by the fans, the dust filters, insect nets, the heat exchangers, dampers etc.

6.2.3.4 New glasshouses and PV electricity generation

Strategy II involved the use of the attic as student space to make up for the lack of space that the Faculty currently has. In Strategy III however this is not possible, as the attic will be used as an extraction chamber (*see §6.2.3.3 Natural ventilation concept and the attic*) while it can, also, house various installations.

The alternative proposed here is the addition of two glasshouses, as shown in figure 83:

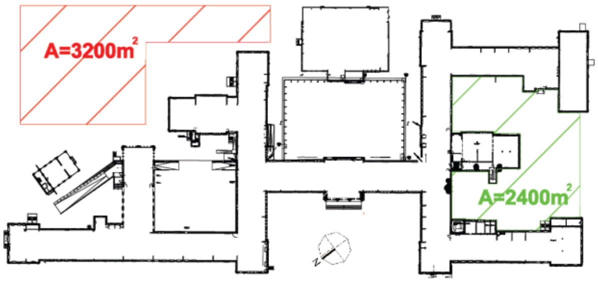


Figure 83 Addition of two glasshouses to cover the lack of space in BK City

With this configuration, at least 5.600m² are created for BK City that can be increased with a suitable design of the interior spaces, such as adding extra levels. One should remember that the attic conversion offered 6.500m². The west glasshouse (in green) apart from adding space will act as a buffer zone for the adjacent wings of the existing building, which will result in significant reduction of the transmission losses.

The construction of the glasshouses is a chance to make them a display of solar energy cutting-edge applications with the installation of PV glazing instead of common glazing units. This revolutionary building material is based on silicon technology, its innovation lying in the extremely thin silicon layer – around 0,3 micrometers – which in effect needs less energy for its manufacturing (175).

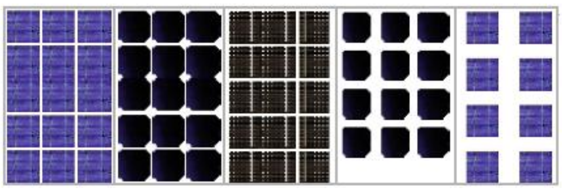


Figure 84 PV glass transparency and cell distance can vary largely. In the figure above transparencies 13%, 15%, 22%, 36%, 43% - from left to right.

A range of modules exists, varying in size, efficiency, visible light transmittance, cell spacing and color etc (*figure 84*). As a result, the maximum power output also varies (*table 36*). One of the main drawbacks of thin film technology that has to be taken into account is the lower efficiencies (1-12,5%) compared to conventional technology (147).

Another issue that needs to be tackled is the high U values that PV glazing usually has, usually in the range of 4,5-6W/m^{2}K (176). If this is indeed a problem in BK City's new glasshouses, then an insulated glass façade can be used, such as the one proposed by *Ertex Solar* (177) that achieves a U-value between 0,5-1,1 W/m^{2}K (*see figure 85*).

Company	PV glass			
	Size [m*m]	Transparency [%]	Output power [W]	Output power [W/m^2]
TSNergy Inc. (176)	0,95*0,99	1	52	55
		5	50	53
		10	42	45
Solar Power Solutions OSKOMERA (178)	1*1	25	109	109
		45	80	80
	3*2	43	509	85
PV Glaze (179)	2,6*2,2	0	340	59
		50	175	31
	1,3*1,1	0	80	56
		50	40	28
Ertex solar – photovoltaics (177)	1*1	15	178	178
		22	122	122
		43	84	84

Table 36 Examples of module size, transparency and power output dependency for PV glass

Alternatively a ventilated facade panel can be used, as proposed by *Mootz et al.* (180), that acts as a lightweight version of a Trombe-Michel wall (*figure 86*). The operation of this panel is simple: air passes through the inlet section, is heated up in the 'convection channel' due to solar radiation and is thereafter released into the space. During night hours the inlet and outlet sections need to be closed in order to reduce the heat losses. This solution, however, will significantly reduce the visible light admittance inside the glasshouse, so it can only be used in part at selected sections.

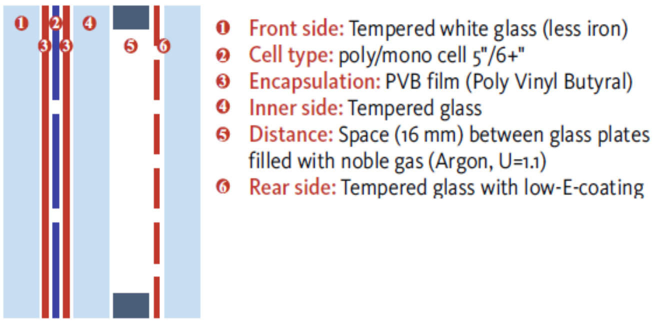


Figure 85 PV glass facade and roof insulation

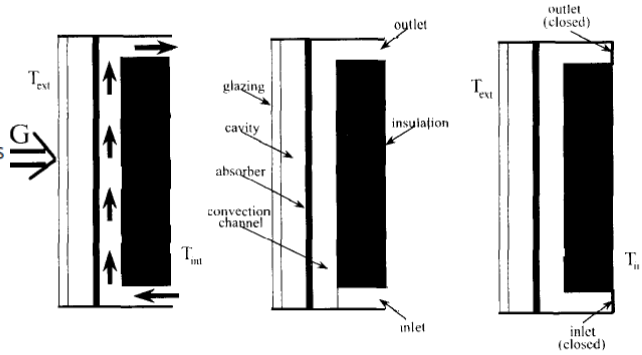


Figure 86 Ventilated facade panel as proposed by Mootz et al. (on right is the operation during night hours)

In addition to the PV glass installed on the new glasshouses, the existing ones will also be covered with PV modules, as will the parts of the roof that are facing towards the inner courts (see §*5.3.3 Permissible interventions*). The flat parts of the roof will, also, be designed to accommodate PV modules except for the parts occupied by the exhaust ventilation towers.

The estimation for the possible electricity generation from the installation of PV modules in BK City – the glasshouse facades have not been taken into account – are based on the previously used rule of thumb 100kWh/year/m^2 of module surface area.

E = 100*(9.533+3.244) = 1.280MWh per year

The annual generation is naturally higher than the one in Strategy II (1.280MWh compared to 560MWh) but, still, the total amount would not suffice to meet the entire yearly electricity demands (2.000MWh according to the yearly bills for the current situation). This is, partly, due to the low efficiency of the PV modules – especially the PV glazing – and the low load factor for The Netherlands. However, PV cells could, possibly, cover the operation of the heat pumps.

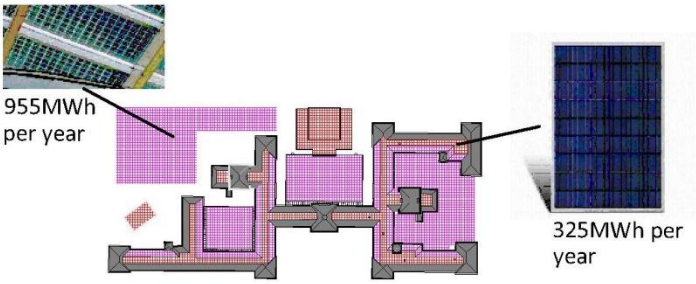


Figure 87 Electricity generation through PV cells for Strategy III

Despite the non-full coverage of the electricity demands, the operation of the modules is still advantageous. Apart from being totally CO_2 free and very cheap (with regards to their operation) they have high educational value and will also add to the public image of the building. It should also be expected that subsidy programs will cover the installation costs, at least partly.

6.2.3.5 Exploration of geothermal heating

The use of water as a heat carrier was examined previously for Strategy II, in combination with slinky coils. In Strategy III a more advanced energy system is proposed, i.e. a geothermal energy system coupled with a groundwater heat pump. This type of technology has been growing rapidly in The Netherlands, despite the lack of government subsidies (181).

The principle of geothermal heating is, fairly, simple. In our case, it is best to talk of a 'geothermal doublet'- consisting of one production and one injection well. During the heating season hot groundwater, that is extracted from a production well, transfers its heat through an intermediate heat exchanger to the working fluid of the energy system of the building. Using this heat the groundwater heat pump (GWHP) can produce low temperature heating, while the now cooler groundwater is injected back into a cold well. With the use of an intermediate heat exchanger the heat pump remains in a closed loop and is protected from abrasive or corrosive well water.

Advantages of geothermal systems are the high efficiency compared to soil systems, the low CO_2 emissions involved and the high levels of comfort (181). However, several hindrances exist in their application while serious preparation has to be made in the pre-design phase. Some of the preconditions that should be fulfilled are (145), (158), (181):

- Acquisition of legal permissions from water authorities for the pre-design and production phase
- Ensure no interference with drinkable water sources occurs
- No natural groundwater flow should be observed
- Research into the mineralogy and underground chemistry to prevent damage caused by clogging, scaling etc.
- Comparable building heating and cooling demands throughout the year
- Sufficient groundwater supply
- Aquifer thickness 20-50m

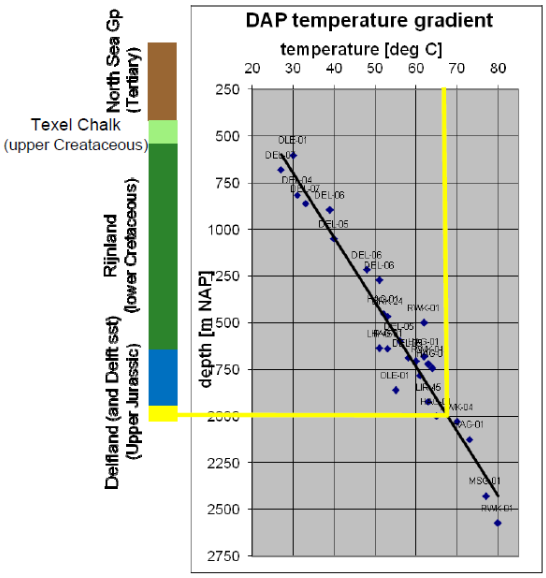


Figure 88 DAP temperature gradient. Figure retrieved from (183)

For BK City the proposed strategy is based on the research carried out by the Delft Geothermal Project – DAP[47]. As part of this, the University has applied for

[47] *Delft Aardwarmte Project*

an exploration licence for the campus area. The drilled wells on the campus and the nearby area have provided very useful insight into the geological structure and the possible exploitation of aquifers (182), (183), (143), (184):

- Huge water volumes are available ($4.8*10^8$ m^3 for an area of $61km^2$)
- A temperature of 70-82°C is estimated for a depth of 2,3km (geothermal gradient ca. 3°C/100m – *see figure 88*) in the Delft Sandstone Formation.
- A loss of 2°C should be expected as the water flows from the well to the surface
- Simulations have shown that a decline in the hot well temperature should be expected after some years (*see figures 89 & 90*)
- With the estimated production rate ($150m^3/h$) the period for a viable exploitation is at least 30 years

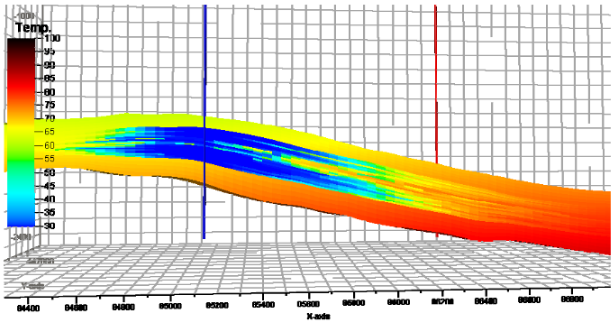


Figure 89 Cross section showing temperature flow from injection well CI (blue well) to production well CP (red well) after 30 years. Figure retrieved from (183)

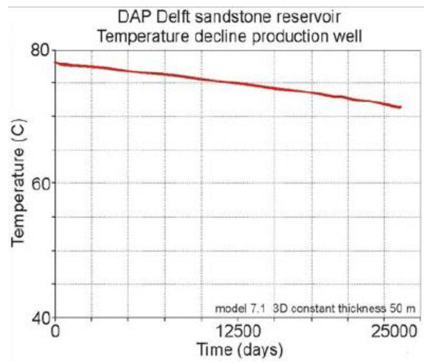


Figure 90 Temperature decline versus time at the production well. Figure retrieved from (143)

Currently, the Geotechnology department of TU Delft is doing additional research into the effect of the cold water injection on well clogging, failure of the rock structure etc. Ways to optimize the aquifer are now being explored, while three systems have already been planned in the Delft area for a capacity of 4-7MW (each one). The wells are planned to produce and inject $3.600m^3/day$.

For BK City a flow of $13m^3/h$ is needed, which is, of course a very rough estimation, just to provide an idea of the order of magnitude and should, therefore, not be used for further calculations. The distance between injection and production well is 2m at surface but around 1,5km at the depth of 2km (maximum drilling deviation is 60 degrees from vertical).

The provided temperature of 80°C can be coupled with the underfloor heating system described in Strategy II. In this case, it would probably be wiser, in terms of efficient exergy use, to reserve the high temperature water for supplying radiators in spaces of BK City where underfloor heating cannot be installed. The surface heating system can then be fed by lower temperatures from more shallow depths (e.g. 25°C at a depth of 500m).

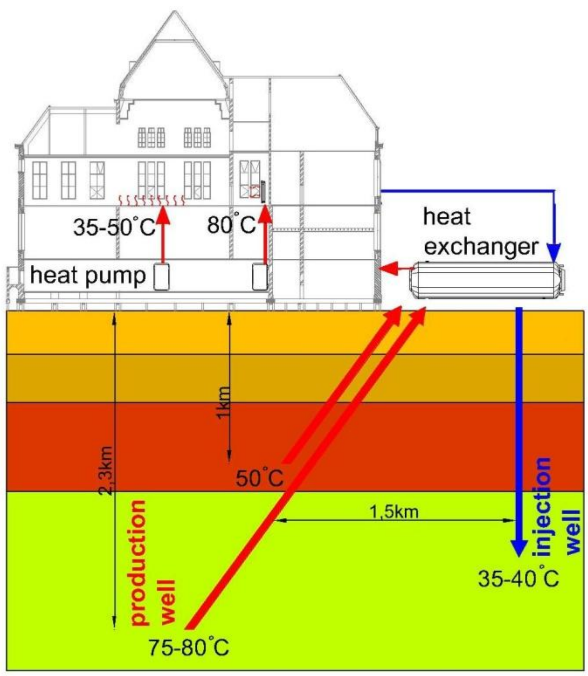


Figure 91 Schematic representation of the geothermal doublet system for BK City.

6.2.3.6 Fuel cell CHP

It is doubtful whether the building can rely on the PV modules and the aquifer system to fully cover its needs in electricity and heating, respectively. The gap between the production and the actual needs will be bridged with a micro-CHP unit that generates electrical and thermal energy simultaneously.

Micro-CHP and small scale CHP, recent developments following the trend towards distributed CHP units instead of centralized ones, are the terms used for an electrical production of less than 100KW or 200KW respectively. Both are still at a development phase mainly due to the lack of sustainable fuels, the high initial costs involved and the resulting long payback time (185), (186).

Several types of small scale CHP alternatives exist (reciprocating engines, micro turbines, Stirling engines, biomass-CHP and fuel cell systems). The promising technology of fuel cells[48] will be proposed and elaborated for Strategy III. Currently, the fuel cells' potential is investigated mainly in the automobile industry, while building applications are either at a conceptual phase or, at most, generously subsidized experiments (187), (188). The benefits that fuel cells offer are the high electrical efficiency (max. 55%), the minimal environmental impact (if pure hydrogen is used, the only emission is water), their silent operation and reliability. On the other hand, the investment cost (as high as three times the cost of reciprocating engines), the transportation and storage needs are the major drawbacks.

From the available fuel cell types (*see table 37*) Proton Exchange Membrane Fuel Cells (PEMFCs) and Solid Oxide Fuel Cells (SOFCs) have the largest potential for being commercially feasible. As the performance of PEMFCs, till now, has been below expectations (188), the most viable technology for the Julianalaan building seems to be SOFCs that outperform PEMFCs with regards to the necessary external equipment. Another reason for opting for SOFCs is the possibility to reform fuel internally so that external reformers are unnecessary. The main disadvantage of SOFCs at the moment is the high temperatures that require special shielding to protect the staff and to insulate from heat losses. Additionally, the costs are expected to skyrocket, due to the demand for very high quality materials in terms of durability.

Fuel Cell Type	Operational Temperature [°C]	Source of hydrogen
Alkaline	50-200	Clean hydrogen or hydrazine
Direct methanol	60-200	Liquid methanol
Phosphoric acid	160-210	Hydrocarbons or alcohols
Sulphuric acid	80-90	Alcohols or uncleaned hydrogen
Proton exchange membrane	50-80	Hydrocarbons or methanol
Molten carbonate	630-650	Clean hydrogen, natural gas, propane, diesel
Solid oxide	600-1000	Natural gas or propane
Solid polymer	80-90	Clean hydrogen

Table 37 Existing fuel cell technologies (185)

Figure 92 The *Hexis Galileo* unit. It occupies a space of 3m^2 and generates 1kW electricity and 2,5kW heat.

SOFCs developers at the moment produce only low power units. As an example, the *Hexis Galileo* by Swiss Hexis AG is mentioned. Still at design phase, the *Galileo* generates approximately 1kW of electrical power and 2,5kW of thermal power (electrical efficiency 25-30%, overall efficiency 90%). For excess heating demands, there is the possibility of integrating a gas burner that covers a 20kW of heating demand (189). Other SOFCs manufacturers are Bloomenergy, CellTech Power, CeramaTec, Ceramic Fuel Cells, Ceres Power, Acumetrics, Topsoe and Kyocera and HTceramix.

48 A fuel cell is an electrochemical cell that produces electricity electrochemically with water and heat being the by-products

In BK City, a small scale CHP unit can be installed that will initially run on gas. A switch to either hydrogen or biofuels can be made when they become locally available and the necessary infrastructure is sufficiently developed. The source of hydrogen, however, is the most important parameter if zero emission energy generation is sought – if fossil fuels are used for hydrogen generation, CO_2 formation remains a problem. However, hydrogen can be extracted from water via electrolysis[49], in which case hydrogen should be pursued along with solar power to run the electrolysis. Exploring the possibilities for fuel cells is a chance to involve other Faculties of the University in the project (Applied Sciences Faculty, 3ME).

The electricity produced can be directly used or, preferably, fed to the local power grid. During warm periods, when the building doesn't require heating, the excess heat can be used by an absorption cooling machine powered by 80-85°C heat to provide the necessary cooling – in this case, an output temperature of 100°C will be necessary.

6.2.3.7 The water tower and PCM storage

In the previous section, the water tower was converted into a storage tank, with water as the means of storage. The energy storage will allow the constant running of the SOFC plant during periods when mismatches between thermal and energy demands occur.

Strategy III keeps the same storage concept but, instead of water, Phase Change Materials[50] (PCMs) will be used. Compared to water, PCMs require much less space, so larger storage capacities are possible. This can affect the dimensioning of the heat pumps, the aquifer system and the small scale CHP unit with multiple additional benefits (lower infrastructure costs, lower physical sizes). PCMs also solve the issues of stratification that occur in water tanks during charging and discharging. On the other hand, PCMs have a finite lifetime and after a certain number of freezing/melting cycles their degradation will begin.

The British company *PCM Products Ltd* offers a variety of PCMs (Sub Zero Eutectic, Positive Temperature Salt Hydrate, Positive Temperature Organic, High Temperature Salt, Solid / Solid PCMs) (190). Suitable for BK City could be organic PCM solutions that have a transition temperature in the range of 160 - 2°C. For the desired phase-change temperature (around 80°C), the heat capacity is 200kJ/kg. Organic PCMs are easy to handle though they can be expensive compared to other alternatives. However, organic PCMs have a low tank capacity (~25kWh/m^3), so salt based PCMs will be chosen (for a phase temperature of 80°C the tank capacity is 55-60kWh/m^3). These are superior in terms of price, latent heat/density, phase change temperature range and (non-)flammability. However, their capacity is the same as that of water so no significant improvement is made. Choosing for lower phase change temperatures might result in higher capacities (for example 73kWh/m^3 for a temperature of 48°C will result in a 40MWh storage load).

Figure 93 Customized PCM solutions

PCMs are produced in various encapsulated forms, shapes, materials, colors etc. The final product may be in the shape of rectangular containers, tubes, metallic pouches etc. (*see figure 93)*. After stacking the PCMs in the tank, there will be sufficient gaps to allow easy water circulation between them.

[49] Electric current passes through water to separate hydrogen from oxygen

[50] PCM is a material '*with a high heat of fusion (or 'specific melting heat') which by melting and solidifying at certain temperatures, stores and releases heat*.' (133)

In conclusion, PCMs have a larger density (kg/m^3), but their specific heat capacity (kJ/kg*K) is nearly half the specific heat of water, so the storage space needed for the same load is practically the same.

However, by storing the heating energy equivalent to a few days usage the tank can provide the necessary heating or cooling load and reduce, in this way, the running hours of the pump and the micro-CHP.

6.2.3.8 Waste water treatment

Treating and reusing waste water usually requires a very complex design. That is due to its contamination arising from humans and its relatively high temperature that favors the growth of bacteria, germs etc. Thorough treatment and special storage conditions are required as a result, while the utilized disinfectants can be energy intensive to produce. Several studies have shown that the environmental impact of treating grey water for reuse nullifies its benefits and can be extremely expensive to operate (191).

Resolving the above mentioned issues can be done via ecological treatment methods, which mimic natural principals, based on the interaction between water, soil, bacteria and plants. From the three main types of such systems (constructed wetlands, aquaculture and living machines) the latter will be explored for BK City. This fairly new technology does not use hazardous chemical or industrial processes, while the amounts of biowaste are relatively small. Compared to other waste water treatment methods, living machines perform *'very good'* in terms of TSS[51] and BOD[52] removal (192).

With regards to financial issues, the design and construction costs are usually the limiting factor, whereas operation and maintenance costs are usually at low levels. Literature mentions $1.000 (€700) as a starting price for the installation cost but case studies have demonstrated the very high actual investment expenses ($500.000 for a school[53] in New York, USA, $220 million for a Water Pollution Control plant[54] in San Francisco, USA). However, the final costs strongly depend on the availability of locally found materials and accurate estimations can be made after the design phase has started (192), (193), (194), (195).

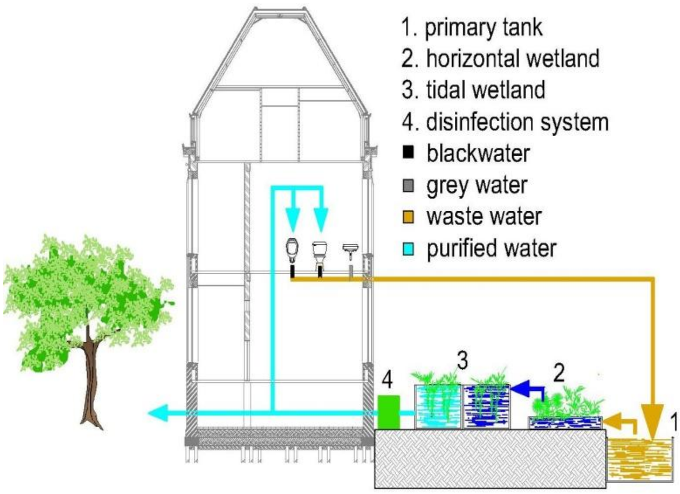


Figure 94 Ecological waste water treatment concept for BK City

The process of the water purification is shown in figure 94. Before entering the system, waste water (both grey water[55] and blackwater[56] can be treated) goes through a primary tank where solid settling takes place (this solid, known as sludge, can be used agricultural purposes or even for the production of biogas). Next, is the horizontal wetland stage, where a combination of gravel, biofilms, microorganisms and plants perform the initial treatment. In the aerobic phases that follow, nitrification and de-nitrification take place, while the majority of the BOD and TSS are removed (tidal wetland). This stage is the most impressive, in terms of aesthetics, as plants and aquatic organisms

[51] Total Suspended Solids
[52] Biochemical Oxygen Demand
[53] Darrow School, http://www.darrowschool.org/. The Living Machine treats 7.000 gallons per day (25.000 liters)
[54] The Living Machine treats 15.000 gallons per day (≈57.000 liters)
[55] Water originating from sinks, baths, washing machines, kitchens etc.
[56] Water originating from toilets (faeces, urine, toilet paper and flush water)

(fish, snails, frogs) either assist in the cleansing process, or are home of the necessary bacteria. Commonly, goldfish are used as, apart from their pleasing appearance, they have a relatively long lifetime, need little oxygen and are fed by algae. For BK City it is most probable that, due to the temperate climate of Delft and the need to maintain high temperatures for the plants, this installation will be located in a greenhouse. At the end of the system, 'polishing' takes place, where ozone or UV are used to disinfect the left-over pathogens. Water is now ready to be re-used for non potable uses, such as toilet flushing and garden watering, or it can be safely discharged into the canals of Delft. The whole process is managed by a central system where water levels, flow rates and water quality are constantly monitored.

Figure 95 IslandWood school living machine, Seattle, USA

During the design phase it is important to find the necessary open space where the living machine will be constructed. Ideal for this purpose is the area behind BK City that is already a park, where the greenhouse can be placed. Important to note that high levels of natural light will be needed, so the basement areas of the Faculty should be excluded from this design.

A rough calculation shows that, for a total 4.000 users of BK City, 60.000 litres of blackwater[57] are driven to the central sewage systems on an average day. The installation of a living machine will result in an additional energy consumption of 7,8kWh[58] and a 220m^2 footprint[59]. On the other hand, the living machine, if managed appropriately, can offer valuable by-products:

- The idea of sustainable refurbishment can be promoted in a visible way for the general public
- The Delft community can be further involved by organized visiting tours, which will stimulate their ecological behaviour
- Environmental courses of the University can evolve around the waste water treatment facility (biological and chemical water quality monitoring, mechanical maintenance works, maintenance of plants etc.) enhancing its educational character
- Setting a good example for other Universities and Institutions
- Creating an aesthetically pleasing environment
- Marketable products can also occur (e.g. sludge, flowers, fish)

Among others, designers of ecological wastewater treatment are Worrell Water Technologies, Living Technologies Ltd., Biomatrix Water, Dharma Living Systems and BioPetroClean. In The Netherlands, the Noorder Dierenpark Zoo, in Emmen, was equipped with a living machine that treats the wastewater originating from visitors and the maintenance needs of the zoo.

6.2.3.9 Rainwater harvesting

The last measure proposed as part of Strategy III deals with the possibility to harvest rainwater. As water treatment measures usually have long pay back times (due to the low cost of water), a more cost effective option can be sought, and BK City's attic offers an excellent opportunity for rainwater collection.

[57] 15 liters per flush * 4.000 flushes per day
[58] 0,13Kwh/1000 lit/day (210)
[59] 3,68m^2 for 1000 lit/day (210)

Interestingly, as de Graaf points out, in The Netherlands little has been done towards rainwater use. Reasons for this might be the non supportive government policy, as well as the '*perceived abundance of water*' (181).

However, the Julianalaan building is suitable for rainwater harvesting due to its large roof area and the high non-potable water consumption, compared to other types of buildings (e.g. residences). A header tank gravity system will be designed, which is relatively simple and water will be available even during power cuts (*see figure 96*).

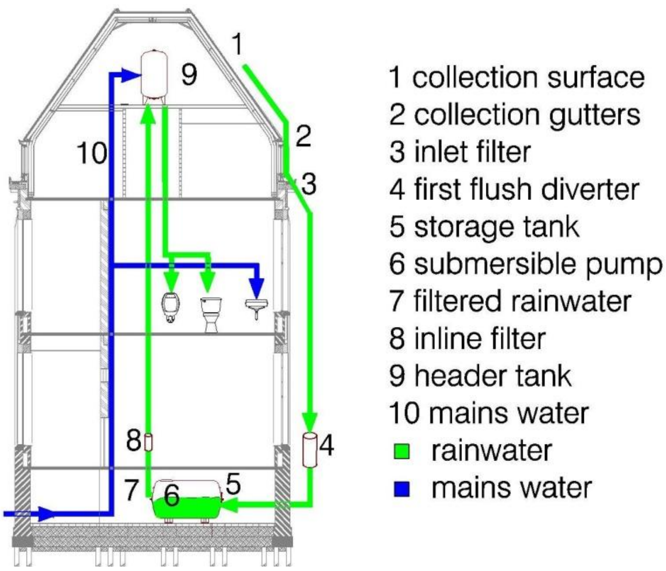


Figure 96 The rainwater harvesting concept

Several capture points will lead the stormwater from the collection surface through primary filters (solids such as leafs, debris etc. will be captured) into the storage tanks located in the basement. First flush devices will ensure that the water from the first spell of rain will not enter the tanks (air and roof pollutants are in high concentrations). Smooth flow into the tanks has to be ensured so as to prevent sediment (that rest at the bottom of the tanks) mixing and water contamination. The sectional (storage) tanks can be manufactured from a variety of materials and will comprise of modular panels that will be connected together on site in order to allow flexibility in their shape and size. Water will be fed to the header tank with the help of submersible pumps. Switching to mains water supply, during dry periods, should, also, be possible with the use of automatic valves. When needed, the water will be extracted from the tanks and driven through conventional plumbing systems to the points of use through gravity forces. The low pressure means that WC's will fill slowly, but the use of extra pumps will be avoided. Syphoned systems are, also, available that suck the water from the roof to the storage tank, in case gravity flow is not enough, or requests a complex piping network.

The annual collection will be estimated with the simple formula:

RW_{ANNUAL} [liters] = Roof Area [m^2]*Annual Rainfall [mm]*Filter efficiency*Run-off coefficient

roof area = 7200m^2 (effective collection area, only the stone slate roof is taken into account)
annual rainfall = 834mm (weather station *Zestienhoven*, 1957-2010, (82))
filter efficiency = 90% (191)
run-off coefficient = 75% (for pitched, slated roof (191))

$\Rightarrow RW_{ANNUAL} = 4.053m^3$

For sizing the tanks a rule of thumb is to design for a 5% of the annual rainwater supply (191), (196), i.e. 200m^3 should be sufficient. The annual water consumption for BK City was around 5.500m^3 for year 2009, from which an estimated 70% is needed for amenities (toilets, kitchenettes etc.), i.e. 3.850m^3. The large water volume that is stored could be partly used for fire fighting.

Apart from prevention measures (water treatment and/or rainwater harvesting), *curing* measures should also be taken which aim at reducing water consumption such as dual flush WC's and aerated taps for personal washing and kitchen uses.

6.2.3.10 Synopsis

An overview of Strategy III and the proposed measures is provided in the following image. The measures have been classified as in *§6.1 A pallet of measures for BK City*.

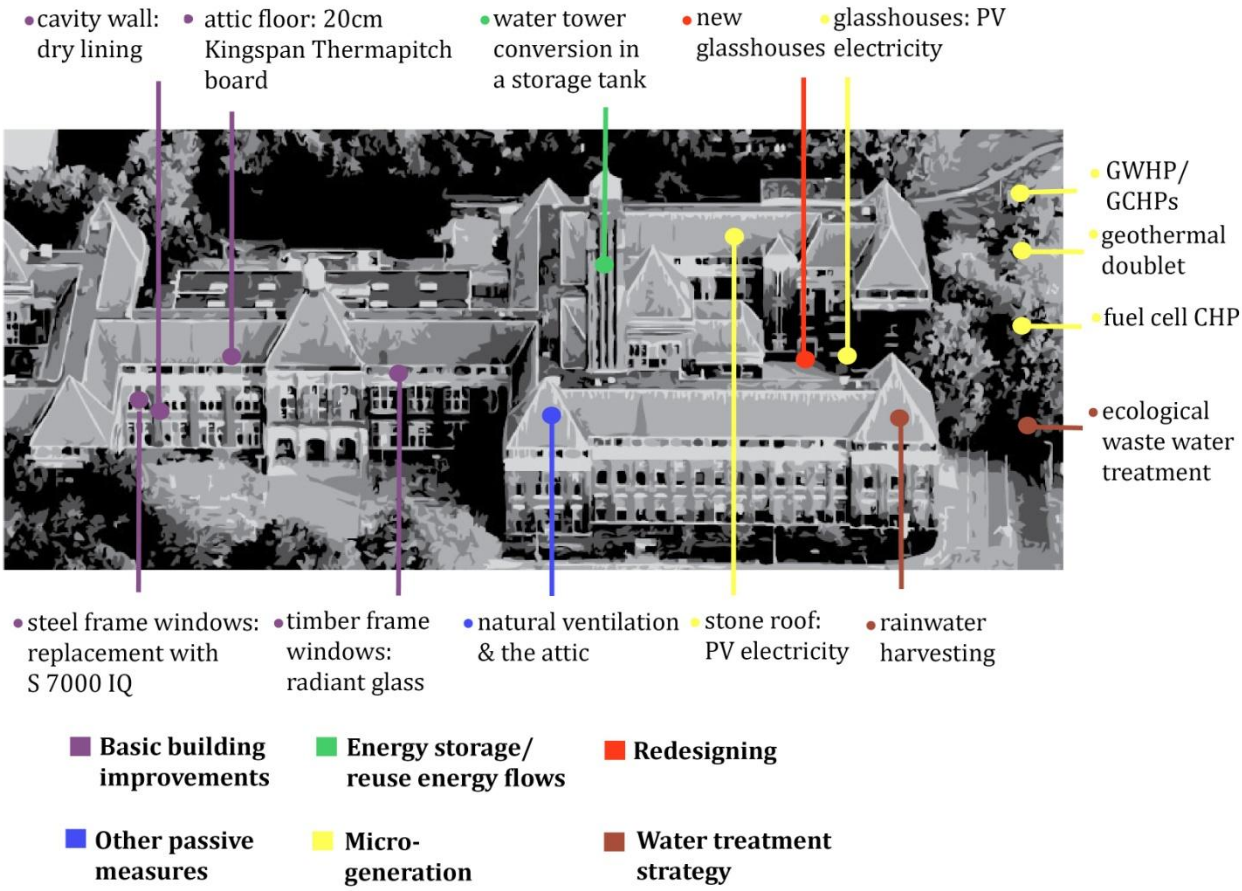


Figure 97 Overview of Strategy III

7 Valuation of refurbishment actions

In this chapter an effort is made to evaluate several refurbishment actions on BK City. For this purpose, a reference building was simulated and the heat load transfers were calculated for the period of one year. This enabled to determine the necessary heating and cooling capacity required to maintain the prescribed indoor climate conditions. It was by no means attained to simulate the actual performance of BK City, as this was unrealistic with the tool used. Instead, the reference building will serve as a comparison model for the improved situations.

7.1 The tool

Time restrictions did not permit the precise dynamic simulation of the building as a whole. However, a simple calculation still gives some insight into the order of magnitude of the effect of different measures. Excel was considered a sufficient tool, provided one is aware of the restrictions that follow from this choice. These, along with the necessary assumptions, are described in the next paragraph.

7.2 Assumptions and restrictions

Assumptions for reference building		
U values [W/m²K]	brick façade	1,17
	basement floor	3,59
	ground floor	2,46
	glasshouse floor	0,63
	second floor roof	0,64
	attic roof	3,11
	steel frame openings	5,90
	timber frame openings	3,50
Ventilation	occupancy [m²/p]	12[60]
	mechanically ventilated parts [m²]	24.106[61]
	naturally ventilated parts [m²]	2.890
	fresh air requirements [m³/p/hr]	35
	mechanically supplied air temperature [°C]	20
Infiltration	rate for BK old building [ACH]	1
	rate for glasshouses [ACH]	0,2
Temperatures [°C]	indoor (winter - summer)	20 - 24[62]
	basement[63]	15
	ground	9
	attic	outdoor
Internal gains [W/m²][64]	people	6,7
	lighting	12
	equipment	15
Solar gains	g values window (glass & frame)	0,5 – 0,8
	g values shading devices	0,2 – 1

Table 38 Assumptions made for the reference building

[60] Building class B3, according to Dutch national regulations
[61] See also **§5.4.2.1 Ventilation**
[62] When outside temperatures are between 20-24°C indoor temperature has been assumed equal to outdoor
[63] Placed outside the building envelope, see also **§6.2.1.1 Thermal skin**
[64] According to CIBSE guide A

The building that serves as a reference is 'ideal' with regards to its indoor climate, i.e. it is assumed that all requirements are fulfilled (indoor temperature, relative humidity, fresh air requirements[65] etc.), which is not true in reality. The building envelope, however, *is* an approximation of BK City's actual envelope (surface areas, materials, U values, airtightness etc.). Finally, it has been assumed that the building is not fully functioning for a period of 40 days during summer holidays (10 July – 20 August).

Table 38 shows some of the assumptions that were made for the calculations (more information on the calculations can be found in Appendix II).

When using excel to set up the simulation model, only a static calculation can be achieved. From this, a series of restrictions follow:

- Very simple boundary conditions are assumed
- The heat transfer coefficients are constant
- The thermal mass and the heat storage (as a function of time) of the elements is not taken into account
- Ignoring the interaction between heat gains and thermal mass (absorption and re-radiation) usually leads to excessive cooling loads
- The heat capacity of air is ignored
- The indoor air temperature is considered constant and temperature gradients are ignored
- The dependence of the natural ventilation on the wind speed and wind direction is not taken into account

As is understood, not all variables can be altered to verify their impact. For example, replacing the energy generation or distribution means cannot be evaluated nor can the effect of a BMS controlled strategy.

7.3 Formulas used

The following formulas have been used[66]:

	Equation	Variables
Transmission losses [W]	$U*A*(T_i-T_o)$	U: heat transfer coefficient A: surface area T_i: indoor air temperature T_o: outdoor air temperature
Ventilation losses [W]	$m_V*C_P*(T_i-T_o)$	m_V: mass flow rate C_P: specific heat of air
Infiltration losses [W]	$m_i*C_P*(T_i-T_o)$	m_i: mass flow of infiltration air
Solar gains [W]	$\Sigma(P_{sol}* A_W*g_W*g_S)$	P_{sol}: total incident solar radiation (diffuse and direct) A_W: surface area of opening g_W: solar factor of opening (glass and frame) g_S: solar factor of sun shade

Table 39 The formulas used in the calculation

The weather data used is from the De Bilt reference year 1964-'65. For the calculation of the mechanical ventilation the Mollier diagram was used – the delivered air is assumed to have a temperature of 20°C and a relative humidity of 50%.

[65] Only a 60% will be assumed for the calculations
[66] These are suitable only for rough estimations

7.4 Results

7.4.1 The reference building

With the above mentioned assumptions and the U values of the existing building envelope, the following results were found:

	max [kW]	total annual [MWh]	AHU [MWh]	total surface area [m^2]	total energy [kWh/m^2]
heating demands	1.638	2.845	1.735	26.997	169
cooling demand	1.890	1.738	174		70

Table 40 Reference building energy consumption

As seen in the table above, *cooling requirements* have also been calculated, whereas the building currently has no means of cooling the indoor air. The cooling energy is surprisingly high, when considering that only minor overheating problems have been reported (see *§5.4.3*) in BK City. This demonstrates the inherent inability of static models to take into account the effect of the thermal mass, which becomes more misleading in buildings with high thermal mass such as BK City. Finally, the cooling load is also overestimated, due to the assumed indoor temperature of 20-24°C.

The deviation from the actual *heating* energy requirements of BK City (3.802MWh as opposed to the calculated 4.580MWh) can be attributed to the following parameters:

- according to the assumptions, the building has a non flexible set temperature of either 20°C in winter or 24°C in summer
- constant presence of people is assumed
- the temperature of the air provided through mechanical ventilation is constantly at 20°C
- the relative humidity of incoming air is also assumed to be controlled (AHU calculation), which is not true for the actual building

The following chart depicts the various components of the heat demand calculation (losses and gains). These should serve only as an *indication* of the contribution of each component to the final result.

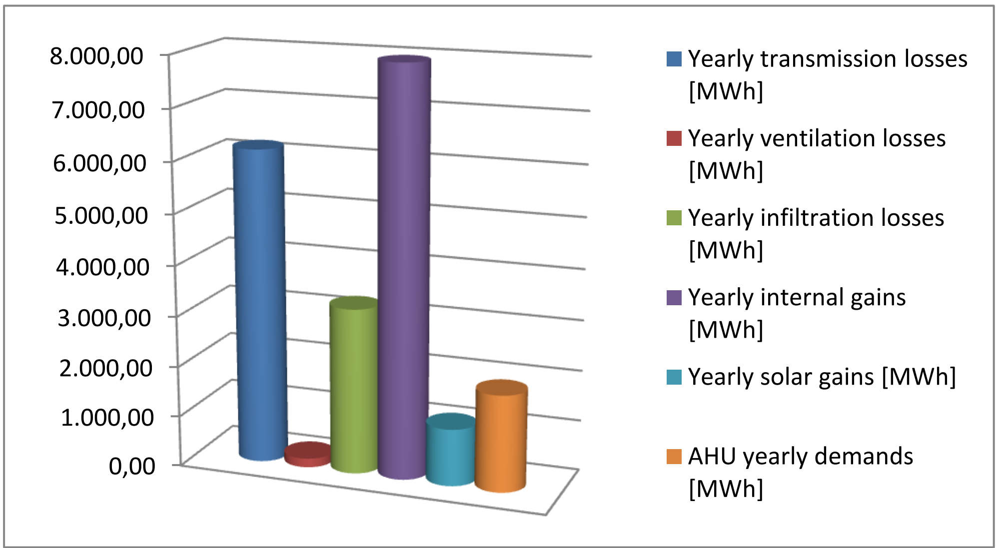


Chart 10 The various components of the heating/cooling demand calculation

As expected, the largest impact is attributed to the internal loads, which is a common characteristic of university and office buildings due to the IT equipment and the lighting needs. The high transmission losses should be attributed to the poor insulation of BK City.

7.4.2 Insulating the building envelope

One of the basic improvement measures in most refurbishment projects is the enhancement of the insulation of the exterior fabric. This has been included in both Strategy I and III. Following, are the predicted results of these measures (*table 41*).

	U values [W/m^2*K] facade	ground floor	heating load [kWh/m^2]	cooling load [kWh/m^2]	heating capacity [kW]	cooling capacity [kW]
Existing situation	1,17	2,46	169	70	1.638	1.890
Strategy I	0,28	1,02	130	85	1.288	1.932
Strategy III	0,14	1,02	125	86	1.244	1.920

Table 41 Impact of post insulation measures on the energy demands of BK City

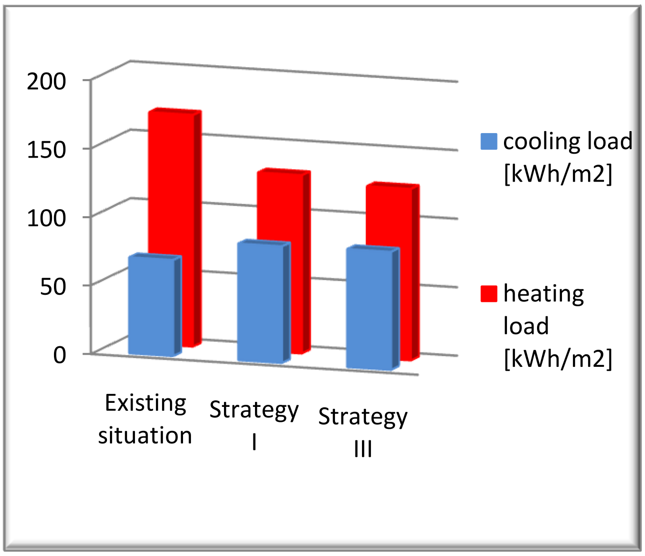


Chart 11 Impact of post insulation measures on the energy demands of BK City

The results demonstrate how important it is to improve the performance of the envelope of old and obsolete structures. According to the calculations, this measure can result in a 23% reduction of the heating demands (Strategy I). The cost effectiveness of post insulation seems to have a threshold, beyond which further improvements of the fabric, though expensive, will not yield impressive savings (Strategy III).

Notable is, also, the apparent increase of the cooling demands, which is a particularity of moderate climates, such as the Dutch one. In a warmer climate, where high outdoor temperatures are more common, enhanced insulation will, indeed, reduce the cooling demand.

Finally, it is impressive how the heating *capacity* is reduced for both Strategies. This will, in effect, reduce the acquisition and installation cost of the energy generation means (whether that is a heat pump, boreholes or a CHP plant). Furthermore, less space will be occupied by the machinery, less storage area will be needed for the fuel, the operation costs will drop and, finally, the storage of energy will be more effective.

7.4.3 Treating the windows

In BK City, despite the complications, it has been shown that *it is* possible to improve the performance of the glazed surfaces. The effect of the measures elaborated in the three Strategies (the rest of the building envelope remains obsolete) is shown in the following table.

	U values [W/m^2*K] steel frames	timber frames	heating load [kWh/m^2]	cooling load [kWh/m^2]	heating capacity [kW]	cooling capacity [kW]
Existing situation	5,9	3,5	169	70	1.638	1.890
Strategy I	3 – 4,5	1,8	135	78	1.300	1.800
Strategy II	2,5	1,5	129	80	1.240	1.786
Strategy III	1,2	0,04	113	85	1.068	1.740

Table 42 Impact of window strategies on the energy demands of BK City

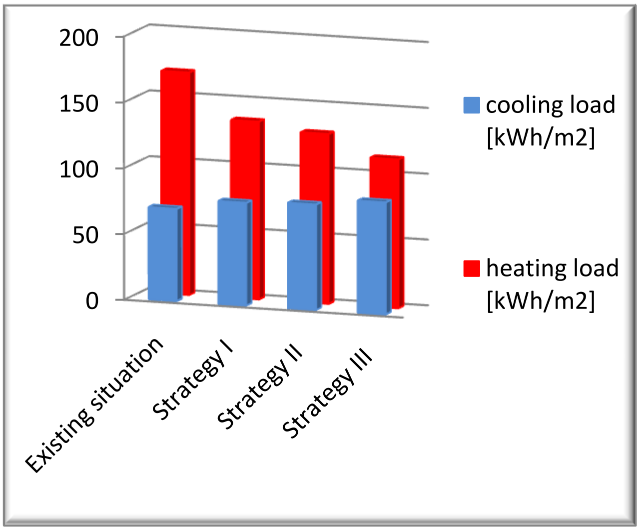


Chart 12 Impact of window strategies on the energy demands of BK City

The results are similar to the ones achieved through the insulation of the walls and roof. The large impact the openings have on the energy demands can be explained by the large glazed surface areas of BK City and the very poor U values of the existing windows (even for the modest U values of Strategy I, a 20% reduction in heating demands is calculated). Capacities are also impressively reduced (35% reduction in heating capacity for Strategy III). The extremely low U value achieved for the timber frames (Strategy III) will require some consumption of electricity but this will be given back to the spaces as radiant heat.

7.4.4 Improving the airtightness

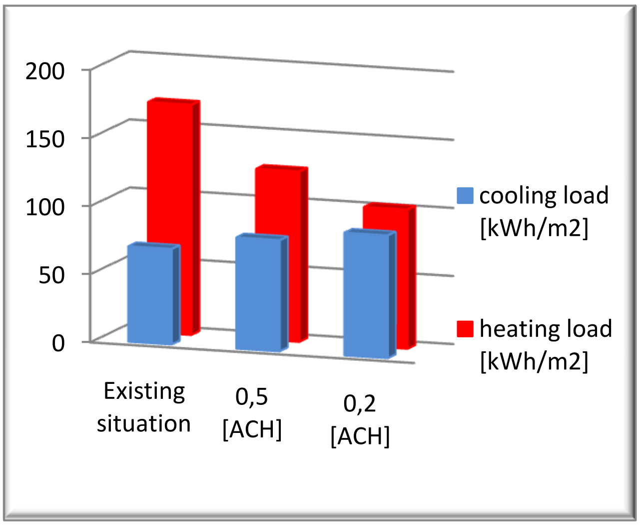
An accurate sizing of the heating and cooling design loads depends on the proper estimation of the airtightness of the building and the amount of air that penetrates the exterior fabric through cracks, and slits. An air leakage test should be carried out for a more precise calculation.

In any case, the efficiency of the refurbishment measures strongly depends on the limitation of air infiltration, while the ventilation strategy is also interconnected with the airtightness strategy.

The following table demonstrates the influence of air-sealing measures (Strategy I). Two values of infiltration rates have been examined, as actually achieving an extremely airtight structure (0,2 ACH) is quite difficult. Besides, PassivHaus standards require a rate of less than 0,6 ACH.

	infiltration rate [ACH]	heating load [kWh/m^2]	cooling load [kWh/m^2]	heating capacity [kW]	cooling capacity [kW]
Existing situation	1	169	70	1.638	1.890
Strategy I	0,5	125	81,5	1.200	1.775
	0,2	102	90	940	1.700

Table 43 Impact of air tightness measures on the energy demands of BK City



This time the results are rather impressive. The heating load has decreased by 26% and 40% (for 0,5 and 0,2 ACH respectively) while the heating capacity is nearly halved (0,5 ACH). On the other hand, the cooling loads have increased. This effect can be mitigated by a series of measures that are examined in following paragraphs.

Chart 13 Impact of air tightness measures on the energy demands of BK City

7.4.5 Enhancing solar protection

Crucial to the calculation of the solar heat gains are both the openings (glass surface) and the available shading device. This effect is expressed by the solar heat gain coefficient – the lower the number the more effective the protection is.

For example, external shading devices have a lower coefficient as they stop the solar radiation before it even enters the building. On the other hand, curtains, blinds and louvers installed on the inner side of the walls allow radiation to enter and heat up the surfaces as well as the air that is trapped between them and the wall. However, increasing the control over solar gains will have a negative impact on the amount of light that reaches the indoor space, while the visual impact of exterior blinds is not always desirable. The various types of glass that are used can also help in the effective solar protection of the building – low e coatings, solar control films etc. – without reducing so much the natural light levels.

The following table gives some indication on what degree these measures can affect the yearly loads[67].

		g values						heating load [kWh/m²]	cooling load [kWh/m²]	heating capacity [kW]	cooling capacity [kW]
		steel frames		timber frames		glasshouse					
		ext. blinds	int. blinds	ext. blinds	int. blinds	facade	rooflights				
Existing situation	glass	0,8	0,8	0,7	0,7	0,5	0,5	169	70	1.638	1.890
	shade	0,2	0,7	0,2	0,7	0,7	1				
Strategy I	glass	0,5	0,5	0,5	0,5	0,5	0,5	173	60	1.638	1.622
	shade	0,2	0,5	0,2	0,5	0,5	0,5				

Table 44 Impact of solar shading measures on the energy demands of BK City

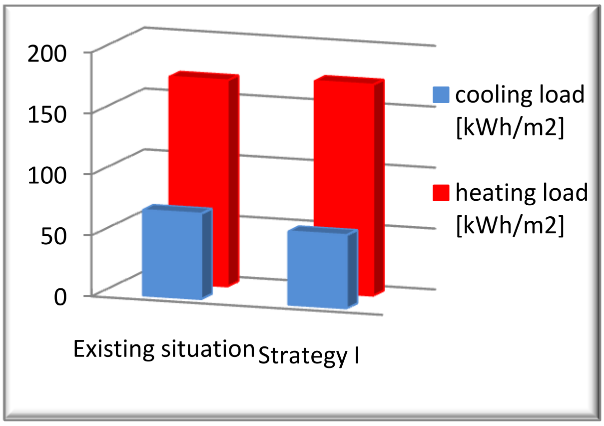


Chart 14 Impact of solar shading measures on the energy demands of BK City

As expected, the enhanced solar protection does not affect at all the heating demands while the cooling load and the peak cooling load are reduced by 15% (the internal heat gains seem to be the decisive factor here). The latter shows how this simple measure can reduce the number of overheating hours.

As mentioned previously in this research, the lighting levels have been measured and estimated as 'very good' while occupants have also expressed their satisfaction (see §*5.4.3 Indoor climate and comfort*). As a consequence, altering the current solar protection means should be done cautiously, as the overall effect of enhanced shading might prove less advantageous than expected.

7.4.6 Reducing the internal loads

With the current estimation, lighting and equipment in BK City account for a 12W/m² and 15W/m² internal load respectively. Ways to lower these loads have been examined in Strategy I (§*6.2.1.7 Energy saving through electric equipment* and §*6.2.1.8 Controls*). Table 45 and chart 15 depict the effect of applying such measures (the assumption made is that the total internal load is reduced to 30W/m² from 33,7W/m²).

[67] This way of calculating solar gains represents only a rough approximation. The same goes for the g values.

	internal load [W/m²]	heating load [kWh/m²]	cooling load [kWh/m²]	heating capacity [kW]	cooling capacity [kW]
Existing situation	33,7	169	70	1.638	1.890
Strategy I	30	188	60	1.738	1.791

Table 45 Impact of decreasing the internal loads on the energy demands of BK City

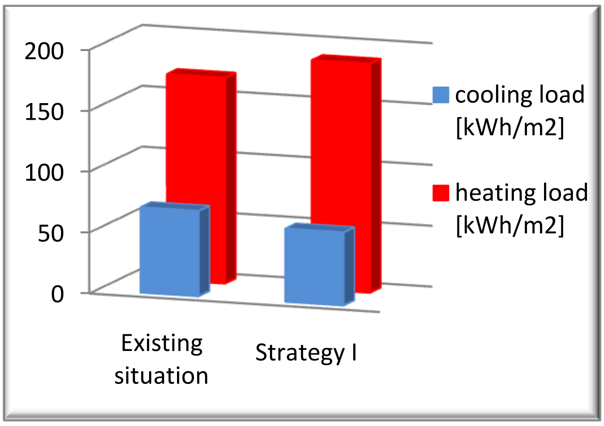


Chart 15 Impact of decreasing the internal loads on the energy demands of BK City

Measures that reduce the internal loads will affect both the heating and the cooling demand, in a negative and a positive way, respectively. The importance of internal loads in buildings with IT equipment and specific needs in lighting, such as offices, laboratories, universities etc., is well known and becomes even greater in new buildings that are designed to comply with high air tightness levels. Especially in temperate and hot climates, it is possible that office buildings will only need *cooling* provisions, as heating is covered by the internal loads.

7.4.7 Rationalizing the set temperatures

Till now, it has been assumed that the building has a non-flexible indoor temperature of either 20°C during winter or 24°C during the hot months. However, as explained in §*6.2.2.6,* the adaptation of building occupants to the external environment (e.g. clothing) and the availability of local controls may significantly affect the range of temperatures for a comfortable indoor environment. Additionally, the mechanically incoming air is provided at a constant of 20°C which, in the actual building, has caused complaints related to overheating (see §*5.4.3*).

Now, a more rational approach is attempted by allowing maximum temperatures to reach 28°C, while the temperature of the incoming air is lowered to 18°C. The results are as shown in table 46 and chart 16.

The calculations show that only minor changes should be expected from these measures. These will, however, improve both the heating and the cooling demands with zero extra costs. Adapting the set temperature to a maximum of 28°C during summer[68] might not prove to be a radical measure, as the number of hours during which outdoor air is very hot in The Netherlands is very limited (T_{ext} > 28°C for 0,1% of the time).

	heating load [kWh/m²]	cooling load [kWh/m²]	heating capacity [kW]	cooling capacity [kW]
Existing situation	169	70	1.638	1.890
Rationalizing set temperatures	157	68	1.666	1.662

Table 46 Impact of rationalizing the set temperatures on the energy demands of BK City

[68] For an exterior temperature between 20°C – 28°C, indoor temperature has been assumed equal to outdoor. For higher outdoor temperatures, indoor temperature is assumed equal to 28°C

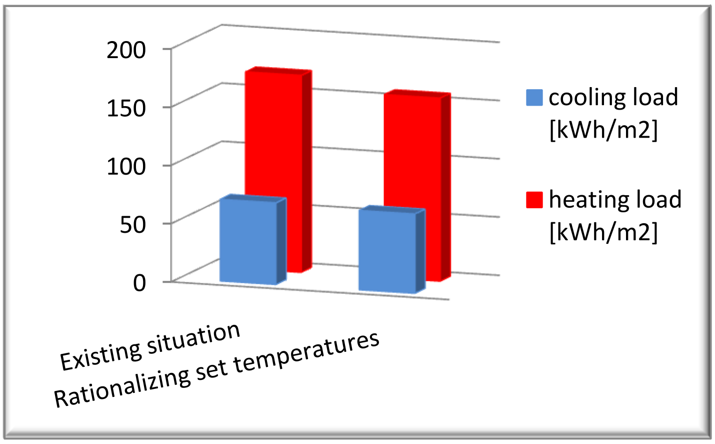


Chart 16 Impact of rationalizing the set temperatures on the energy demands of BK City

7.4.8 Combining 'basic' measures

The measures evaluated till now are all considered as 'basic' due to their simplicity, cost-effectiveness and straightforward philosophy. After having investigated the effectiveness of each one separately, this paragraph examines their cumulative effect. In other words, what will happen if we apply them successively to BK City – the order by which the measures appear in the calculations does not imply the actual implementation order.

After having improved the insulation of the building (Strategy I), vacuum glazing is applied to the steel-frame windows, while the timber-frame windows are entirely replaced (Strategy II). Next, cracks and slits are sealed (airtightness rate = 0,5 ACH) and the solar protection of the building is enhanced to reduce the cooling loads (as in table 44). Additional measures to improve the performance during summer are the reduction of the internal loads to 30W/m^2 by using low energy equipment, and the rationalization of the maximum allowed temperature (28°C) in the rooms and the temperature of the incoming air (18°C).

It should be noted that all mentioned measures are *realistic*, e.g. Strategy I was selected as the insulation alternative (and not the more ambitious Strategy III), Strategy II for the windows, an achievable airtightness rate was chosen, and so forth.

Chart 17 and 18 depict the progressive improvement of BK City as the measures are applied (to evaluate the distinct contribution of each one) as well as the end result (when all measures have been applied).

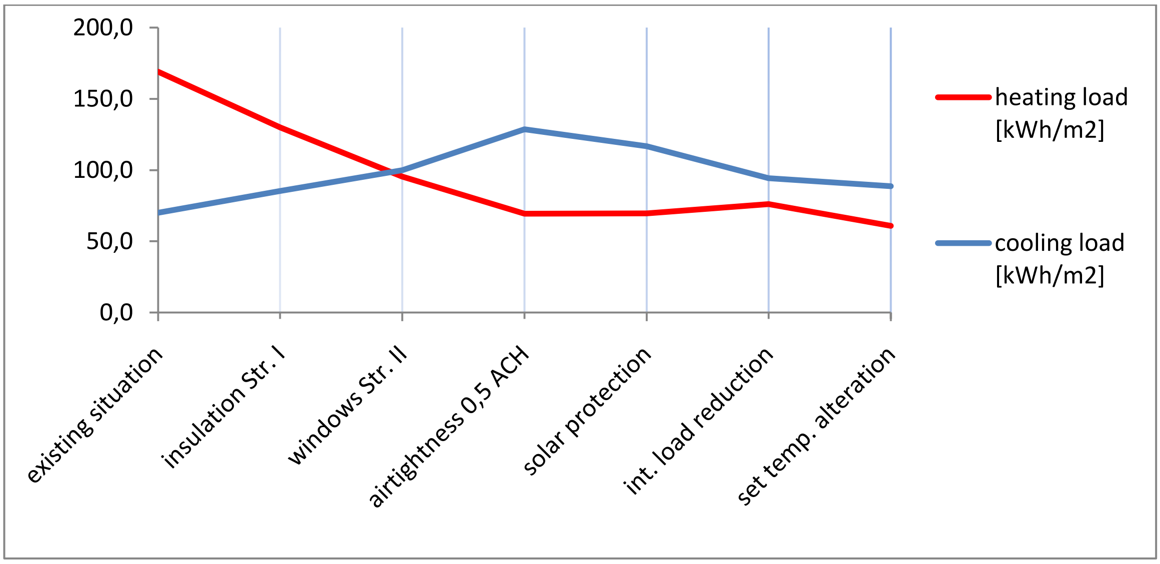


Chart 17 The cumulative effect of some 'basic' measures on the energy demands of BK City

The results manifest the value of the so-called 'basic' measures. Huge savings (64% in heating demands) can be achieved by applying them, while the necessary expenses are kept at very low levels. The cooling load, as depicted at the end of the scenario, is relatively close to the cooling demand assumed originally, which, as argued in *§7.4.1*, is not actually needed (in today's building). It is expected that a dynamic calculation will estimate it more accurately, while a smart combination of night ventilation and the mass of BK City can render mechanical cooling means unnecessary. If, eventually, there is still a need for cooling, this can be easily provided by heat pumps and an underfloor heating system (see *§6.2.2* and *§6.2.3*).

The above results are significant for one more reason. They demonstrate that, even if some measures, when implemented *alone* have no significant effect, they might be valuable when they are combined within a *package* of measures. For example, the adaptation of the indoor allowed temperatures and the provision of cooler than 20°C air seemed insignificant by themselves (§*7.4.7*), but are valuable alongside other interventions. The same is true of the solar protection enhancement. The conclusion is that the choice of a package of measures needs to be done wisely, taking into account all the parameters affected, otherwise, the risk of creating new problems and/or increasing the already existing ones is considerable.

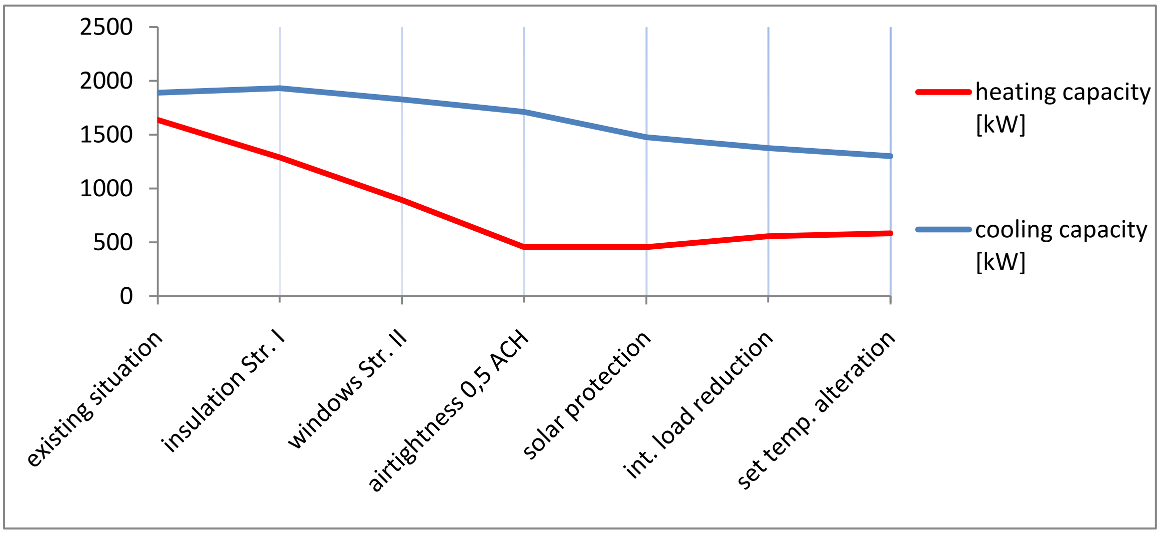


Chart 18 The cumulative effect of some 'basic' measures on the maximum heating and cooling demands for BK City

Chart 18 confirms the beneficiary effect of this package of interventions. Both the heating and the cooling capacity have been drastically reduced (by 64% and 31% respectively) which will reduce investment and operation costs for the new equipment and, also, the space occupied by the equipment and the fuel.

7.4.9 Applying heat recovery and increasing the ventilation rate

One of the main benefits of mechanical ventilation is the possibility it offers, provided mechanical *exhaust* is also existent, to apply an air heat recovery system (see §*6.2.1.6 Ventilation concept*). Depending on the efficiency of the heat recovery mechanism (up to 95%) the heat losses can be diminished. For the calculations, a heat recovery efficiency of 90% will be assumed.

Recovering heat from the exhaust air will allow the increase of the amount of provided air, so that the needs in fresh air are fully covered. Providing abundant fresh air is very important in buildings with high internal loads and high particle concentrations – these buildings usually suffer from the Sick Building

Syndrome[69]. The Faculty of Architecture seems to have similar issues, as high levels of CO_2 have been measured in certain spaces, while users have characterized the air quality as 'poor' (see §*5.4.3*). Besides, refurbishment scenarios, usually, include high insulation standards combined with strict weatherstripping measures. Issues that arise from such efforts are commonly:

- increased risk of overheating
- high indoor relative humidity
- increased risk of condensation on cold surfaces (thermal bridges, corners etc.)
- increased pollutants' concentrations

As mentioned already, increased ventilation rates can tackle several of the aforementioned issues. One should be aware, however, that, by increasing the ventilation rates above the necessary, the occupants will complain for excessively dry conditions, while the unavoidable ductwork will take up valuable space. For the calculations, the assumption is that the fresh air requirements in BK City are fulfilled (as estimated: $35m^3$/p/hr).

The results of the calculations are shown in table 47 and chart 19.

#		heating load [kWh/m²]	cooling load [kWh/m²]	heating capacity [kW]	cooling capacity [kW]
1	**Existing situation**	169	70	1.638	1.890
2	**Heat recovery (90%)**	112	65	1.638	1.941
3	**Heat recovery & increased ventilation rate**	119	65	1.668	1.945

Table 47 Impact of heat recovery and increased ventilation rates on the energy demands of BK City

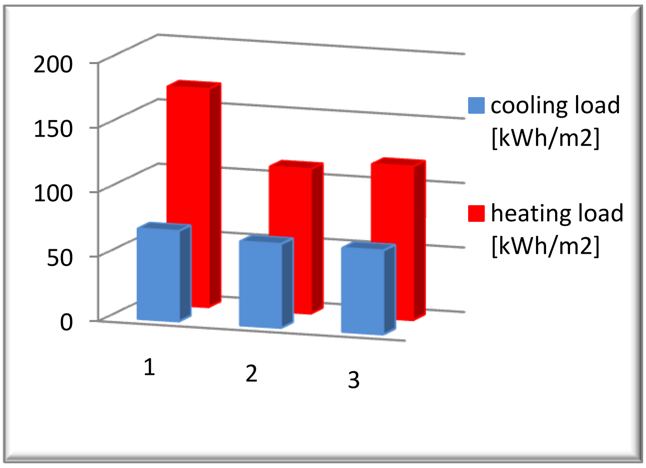


Chart 19 Impact of heat recovery and increased ventilation rates on the energy demands of BK City

The results show that even without enforcing any other refurbishment measures, heat recovery, on itself, will bring about significant savings in heating demands (33%) and a minor decrease of the cooling load (7%). These seem to be high enough to counterbalance the electricity needed to drive the exhaust and supply ventilators. Furthermore, the high efficiency of the heat recovery system allows the increase of the ventilation rates to ensure indoor air quality, without compromising the low energy consumption targets.

7.4.10 Applying natural ventilation

Now it is assumed that *all* necessary fresh air is provided through natural ventilation. This solution has been elaborated in §*6.2.3.3 Natural ventilation concept and the attic*. The results are shown in the

[69] *'The term "sick building syndrome" (SBS) is used to describe situations in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building, but no specific illness or cause can be identified'* (211).

following table (note that in the existing building most of the ventilation comes from mechanical supply – see §*5.4.2.1 Ventilation*).

	natural ventilation rate [kg/s]	heating load [kWh/m^2]	cooling load [kWh/m^2]	heating capacity [kW]	cooling capacity [kW]
Existing situation	2,8	169	70	1.638	1.890
Natural ventilation	26,2	146	58	2.017	2.047

Table 48 Impact of providing fresh air only through natural ventilation on the energy demands of BK City

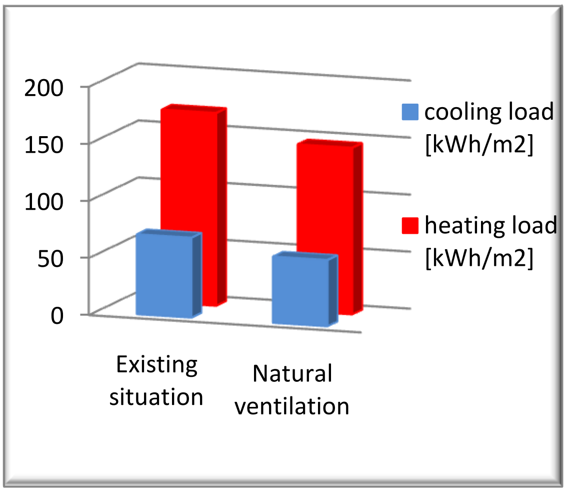


Chart 20 Impact of providing fresh air only through natural ventilation on the energy demands of BK City

The results indicate that natural ventilation can be beneficial for BK City, as the huge amount of energy needed to treat the air mechanically seems to be more significant than the losses brought about when fresh air from outside is directly drawn inside the building. The high internal loads also seem to be a crucial factor in this respect.

On the other hand, a 100% natural ventilation scheme requires very well thought-of design and its effectiveness in real situations is doubtful for a building with large spaces and a complex layout as BK City. Moreover, relying solely on natural ventilation is not a viable prospect for lecture halls with abrupt changes in fresh air demands and large crowd gatherings. The same goes for technical rooms, especially if facing towards the south.

7.4.11 Adding more space

Two sections of this research have explored the possibilities of increasing the floor space to meet the increasing demands of the Faculty. This paragraph will only deal with the conversion of the attic into a student area (§*6.2.2.1 Converting the attic into a student area*), while the drawn conclusions can be similarly used for the glasshouse additions.

For the calculations it was assumed that the attic roof is well insulated (U=0,35W/m^2*K), airtight (0,2ACH), energy efficient equipment is used (internal load=30W/m^2) while mechanical ventilation is provided. The results are shown in table 49 and chart 21.

	heating load [kWh/m^2]	cooling load [kWh/m^2]	heating capacity [kW]	cooling capacity [kW]
Existing situation	169	70	1.638	1.890
Attic conversion	134	99	1.572	2.181

Table 49 Impact of converting the attic into a student space on the energy demands of BK City

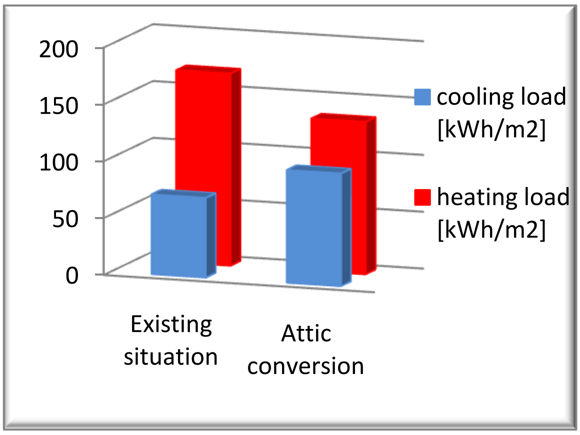


Chart 21 Impact of converting the attic into a student space on the energy demands of BK City

Expanding the usable area has resulted in the paradoxical, at first sight, reduction of the heating demand (by 20%). However, we shouldn't forget that the attic has been assumed as efficient (in terms of insulation, airtightness etc.) and the results are expressed per surface area. Additionally, converting the attic, takes away all the losses that occurred from the obsolete ceiling of the second floor of BK City. Lastly, the outcome is also a result of the extra internal loads that have been added, parameter which is expressed in the increase of the cooling demands.

7.4.12 Résumé

In this paragraph a final package of interventions on BK City is evaluated. The criteria for the selected measures were, first, their efficiency and, second, the possibility of realization (i.e. only reasonable measures have been chosen). The measures are being applied progressively, simply to highlight the contribution of each one to the final result. In this respect, the order by which the interventions appear is meant to reveal the *full extent* of each contribution, and does not imply anything further than this (such as time or priority issues etc.). Besides, the most important conclusion will be drawn from the end result, after the effect of all measures has been taken into account.

At first, the building is provided with the necessary space in the attic, as explained in §*7.4.11*. Then, the rest of the building is insulated according to Strategy I U-values, and the window policy of Strategy II is applied. These measures go along with sealing the envelope of the building (assumed infiltration rate 0,5 ACH). To deal with the increasing cooling load, the range of allowed temperatures becomes more flexible (maximum 21°C and 28°C for winter and summer respectively, see also §*7.4.7*), while enhanced solar protection is also provided. The assumed ventilation scheme comprises of 40% mechanical ventilation with heat recovery (for spaces such as lecture halls, computer spaces etc.) and 60% natural ventilation for the rest of the building. To decrease even more the cooling demand the internal loads are lowered by 3W/m^2.

The results of the described above process are shown in chart 22. These are compared with the PassivHaus standards for both new constructions and renovated buildings, and with the lower energy-renovation standards (112). The current heating demands of the building are also shown, in order to have an idea of the accuracy of the initial assumptions.

The end result illustrates, apart from how wasteful BK City is today, the huge possibilities that lie in its refurbishment. Even more so, if we consider that, for all proposed interventions, a modest level of efficiency has been assumed. Of course, the numerical values should be treated as *indicative* figures, as they are a very rough representation of reality. A more detailed dynamic simulation of the building and some reference rooms should take place to better appreciate the effectiveness of the various measures.

Even so, useful guidelines can be deduced. For example, reaching close to PassivHaus levels *is* possible, by insulating tightly and sealing the gaps. This might give rise to overheating issues, which can cause serious comfort problems, while it shouldn't be neglected that cooling is much more costly than heating a building. Despite the inherent incapability of a static model to assess the cooling loads[70], the

[70] Furthermore, a constant generation of internal gains for 24 hours a day has been assumed

calculations show that, with the right combination of measures, they can still be decreased to low levels – in our case, very close to the originally assumed cooling demands, which in the actual building are not even provided. In this respect, a variety of *passive* measures can be further investigated:

- solar protection in specific rooms
- enhancing the role of thermal mass (exposing concrete surfaces, adding PCM materials etc.)
- further reduction of the internal gains
- increased natural ventilation rates
- extended use of night cooling
- more flexible range of allowed temperatures
- adapting appropriately the layout of the building etc.

The effectiveness of passive measures is even greater, if we take into account that, according to the calculations, a large amount of cooling loads is needed during winter, even for hours when the outside air temperature is 10°C (!). For spaces with high internal loads or large crowd gatherings, *mechanical* means should be foreseen to ensure a better control of the indoor air, independently of the outdoor environment. If, after all these measures, cooling is still needed, it is expected that an underfloor cooling system will suffice to provide a comfortable indoor environment. As seen previously, feeding an underfloor cooling system can be easily done with renewable and very low-CO_2-emission means. In any case, a right balance between heating and cooling demands needs to be found.

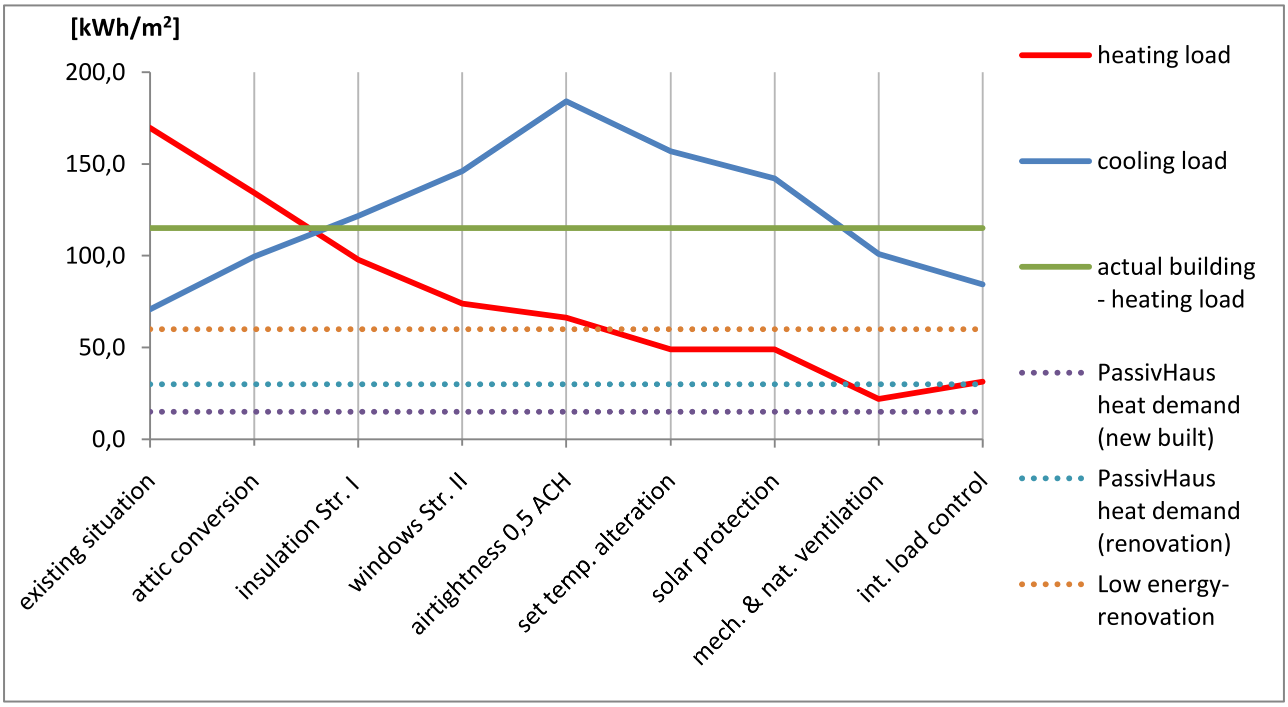


Chart 22 The cumulative effect of selected measures on the heating and cooling demands of BK City

8 Closing remarks

8.1 Conclusions

The starting point of this research was the acknowledgement that, as part of a more general trend towards the energy-driven refurbishment of historic buildings, the building that houses the Faculty of Architecture at TU Delft is in need of a sound refurbishment scheme, that will balance the dual challenge of a sustainable building and the need to protect its monumental character. In order to attain the main objective of the research, i.e. to propose a refurbishment strategy for BK City, several sub-questions had to be answered.

The study started out by exploring the concepts of a) sustainability, b) refurbishment and c) historic buildings, and how these are linked. After having set out the framework of the sustainable refurbishment of historic buildings, in terms of legal, ethical and procedural aspects, a list of refurbishment measures was provided, based on the most widely accepted energy approaches.

The next sections were an overview of refurbishment in European countries. First, the age of the existing European building stock was examined (according to the figures, a 28,8% of the residential building stock is more than 65 years old, while the 60% of all non-residential buildings have been built before 1975) and, then, it was argued that the energy performance of a building is closely related to its time of construction. Most policies regulating energy efficiency standards were developed after the oil crisis of 1973, and it wasn't until the '90s that people started to be aware of climate change and its consequences. As a result, old buildings, comprising of an obsolete fabric, exhibit significantly low performance in terms of energy use and CO_2 emissions. One of the proposed solutions is, apparently, the refurbishment of a large part of these outdated buildings, the predictions for such strategies being very promising. This part of the research ended with a brief summary of the current status in four European countries with outstanding refurbishment policies, with the observation, however, that impressive outcomes are still lacking.

In the second part of the study, the spotlight was turned on the case-study building, BK City, which is situated in the western part of The Netherlands and dates back to the early 1920's. Necessary information concerning the building was presented, ranging from climatic and geographical data, to the milestones of its historical past. The building itself was described in detail, with regards to its layout and functions, with special reference to its distinguishing features (such as the original façade and the openings, the water tower and the stone slate roof) and the permissible interventions, as these have been defined by the Monuments' Department of Gemeente Delft.

An analysis of the physics of BK City was, also, carried out. The out-dated fabric and mechanical equipment of the building, it was argued, should be blamed for the poor indoor environment, in terms of air quality and indoor air temperature, despite the high energy consumption. The intention of this section was to identify the weaknesses of the building but, also, to point out its significance. The information collected here was necessary for the next phases of the research, specifically for the development of the refurbishment Strategies.

Before proceeding to specific proposals for BK City, it was essential to cluster all possible and suitable measures that have had a proven impact on previously refurbished buildings. For this reason, relevant showcases and good practice examples were investigated, ranging from the prominent 'Bussumse Watertoren' to the University campus of TU Eindhoven. A selection of the aforementioned measures was integrated in three refurbishment Strategies, each one of which takes a step further from the previous one. The proposals range from wall insulation alternatives to the use of fuel cell technology, with an increasing degree of expenditure costs, intervention level, implementation difficulties but, also, an enhancement of the anticipated outcome. The main target of the Strategies was to equally treat the energy demand, the waste flows, the sustainable energy resources and, lastly, the influence of the user on the indoor environment. Finally, the advantages and disadvantages of the various measures were presented, and application guidelines, along with specifications on market availability (where applicable).

To complete the research, it was necessary to evaluate the proposed interventions to the building. To this end, a model was set up in order to calculate the heating and cooling demands that will keep the indoor climate at comfort levels. The static nature of the model, along with the high sensitivity of the outcome to the initial assumptions, did not allow the comparison of the results with the figures of the actual building. However, the model was useful for comparing variants and succeeded in predicting the trends that would follow the implementation of the measures. In this sense, it served its purpose in providing guidelines. The main conclusions that can be drawn from the calculations are:

- The building, as is today, is *extremely wasteful*, thus, huge possibilities lie in its refurbishment.
- *Straightforward* and *simple measures* can offer cost-effective solutions for reducing the energy demands of BK City.
- Several measures when applied alone have minor effects on the energy profile. These, however, when combined in a *package of measures* can make a significant contribution.
- On the other hand, a package of measures needs to be carefully designed, otherwise the risk of *introducing new problems* or *increasing the existing ones* is considerable.
- *Stand-alone measures* exist that can, by themselves, bring about important savings. As such are mentioned the insulation of the envelope, the provision of natural ventilation, the application of heat recovery etc.
- Reaching close to *PassivHaus levels* is possible, but an energy neutral building seems unrealistic with the currently available technology.
- Sealing up the building to meet PassivHaus standards might give rise to overheating issues, which can, however, be dealt with effectively by applying *passive measures*.

The aforementioned conclusions all deal with energy consumption reduction. However, the energy provision issues, as these have been elaborated in the three Strategies but were not included in the calculations, need equal attention.

8.2 Further research

When looking back at the questions that this research has posed, these seem to have been answered, to a greater or lesser extent. However, there exist several issues that require further development and research. In this respect, further research might focus on the following:

- The demands on realizing the Strategies, in terms of *time* and *financial* issues.
- Detailed elaboration of each measure or Strategy, with regards to the *technical feasibility* and the interaction with *functions* and *layout* of the current building. For example, structural issues have, deliberately, been set aside in this research. In this sense, each proposed measure can form by itself a research topic, either in the context of the academic environment or a building technology office.
- *Precise calculations* for assessing the influence of each measure on the energy demands, the indoor climate and the environmental impact of BK City.
- To be more consistent with the term 'sustainability', more data is needed on the life cycle analysis of the used *materials* and, also, on the occurring *waste flows*. Forming closed cycles, as these are defined by the C2C approach is a challenging, but, achievable target.
- BK City's *particular elements* provide wonderful opportunities for sustainable energy applications and, thus, deserve meticulous attention. As such are considered the empty attic

space, the water tower, the flat parts of the roof and the decorative elements on the facade. For example, ways to turn the attic into an autonomous and zero energy consumption space can be investigated, or the integration of ventilation means in the decorative façade elements.

- Ways to involve the *users* in the operation of the building. This may include a more direct interaction with the energy consumption of BK City. For example, creating workspaces with automatic metering that will be accessible to a certain group of students, who will, in effect, be responsible for any consumption that occurs. Another scheme could involve the splitting up of the costs for the operation of an appliance among its users. The costs could then be broken down to direct costs and indirect ones (for instance, a coffee machine needs energy to produce a cup of coffee but, energy is, also, consumed for maintaining the water warm throughout the day or for harvesting and transporting the coffee beans). Becoming aware of our personal carbon footprint is crucial in order to adapt our activities and appreciate the value of the shared resources.
- Finally, how the refurbishment project of BK City can become the cornerstone of a *broader Governmental, Municipal* or *University refurbishment program* could be investigated. For example, a refurbishment scheme that involves other TUD Faculties or even the entire city of Delft. This will, moreover, make the claims for subsidies and financial support stronger.

8.3 Reflections

Since the decision was taken to extend the housing of the Faculty of Architecture in the Julianalaan building, a project group has been assigned with the challenging task of transforming BK City into an '*energy neutral and CO_2 neutral*' building. In this context, it is hoped that this research will act as a tool in the quest for '*smart solutions*'.

Beyond any doubt, BK City can reduce its energy consumption to an extent where it will be possible to provide the remaining demand with *only* renewable and low carbon energy. It is obvious that there is no perfect remedy, i.e. one that can ideally balance between the preservation of the character of the building and the goal of sustainability. This research has dealt with the scientific part of this dilemma, by analyzing the available options. The final decision seems to be, however, a 'political' one rather than a scientific one. In this sense, it should be clear what the main target of the refurbishment is: a firm statement in favor of Heritage Preservation or a contribution to the battle against Climate Change? With regards to this, the particularity of the building as a Faculty of a leading Technology University seems to tip the scales in favor of the latter, with the necessary preservation precautions taken, of course, into account.

Finally, a successful transformation of BK City can and *will* promote the idea of transforming much-cherished buildings into ecologically sound edifices. For this reason, a focus of attention for the present research has been the development of transferable generic solutions that can be applied in a variety of listed buildings. Especially in countries like The Netherlands, with a plethora of monumental buildings (churches, factories, castles, water towers etc.) and an increasing interest in their sustainable refurbishment, the outcome of a generalized refurbishment policy can make a real change to the built environment as we know it today.

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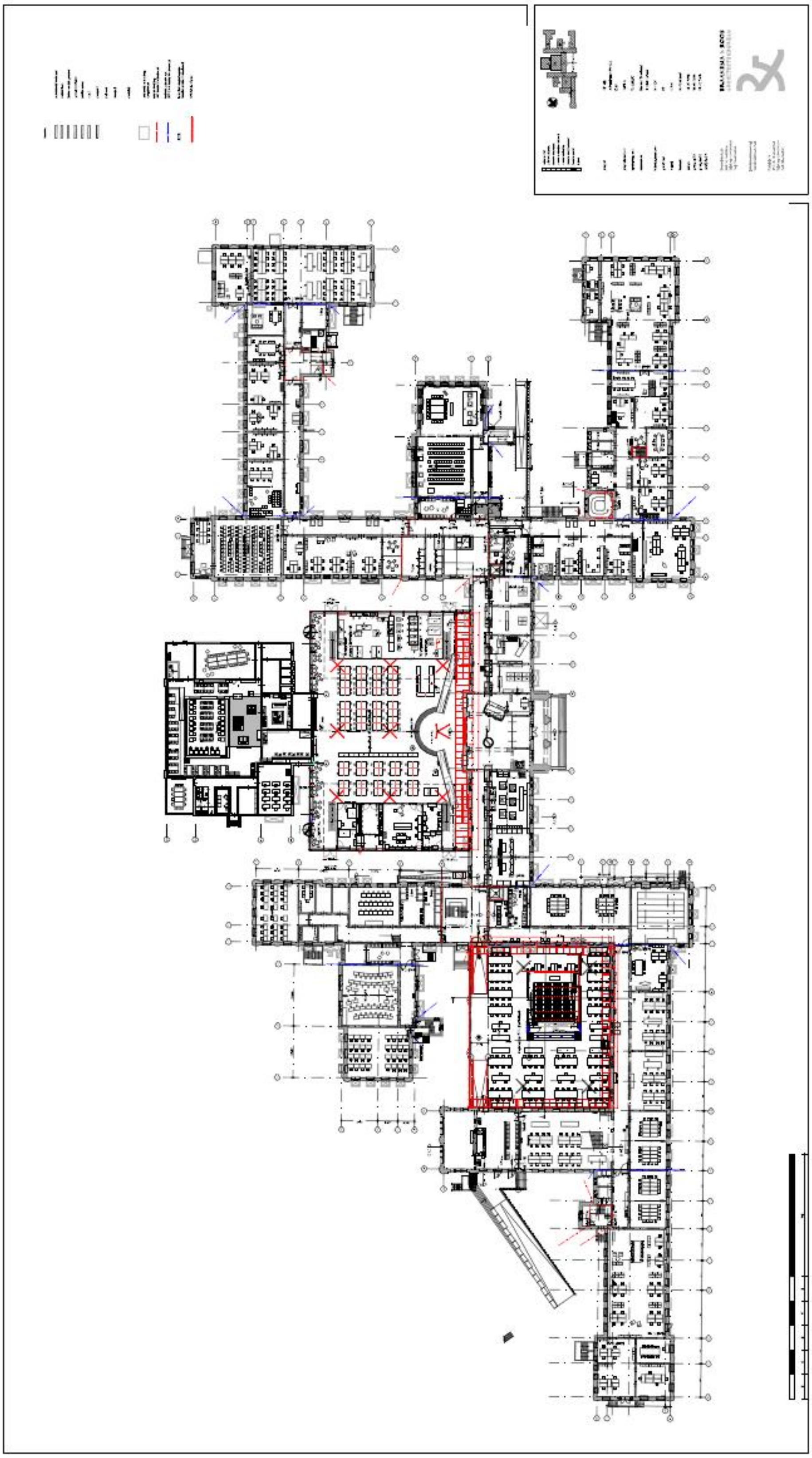
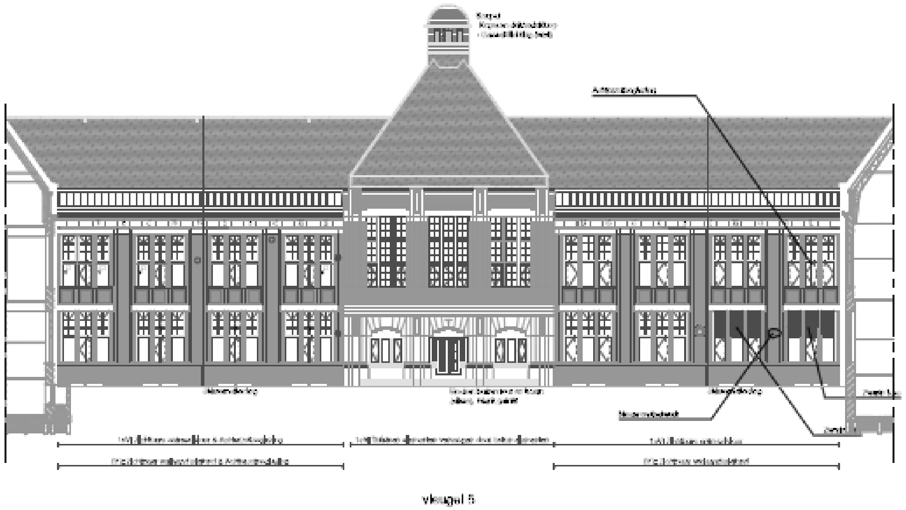
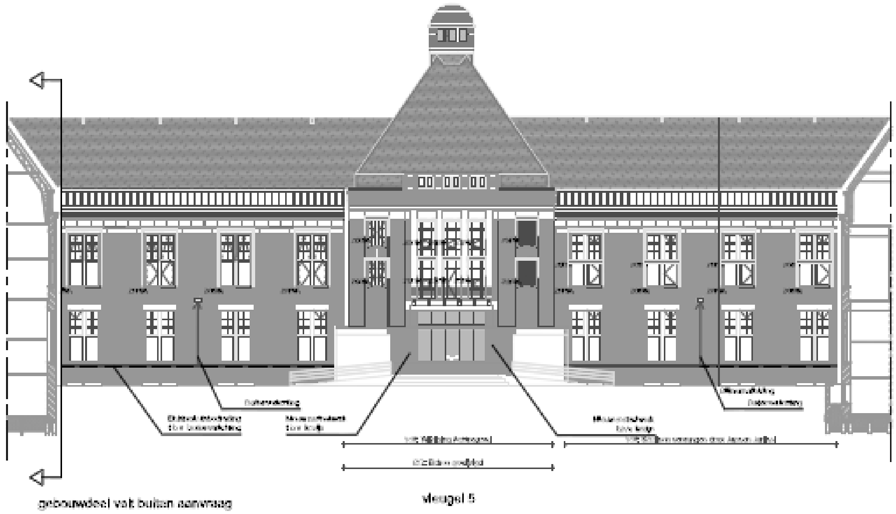
APPENDIX I: Plans, Elevations and Sections of BK City



Plan of the ground floor

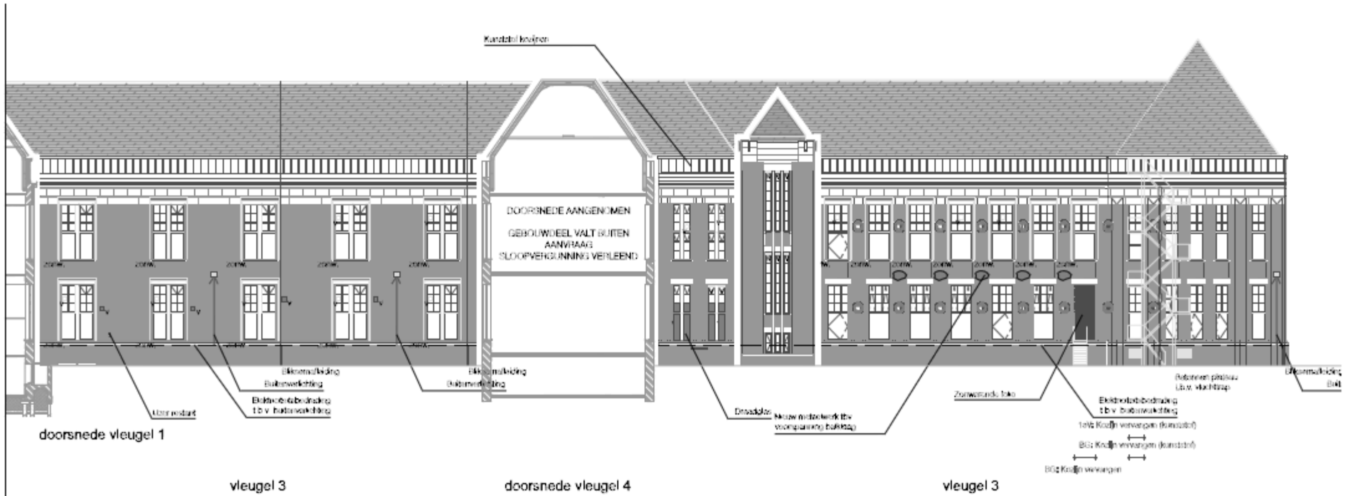


Aanzicht 1: Hoofdentree aan Julianalaan



Aanzicht 2

Front and back elevations



Aanzicht 6

Sections

APPENDIX II: Calculation sheets