CommONEnergy

DELIVERABLE 2.5

Main drivers for deep retrofitting of shopping malls

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Executive summary

This report has as its focus to definition of the main drivers associated with deep energy retrofitting of shopping centres. The drivers will provide the basis for developing practical and economically viable overall concepts for future shopping centre retrofits. The intention is that by providing integrated concepts that raise the level of ambition among decision-makers, improve control and collaboration with tenants, securing a suitable building shape, building structure and materials, it will be possible to ensure that different technologies are assembled and operated optimally.

Chapter two in the report sums up and further develops the analysis developed in CommONEnergy reports D2.2, D2.3 and D2.4, as well as considering findings from D2.1. The main intention being to recognise barriers and drivers for deep energy retrofitting in shopping centres, as well as considering different types of drivers and how their role and influence may be strengthened. In chapter three the key predictor variables and performance indicators are identified. Energy consumption was divided into heating, cooling and electricity for different uses and a protocol for sub-metering of energy consumption and flows (mainly heat and electricity, but also other sources and common services) were defined as the main basis when tracking inefficient use. The final chapter provides a parametric analysis of retrofitting drivers and this is used to assess possible cost-optimal retrofitting actions for shopping centre managers. Cost optimisation was analysed taking initial operation and maintenance into account. A module for parametric analysis enabling identification of the most important parameters for energy, comfort and economic shopping centre performances has been developed and used together with simplified energy tools.

The majority of European shopping centres are already built, but there is a still huge potential for energy savings due to the practice of regular rehabilitation and redesign of shopping centres. This state of constant flux offers the advantage of regular opportunities to improve the technical systems, such as lighting and ventilation, or the building envelope and monitoring systems. Efforts to improve energy efficiency and provide sustainable solutions for shopping centres must take these opportunities into account and also when implementing changes provides solutions which allow for future rehabilitations and change. A consideration of these aspects along with the other drivers has the potential to achieve significant energy reductions and Indoor Environmental Quality (IEQ) improvement. There are, however a number of major barriers to achieving the desired energy reductions and not all of these may be solved by the installation of new technical solutions. Pleasing customers is of primary importance in shopping centres, because customers provide the necessary profits for owners, managers and tenants. However customers are not demanding energy use reductions in shopping centres and as long as there is no direct demand then shopping habits cannot be considered a driver. This may potentially hinder actions to reduce energy use by owners, managers and tenants. They are not pushed by customer demand to take direct actions and as long as their profits remain stable or continue to increase this will not

change. However, consumer awareness is increasing, and increasing knowledge about the implications of their behaviour by customers in shopping centres may put pressure on the industry to increase actions aimed at energy use reductions.

According to results from the CommONEnergy survey, shopping centre tenants also lack knowledge about how energy is used in shopping centres. The implication is that the lack of knowledge among a large group of employees in shopping centres is hindering the work towards energy use reductions in shopping centres. At the moment knowledge or lack of knowledge is a barrier, but this trend could be turned around, with knowledge about energy use in shopping centres increasing on all stakeholder levels and becoming a driver for energy efficient upgrades. At the moment it is still a barrier and only has potential as a driver for energy use reductions. Changing the current situation requires actions on management level, in the form of for example the use of certification schemes and/or energy awareness programs for customers and tenants, as well as greater collaboration between management and tenants in efforts to reduce energy use.

Upgrade costs and rental costs are closely associated, if a retrofitting process is extensive and costly it may be expected that this will influence the price of renting retail space in the shopping centre. Owners, managers and tenants aim during rehabilitation to balance the need to be attractive and up to date with being cost effective. If rental prices are too high this may affect retail profits and cause problems for owners, managers and tenants. Cost reduction may be understood as a driver for energy retrofits, because the value achieved by reducing overheads/rental costs and operational costs may be seen to outweigh the costs associated with the retrofitting. However drivers and barriers for an energy related retrofit should be seen in collaboration. This is because although there is positive momentum associated with the need to reduce energy use in shopping centres, if the costs are too high for the stakeholders, a deep energy retrofit will not be conducted.

Size does has an effect on energy use. The implication is that smaller centres will use less overall energy, although some smaller centres may have a slightly higher specific energy use than larger centres. Changes in user behaviour are influencing shopping centre size. In the UK shoppers are increasingly shopping little and often, and this may affect the kind of shopping centres built but this kind of user behaviour cannot be said to be a direct driver for energy use reductions. Existing shopping centres are not expected to decrease in size due to the aforementioned trend. Some markets in Europe are saturated, but the general trend worldwide and in Europe is an increasing number of GLA per person. Some shopping centres are increasing in size and the reasons for this are also based on changing shopping habits, for example more leisure based activity which requires more space and this potentially affects shopping centre energy use. Customer behaviour can be seen to influence the kind of shopping centres being built, but it is only an indirect driver for energy use or energy use reductions because although customers are asking for new kinds of services which require more space or a redesign of an existing centre, they are not asking what the implications the services will have on shopping centre energy use.

A list of analysis variables has been chosen for assessing (through the steady-state simulation tool PHPP) the energy reduction of different shopping centres in Europe. These have been grouped according to different levels of ambition (set1 to 3) to define several energy saving measures regarding for example envelope characteristics, equipment performance and interior gains. Such measures have been applied to different shopping centres in European regions with differing climatic conditions (from Mediterranean to Continental and Sub-Polar climates). The primary energy and the energy uses for heating, cooling and electricity use have been calculated. The calculation of total primary energy (PE) of the selected shopping centres showed that the measures of reduction of the installed power density of lighting and appliances, has the largest PE savings. A cost analysis has been performed and the results show positive net present value for reduction in lighting density, infiltration, thermal bridges and increase in summer temperatures. In addition, payback period (PBP) calculations have been conducted:

- The PBP for lighting (with a lifetime of 20 years) is in the range between 1.5 and 7.6 years. The values vary also for the defined three sets of ambitious, with a range of PBP for set 1 between 1.9 and 7.6 years, for set 2 between 1.5 and 6.1 years, and set 3 between 1.8 and 7.2 years.
- The PBP for improvements of windows (with a lifetime of 30 years) is in the range between 3 and 116 years and depends on the climate and building design. But only four buildings show positive PBP with two buildings only, positive PBP for set 3 (Silute and Klapeida). The best PBP is provided by the shopping centre in Vienna (PBP=6.2 years for set 2 and 3.1 years for set 3).
- The ventilation components (with a lifetime of 20 years) provide PBP between 3 and 35 years. The results depend more on the specific building as on the chosen sets. For set 1 PBP range between 7.3 and 35 years, for set 2 PBP ranges between 4 and 26 years and for set 3 PBP ranges between 3 and 18 years.

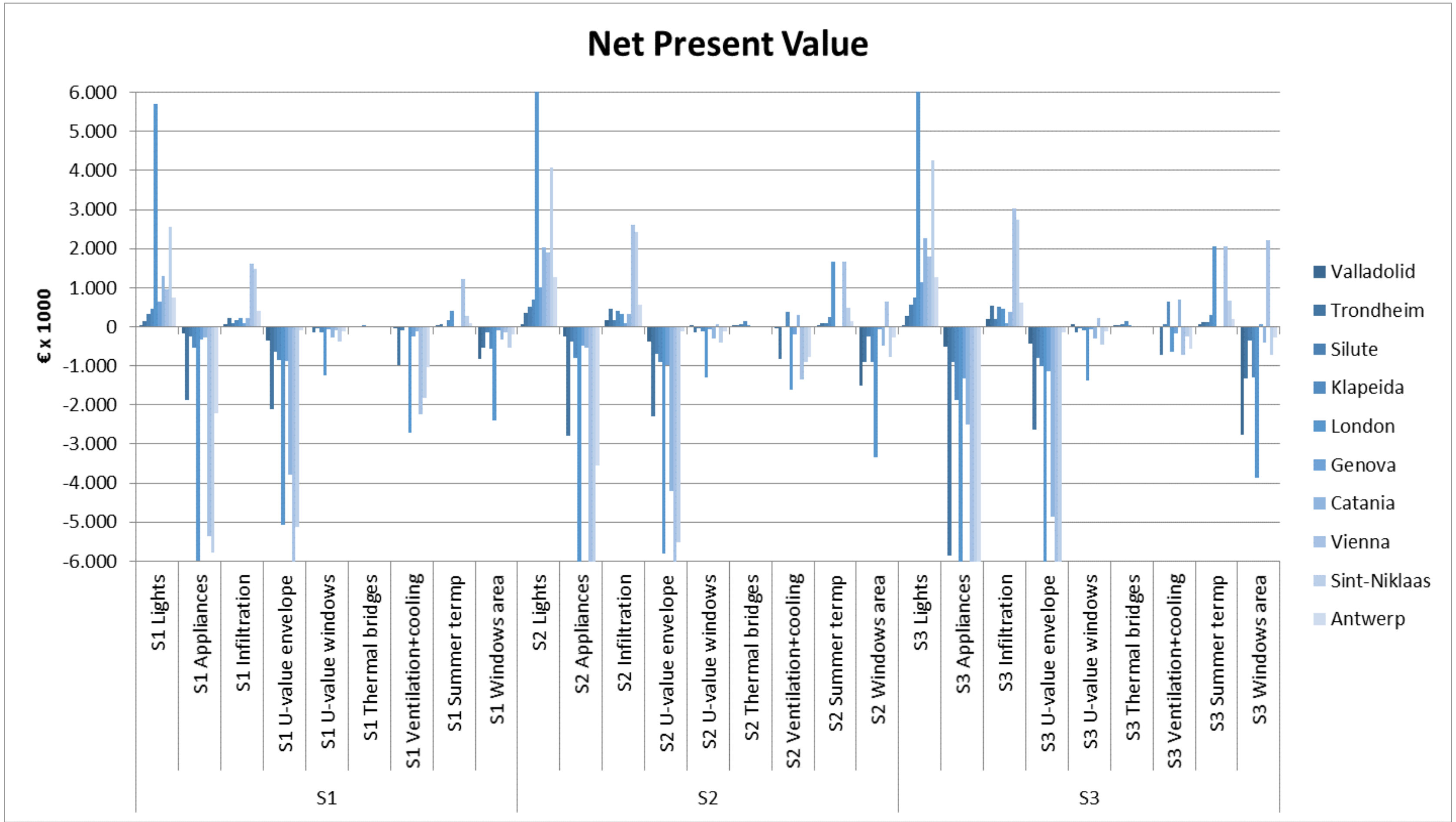
In conclusion:

- Shopping centres are complex buildings which are subject to regular change, have complicated layouts, sophisticated utility plants and a high concentration of customers and workers. Efforts to improve energy efficiency and provide sustainable solutions for shopping centres must take its state of constant flux into account, by providing systems that may be easily moved, reused or redeveloped.
- Four main areas of energy use inefficiencies were identified: lighting, HVAC measures, plug-loads and refrigeration, and architecture and design. The need to achieve energy use reductions within these four areas may be considered major drivers for energy retrofitting in shopping centres. Architecture and design touches on a wide number of issues which have implications for the broader understanding of sustainability, and therefore includes issues such as accessibility, ergonomics and safety. The four main areas may also be considered drivers for energy use reductions.
- Reducing costs associated with energy use may be drivers for energy retrofitting, but since costs associated with retrofitting may be barriers it was considered in a net

present value evaluation. In this way ensuring that costs of implementing energy efficient measures do not outweigh the costs achieved by energy use reductions.

- A list of variables has been developed for assessing the energy reduction of different shopping centres in Europe. These have been grouped according to different level of efficacy, called sets, to define several energy saving measures. Such measures have been applied to different shopping centres in European regions with different climatic conditions.
- The primary energy and the energy uses for heating, cooling and electricity use have been calculated. The calculation of the total PE of the selected shopping centres showed that the measures for reduction of the installed power density of lighting and appliances, has the largest PE savings.
- A cost analysis has been performed and the results show positive NPV for lighting, infiltration, thermal bridges and allowing increase in summer temperatures. Net present value results can be used to inform the stakeholders about investing in energy refurbishment. However, in the analysis, only single measures have been considered.

The next page shows the Net Present Value (NPV) of all combinations of variables and sets for 10 investigated shopping centres in Europe.



Total Net Present Value (NPV) of all combinations of variables and sets. Values are expressed as absolute cost values in Euros

Introduction

The CommON*Energy* project aims to "re-conceptualize shopping malls through deep retrofitting, developing a systemic approach made of innovative technologies and solution sets as well as methods and tools to support the implementation and to assess their environmental and social impact in a life cycle approach." The project encourages the development of sustainable shopping centres by supporting the energy efficient refurbishment of existing shopping centres and providing knowledge which will further the efficient planning and design of new shopping centres. This aim is achieved with the support from seven work packages. Work package 2 is responsible for the development of this report focusing on defining the main retrofitting drivers. The drivers will provide the basis for developing energy retrofitting concepts such as constructive technology, an understanding of typical function patterns and socio-cultural aspects and highlighting potential benefits of interacting with local energy grids. The majority of shopping centres are already built and there are therefore large energy potentials to be gained through redesign and reorganisation of existing shopping centres. This report will consider the potential associated with architectural quality and user friendliness and make retrofitting drivers quantitatively assessable. A parametric study has been used to identify the most important variables.

Shopping centres are not interchangeable with other kinds of complex buildings, such as office blocks, hospitals or schools. The character of shopping centres, form, function, usage, and users has implications for energy use. To support the understanding of what causes the main inefficiencies in energy usage and how to develop the best solutions sets, a CommONEnergy definition of shopping centres was developed, based on existing literature. The definition chosen in this study describes a shopping centre as "*a formation of one or more retail buildings comprising units and 'communal' areas which are planned and managed as a single entity related in its location, size and type of shops to the trade area that it serves*" (Bointner, et al., 2015). The definition gives an indication of the main form and function in shopping centres. In addition, location, type of development, the size and the GLA, the type of anchor stores and the trip purpose are all aspects that have been used to indicate the needs that a shopping centre serves within social and physical context; these are presented in Table 1. CommONEnergy is a European project. In addition climate and regional differences have implications for retrofitting practice. The definition and supporting table present climatic and regional differences and are registered in the description of the reference buildings associated with the CommONEnergy project (Bointner, et al., 2015).

Table 1 – *CommONEnergy definition of shopping centres*

Location	Type of development	Size	GLA [m^2]	Anchor store	Trip purpose
Town Centre Shopping/ urban	Neighbourhood centre/ community centre	Small shopping centres	5,000 – 19,999 m^2	Supermarket or hypermarket	Convenience shopping
	Speciality centre (market halls, historical buildings, other)		Usually 5,000 m^2 and above	Traditional markets, tourist shops	Leisure, convenience shopping
Out-of-Town	Retail Park and Factory		5,000 – 30,000	None	Household shopping,

Shopping/ suburban	Outlets		m²		Comparison shopping, leisure
	Regional centre	Medium/ large shopping centres	20,000 – 79,999 m²	One or more department stores	Comparison shopping
	Super-regional centre	Very large shopping centres	80,000 m² and above	Several department stores, entertainment centres	Comparison shopping, leisure

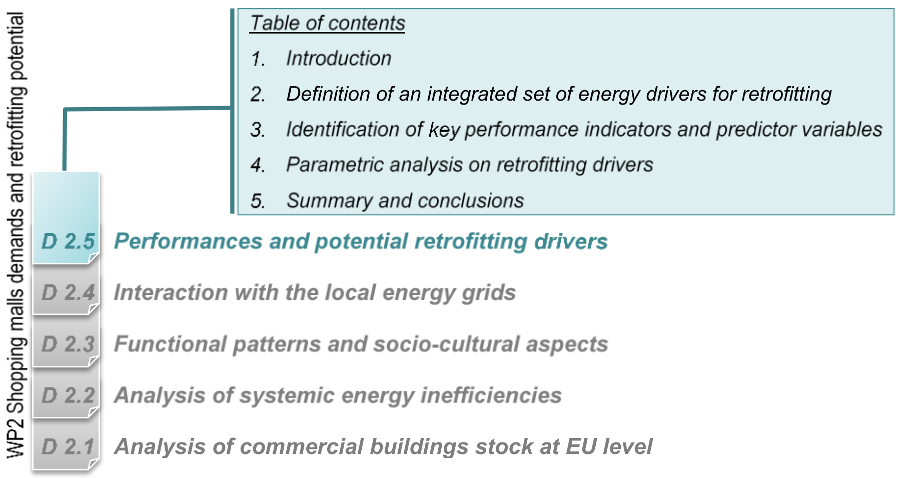


Figure 1 Overview of this report

CommON*Energy* considers all sides of shopping centre management and operation from a sustainable standpoint. This was organised in activities in dedicated tasks; Task 2.1 (definition and main features), Task 2.2 (inefficiencies), Task 2.3 (functional and socio-cultural aspects) and Task 2.4 (interaction with energy grid). The results from these activities provide the background for the analysis done in this report. Results and conclusions from previous WP2 deliverables are therefore included; they have been further analysed and provide a background to define the main retrofitting drivers and the potential impacts of generic retrofitting solutions.

A reader's guide

The following aspects will be considered in the report:

1. A definition of an integrated set of energy drivers for deep energy retrofitting which are based on results established in in the reports D 2.1 (Bointner et al., 2014), D 2.2 (Woods et al., 2015), D2.3 (Haase et al., 2015) and D2.4 (Antolin et al., 2015). The intention is to establish the aspects that should be focused on during the interventions. The reader is provided with an analysis of retrofitting drivers to assess

the possible retrofitting actions with a cost-optimal vision for shopping centre managers.

2. The identification of main predictor variables and performance indicators. Energy consumption will be divided into heating, cooling and electricity. A protocol for sub-metering of energy consumption and flows (mainly heat and electricity, but also other sources and common services) will be defined as necessary basis in order to be able to track inefficient use and user implications. User profiles will be split into sub-categories, owners/ managers, tenants (shop owners, differentiating by size and type) and customers (with appropriate differentiation).
3. An assessment of the possible retrofitting actions including a cost-optimal vision for shopping centre managers is performed through parametric analysis assessing the impact on the output variables or KPI.
4. A summary of the main performances and potential retrofitting drivers in the European shopping centre building stock today. The potentials for reductions in energy use associated with retrofitting are discussed highlighting which drivers have greater impact.

Figure 2 – A consistent colour pallet helps identify the three stakeholder groups, the same colour coding is used in D. 2.2 and D. 2.3.

1.1.Method

The methods used to collect the data presented in this report are primarily quantitative, although chapter 2 does include data that was collected using qualitative methods. The activities are based on literature reviews and the CommONEnergy questionnaires and interviews, and are presented in D2.2. (Woods et al., 2015). The presentation includes intentions, challenges faced, the amount of data gathered, and the kinds of data presented.
The development of an integrated set of energy drivers for deep energy retrofitting in D2.2 is based on a comprehensive understanding of the different existing shopping centre types, the typical functional patterns associated with the types and the role of different stakeholders involved with shopping centres. In addition, the influences from architectural and aesthetic qualities as well as the socio-cultural aspects were taken into account (D2.3). Results from the market situation and the analysis of the valid building codes in the countries included in the study also give valuable input related to potential retrofitting drivers (D2.1). The results from the analysis of systemic inefficiencies (more specifically decision making structures, user behaviour, technical inefficiencies and economic models) are considered (D2.2). Finally, the results from interaction with the local energy grids provide valuable input (D2.4). The four main inputs provide the basis for identifying the main predictor variables and key performance indicators. These are used to run parametric study in order to be able to assess the possible retrofitting actions with a cost-optimal vision for shopping centre managers. Cost optimization was analysed with state-of-the-art evaluation tools taking initial, operational, and maintenance into account. This was based on the "cost optimal methodology" defined in 2012 within the EU directive 2010/31 and relative applied regulation 244/2012. A module for parametric analysis was developed accordingly.
Based on the identified drivers a list of main predictor variables was identified. To assess the varying impacts of the predictor indicators a list of key performance indicators is defined. This includes energy consumption associated with heating, cooling and electricity for different end uses. Additionally, since tenants are often renting space within the shopping centres, sub-metering of energy consumption and flows (mainly heat and electricity) will be defined to track inefficient use and user implications; therefore, associated performance indicators are defined. User profiles will be split into sub-categories, owners, tenants (shop owners, differentiating by size and type) and end-users (shopper, with appropriate differentiation). Other categories will be explored where appropriate (see also D2.3).

2. Definition of an integrated set of energy drivers for retrofitting

2.1. *Aim*

The aim in this chapter is to define an integrated set of energy drivers for deep energy retrofitting. Drivers are understood as factors which cause a phenomenon, in this case deep energy retrofitting, to happen or to develop. The purpose here is therefore to identify a range of aspects that are significant for the main stakeholder groups, customers, tenants, owners and manager and community, and that are expected to influence deep retrofitting and design processes in different types of shopping centres. The results and conclusions presented in CommONEnergy reports 2.1 (Bointner, et al. 2015) 2.2 (Woods, et al. 2015), 2.3 (Haase et al., 2015) and 2.4 (Antolin et al., 2015) provide the basis for establishing what the main drivers are; these results have been further analysed and elaborated upon.

What are energy drivers?

Drivers are, as mentioned above, factors which cause a phenomenon. They make things happen. There are three different kinds drivers mentioned in this chapter:

1. Direct drivers: actually cause phenomenon/ deep energy retrofitting to happen.
2. Indirect drivers: provide the support or background for the direct drivers.
3. Potential drivers: not actually causing an effect at the moment, but with right set of circumstances in place, such as well functioning indirect drivers, they have the potential to become direct energy drivers.

Examples of the three different kinds of drivers are presented alongside the stakeholder analysis later in this chapter.

Integrated concepts

Energy drivers in shopping centres are the specific aspects that should be focused on during retrofitting interventions. Integrated concepts for energy retrofitting take various drivers for energy retrofitting and combine them. The integrated concepts include the following aims:

- Turn potential drivers among decision-makers into direct drivers
- Turn potential drivers among tenants into direct drivers
- Identify the drivers of retrofitting the building envelope
- Identify drivers in operating the building
- Identify drivers in assembly and enhanced operation of technical equipment

A pre-requisite for realizing low energy buildings is complementary technical installations that are tailored to the passive design of the building, together with an appropriate control system. The potential use of passive strategies with regard to heating, ventilation, air conditioning, lighting and refrigeration (HVAC+L+R) systems and control systems need to be put together into practical and economically viable overall concepts that serve the main stakeholder groups. The potential energy drivers will be used to identify the main predictor variables for a parametric analysis and estimated performance.

2.2. *Setting the scene*

Figure 3 – Examples of design solutions found inside three shopping centres: Emporia - Sweden, Brent Cross – UK, Donauzentrum – Austria. Photo SINTEF Byggforsk

There is a background to any retrofitting process in shopping centres; it does not take place within a technical vacuum which simply aims for greater optimisation. Retrofitting takes place within a context, which includes retail, technical, social, functional and aesthetic aspects and it is within this context that the drivers for deep energy retrofits are established. This section presents the main themes associated with the retrofitting process.

2.2.1. User behaviour and typical functional patterns in shopping centres

Shopping centres are made up a number of systems, all of which support the main activity, shopping, and they are all intended to supply maximum customer satisfaction. It is suggested here that there are two primary systems in shopping centres: technical systems and social systems. It is suggested here that understanding the general everyday workings of a shopping centre is of primary importance if one is to be able to establish where potentials for energy use reductions lie and what the main drivers for deep energy retrofitting are. Users influence how energy is used. Knowing how and why energy is used in shopping centres will make easier to influence user behaviour, so that they actively approve and instigate the solution sets chosen by this project. The focus of the analysis is therefore the social systems found in shopping centres.

The role of different stakeholders in retrofitting processes

The CommONEnergy project has focused on four main stakeholder groups, customers, tenants, owners and managers and community (Figure 4). Four tables, one for each of the four stakeholder groups, are presented, condense the main social, technical and economic factors associated with each group (Table 2 – Table 5). The analysis is based on results and discussions initially presented in CommONEnergy deliverables D2.2 (Woods et al., 2015) and D2.3 (Haase et al., 2015) and the different aspects are presented in more detail in these reports. The four tables present the needs associated with each stakeholder group and how these may function as barriers, or be understood as drivers, indirect drivers or potential drivers for energy use reductions. The implications for energy use reductions are summarised and presented after each table.

The four stakeholder groups all have different but interconnecting roles in shopping centres. It is suggested here that the stakeholders may be differentiated in relation to their influence on decision making practices and by their use of energy in shopping centres. These differences are summarised along with the four tables:

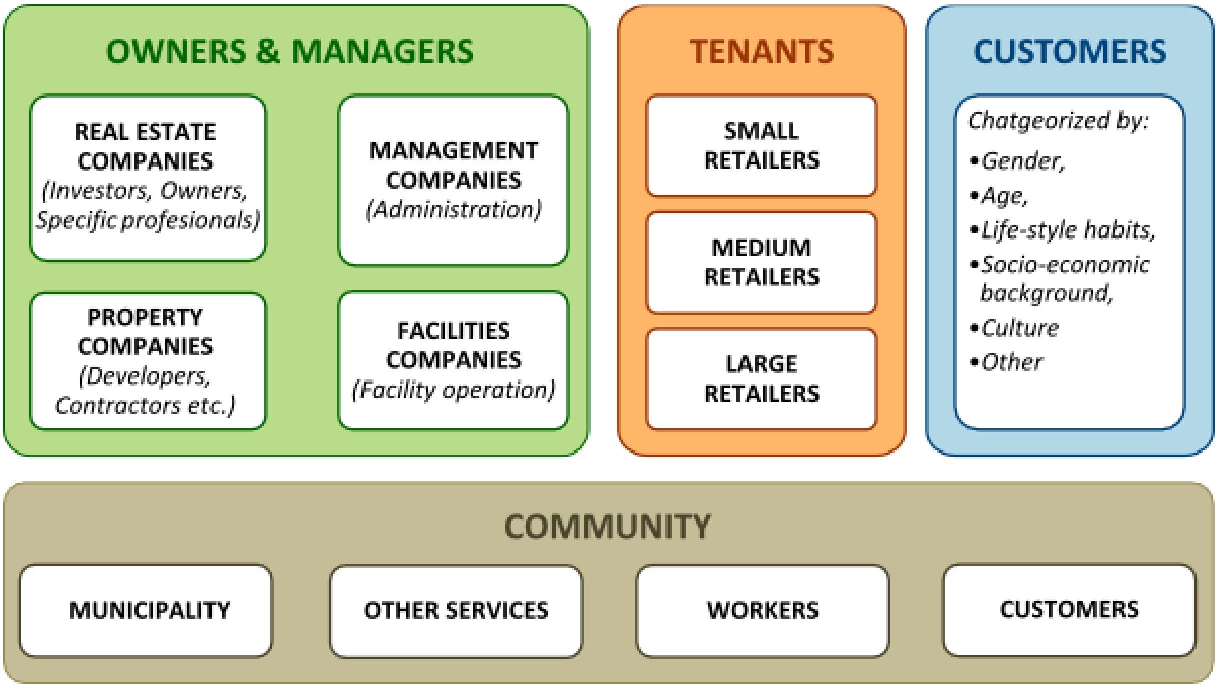


Figure 4 – Introducing the four stakeholder groups

Customers

Customers are an important part of the European economy; there are 500 million potential customers/consumers across Europe (ICSC, 2008). Encouraging customers to spend time in shopping centres is important to tenants, owners and managers in shopping centres.

Energy needs: Providing customers with a comfortable and functional place to shop influences energy needs. For example the shopping centre should be warm enough but not too warm, which has implications for heating and ventilation. The main barriers associated with reducing customer energy needs are associated with comfort and cost, although changing usage in shopping centres and knowledge about energy use in shopping centres also has implications. The CommONEnergy survey suggests that customers are more flexible in terms of their thermal comfort than is suggested by tenants and management. 87% of customer who participated in the survey would accept lower temperature in winters, and 66% of the customers stated that they would also accept higher indoor temperatures in the summer (D2.2: Woods et al, 2015).

Table 2 – A summary of the social, technical & economic factors influencing customers (Haase et al., 2015).

Customers				
	Description of needs	**Barriers against energy savings in SC**	**Indirect drivers for energy savings in SC**	**Direct drivers for energy savings in SC**
Social, technical & economic factors influencing SC stakeholders	Range of products and services			
		Lack of knowledge about energy use in shopping centres	Knowledge about energy use in shopping centres	Customer education organised by tenants, owners and managers
			More attractive places	
	Meeting places Leisure facilities	Increased size	Better shopping conditions for customers	Good architecture & design
	Accessible, safe, comfortable shopping environments	Air quality and comfort expectations		
			Reduced price of goods	Increase in number of customers and extension of visit length
		Presentation of goods Architecture & design	Increased pedestrian travel & by public transport	
	Low priced goods			
		Increased price of goods		
	Free parking Location Public transport Car parks	Increased travel by car	Increased control of the (visual and thermal) comfort conditions adapted to the climate	

Decision making: The location, the range of products available and the price of goods are the three main factors which influence the choice of a shopping centre (D 2.3: Haase et al., 2013). The results from the table imply that customer actions do not have direct implications for energy use in shopping centres. However there are areas associated with customers and energy use reductions in shopping centres which have the potential to become drivers, these are improved knowledge, good architecture and design, and an increased number of customers. Customers need to demand energy use reductions for it to make a direct impact on how the major decision making stakeholders in shopping centres act, causing them to change or improve energy actions. To be able to demand energy use reductions or the retrofitting of shopping centres customers need to have more knowledge about energy use, be given a clear indication about how energy is used, through for example the architecture and design of the shopping centre (visualising through architecture), and their shopping habits should be affected by a change in the price of goods. If retrofitting has implications for what customers pay for goods then this can affect their decision about where to shop which will in turn influence how owners, managers and tenants decide to act.

In the John Lewis Sustainability report 2013 it is stated that *"While quality and value remain top of customers' minds, customers are increasingly becoming more interested in the social and environmental aspects of the products that they buy. Our challenge is to provide easy access to information, should they require it, at the point of sale"*. This has implications for in-store technology use and store construction. In 2014 John Lewis opened a department store in York which is certified as Breeam Outstanding, and is the first department store in the world to reach this level of certification[1]

John Lewis department store, York, UK. Photo www.retail-week.com/

Tenants

More than 30 million Europeans work with retail related activities (ICSC, 2008). Tenants lease retail and other property in shopping centres (for example storage space) providing employment in the form of sales jobs and retail management. Tenants may also work with food or the supply of services in the shopping centres, for example child care and shoe repairs. Tenants are often part of a consortium, managed by owners or a management company. The tenant mix in shopping centres is a retail agglomeration, which influences customer choice of shopping centre, offering them one solution to a number of retail needs.

[1] http://www.responsibledevelopment.co.uk/

Table 3 –A summary of the social, technical & economic factors influencing tenants (source?)

Tenants				
	Description of needs	**Barriers against energy savings in SC**	**Indirect drivers for energy savings in SC**	**Direct drivers for energy savings in SC**
Social, technical & economic factors influencing SC stakeholders	Customer satisfaction. Sales maximisation & profit increase	Customer needs come first	Customer demands	Increase in number of customers
		Knowledge about energy use in shopping centres	Knowledge about energy use in shopping centres	Tenant education organised by tenants, owners & managers Energy performance certificates
	Retail agglomerations Customer traffic Working comfort and controllability of conditions Safety Functional space	Air quality Presentation of goods Installation and upgrade costs Increased rental costs All in one revenue based rents Low electricity prices Length of lease	Better working conditions for tenants and better indoor environments for customers Greater transparency about how energy is used in SC Green leases Independent rents High electricity prices	Cost reduction Lighting HVAC measures Refrigeration (depends on the kind of store) Increased electricity prices
	Low rental costs and electricity bills	Poor architecture & design Larger stores, a wider range of stores, services and leisure facilities leading to bigger SC	More attractive places	Good architecture & design More functional and controllable systems
	Attractive shopping centres	Larger brands have special requirements and fit-all approach that doesn't consider energy efficiency		

<u>Decision making</u>: In an effort to describe the different kinds of tenants found in shopping centres in table 3 this stakeholder group is divided into three main groups; small, medium and large retailers. This describes their size in relation to them being local, national and international companies and the size of the retail network that they are part of. The description is not directly connected to the type of goods or services sold or the GLA; although national or international companies may on occasion also require more retail space

for their stores. The size of the company or retail network a tenant is part of may also affect how influential they are during decision making processes in shopping centres[2].

The Apple Store is a major international brand. The store is owned and operated by Apple Inc., and deals primarily with computers and consumer electronics such as iPods, iPads, iPhones and third-party accessories. All stores offer a "Genius Bar" for technical support and repairs. Some high-profile stores feature a theatre for presentations and workshops and a studio for training with Apple products. When Apple moves into a shopping centre it has bargaining power when installing its in-store specifications. At Brent Cross the store below the Apple store was closed to accommodate Apple's needs when installing their retail concept in the shopping centre. A locally owned store which is part of a smaller retail network and perhaps trying to establish its place on the retail market will have less bargaining power.

The Apple Store, Brent Cross, UK

Tenant associations also influence decisions made about shopping centre upgrades. Tenant associations are involved in negotiating and implementing guidelines for overheads such as rental of GLA and the billing of energy costs. When operating as a group the influence that tenants have over decisions made about upgrades or the changes in the billing systems is greater than if they operate individually. However tenant associations also have the effect of restricting how tenants behave. There may be a close association between the tenant association and shopping centre management. Dawson and Lord suggest that the main

[2] An example which offers insight into the differing influence of retailers is the "major tenant approval clause" which gave major anchor tenants the right of approval over retailers who were potential competitors before they were established as tenants in shopping centres (Dawson, 2013). The assumption was that the clause would help to ensure the profitability of the major tenant, and encourage a strong retail group which would compete with other shopping centres rather than competing internally. The clause has largely been eradicated from shopping centres. North American shopping centres had eliminated it by the early 1980's because federal law was sceptical to the unfair economic advantage that the clause gave larger stores (Law catalogue, 2001).

reason for tenant associations is to make shopping centres more competitive in relation to one another and to limit the pricing practices of tenants (Dawson & Lord, 2013).

Energy needs: The results from the survey D2.2 (Woods et al., 2015) point to tenants (the majority of the respondents worked on a shop-floor managerial level) knowing little about in-store energy use and a lack of engagement about energy issues.
As long as tenants know little about how lighting, HVAC and how architecture and design affects the overheads that they pay, the impact of them as drivers is limited. Aspects which have the potential to become drivers for energy use reductions are an increase in knowledge about what can be achieved by reducing energy use, for example through the use of energy performance certificates, or labelling scheme. An increase in the number of customers due the shopping centre becoming more attractive through its actions to reduce energy use has also the potential to become a driver for energy use reductions.

Owners and managers
The activities of customers and tenants are supported by owners and managers in shopping centres. The actions of owners and managers are motivated by the need to run a shopping centre which is attractive to customers and tenants. A shopping centre which is attractive to customers leads to sales maximization for its tenants and profits for management and owners. Owners and managers are described here and in CommONEnergy deliverables D2.2 (Woods et al., 2015) and D2.3 (Haase et al., 2015) as one stakeholder group. They are in fact two stakeholder groups.

Owners are primarily associated with the development of centres and with shopping centres as real estate, which means the long-term investment decisions and strategic development. Owners may also coordinate a number of shopping centres and therefore be able to negotiate framework agreements with energy companies for all their centres.

Management companies are responsible for the day to day running of the shopping centres. They determine the overheads, the billing of energy consumption (allocation of common costs etc.) and coordinate initiatives with tenants or tenant associations. Typical management tasks are choosing tenants, making decisions about the location of tenants within the shopping centre and marketing activities.

There is however often no clear separation between the activities of owners and the activities of managers. They are often part of the same company, with overlapping roles and this is why they are described as one stakeholder group in the CommONEnergy project.

Decision making: Owners and managers are the stakeholder group which is most influential when decisions are being made about how to reduce energy use in shopping centres. They are associated with the daily running of the centre and with planning for the future. Their actions have direct implications for all the stakeholder groups involved in shopping centres. They are often also the stakeholder group in a shopping centre with most knowledge about how much energy is already used in the shopping centre, how to reduce energy use and the implications of future energy use. Among respondents to the CommONEnergy survey more than 70% said that their knowledge about energy efficiency in shopping centres was extensive, and less than 10% described it as limited. It is suggested here that this knowledge is important when making decisions about energy retrofitting. Combined with their interest in running attractive, cost effective shopping centres, the knowledge of owner and managers has the potential to become a direct driver for deep energy retrofitting.

The actions of owners and managers have implications for the knowledge available to other stakeholders and they influence how they act. For example the billing system chosen by the management company has implications for tenant energy use, because it affects knowledge about how tenant actions affect in-store and wider shopping centre energy use (see section 2.3.2). Another action which promotes energy awareness and actions is green leases, which include common goals on energy efficiency. However green leases are so far not common within the retail industry.

Table 4 –A summary of the social, technical & economic factors influencing owners and managers (source).

Owners and Managers				
	Description of needs	**Barriers against energy savings in SC**	**Indirect drivers for energy savings in SC**	**Direct drivers for energy savings in SC**
Social, technical & economic factors influencing SC stakeholders	Customer satisfaction.	Customer & tenant needs come first	Customer & tenant demands	Increase in number of customers
	SC occupancy	Knowledge about energy use in shopping centres	Knowledge about energy use in shopping centres	Knowledge building schemes on all stakeholder levels
	Sales maximization for tenants and profits for management and owners.	SC vacancy Increasing size of the SC	Property value Growth in profits High occupancy	Building certification schemes i.e. Breeam Certification schemes specifically for SC/retail
	Facilities management Technical control systems Low maintenance costs	Installation and upgrade costs Increased rental costs Time consuming individual billing systems	Customer & tenant satisfaction due to a better indoor environment Individual billing systems	Local and national regulations i.e. building codes, carbon reduction commitment
	An attractive shopping centre	Challenging to recover the energy efficiency investment Poor architecture & design	Reduced energy costs allowing increased/ decreased rental costs (depends on management philosophy & needs)	Reduced energy use Cost reduction Lighting Hvac measures Refrigeration Improved management systems
		Wider range of shops, services and leisure facilities	More attractive places	Good architecture & design

"Initially it is always about good housekeeping and monitoring of consumption loads. They are critical. We could do a huge amount to make this better, but it comes down to investment in technology and it always comes back to good management. We won't get good results without someone watching how it is doing". Management quote from the CommONEnergy survey.

Energy use: Owners and managers are, as mentioned above, the most knowledgeable stakeholder group about energy use. This however does not necessarily mean that their actions are primarily motivated by reducing energy use. Tenant and customer needs come first and if they believe user comfort will be affected or that rental costs will be increased due to retrofitting then they will not make the decision to instigate actions aimed at reducing energy use.

"*Tenants look after their own space. Climate and lighting is their domain. They are given space on the roof for their own chillers. That means we don't have to repair them, it is easier for us. There is a service charge for lighting and heating in common areas, and for the use of water. There is a very strict code for what can be service charged. Relationships are on the whole pretty good. Rental price is a business transaction. We have a person who is responsible for tenant liaison and we have tenant groups. They are not very interested in environmental issues; they are more interested in community issues. Energy efficiency is about how they do their fit-out. Multi-national companies have very specific systems. It is difficult for us to change that. We do have tenant handbooks and guides, and these are being updated in light of performance standards. We have a lot of interaction with tenants through retail delivery. We can achieve more energy efficiency. It depends on the retailer*." Management quote from the CommONEnergy survey

The actions of owners and managers are also affected by retail change which demands a wider range of shops services and leisure activities, which in turn can cause shopping centres to expand and also affect the architectural and technical quality of shopping centres (see section 2.3.5). This can have a negative effect on energy use. A driver for energy savings in shopping centres is building certification schemes. It is suggested here that certification schemes that are tailored for the retail trade will have most impact, because of the need for flexible building structures and the changing demands of the retail industry.

For instance, Donauzentrum in Vienna which is a reference building in the CommONEnergy project is also BREEAM certified. However, BREEAM is not very common in today's shopping centres. Only 25-30 centres worldwide[3] are certified according to this standard.

Since energy costs make up only small share of the total costs in the commercial buildings, financial and economic benefit does not always ensure the investments of the energy efficiency measures. However, certifications enhancing Green branding play an important role in the decision of the investments of the energy efficiency measures. The implementation of this type of model or programme does not obligate the companies to invest in the energy efficiency measures, but they do encourage energy-efficiency investments indirectly. Building codes have the potential to have a similar motivational function as certification schemes, both on a national and regional level. However, there is so far no indication that they are currently functioning as drivers for energy retrofitting (see section 2.2.2).

BREEAM certification has been used by a number of new shopping centres. Fornebu S, Oslo, Norway has is certified as BREEAM outstanding. Fornebu S is the only shopping centre that has achieved this certification level and therefore claims to be "*the most environmentally friendly shopping centre in the world*"[4]. Areas considered during certification include building energy consumption, indoor air quality, lighting, choice of materials, transportation and waste management. The shopping

[3] http://www.greenbooklive.com/search/scheme.jsp?id=202

[4] http://www.fornebu-s.no/2014/10/03/fornebu-s-utkonkurrerer-alle/

centre has 2000 m^2 of solar panels on the roof, and has the potential to produce at least 100 000 kWh per year. The shopping centre has used a lot of natural materials such as wood and stone. Fornebu S has a Gross floor area of approximately 32 000 m^2 and 27 500 m^2 of parking space. The estimated consumption energy consumption is: 50.1 kWh/ m2 (to NS 3031[5]). The KLP (Kommunal landspensjonskasse) insurance company owns Fornebu S and considers their energy actions in the centre to be a long term investment.

Left: Solar panels on the roof, right: Energy use information for customers, Fornebu S Oslo, Norway, Photos http://www.fornebu-s.no/ , SINTEF Byggforsk

Direct drivers for energy savings in shopping centres for owners and managers are reduced energy use and cost reduction through measures associated with lighting, HVAC, refrigeration, architecture and design. These actions have greatest implication in the common areas in shopping centres, both front-stage in entrance areas, corridors and food courts and back-stage for example in loading areas, storage and technical rooms. The impact on leased areas depends on the demands made on tenants and tenant motivation. This aspect is linked to knowledge schemes where tenants and other stakeholders are informed about the implications of their energy actions in shopping centres. The use of individual billing systems may be associated with these actions.

Community

A community provides a social and physical framework around the shopping centre and shopping centres depend on the community around them. The community provides the shopping centre with customers and workers. In addition the authority within the local municipality is a link between the shopping centre and services which it requires, such as the road network and repairs. The shopping centre provides the community with jobs and services, providing often much needed revenue. Despite the provision of jobs and services shopping centres are not always welcomed by the local community, because of the impact on the physical environment, such as overloading the transport network and the effect they can have on the existing retail environment.

[5] Norwegian standard NS-3031:2014 "Calculation of energy performance of buildings - Method and data".

Table 5 – A summary of the social, technical & economic factors influencing the community around SC.

Community				
Social, technical & economic factors influencing the community around shopping centres	**Description of needs**	**Barriers against energy savings in SC**	**Indirect drivers for energy savings in SC**	**Direct drivers for energy savings in SC**
		Knowledge about energy use in shopping centres	Knowledge about energy use in shopping centres	Education organised by tenants, owners and managers
	An attractive place to shop & work	Needs of inhabitants come first	Municipal, resident & customer demand	Building certification schemes i.e. BREEAM
	Provides jobs services and leisure possibilities			Local and national regulations i.e. building codes, taxation, planning permission
				More jobs & increased revenue for the municipality
	Need for jobs and revenue	Improved access for customers & workers	Overloaded transport network	
	Transport network			

Decision making: the community has most influence over shopping centre energy use during planning and regulation when a new shopping centre or a major expansion is being planned. The municipality often negotiates with investment companies about issues such as size, location and grid access. However enthusiasm or protests from local residents can also influence the development and redevelopment of shopping centres. The development of a sustainable shopping centre, one which has low energy use and looks after green areas or established new ones, could potentially meet with less protest.

A retail analysis done by Trondheim municipality in 2012 states that local (neighbourhood) centres cause lower CO_2 emissions than retail activity established in centres on the city outskirts. It is suggested that in proportion to resident population in the city there is an over-establishment of retail on the city outskirts. It is also suggested that any further developments in these areas will increase transport to the centres and CO_2 emissions (Trondheim kommune, 2012). There is therefore support for the development of local centres, which it is suggested offer neighbourhood quality and provides a broader range of retail and services than a local shop, and it is suggested will contribute to reducing transport and CO_2 emissions.

A neighbourhood centre: Byåsen butikksenter, Trondheim, Norway,
Photo https://www.facebook.com/byaasenbutikksenter

Energy use: The community does not have any direct impact on energy use. There are a number of potential drivers for reducing energy use associated with the community. These are knowledge schemes which encourage demands for reduced energy use in shopping centres; building certification schemes could play a role here. Building codes could also cause demands for greater energy use reductions through the tightening of demands during the rehabilitation of shopping centres. There is however so far no indication that this is actually happening during rehabilitation although there is some indication that building codes are having an effect on energy use in new shopping centres (see section 2.2.2. Building codes).

2.2.2. Legal/economic issues between owners and tenants

Legal and economic issues affect how costs associated with the day to day running of the shopping centre, maintenance and upgrades are distributed among stakeholders, and they influence stakeholder actions with regards to energy retrofitting. Commercial leases are one of the tools implemented to distribute costs and they can function as major systemic barriers to energy efficiency in commercial buildings (Langley et al, 2008). There are a number of potential reasons for this, such as a lack of defined obligations and responsibilities with regard to energy use, ineffective communication and payment structures and problems faced by owners and managers when justifying investment in equipment or operational changes (Ibid, 2008). It is suggested here that actions to achieve energy use reductions will be implemented if they are seen within the wider context of retail success and profits "*successful retailers will be those who respond most positively to the changing patterns of shopping behaviour. Retailers need to plan for the future in imaginative ways that will allow them to maximise their potential for incorporating the most appropriate permutations of the "Three C's" – comfort, convenience and conviviality*" (O'Brien & Harris, 2013). If communicated effectively to the different stakeholder groups and when combined with efforts to respond to changing patterns in shopping behaviour, legal and economic actions could become direct drivers for deep energy retrofitting. In addition the inclusion of non-technical clauses for example requiring energy use reductions or the meeting of energy targets in in tenant leases will support the more technical actions, potentially strengthening their impact.

A number of legal and economic issues which influence stakeholder activity in shopping centres were mentioned in the previous section about user behaviour. These are:

- Customers: price of goods, free parking
- Tenants: sales maximisation and profits, rental costs, billing systems, reduced costs, transparent billing systems, green leases, length of leasing period
- Owners and managers: sales maximisation and profits, rental costs, billing systems, reduced costs, high occupancy, building codes, property value
- Community: Building codes, jobs and revenue

Not all of the aforementioned aspects have implications for deep energy retrofitting. Free parking although it affects customer choice, is an example of this. Aspects such as sales maximisation and profits do not at first glance appear to have anything to do with deep energy retrofitting, but they are important to owners, managers and tenants. The whole retrofitting process has implications for profits and the price of goods, because it can have implications for property value and the rental price. These can in turn affect occupancy levels and thereby the popularity of shopping centres among tenants and customers. In addition although tenants and managers are interested in sales maximisation and profits, their attitudes towards how and why this is to be achieved vary. The goal of the owners is to increase property values while tenants aim to minimize rent and ancillary rental costs. This section will therefore consider billing systems, overheads/running costs, green leases and the length of the leasing period. These aspects affect the relationship between owners, managers and tenants.

The length of the leasing period

Owners and managers have a long term investment in the main physical structure of the shopping centre. Tenants rarely have such a long term relationship with a shopping centre[6].The length of the tenant's lease affects how willing they are to invest in the retrofitting of a shopping centre. In the UK there has been since 1998 a general trend towards a reduction in lease lengths, with shorter leases of around five years being favoured. In general it is suggested that newer higher value property will have longer leases than second hand lower value property (Langley et al, 2008). A large number of tenants do not have a long term relationship with the shopping centre where they are leasing retail space. Amongst respondents to the CommONEnergy survey almost 45% of tenants had been leasing space for five years or less (see Figure 5). It is suggested here that this group will be less willing to invest in the upgrading of the shopping centre.

[6] An exception is the John Lewis department store in the Brent Cross shopping centre which has a 100 year lease.

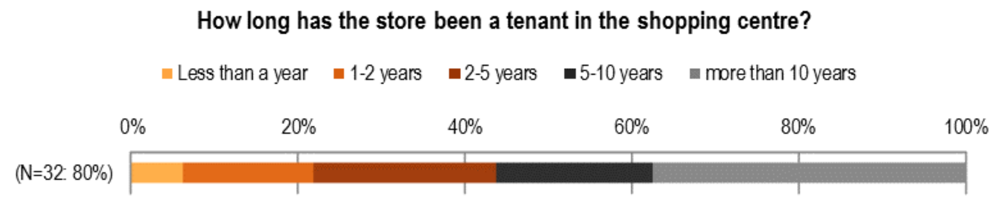


Figure 5 – Answers from the tenants questionnaire: "How long has the store been a tenant in the shopping centre?"

Almost 40% of the respondents had long term leases of more than 10 years; and it is suggested here that this group is more likely to invest in deep retrofitting because of the lease length suggests a long-term investment in the shopping centre[7]. However it is possible that long leases may be a barrier because the lease may specify the tenant's financial load and amendments to the lease may be difficult and costly to negotiate (Langley et al, 2008).

The number of tenants with short-term leases in the shopping centre will have implications for how much support deep energy retrofitting actions will have in the shopping centre. Actions which require an investment in the physical structure of the shopping centre or an increase in rent may be met with scepticism because the retailer only expects to be in the shopping centre in the period defined by the lease for example two to five years.

Low cost investments or actions which are aimed at general maintenance or improving the attractiveness of the shopping centre will potentially receive less opposition. Actions aimed at reducing energy use should therefore be combined with these actions and their implications for reducing running costs should be emphasised. This has the potential to encourage a wider stakeholder group to invest in actions to reduce energy use. Integrated design processes should therefore be encouraged.

Rental costs and billing systems

The average shopping centre lease includes a rental payment with a fixed portion based on occupancy square footage and a variable portion related to sales activity. Possession and use of the premises, build out criteria, signage criteria and the mechanical and electrical schedule may also be defined by the lease. The management may have the right to relocate the tenant during the term of the lease and the right to audit tenant sales when validating the percentage of rent obligations[8].

Standard leasing practice in commercial buildings is a split incentive billing system that shares operating and capital expenses between landlords (owner and management) and tenants. With regard to energy investments it means that the building owner often pays for energy retrofits, but cannot recover savings from reduced energy use that accrue to the

[7] The question could have been formulated differently to gain a clearly picture of the leasing system in shopping centres. The question asked was how long the store has been a tenant and not how long the lease lasts.

[8] http://definitions.uselegal.com/1/landlord-tenant-shopping-center/

tenant (Economidou, 2014). This often means the decision to retrofit lies primarily with the owners. This can result in inaction, even in the face of rising energy prices and other pressures to improve the sustainability of buildings (NRDC, 2011). However this is more of a problem in long term single tenant leases. Splitting the costs and incentives in a balanced way, for example by energy cost savings being used for investment repayments, has the potential to encourage investment. This would mean tenants are subject to a repayment fee through their utility bills and owners participating in the investment cost due to property value increases (Ibid, 2014). The billing system should make energy efficiency a shared objective for both owners and tenants and provide sufficient information as well as sufficient economic motivation. There are some economic models for reducing energy use in place in shopping centres, but results from the CommONEnergy survey show that for example, green leasing programmes only play a minor role. Less than 10 % of tenants who participated in the CommONEnergy survey said that they had a green lease (D2.2: Woods et al., 2015). Existing business models in shopping centres do not offer many incentives to increase energy efficiency, and no standardised economic models to increase energy efficiency in shopping centres were identified by the CommONEnergy survey or interviews (Ibid, 2015).

The exchange of all-in and revenue-based rents for a system with clear pricing of running costs which is independent of the rental price, and which is mainly based on energy consumption would provide a greater incentive to reduce energy use. There is no sufficient data to explain why there is so little interest in that kind of system, but streamlining management activity may be an influential issue. Individual billing based on actual running costs, is more time consuming and would require the installation of new management systems and possibly also supply systems. In addition business decision-makers often have a commodity view of energy, they only consider its cost, and if energy cost is low and/or perceived as necessary to core business activity i.e. providing tenant and customer comfort, then the cost reduction induced by energy efficiency investments is not going to be a powerful decision making factor (Cooremans, 2008).

Green leases

Green leases (also known as aligned leases, high performance leases, or energy efficient leases) align the financial and energy incentives of building owners and tenants so they can work together to save money, conserve resources, and ensure the efficient operation of buildings (Green Lease, 2014). They provide both owners and tenants with obligations to minimise adverse environmental impact in areas such as energy, water and waste (Economidou, 2014). Green lease agreements are voluntary. There exist no European rules demanding the use of green leases and although a number of countries have green leases, they vary with regard to content, form and procedure.

By taking in use a green leasing system which avoids split incentive leases and includes a transparent billing system, both owners and tenants can accrue benefits, for example (NRDC, 2011):
<u>For owners</u>: Tying capital costs to recovery associated savings - Imposing control on tenant demand for electric service - Separating energy expenses from other operating costs for

better tracking and expense recovery – Attributing more accurate energy consumption to tenants
For tenants: Greater assurance of efficient operations and control over operating costs – Ability to measure energy consumption, including sub-metering wherever possible – Better measurement of base building energy use for accurate allocation of operating expenditures – efficiency standards for major equipment replacement

In Norway some real-estate investors use a green lease template which consists of a green voucher and a voluntary green usage agreement, these state the requirements for how the building/ premises may be said to be energy efficient and environmentally conscious. Green vouchers mean a change in the principle that a lease means handing back a building in exactly the same condition as it was when the agreement was entered into. Instead, the landlord and tenant cooperate on reducing negative environmental impact and promote sustainable development (Bramslev, 2014). Green usage agreement specifies requirements for energy use, materials, indoor air quality, recycling, water supply, transport and the care and provision of outdoor spaces, so that both tenants and landlords contribute to the sustainable management and use of the premises. The requirements should be printable, making it possible to continuously check that agreements are followed. Such agreements require commitment from all parties and can be challenging to negotiate if there are multiple tenants in the building (Ibid, 2014).

Combining the aforementioned aspects increases awareness of the results associated with energy actions and connects them with reduced running costs. Another major incentive for both stakeholder groups is the increased value of the building. International research in the United States, Europe and Canada documents an increase in the value of green building. There are reports of 5-20 % higher rental income and 10-25 % higher sales price for green buildings in surveys which also considered the location, size and age of the buildings. It is suggested that higher rental income is achieved because the premises have lower operating costs and improve the reputation of the tenant. Higher selling prices are achieved because the expected return is lower (Bramslev, 2014).

Reduced running costs

If the design of a building integrates sustainability at the outset then extra costs associated with greening will be a minimum (Gomez, 2008). Effort is placed on achieving precise execution, and efficient planning of critical details during the early phase of the project. In existing shopping centres the cost of retrofitting may be seen as coming in addition to already existing overheads associated with the day to day running and maintenance of the shopping centre. However tenants associated with the CommONEnergy survey predicted a decrease in overheads due to reduced energy use/costs in shopping centres (see Figure 6). This positive expectation is in contrast to the barriers the same group associated with upgrade costs, more than 90% saw upgrades costs as a major barrier to in-store energy efficient upgrades and more than 70% suggested that rental/ overhead costs were a barrier against energy upgrades.

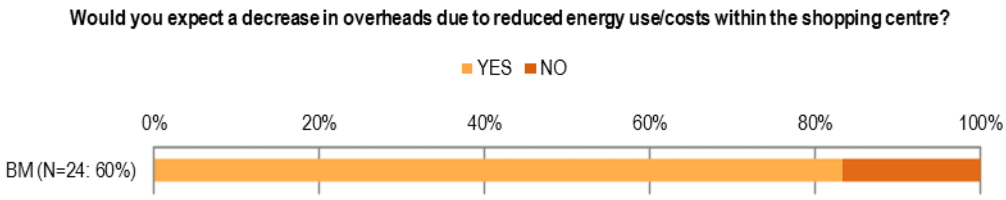


Figure 6 – Answers from the tenants questionnaire: "Would you expect a decrease in overheads due to reduced energy use/costs within the shopping centre?"

Tenants were also asked if they would accept an increase in overheads due to shopping centre rehabilitation and more than 60% said yes and more than 70% said yes to an increase in overheads due to in-store rehabilitation. The answers to these questions suggest some conservatism in relation to investing in energy efficiency measures, but at the same time they are willing to invest in energy actions through an increase in overheads. Amongst owners and managers who participated in the CommONEnergy survey there was agreement with tenants that rental costs (85%) and upgrade costs (90%) were the main barriers against energy efficient upgrades. Owners and managers were not asked if they would expect a decrease in overheads due to reduced energy use costs in the shopping centres, but they were asked if they would be willing to offer tenants incentives to reduce energy use in shopping centres through the investment in technical equipment (see Figure 7). A reduction in overheads could be potential incentive. More than 80% said no to this question.

Despite expected environmental impact and the potential economic advantages associated with reduced energy use. Economic investment in energy retrofitting remains a barrier.

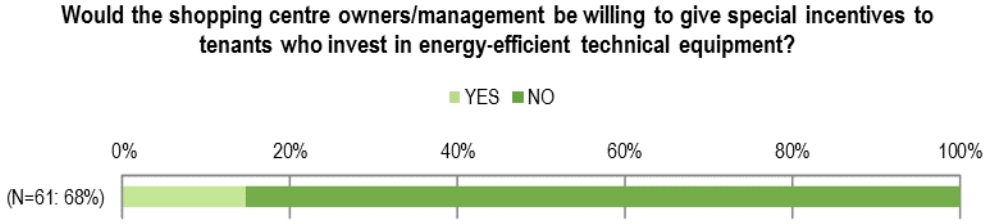


Figure 7 – Answers from the owners/managers questionnaire: "Would the shopping centre owners/management be willing to give special incentives to tenants who invest in energy-efficient technical equipment?"

The Carbon Reduction Commitment Energy Efficiency Scheme (or CRC Scheme) offers energy efficiency incentives and encourages emission cuts by large energy users in public and private sectors across the UK. Participants include supermarkets, water companies, banks, local authorities and all central government departments. Under the current rules, organisations that are part of a larger organisational group such as tenants in shopping centres must act together as one entity. Companies that demonstrate CRC compliance avoid financial penalties. Organisations which fully engage in CRC can generate significant benefits, including cost savings through reduced energy usage, reduced expenditure on CRC allowances and an enhanced "green" reputation, through the published league tables showing performance and renewable energy usage[9].

[9] http://www.lifestyle.co.uk/homes/environment/what-is-the-carbon-reduction-commitment.htm

Stakeholder motivation

Stakeholder knowledge is a factor which has the potential to encourage energy actions. This is supported by the UK lease review by Langley et al in 2010, which indicates that tenants in multi-tenanted buildings had not generally investigated opportunities to improve their environmental performance or resource consumption through changes in their lease contracts. This was largely due to energy supply, base load consumption and control, largely not being under the control of their rented areas. The same study found that there is no requirement for tenants to employ energy efficient management or technology within their rented areas and that there is a general lack of lease clauses relating to energy efficiency measures. Tenants therefore lack knowledge about how much energy they currently use and what actions they could potentially take to improve the situation. However current interest in green buildings suggests that this may change in the near future. According to recent research, investors are now more interested in green buildings (Bramslev, 2014, Langley et al, 2008 & Gomez, 2008).

During an analysis of leasing practice in commercial buildings in South Wales, Langley discovered that the meetings to gather information about how well the leasing system worked also encouraged better communication between tenants. This lead to them being more aware of best practice among their fellow tenants and also encouraged them to initiate similar actions themselves (Langley et al, 2010). However interviews with owners and managers during the survey indicated that there is little pressure on tenants to have an environmental profile. An additional action which has the potential to support reduced energy use is that the environmental credentials of prospective tenants should be investigated alongside their financial credentials.

A representative from a company, who owns a number of shopping centres in Norway, said that energy saving and environmental awareness was important to the brand image but that they did not demand it from their tenants, although they encouraged tenants to have an environmental profile and take part in environmental certification schemes. In another company which owns and runs a number of centres in the UK, the representative answered that the an environmental profile was important to the company, but they did not demand it from their tenants and that they would "*never turn a tenant down*" because of their environmental profile. There are, the representative suggested, a lot of tenants who do not have time to deal with these issues, the company therefore runs it centres "*to make it easier for tenants to do the right thing*."

Lack of formal monitoring of energy use is also understood as barrier against tenant energy actions (Langley et al, 2010). Tenants may be encouraged to participate in deep energy retrofitting if they are supported by a guidance documents such as tenant handbooks, which state what kind of metered information will be made available and why, what the performance rating of the building is and the maintenance schedule. The introduction of resource reduction targets is potentially useful to both management and tenants. Stakeholder motivation requires actions on a number of levels for example through technical

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https://www.gov.uk/government/policies/reducing-demand-for-energy-from-industry-businesses-and-the-public-sector--2/supporting-pages/crc-energy-efficiency-scheme installations, through legal actions such as the inclusion of green clauses in the lease and economic actions through changes to the billing system. However none of these actions will take place without effective information dissemination on all stakeholder levels. Continuing work with energy issues and increasing improvement requires regular information about actual use and further potentials.

Building codes

A building codes analysis was provided in work package 2.1 and provided a general overview of the most relevant national building codes, regulation constraints and policies on buildings' energy performance that have been enacted by worldwide governments in recent years (Bointner et al., 2015). The work concluded that it is very hard to compare the different systems given the variety of calculation methods used to measure compliance and major differences in definitions (e.g. definitions of primary and final energy, heated floor area, carbon conversion factors, regulated energy and total energy requirement etc.). In regards to this problem, there is a surge of interest in Europe in the harmonization of methodology procedures because the Commission will need to demonstrate that all Member States are delivering equivalent outcomes.

While Building codes set the minimum performance requirements for new buildings, in the EPBD directive (revised 2010) member states were to impose requirements for cost effective energy measures to be performed when 'major renovation' take place (EPBD, 2010). Comprehensive retrofitting of buildings will in many countries bring along the same requirements made for new buildings[10]. All countries were enabled to choose to define a 'major renovation' either in terms of a percentage of the surface of the building envelope or in terms of the value of the building. Additionally or alternatively, requirements may be applied to the renovated building elements. The application of minimum requirements is to ensure that when technical systems and building elements that have a major impact on energy performance are retrofitted or replaced, the energy performance of the components meets minimum energy performance requirements, in so far as this is technically, functionally and economically feasible.

However, according to Stensson (2014), the focus is always on the energy supplied to the building rather than on an analysis of the functions for which the energy is used. Shopping centres are not yet a well-defined building type, compared to for example office buildings. This means that there is almost no standardizsed data characterizing the activities in a shopping centre and only very limited statistics is available. The relatively large energy use in comparison to other building types, together with an increased numbers of shopping centres, makes it important to enhance the knowledge about energy use in shopping centres. Stennson (2014) concluded that "...*energy efficiency measures related to the installation of more energy efficient lighting is a major challenge in relation to energy retrofit of existing, as well as new, shopping malls. Furthermore improved HVAC systems, as well as improved knowledge about air infiltration heat losses in large buildings, are other challenges in relation to shopping malls.*" Stensson (2014) concluded that present energy

[10] For further reading: http://www.eceee.org/policy-areas/buildings/EPBD_Recast

requirements on buildings which focus on landlord energy and exclude energy requirements on tentant energy are less effective in reducing total energy use in shopping centres (Stensson, 2014).

The energy declarations are supposed to give valuable suggestions regarding energy efficiency measures in existing buildings. However, the present control and handling of the energy declarations does not enhance energy efficiency measures in shopping centres. "*There are further a number of difficulties related to the present way of stating the energy performance of complex buildings, as there is a lack of tools that complement the definition of energy performance. With current requirements there is even a possibility that one building using less total energy does not satisfy the building requirements while another building using more energy does do so.*" (Stensson, 2014)

For example in Denmark the energy requirements are adopted for the individual building construction elements and there is no specific energy requirement on building level. In France, on the contrary, the regulation for existing buildings sets standards for the total energy consumption of refurbished buildings that must be at least 30% smaller than before the refurbishment (Bointner et al., 2015). However, the gap between original standard and coming sharpened requirements on energy demand for existing buildings, can be too difficult to bridge in many cases. There are several difficulties and such hampers lead often to dispensation or exemption from the energy requirements. Rules should, however, be established to secure that comprehensive reconstruction fulfil energy requirements.

Shopping centres are not interchangeable with other kinds of complex buildings. The form, function, usage, and users have implications for energy use. To support the understanding of what causes the main inefficiencies in energy usage and how to develop the best solutions sets, existing building codes do not contribute much and cannot be seen as drivers. However, location, type of development, the size and the GLA, the type of anchor stores and the trip purpose are all aspects that have been used to indicate the needs that a shopping centre serves within social and physical context. If this or at least some of these aspects can be included in revised building codes these could act as drivers. Well defined interactions with the local energy grid could help to increase interest in a more regenerative way to improve local grid interaction and thereby reduce impacts on local energy grids (Cole, 2012). These new sets of building regulations are just emerging and far from complete but it is envisioned that new building codes will in the near future include a common definition of nZEBs (Voss and Musal, 2012; Sartori et al., 2012). Then building codes could have potential to act as key energy retrofitting drivers.

nZEB development

The emerging idea of 'net-positive energy' buildings raises new questions and presents a number of new design considerations and opportunities (Torcellini and Crawley, 2006). Net-positive energy is explored though viewing the role of a building for adding value to its context and systems in which it is part (Kurnitski, et al. 2011). Rather than considering only the generation of more exported energy versus its importation to individual buildings or the grid, the emphasis shifts to the maximization of energy performance in a system-based approach (Georges et al., 2015). "*Net-positive energy approaches open a host of new technical, behavioral, policy, and regulatory issues and opportunities not currently evident with net-zero energy buildings.*" (Cole and Fedoruk, 2013) These contest the importance of 'individual' buildings as the most effective unit to make significant energy gains and the established "*expectation that each and every new building should be required to attain net-zero performance.*" (Cole and Fedoruk, 2013, p.112) and points to the importance of rethinking the system boundaries of energy analysis and emphasize the importance to develop a comprehensive framework and methodology for the transformation of the existing building stock (Cole and Fedoruk, 2013).

2.2.3. Trends which have implications for the retrofitting of European SC

When and why do shopping centres retrofit?

The term retrofitting is commonly associated with buildings and implies the addition of new technology or new features to older systems. However there is no clear definition of the action which includes a large number of related terms (Thuvander et al, 2012). Ebbert suggests that the term retrofit combines a number of expressions which suggest interference with the original building structure, such as restoration, renovation, maintenance, repair, refurbishment, conversion and transformation, in addition to gutting, extension, reconstruction, deconstruction and demolition (Ebbert, 2010). Retrofitting implies the repairing and making use of an existing building, as well as the adding of something that was not put into place during the original build, for example components such as an advanced ventilation system or solar panels. It suggests a major repair or change, whilst, for example, a refit is a minor improvement (Ibid, 2012).

The state of constant flux due to ever-changing retail needs is a characteristic of shopping centre buildings (Woods, et al., 2015). In their description of centre revitalisation O'Brien and Harris state that "periodic refurbishment is vital if shopping centres are to maintain their attractiveness to an increasingly sophisticated shopper" (O'Brien & Harris, 2013). This means the shopping centre which offers the best choice of goods and services and a place to shop that is more appealing than its competitors. In relation to the physical structure, the aim of shopping centres, in the face of competition in the retail market, is to appear new, different and fresh to customers. Merchandise changes from year to year and season to season, and shopping centres and stores redesign their interior according to the needs of the merchandise that they are presenting, the changing needs/interests of tenants and customers and competition between retailers, "As soon as a chain is seen to be revamping its image, so competitors will feel it necessary to jump on the refurbishment bandwagon in order to protect their market share" (Ibid, 2013). Retail units/stores must be refreshed and sometimes replaced. This requires highly flexible architecture, e.g. City Syd in Trondheim, Norway has gone through a number of rehabilitations and a major retrofit in 2000, when the building went from 28,500 m2 to 38,000m2. A further expansion of 22,000m2 GLA is proposed and is awaiting approval from Trondheim Municipality and investors.

This state of flux is also represented in the CommONEnergy survey. More than 40% of respondents to the CommONEnergy owners and managers survey had been involved in the rehabilitation of shopping centres within the last five years. Examples from the reference buildings also point to the same tendency. Efforts to improve energy efficiency and provide sustainable solutions for shopping centres must take this state of constant flux into account, by providing systems that may be easily moved, reused or redeveloped.

Size and location matters

The focus here is how the physical structure of the shopping centre is changing and what the implications are for energy use and not the general growth in the industry which is based on wider demographic and economic growth. Worldwide 1,659 shopping were opened in 2013-2014, representing 7% growth. 350 of the shopping centres were opened in Europe (the total retail space in Europe is in 2014 is now approximately 153.8 m^2 GLA). Central and Eastern Europe are responsible for 69% of this growth and the region is expected to remain a development hotspot, providing 66% of the projected retail space to be completed in 2014-15. The growth in new shopping centres being built does not mean that older shopping centres are being closed down or replaced. In addition to new European developments, 86 extensions are set to be opened in 2014 and 32 extensions are in the pipeline for 2015[11]. However, although there are still a large number of smaller retail centres, there is an apparent growth in the shopping centre industry.

Size matters The CommONEnergy shopping centre definition and ICSC's definition from 2005 both suggest that to be defined as a shopping centre, the retail space should be a minimum of 5,000 m^2 (Bointner et al., 2015, ISCS, 2005). A football pitch is between 5 – 8,000 m^2. This suggests that a shopping centre is at least the size of a small football pitch, which implies a physical structure which covers a large area. The largest shopping centres can be more than 100,000 m^2 (the equivalent of more than ten football pitches). If the car parks which surround shopping centres are also included in the equation, the proportions suggest an area the size of a large neighbourhood or a small town. Size has implications for energy use, because despite efforts to reduce energy use, the larger the shopping centre the more energy it will use. Reducing the size of the shopping centre, the size of store and the number of opening hours would have direct results on energy use (Multiconsult, 2014). However we do not have any examples of shopping centres which are actively downsizing. Changes in shopping habits are influencing size, such as including leisure activities such as sports arenas and cinema centres within the shopping centre complex.

However although the shopping centre industry itself is growing, this does not necessarily mean that physical structures of the majority of shopping centres buildings are at the larger end of the scale. In 2008 ICSC described two-thirds of the shopping centres, not defined as retail parks, factory outlets or leisure parks, as small (5,000-19,999m^2). In the 51 countries tracked by Cushman and Wakefield in 2014, the majority of the shopping centres were classified as small[12]. The average size of a shopping centre was 19,700 m^2. Over 40% of the shopping centres which participated in the CommONEnergy survey were in the smallest size range from 5 000 to 20 000 m^2 (Figure 8). Less than 10% were over 100 000 m^2. The results imply that the European shopping centre industry is actually dominated by smaller shopping

[11] www.cwglobalretailguide.com The data is based on an analysis of 51 countries worldwide.

[12] The same size scale as CommONEnergy and ICSC was used. The largest average size of shopping centres was found in developing countries in Asia and Latin America, between 52,700m^2 and 29,200m^2. In established markets in Europe and North America, the average size is between 21,400m^2 and 17,700m^2. www.cwglobalretailguide.com

centres. The data gathered in the CommONEnergy survey is influenced by the Norwegian shopping centre industry which provided almost 50% of the responses to the owners and managers questionnaire.

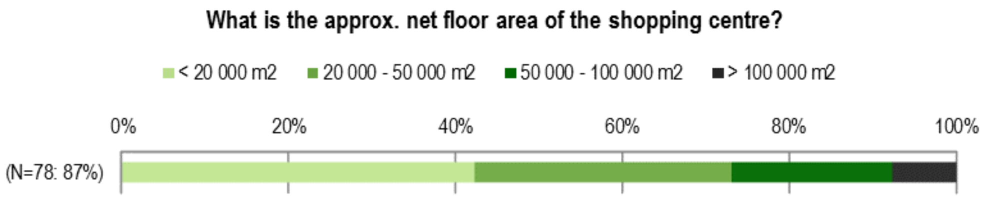


Figure 8 – Owners and managers questionnaire: What is the approx. net floor area of the SC?

The shopping centre industry in Europe varies from country to country due to demographic, climatic and cultural differences/preferences. The Norwegian shopping centre industry although it has one of the highest ratios of m^2 GLA per capita in Europe is not dominated by large shopping centres, smaller neighbourhood centres are common (D2.3: Haase et al, 2015)[13]. A recent trend in some larger Norwegian cities is to provide a number of smaller neighbourhood centres. Also in the UK supermarket chains with large commercial establishments providing for convenience shopping are now, after a number of years of growth, struggling in competition with cut-price stores and retail chains which offer smaller grocery stores. It is suggested that shoppers in the UK are "*shopping for little more often*" and that they are shopping in a larger number of stores than they were before. It is also suggested that the main reason for this change in shopping habits is the variety of choice that is available. Shoppercentric who presented this retail data suggest that "*It has never been easier to find the right product, at the right price within easy reach*."[14] This change in shopping habits is a result in changes in the retail trade, for example the large number of centres and types of shopping centres.

The shopping centre definition is a broad definition, encompassing a large number of shopping centre types. A number of types have been looked at in more detail in D2.3 (Haase et al., 2015): neighbourhood centre, community centre, strip mall and precinct, retail park and factory outlet, shopping centre, regional centre, super-regional centre, and speciality centre.

Reference buildings

The ten reference buildings in the CommONEnergy project include a number of sizes, types and stages of development within the shopping centre industry. In this way they represent the variety of retail experiences available and illustrate the way the industry is developing, which is not completely captured by the statistical analysis provided by for example Cushman and Wakefield in 2014 and CommONEnergy's own survey. For example, the Studlendas and Parmarys shopping centres in

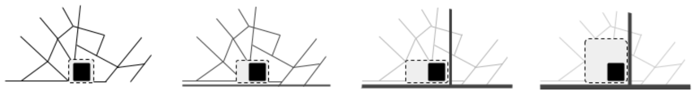
[13] Norway has 638m^2 GLA per 1,000 inhabitants only Sweden had more (702m^2 GLA) whilst the UK had 435m^2 GLA (ICSC, 2008).

[14] http://www.shoppercentric.co.uk/ Passion, pleasure, price and proximity with regard to our shopping needs are understood as guiding factors.

Lithuania are both relatively new centres built in 2006 and 2004. Studlendas is a medium sized shopping centre (12,637 m2) and Pamarys is small (6020 m2). They illustrate the small to medium size range which prevalent in new developments. Donauzentrum in Vienna and Brent Cross in London were both built in the 1970's and illustrate a tendency towards expansion among existing centres. A trend which is not present in the statistics is the re-use of historical buildings as speciality centres. In CommONEnergy this is represented by Mercado del Val in Valladolid and the Grand Bazar in Antwerp.

Within the CommONEnergy project these are represented by the demo cases and reference buildings (see Table 6). There is a certain amount of overlap between the shopping centre types and centres may have more than one kind of usage, for example a community centre may also be a regional centre (this is visualised in table 6 where the different shopping centres have more than one dot associated with each centre). The location, physical environment and the range of products available are major factors which influence the customer's choice of centre (D2.2: Woods et al, 2015).

Table 6 – Shopping centres types, demo cases and reference centres.



Shopping centre, town, country	Speciality	Community	Regional	Super regional
City Syd, Trondheim, Norway (DC*)			•	
Ex-Officine Guglielmetti, Genova, Italy (DC)		•		
Mercado del Val, Valadolid, Spain (DC)	•			
Grand Bazar, Antwerp, Belgium	•		•	
Centro Commerciale Katané, Catania, Italy		•	•	
Pamarys, Silute, Lithuania		•		
Studlendas, Klaipeda, Lituania		•		
Waasland SC, Sint-Niklaas, Belgium			•	
Donauzentrum, Vienna, Austria				•
Brent Cross, London, UK				•

** Demo cases (DC) are specified. Other centres act as reference buildings in the CommONEnergy project.*

These factors also indicate the type of shopping centre and what it is being used for, such a convenience shopping or comparison shopping. Where we choose to shop is therefore influenced by a number of factors which are social, functional, value and impulse based. Smaller neighbourhood centres provide a convenient local solution, whilst regional and super-regional centres offer a broader range of shopping and entertainment opportunities. Changes in customer needs and interests influence the way shopping centres develop, the desire to shop for little and often will encourage the development and survival of smaller shopping centres and the link between leisure needs and shopping will encourage already established centres to expand to include a wider range of leisure activities.

Leisure and pleasure

Shopping has traditionally been understood as a social activity (Miller, 1998). Shopping centres by catering to the changing needs of the customer are strengthening their position as social places, where customers can meet friends and family and engage in leisure activities. Modern shoppers are attracted to centres that recognise and cater to their specific lifestyle and attempt to cater to specialist groups instead of trying to please all tastes (O'Brien, et al., 2013).

Vestkanten shopping centre in Bergen, Norway includes a water park. The head of marketing explained "*in the fight for customers, it is not enough to just offer them shops*.", only 8 out of 10 who visit the shopping centre actually shop[15]. The maintenance and running of the water park is costly, but the head of marketing claims that it gives "*good synergies*".

Vestkanten shopping centre, Bergen, Norway. Photo Olav Thon Gruppen

An additional factor which may or may not influence the physical character of shopping centres is the increasing competition between shops, shopping centres and internet "bricks and clicks". The management at Brent Cross, UK suggested that the increasing focus on leisure activities other than shopping was one result of this as is the use of shops to showcase and test goods that will eventually be bought on the internet (D2.3: Haase et al., 2015).

Shopping centres are increasingly places where people go to not purely to shop, but they are also places where people shop when they are already out enjoying themselves. Providing a sense of place is a central aspect when encouraging customers to visit the centre, shopping centres should not be all alike but offer individual atmospheres, leisure and lifestyle are linked to this aim. Shopping centres developers are exploring the idea that retail is an anchor for community life (Jones Lang LaSalle, 2008). Retail increasingly means providing mixed use schemes which offer different leisure opportunities. Cinemas featured in 85% of new builds in 2008. Sports facilities are also used to attract customers, snow domes, ice rinks, football stadiums and swimming pools can all be found in association with shopping centres. However sports facilities do not transcend all markets, the interest may be limited to certain customer groups and investors can see them as a greater risk (Ibid, 2008).

[15] Dagens næringsliv, 04.07.2014.

Providing opportunities to eat and meet is central in improving the sense of place in shopping centres, this means locating restaurants and cafes throughout the centre.

Change in usage to include leisure facilities has implications for energy use in shopping centres. This is explained in more detail in chapter 3.

Green Retail

Green retail or marketing suggests the sale and marketing of products that are intended to be environmentally more sustainable. This includes the modification of products and their contents, changes to the production process, sustainable packaging, and advertising[16]. Green retailing is often associated with green-washing where industries that adopt green acts with an underlying purpose to increase profits by providing consumers with the impression that the organisation is taking steps to manage its ecological footprint. In shopping centres all efforts to improve and renew the retail environment are based on fulfilling customer needs. The customer according to the CommONEnergy survey is still not focusing on sustainability when shopping. When asked how important a shopping centre's energy efficiency was to them, more than 75% of customers responded that it was very important (see Figure 9).

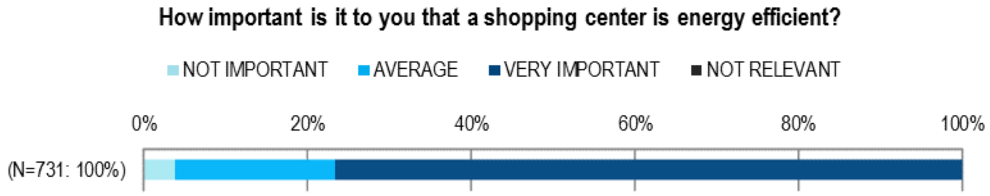


Figure 9 – Owners and managers questionnaire: How important is to you that a SC is energy efficient?

However when asked what the main reasons for choosing a shopping centre were, less than 5% stated that they chose the shopping centre because of its energy efficiency (D2.2: Woods et al., 2015). Customers were also asked how important the availability of organic or fair trade products was to them, 40% stated that it was of high importance and almost 80% stated that transparency concerning product origin was of high importance. However when asked what influenced their choice of shopping centre the price, range of the products and location of the shopping centre scored highest. Less than 10% stated that the availability of organic or fair trade products was important to their choice of centre.

However, although green retail, at the moment, only makes up a small part of the total retail market it is expected that green consumption will have a growing in commercial importance. The widening appeal of green stems from a general dissatisfaction with the character of the modern western economy, its materialism and waste. Green retail includes a wide number of issues which have their roots in 1960's radicalism but which can now been seen to have found a focus in personal consumption, and where using daily consumption is used to show

[16] http://www.green-markets.org/context.htm

an active interest in saving the earth (O'Brien & Harris, 2013). The public is increasingly concerned about how products are made, where and by whom. Green retail affects what people buy, where they buy it and how they buy (transport, internet).

Customer interest in sustainable shopping may be expected to put increasing pressure on the retail market (see John Lewis section 2.3.1) to provide sustainable products and a sustainable environment to shop in. However, there is at the moment little pressure on retailers to present goods in sustainable shopping centres. The market is often the one to create the demand for its products. It is often the case that the market itself creates demand, customers do not always know what they want before retailers make it available[17].

2.3. *Improving Inefficiencies in Shopping centres*

In the previous section the background for the changes taking place in shopping centres was considered; user behaviour, legal and economic issues and trends. These all have implications for the physical structure but not all of the aspects mentioned are direct drivers for deep energy retrofitting. This section will consider the main causes of energy inefficiencies in shopping centres; the suggestion is that solving these problems may be understood as direct drivers for energy retrofitting in shopping centres. The CommONEnergy report D. 2.2 (Woods, et al. 2014) established four main areas of energy use inefficiencies in accordance to the merit order that these areas have on energy consumption in shopping centres: lighting, HVAC, plug-loads and refrigeration, and lastly architecture. The focus of the analysis is on the technical side with cross over to facilities, functions, management and logistical practises. The consequences of inefficiencies can affect costs, indoor comfort, issues along with maintenance and operation time and management.

Increasing energy efficiency is usually considered as a means to improving energy intensity, performance and obtaining energy savings without necessarily decreasing comfort or accepting other caveats in realising the potential. However in a building as complex as a shopping centre, heating and cooling often occurs at the same time, and there are large air exchanges between various areas. The placement and function of thermostats, control systems and strategies becomes important for efficient operation where also different activities with distinct requirements take place. Performance levels, indicators and needs which are important to consider when assessing inefficiencies in shopping centres are further discussed in chapter 3.

2.3.1. Lighting

Lighting is the main cause of energy use in shopping centres (Ticleanu Cosmic C.; Littlefair P. J., 2013; Stensson et al., 2009). In-store lighting is important for commercial purposes as well as for the many people working and spending time indoors, often without access to

[17] Based on "Say's Law": Jean-Baptiste Say, 1821 A Treatise on Political Economy. Longman, Hurs, Rees, Orme & Brown. University of Michigan.

daylight for most of the day. The analysis signifies a potential to develop concepts to limit illumination levels in a centre to a reasonable level and work holistically with lighting design. Shopping centre managers are generally responsible for lighting in common areas, both indoors and outdoors. They have less responsibility for in-store lighting, which usually depends on individual in-store guidelines and fit out specifications which the tenants themselves are responsible for. This division between common areas and in-store areas makes achieving energy reductions through changes in lighting systems complicated because it requires agreement by management and tenants.

Planning often does not consider the more specific and interrelated aspects of lighting design, as accent lighting is often not considered within the overall general lighting level. Implementing a solution with accent lighting and a reduced general lighting level is a sophisticated planning task as it is important to ensure a balanced illuminance distribution. Approaches can be used to harmonize lighting levels in shops and common areas, harmonising lighting levels between different shops, or adjusting lighting levels to the time of day or to different tasks (i.e. cleaning/stocking up).

A list of inefficiencies which are discussed in greater detail in Report D2.2:

- Lack of daylight entries or excessive entry of daylight
- Inefficient lamp technology and inefficient luminaires
- Inefficient electronic control gear and lack of sub-system control division.
- Inefficient room distribution /surfaces
- Not taking into account maintenance effort, environmental impact and life-cycle performance
- Further aspects regarding lighting in shopping centres / retail spaces:
    - Competing lighting levels to attract customers; this could be obtained by other mechanism like using contrasts, highlights, sparkle or brilliance.
    - Addition of more and more accent lighting to present goods, while neglecting to take into consideration the effect this has on the general lighting level.
    - No lighting design strategy for entrance and atrium spaces, their daylight transparency and visibility in relation to light levels in adjacent shops and retail spaces.

2.3.2. HVAC measures

Quality control of the complete energy system is necessary when aiming for energy-use reductions. Good building operation and the quality control of a given system, requires information about building systems and assessment tools. A commissioning procedure that enables the follow-up of the building performance during the building's lifetime can help to detect systemic inefficiencies.
Different assessment tools and different inspection algorithms are in use. In addition comparative analysis including a detailed monitoring system supports efficient energy use by tracking and fault detection during day-to-day operation. Another useful action is the holistic analysis of yearly and hourly energy consumption profiles with separated use and energy carriers. Additional areas which need to be considered are the implications of the simultaneous operation of heating and cooling, the lack of detailed zoning, limited control possibilities, the non-exploitation of heat fluxes and thermal cascade and the coupling with refrigeration.

In CommONEnergy report D2.2 HVAC inefficiencies are structured in three main processes:

- Ventilation inefficiencies: conditioning of fresh air, distribution and demand control.
- Cooling-Specific inefficiencies: production, distribution and end use of cold water.
- Heating-Specific inefficiencies: heat generation, exchange and supply of heat to end users.

The photos show various HVAC retrofitted installations, and outline some of the logistical challenges of fitting new installations into existing buildings. Starting from left; fan speed controls fitted to an older air handling unit, a dual heat pump installation fitted in an existing technical room, new chiller lifted into place on a shopping centre roof, and a small DX condenser unit mounted on the roof for tenant space cooling, or refrigeration cabinets.

Examples of retrofitting of HVAC installations in two existing centres (Photo: SINTEF Byggforsk)

2.3.3. Refrigeration

A high degree of thermal loads occur in shopping centres. Supermarkets, convenience stores and market halls are typical spaces with high density of installed refrigeration units. Restaurants, food courts, cafeterias and small vendors are other examples of tenants that require cold storage facilities. In cold storage units, local split type space cooling and small air conditioning units are often used, but these are also common in conditioned retail spaces when these services are provided by the tenants themselves.

The refrigeration process is basically the same in all of these systems, sustained by electricity, but the cold medium and overall efficiency of the system may vary significantly. One classic inefficiency example are condenser units misallocated in such a way that they dump excessive heat into a space or surrounding area where this in turns leads to increased cooling demand, or a poor system efficiency. However, in many cases cabinets would act as heat sink (or cold source) in the space and the heat rejection happens outside (since the condensers are usually placed outside). Another example is failing to utilise waste heat when there is both a cooling and heating demand in different parts of the building.

A list of inefficiencies and possible measures related to refrigeration (from Report D 2.2):

- General design and operation measures**:** selecting appropriate storage temperatures, planning and optimization of the opening of the chambers, programming defrosts, program revisions and maintenance of the facility.
    - Doors should be installed on open freezers and refrigerators.
    - Night blinds should be installed on all open cooling cabinets, if none exist already.
    - For displays that are accessed less often, consider day covers or plastic strip curtains.
    - Heavy plastic curtains outside the walk-in cooler or freezer keep the warm air out.
    - Larger heat exchangers are more efficient than multiple smaller units so when renovating, try to group cabinets together (or connect them to a common water loop) to better facilitate heat removal or recovery and consider central supply systems.

- Fibre optic lighting piped into cabinets minimizes heat input from direct lighting.
- Insulation in coolers and freezers should be inspected and upgraded regularly.

- Cooling process inefficiencies and improper use of refrigerants.
  - Energy-efficient central compressors needs to be properly sized to match the load.
  - Remote condensers that effectively allow rejection of heat to the building's exterior.
  - Refrigerants may be operating on the wrong process temperatures.
- Lack of control systems and proper monitoring of processes,
  - Lighting occupancy sensors for walk-in coolers or freezers will ensure that lights are only on when needed and will make it easier for employees to carry produce.
  - Demand-defrost controls initiate defrost cycles only when needed, instead of using automatic timers.
  - Dewpoint controls on display cases prevent the buildup of fog on glass surfaces and the buildup of moisture on metal surfaces.
  - Compressor and evaporator fan controllers for walk-in coolers and freezers, such as the variable speed drives, can cut the voltage to the motor and slow down the fan when full air flow is not needed.
- Insufficient thermal energy storage (TES) prevents storage of cool water for later use. In particular for peak demand times in summer.

2.3.4. Architecture and design

The need for flexible building solutions which support the changing needs of the retail industry challenges the architectural and aesthetic quality in shopping centres.

Examples where shopping centres have gone through a number of rehabilitations and extensions, such as **Brent Cross** in the UK, show that this can have a negative impact on shopping centre design aesthetic quality. At Brent Cross the many changes to for example the façade are a visible reminder of the shopping centres retail journey. When Brent Cross opened in 1976 it was constructed in a dumbbell shape running east-west parallel to the North Circular Road. Brent Cross was first expanded and renovated in 1995, with additional shops and restaurants added[18]. Brent Cross will be part of a multi-million pound redevelopment starting in 2015 which will potentially improve the physical challenges that the centre currently faces. The shopping centre on the inside is well organised and attractive, but interviews with retail workers and technical personnel show that there are challenges in relation to the amount of storage space and access to it, as well as technical challenges in relation to the roof space, where new technical installations are continually being added because of the changing individual needs of retail units within the shopping centre.

Brent Cross Shopping Centre Roof, UK (Photo: SINTEF Byggforsk)

Integrated design solutions are more effective than individual actions in improving the quality of the built space, both energy and design wise. Integrated actions should also include

[18] http://www.hammerson.com/property/shopping-centres/brent-cross/

universal design which is associated with ergonomics and accessibility, and has implications for the design of sustainable shopping environments[19]. Accessibility and ergonomics are not drivers for energy use reductions, but combining these actions with those aimed at achieving energy use reductions have the potential to increase the energy impact. Owners, managers and tenants should therefore be encouraged to work with more than one action at once.

Universal design and ergonomics

Shopping centres aim to please the customer encouraging them to stay as long as possible by providing places that are comfortable, legible and safe, and that are accessible independent of age or disability. The CommONEnergy survey among owners and managers places architecture as the third most important issue to be addressed when considering upgrading a shopping centre. Only reducing energy demands and customer satisfaction scored higher (D 2.3: Haase et al., 2015). If owners and managers work towards achieving customer satisfaction by providing tenants and customers with attractive energy efficient architecture, then this bodes well for future shopping centre architecture. In addition, the shopping centres involved in the survey do not have serious problems with accessibility.

Entrance areas should be clearly visible to those who wish to gain access to the shopping centre. Outdoors entrance areas at Emporia are marked by large visible works of art (left photo). Accessibility is an issue when design entrances to shopping centres. They should be easy to use, with simple and efficient opening mechanisms and have enough space to allow wheelchair and pushchair access. Energy demand is another common issue surrounding entrance areas (ASHRAE 2011a; ASHRAE 2011b). In both public and cargo entrances, heat loss, visibility and draft are important design considerations, dependent on the climate location and time of year. Ideally the main entrance should be designed with a form of buffer zone, so that the interior and exterior doors are rarely open at the same time. If automatic doors are used then they should be open long enough to allow comfortable access, while using rotundas may require alternative access.

From left to right: An entrance to the Emporia Shopping centre, Malmø, Sweden (Photo SINTEF Byggforsk). Different grades of daylight transparency for entrance areas of two shopping centres (Photo: © Bartenbach). Inside the multi storey atrium entrance at City Syd, Norway (Photo SINTEF Byggforsk).

They are legible, and although there are some doubts among tenants about how accessible they are to the visually and hearing impaired, they are in general accessible to workers and customers with disabilities (Ibid, 2015). This suggests that the shopping centre industry is

[19] Universal design aims to find solutions with a high degree of usability, solutions that encourage equality independent of people's differences. A consideration of different experiences and uses of buildings is an important strategy that encourages the development of improved solutions for more people (Kjølle et al. 2013).

taking factors such as universal design and ergonomics seriously[20]. Complex buildings combined with the high concentration of customer and workers, implies serious ergonomic and health and safety issues (H&S)[21]. In Europe there is a fairly consistent set of regulations and guidelines related to ergonomics and health and safety, but the options for their implementation are diverse and this results in varying impact on shopping centres.

In the **Emporia shopping centre** in Malmø, Sweden retail activity is organised around a three-storey figure eight where shops are grouped together around atriums, each with a different theme and colour scheme. This is a design solution which is attractive and makes it easier for customers to find their way around, and find what they want in the shopping centre. In addition the centre provides regular seating areas where customers can rest whilst shopping. These factors support legibility and accessibility for customers and workers with and without disabilities. On top of Emporia is a green roof or roof park which reduces noise and delays surface water (reducing the need for a surface water system). The roof also provides good insulation, potentially reducing energy requirements. The roof park is part of the aesthetic experience of the centre offering a place for rest and recreation, and hiding technical rooms. It is a bio diverse landscape with 50 different species of plants which absorbs and binds pollution, and contributes to an improved environment in Malmø[22].


Emporia shopping centre, Malmø, Sweden: Atrium and Green Roof (Photo SINTEF Byggforsk).

Ergonomics deals with dimensions, movement and needs of people at work. Universal design is an approach which aims for usability and accessibility of all products and environments for all user groups irrespective of age, physical disability, mental capability or situation. Considering all kinds of users when developing a design avoids the need to make changes after the technology is taken into use. This means for example that doors and entrance areas should be easy to work with for cleaning and technical personal.

[20] The questions were not posed to user groups with disabilities, but more than 600 customers answered the questions and very little criticism was made about the physical environment. There was an opportunity to write direct comments and if there had been serious issues related to the shopping centres in Trondheim and Genoa where the survey took place, then it is suggested here that we would have been given feedback.

[21] The study of ergonomics is intended to optimise the interaction between people and the environment in order to adapt the positions, environments and organization to the capabilities and limitations of people, minimising stress and fatigue and thereby increasing the performance, safety and comfort of the user (ESPADELADA-project). This is accomplished by combining the design of tasks, with the design of the environment for example, controls, displays, tools and lighting.

[22] http://www.diadem.com/news/view/id/116

2.4. *Interactions with the local energy grids*

Energy retrofitting processes applied in shopping centres has mainly focused on the incorporation of energy producing technologies and the use of highly efficient HVAC and lighting technologies for diminishing energy consumption and capturing a large saving potential. However, in the new energy landscape which is made up of an increasing number of distributed fluctuating generation points, there is the need to also maintain power grid safety and reliability with e.g., less mismatching between electricity generation and demand, or assisting the grid during stress (excess or deficit) periods. Power grid fluctuations in both power demand and generation, even for few minutes, require a supplementary setting on conventional production units. Solutions include the optimal management of the generation and demand profile to shave or shift peaks also based on local storage and/or additional services (e.g., electrical vehicles, hydrogen production). These solutions require detailed monitoring and control devices as well as strong participation by end-users (managers, tenants and customers). Appropriate management of the loads could help matching the demand and generation profile, move the loads to times of excess electricity (i.e., lower costs) or provide additional services to the society (e.g., transportation and supply energy to the grid). Within this context shopping centers can become part of the solution and assist in managing the issues arising regarding the RES integration, energy management and support the grid.

The interaction with the local energy grid and the opportunity for shopping centres to provide additional services has not really been considered as potential driver for energy retrofitting up to now. However, shopping centres use a significant amount of energy, especially electricity (mainly for lighting, ventilation, cooling and refrigeration) it is possible to produce on-site part of the needed, reducing electricity the large fraction imported from the grids. On the other hand, the classification of the demand is feasible since most of the RES has a fluctuating profile dependent on the (predictable) weather conditions. Considering the variation of available electricity and the variable-price tariffs possibilities exist to reduce the energy bills through load management. One could think of shifting the peaks to the times when there is a surplus of on-site generation (therefore maximizing the self-consumption) or moving the peaks from high price times to low price times of the day/week (therefore reducing the electricity bill).
In order to understand the capacity of shopping centres for operating as an energy supplier, (this aspect was considered as a driver in the retrofitting interventions), guidelines should be provided which allow a study of the viability of actuations in the local energy grid (potential and the restrictions). Concerning the building, the characterization must include the identification of the energy demand profile, as well as the capacity to incorporate renewable energies (e.g. available surface for solar panels or for CHP units). Whereas the context analysis includes the climate conditions (linked with the RES potential) and the surrounding context (solar panels may be limited by the shading produced by close buildings, wind turbines can be restricted by the low wind speed achieved in cities and regulations, etc.). This surrounding context must also deal with the grid capacity (current level of saturation and generation profile) and quality (non-existence of interferences in the proper operation of

the system of energy supply) as well as the tariffs available in order to detect if the expansion of the grid capacity and especially to the use of renewable energies can produce stress for the grid (e.g., significant excess production or excess demand compared to production).

A description of these is available in CommONEnergy report D2.4 (Antolin et al., 2015). Based on this an assessment of the flexible (movable) loads must performed and associated solutions to shave/shift the peaks can be detailed. It presents a detailed description of these including an analysis of the potential for modification. The most significant potentials are for modifications related to the interaction among shopping centres and the grid are:

- Load reduction/shaving including: Replacement of inefficient / improperly seized systems
- Exploitation of daylighting, reducing artificial lighting density and use therefore providing a load reduction for both lighting and cooling electricity
- Exploitation of natural ventilation therefore reducing the mechanical ventilation loads
- Exploitation of synergies among thermal fluxes (e.g., thermal cascade)
- Load shifting: Via controllability and change in setting via BMS mainly for the heating, cooling, ventilation and refrigeration
- Storage: Related to the load shifting in order to reduce import from the grid during times of high prices and increases during times of low prices, also based on on-site PV production and potential connection with mobility
- Renewable energy generation: Exploitation of available space for the production of on-site energy (e.g., electricity form PV, wind or CHP)
- Transport: Related to charging station for electric- and H_2-vehicles vehicle for material handling, private costumer and public transportation

2.5. *Definition of an integrated set of energy drivers: Conclusions*

This chapter has covered ten different areas where drivers for deep energy retrofitting are established. These are user behaviour, legal and economic issues, building codes, retrofitting and trends, improving inefficiencies related to lighting (and other plug loads), HVAC, refrigeration, architecture and design, and interaction with the local energy grid. A central aspect within this analysis is the definition of what a driver is, describing the different kinds of drivers and their role in decision making processes. Drivers are primarily the factors which make things happen, in terms of energy use which is the focus of this chapter, drivers may be expected to set in motion an action/s to reduce energy use. Energy drivers are understood as influencing decision-making and energy use and may be divided into three different types: direct drivers, indirect drivers, and potential drivers:

Efforts to improve energy efficiency and provide sustainable solutions for shopping centres should take the state of constant flux which shopping centres find themselves in, as regular opportunities to improve the technical systems, such as lighting and ventilation, or the building envelope and monitoring systems. Consideration of these aspects along with the other drivers has the potential to achieve significant energy reductions and Indoor Environmental Quality (IEQ) improvement. There are, however still some major challenges which are barriers to achieving the desired energy reductions. Shopping centres aim to provide customer satisfaction, but providing customer satisfaction is so far not based on reducing energy use in shopping centres and therefore cannot been seen to be an influential factor when considering deep energy retrofitting. Changing shopping habits and user behaviour influences the non-energy related retrofitting activity and while this may affect the kind of shopping centres built, this kind of user behaviour cannot be said to be a direct driver for energy use reductions. For example some shopping centres are increasing in size, and the reasons for this are based on changing shopping habits, for example more leisure based activity. Shopping centres are increasingly providing for a wider range of leisure activities, and eating, meeting, sports facilities and cinemas all require more space and potentially affect shopping centre energy use. Customer behaviour can be seen to influence the services provided and the kind of shopping centres being built, and is indirectly influencing energy use, but there is so far no sign of customer behaviour becoming a driver for energy use reductions.

The three most influential areas which are already drivers for energy use reductions or have the potential to become drivers can be summarised as follows:

- The need to reduce energy use in shopping centres is in itself a driver based on the needs to reduce operational and overhead costs. However this must be considered alongside the fact that the costs associated with retrofitting may be barriers. Upgrade costs and rental costs are closely associated, if a retrofitting process is extensive and costly it may be expected that this will influence the price retail space. Owners, managers and tenants aim during rehabilitation to balance the need to be attractive and up to date with being cost effective. If rental prices are too high this may affect retail profits and cause problems for the stakeholder groups[23]. Cost reduction may be understood as a driver for energy retrofits, because the value achieved by reducing overheads/rental costs and operational costs may be seen to outweigh the costs associated with the retrofitting. Importantly, the drivers and barriers for an energy related retrofit should be seen in collaboration. This is because although there is positive momentum associated with the need to reduce energy use in shopping centres; if the costs are too high for the stakeholders, a deep energy retrofit will not be conducted.
- A number of the drivers identified are potential drivers; therefore to achieve necessary energy use reductions in shopping centres more of the potential drivers should develop into direct drivers. This means establishing the right set of circumstances. User behaviour is an important factor here, particularly knowledge about energy use among owners/managers, tenants and customers. The right set of circumstances is supplied by providing knowledge about energy use and how it may be reduced. It is suggested that the more knowledge different user groups have about their energy use, the greater the effort they will make to reduce energy use. The results point to tenants knowing little about in-store energy use and having a lack of engagement about energy issues. Owners and managers see a potential for reducing energy use in shopping centres through collaboration with tenants. This is

[23] This includes customers, because rental overheads affect the price that they are willing to pay for the goods and services shopping centres offer.

due to two main factors, firstly tenants are the major cause of energy use in shopping centres, and secondly tenants have a high degree of independent control over their in-store energy use. By supplying tenants with knowledge about how lighting, ventilation and building design (all direct drivers for energy use reduction) affect their in-store energy use (energy bills), owners and managers will encourage tenants to instigate actions to reduce energy use. Without this knowledge tenants will remain unengaged.

- Lack of knowledge on all stakeholder levels is a barrier to energy use reductions. Customers are not demanding energy use reductions and as long as there is no direct demand then shopping habits will not be a driver. This may be a barrier for owners, managers and tenants. They are not be pushed by customer demand to take direct actions and as long as their profits remain stable or continue to increase this will not change. However consumer awareness is increasing. Increasing knowledge about the implications of their actions in shopping centres may put pressure on the industry to increase their actions aimed at energy use reductions.

3. Identification of performance indicators and predictor variables

The following chapter will identify a range of key performance indicators (KPI's). For this purpose performance indicators are defined broadly as quantifiable measures that can be used to represent the goal of providing more sustainable, energy-efficient shopping centres (more of them and with the aim of achieving greater sustainability). There are a large number of performance indicators which tell something about the state of play in shopping centres today, for example those found in building certification schemes (see BREEAM, OPEN HOUSE).

Chapter **Error! Reference source not found.** first provides a more general overview[24] of performance indicators set within a context of the user requirements and six performance concepts of energy use within shopping centres. In chapter 3.2 the main predictor variables are selected for the parametric study in the final section. The predictor variables are selected indicators representing building retrofitting design solutions with potential to lead to energy savings. Some variables, for example "*time-average installed power for lighting in common areas"*, include a number of assumptions of appropriate daylight utilization and control strategies, which in turn may be represented by other performance indicators.

Finally this chapter concludes with a list of KPI's where energy use reductions may be presented in the form of quantifiable results. Whereas the drivers identified in the previous chapter cause actions to take place, KPI's allow measurement of what has been achieved, where the intentions is to in turn point shopping centre management in the direction of the most effective actions. Along with the goal of saving energy, extended goals and indicators can be useful in a retrofitting process, i.e. to ensure that temperature levels fall within a predefined bandwidth.

3.1. *Energy performance indicators in shopping centres*

Sustainable shopping centres are more than simply energy efficient, they are environments that are accessible to all sides of society irrespective of buying power, social class or disability. This section therefore opens with a discussion of architectural qualities in shopping centres, because architecture at its best is often understood as a combination of technology, functionality and aesthetics. The section will develop performance indicators based on the technical functionality of shopping centre architecture, in short meeting user needs. Subsequently, performance indicators associated with several aspects will be discussed through the definition of six energy performance concepts.

[24] The analysis largely draws on report D2.3, a review of OPEN HOUSE indicators.

3.1.1. Architecture, typology and the layout of shopping centres

Architecture encompasses technology, functionality and aesthetics. In this section, architectural form has been considered in context with user and occupant expectations and requirements to build a basis for energy performance indicators that relates to shopping centre form, layout, users requirements and cultural context. There are different types of shopping centres (see chapter 1,

Table 1) and there is a typology associated with the usage that different areas in shopping centres are put to, functional patterns and stakeholder groups are associated with the areas. The different shopping centre types and typologies may vary according to for example size and use, for example it may be expected that speciality centres will have smaller circulation areas and less storage space than regional centres, and some centres do not have restaurants, staff rooms or atriums (Woods et.al., 2015). However if we take into account the variations found within the main shopping centre types, there are certain areas that may be considered standard for all shopping centres[25] and these are presented in table 7. The table describes the five main areas in shopping centres, their usage and different locations within a centre.

The table shows an overlap in usage, for example not all retail takes place in clearly defined retail units; some takes place in common areas in temporary or permanent units. Restaurants, food courts and cafes may be found within retail units and on occasion stores may be found in restaurants and cafes. In addition, centres that offer leisure activities, or specialised functions like conference facilities, are typologies not covered in this overview. Typical examples which impose other usages include cinemas, bowling alleys, or swimming complexes. Hotels or apartments may also be located within shopping centres. For these typologies additional performance indicators apply which are not covered.

Table 7 – Typical Areas in Shopping Centres.

Typology	**Main usage**				**Location**			
					Common areas	**Shop/ retail areas**	**Behind the Scenes**	**Outdoors**
Common Areas	Circulation	Main horizontal circulation	Vertical circulation	Emergency exits	**Main usage areas**	Within retail units and stalls	None	Benches, paths, play areas and other
	Entrance	Main entrance	Side entrance	From car park				
	Sanitary	Toilets	Child care					
	Parking	Entrance	Circulation	Parking				

[25] This typology of typical areas in shopping centres may be considered in relation to the work concerning systemic inefficiencies in the Report D 2.2 (Woods et al., 2015) and the guidelines for thermal zoning of SC developed during the integrative energy modelling.

Restaurants/ cafes/ Food courts	Entrance	Seating	Service	Food preparation	Atrium location	Food serving in-store and restaurants	Kitchens, prep, storage	Pavement cafes
Shops/ Retail/ Other	Entrance	Sales	Service	Staff rooms / storage	Atrium, corridors	**Main retail areas**	Storage, staff rooms	Temporary/ permanent stalls
Behind the Scenes	Entrance Storage Technical rooms Circulation	Trolleys Services Pathway Horizontal circulation	Trucks Waste Shafts Vertical circulation	Sanitary Emergency exits	None	Storage, staff rooms and waste in some units	**Main usage areas**	Delivery waste storage
Outdoors	Restaurants/ cafes Parking Leisure Delivery area	Entrance Circulation Resting/ Recreation Containers	Seating Parking lot Seating	Service Service Other	Benches, paths, play areas and other	Temporary or permanent retail units, or stalls	Delivery and waste storage	**Main usage areas**

Table 7 offers insight in the broad range of activities which take place in shopping centres, giving customer satisfaction requires a broad range of services from shops, toilets and deliveries, to technical rooms, child minders, cafes and car parks. This is highlighted by informants at Brent Cross shopping centre, who told us that the shopping centre "*is open 24-7*" and that "*most of our work takes place before the shopping centre is open to customers*." The range of activity requires a complex and flexible physical structure, one that allows for, amongst other things, changing retail, demographic and technical needs.

3.1.2. Energy use and flows in shopping centres

Shopping centres are complex buildings with specific needs as the breakdown (Table 7) in the previous section reveal. The use that different areas are put to affects energy consumption, whereas the different functional patterns and stakeholder groups influence energy use. They are also associated with specific requirements that make it relevant to consider different types of performance indicators.

"Performance requirements are qualitative statements describing goals of overall design outcomes or products and subsystems within the solution related to user requirements. The act of satisfying a requirement is delegated to a functional element, usually a building component, including their aggregation into a whole building[26]. A performance requirement is

[26] The performance concept is based on the idea that products, devices, systems or services can be described and their performances specified in terms of performance requirements.

the 'user requirement expressed in terms of the performance of a product' and it is represented by a performance indicator. The performance indicator is any quantifiable measure that adequately represents the specific performance requirement, for example, temperature limits to describe comfort satisfaction (*Williamson et.al., 2003)."*

In the scope of this analysis both indicators and requirements with a direct or an indirect effect on energy consumption in shopping centres are identified. When defining the relevance of performance indicators; legal requirements (i.e. for work environment), ownership or authority over parts of the centre, and cultural context also come into play. Therefore, six performance concepts are identified which form the structure of the next sections, all with contextual relevance to energy use and supply of energy in centres:

- Energy follows function
- Energy follows form
- Energy follows user needs

Functional element sub-division

- Energy follows stakeholders
- Energy follows organisation
- Energy follows availability

Organizational element sub-division

Because of the underlining complexity of performance requirements in shopping centres, it may also be useful to distinguish between causes of energy use within a functional sub-division, meaning energy divided by the functions which it is used (by end use or supply system), and organizational sub-divisions of energy use distinguished by who pays for the energy and thus is related to billing practice, tenant agreements, and contracts with energy supply carrier companies[27].

The first three are mainly linked to the demand side and indicators that represent the requirements that can be found in norms, standards and the like. While different stakeholder groups, organisation and contextual aspects such as climate and energy availability, also define the relevance of performance indicators, and suggest which priorities should be given when performance requirements are in conflict. The latter interest groups and contextual aspects also form billing practices, sub-metering and functional units (e.g. kWh/m^2) for dividing the operational energy costs.

Energy follows function – sub dividing processes

Energy can be considered to follow function because energy in the end is used to meet requirements defined by the activities that take place in a shopping centre. In a shopping centre, requirements are diversified by the type of tenants (shops, retail, restaurants, cafes, etc.), by the size of tenants rental space (stalls, retail units, independent anchor stores etc.), or by the type of spaces (common areas, offices, storage etc.). The different activities can be

[27] This terminology can be recognised in a recent study on energy efficiency in Norwegian and Swedish shopping centres where it is argued that a functional division of energy use is required in the evaluation of energy efficiency in SC, while most often only an organizational sub-divison of purchased energy use is commonly available, and translating from one to the other is not trivial (Stenson, 2014)

characterized by functional patterns for various groups; – opening hours for customers will differ from operational hours for technical services and lighting. Facility operation has to meet the requirements of staff before the shopping centre opens to the public. In shopping centres many tasks are performed outside of opening hours which require maintaining the health and safety for workers. Examples are cleaning, sanitation, loading and re-stocking of goods. In relation to this, the ratio of full load hours of HVAC and lighting vs. hours of reduced loads, during customer opening hours is one index that could be used as a performance indicator.

Figure 10 illustrates a functional sub division of energy end use within a shopping centre. Starting with the energy supply and the technical services in place, the energy use associated with heating, cooling and electricity are structured by end use. Centralised HVAC systems may be quite clearly visualised by the diagram, but in principle the structure is the same for all installations localized and managed in tenants' retail space too. In a typical shopping centre there will exist several heating, or cooling loops and many electrical subdivisions (distribution boards) on top of various end uses.

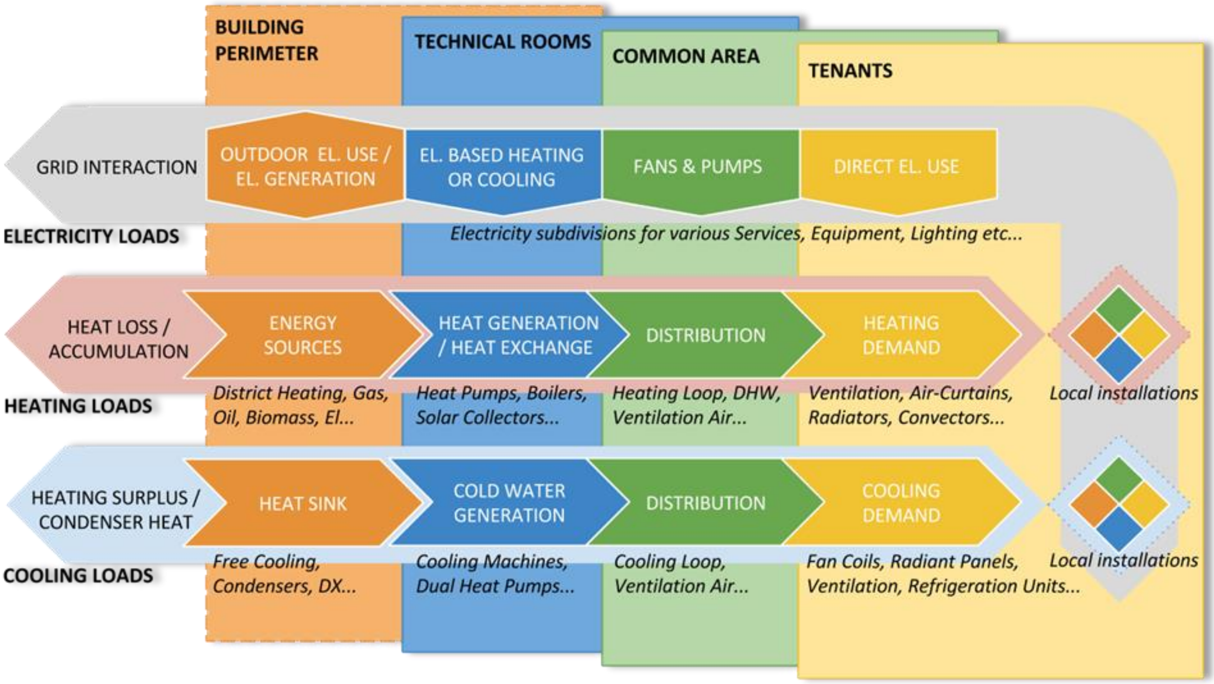


Figure 10 – Sub division of energy flows (electricity and thermal) associated with different end uses.

The illustrated processes are usually in the control of facility managers and technical staff. A multitude of performance indicators can be related to this structure when adapted to a specific context. Some performance indicators are important in the design and commissioning of the systems, other are of use in the day-to-day running of the centre. Reading the diagram from left to right, the potential of increasing energy efficiency lies both in production, distribution and end-use.

Energy follows form – design layout and linking of spaces

In typical shopping centres (see chapter 1, Table 1), the retail units are often heated, cooled and ventilated separately from the common areas. The same retail units are often also connected to the central spaces by large open doorways through which air, odours, light, and noise exchange occur, effectively linking the different spaces.

Key points in shopping centre design are directing the pedestrian flow into the shopping centre and around the shopping centre. The retail sales volume of a store is often in direct proportion to the volume of pedestrian traffic passing through it. Centre design aims therefore at optimizing customer movement past store-fronts but also avoids excessive customer movement (Dawson, 1983). Traditionally this has resulted in the placement of major anchor tenants at the ends of shopping centres and multiple entrances to the car parks along the sides of the centre. There has in shopping centre design been more focus on the ease of customer movement and easy access to retail units than there has been on the implications of this access on energy use. Entrance design, open doorways and location of shops adjacent to common areas and outdoor elements has a considerable impact on heating demand, ventilation and lighting levels. Generally, the higher performance of the elements that form the building envelope may lead to more efficient energy use within the building and easier operation of HVAC systems, due to a more controllable environment which will in turn make it easier to meet user requirements for comfort and indoor environment.

Selected indicators with relevance to energy use and building performance in SC (Haase et al., 2015)

Barrier-free Accessibility and universal access: Providing accessibility for any person.

- The building must provide enough meeting places, areaways with appropriate width and length, planar movement areas and ramps (customer entrances, cargo loading bays etc.).

- **Building form and occupancy efficiency indexes:**
  - Area efficiency: an index for the utilization of floor space inside buildings, i.e. gross leasable area in relation to common area and other heated space, or occupancy ratio.
  - Compactness ratio: building surface area divided by volume.
  - Pressure loss and length of ducts in ventilation layouts seen in relation to building plans.
- **Building envelope:**
  - Median thermal transmittance coefficients of building components $\bar{U}$
  - Thermal Bridges
  - Air-tightness: permeability class for windows , building air exchange per hour at 50 Pa (n50), or (q50)
  - Amount of condensation inside the structure
  - Natural light permeability: Extent to which daylight openings in building envelopes are available
  - Solar heat protection

Energy follows user needs – workers & customers

It is challenging to meet performance requirements, to keep within accepted limits of comfort and meet retailer needs in such an open indoor environment, where different spaces inside the shopping centre are effectively linked (as described in the previous section). However even with greater energy use focus on accessibility and a wide range of issues will remain of primary importance, not only because of retail needs, but also because, as mentioned earlier, sustainable shopping centres should be accessible to all sections of society.

Selected indicators with relevance to energy use and user requirements in SC (Haase et al., 2015).

- **Health & Safety:** Assessing the prevention strategies and the preparedness of a building against accidents, disasters, users' health issues, or damages and losses of building items.
- **Thermal Comfort:** Provision of a comfortable thermal environment supporting productivity and well-being of building occupants (tenants and customers), during both summer and winter.
  - Operative temperature
  - Draught, air velocity
  - Radiant temperature asymmetry and floor temperature
  - Humidity in indoor air
- **Indoor Air Quality:** IAQ affects building occupants and their ability to conduct their activities, creates positive or negative impressions on workers, customers and other visitors to the building.
  - Indoor air contamination with the most relevant indoor air pollutant sources (e.g. formaldehyde, VOCs)
  - CO_2 concentration above outdoor level
  - Subjective reaction as classification of the indoor air quality
- **Water Quality:** Evaluation of water quality in a building is to protect building users' health from the adverse effects from the contamination of water intended for human consumption and produced by water systems installed in the building, by ensuring that it is wholesome and clean.
  - Constant water supply through the day/ year
  - Use of Alternative water supply
  - Ozonation instead of chlorination for water disinfection
  - Provide the appropriate temperatures for hot water production, storage and consummation
- **Acoustic Comfort:** Achieve a low level interference and background noise with speech intelligibility in all rooms to avoid affecting use, health and capability of the users.
  - Indoor ambient noise levels in unoccupied staff/office areas
  - Reverberation period
- **Visual Comfort:** Visual comfort means the influence of daylight and artificial lighting in buildings.
  - Overall light levels and light distribution
  - Availability of daylight in regularly used working areas
  - View to the outside
  - Preventing glare from daylight and artificial light
  - Colour rendering
  - Flickering lights

The needs of customers and workers may collide at times, with regard to the time spent in the centre, the clothing and activity level varies between different groups. The surveys suggested that customers generally were more eager to accept lower light levels, lower temperatures in winter and higher indoor temperatures in the summer season. Owners & managers were also reluctant to broader temperature bands, in some cases this was related to past experiences. Feedback from employees or customers is part of facility manager's daily routines. In relation to this, some interviewees claimed that a lack of control under all eventual conditions is one of the issues that limit the more stringent operation of HVAC systems.

Energy follows stakeholders – decision makers

Comfort needs are not only technical requirements they are also socially constructed. In the design process, operation, meetings between tenant associations and management, or labour meetings, performance indicators can be important quantitative statements. From chapter 1, the main stakeholders in shopping centres are identified as; Investors, owners, developers, contractors, managers, facility technicians, tenants and other working staff etc. While in a building or retrofitting process stakeholders may also include architects, contractors, distributors, engineering consultants, city executives and community among others. When performance requirements conflict these may be negotiated in the design team, to prioritize and reach acceptable solutions. It is important to establish a joint understanding of shopping centres as a specific physical and social context, because energy follows users and function and not just technology. Thereby it is possible to avoid making decisions primarily based on energy efficiency and cost effectiveness.

Measurement and verification of energy performance

In order to validate targets for energy performance it is necessary to plan for measurement and verification before and after retrofitting. How precise the reported savings needs to be is one of the key issues to consider. In *the International Performance Measurement and Verification Protocol* four verification options are defined (EVO, 2014);

a) Isolation of equipment/affected part and key parameters: Partial measurement before and after retrofit (spot metering of load, or operational hours).
b) Isolation of equipment/affected part with full measurement under all operating conditions before and after retrofit (sub-metering data series).
c) Whole building energy data correlated with variables such as outdoor temperature, where before and after energy use is adjusted and compared to the same set of conditions.
d) Calibrated simulations. Energy use of the building is modelled using building performance simulation and the models are calibrated to accurately predict the buildings energy use before and after a retrofit. The two models are adjusted and compared to the same set of conditions in order to determine energy savings.

For the first two methods, the system boundary is particularly set in order to focus on the individual retrofit, while in the two latter options the requirements for data collection and the level of effort and costs to implement are higher, as they typically focus on the entire building. In the report by Hedron (2013) suggestions are made for the appropriate application of the different approaches,

Energy follows organisation – functional unit of KPI's

Organisational forms can be observed in Real estate companies, property companies, management companies, facilities companies (outsourcing or within the same owner company) and tenant associations. Contracts between those organisations and the indicators used in those agreements are often based on KPIs which offers potential for introducing energy intensity related KPIs. For example, a facility company may have a contract that says that purchased energy should be in a threshold, or a contractor may get a contract to reduce primary energy use by 25 % within x years. Tenants may also have energy related KPIs in their rental contracts, or receive reports with such indicators from the centre management on a regular basis. This shows that KPI's can be used to motivate organisational changes such as billing and metering and information distribution.

Sub metering of energy and applying functional units in shopping centres
When energy consumption is sub-metered in shopping centres, the performance indicator is usually expressed as (MWh, kWh, etc.), but functional units may also be applied (energy use per tenant, per facade meter, per leased floor area, per heated floor area etc. (i.e. kWh/m^2)). Energy use and associated costs may be weighted using a simplified functional distribution key (i.e. hot water, or ice water consumption). Conversions to primary energy, or CO_2 equivalents are also typically performed on the supply side according to the type of energy carriers. Billing practises may also introduce weighting factors, e.g. splitting annual heating costs into quarterly energy utility bills of equal proportions.

Energy follows availability

Nowadays, it is a challenge to transform the current energy system into modular power generation in order to improve the quality and the reliability of the electricity supply. The renewable energies and efficient solutions can overcome the oversizing problem of the electrical infrastructure for meeting the energy demand peaks as well as the energy transmission losses. However, the incorporation of renewable systems in shopping centres must take into account that some problems in the supply can appear given its dependence on climate conditions as well as impact the quality of the grid since it can generate frequency and voltage fluctuations and outages. Furthermore, any interaction in the grid must consider grid capacity to admit new compounds. However, there exists a possibility to mitigate this impact by means of cooperation among the shopping centre with the energy infrastructure they are part, reducing the energy demand through peak shaving of the demand curve or adaptation to the conditions generated by the utilities (Antolin et al., 2015).

Selected indicators with relevance to energy availability in the grid (Antolín, et al., 2015).
There are two main closely-related phenomena of interest: the resulting energy import from/export to the energy grid and the interplay between on-site generation and consumption. Performance indicators which measure these phenomena are:

- Grid interaction (GI) characterizes the energy exchange between the building and the grid within a year normalized as well as the overall impacts of the grid.
- Load matching (LM) describes the degree of utilization of on-site energy generation related to the local energy demand. It is defined as the average value over the evaluation period of what fractions the energy load is covered by the generation. A high load match means that a great fraction of the load is covered by the on-site generation, while a low value means that the generation covers only a small fraction of the demand
- Peak load management and shifting indicators (Antolín, et al., 2015).

3.2. *Main predictor variables for the parametric study*

Taking into account some of the common inefficiencies identified in shopping centres (see D2.2) and the above analysis of performance indicators, this section describes the main predictor variables that could be adopted to save energy. Most of measures create an interconnection between the effects they can generate. For example, the use of daylighting may decrease the electrical consumption of lighting but at the same time can generate an increase of the cooling consumption if the use of daylighting is not correctly integrated with shading devices. Therefore, the combined effects need to be considered. The main predictor variables are divided into four topics:

- Envelope
- Internal loads (lighting, appliances and plug loads)
- HVAC system
- Refrigeration

3.2.1. Envelope

The envelope is defined as the structure that separates the internal space from the surrounding environment to help create a comfortable indoor climate all year around. There are several possible predictor variables associated with the envelope which influence the energetic needs of different systems (heating, cooling, ventilation, and lighting) as well as the occupant's comfort. Central aspects are high thermal insulation for windows, roof and walls, thermal mass as well as an airtightness of the envelope and interrelating parameters. These will be studied in section 4.

Table 8 – The most critical parameter for the building envelope

Predictor variable	unit
Thermal insulation of exterior walls reduces peak heating loads	U-value ext. wall (W/(m^{2}K)
Thermal insulation of roof reduces peak heating loads	U-value roof (W/(m^{2}K)
Thermal insulation of floor reduces peak heating loads	U-value floor (W/(m^{2}K)
Thermal insulation of windows reduces peak heating loads	U-value windows (W/(m^{2}K) g-value windows (-)
Thermal insulation of doors reduces peak heating loads	U-value doors / ports (W/(m^{2}K)
Thermal bridges increase peak heating loads	Normalized thermal bridges Ψ" (W/(m^{2}K)
Air tight building envelope reduces peak heating loads	air tightness (ach)
Window/skylight area (number of windows and size)	Window/wall ratio (-)
Solar shading (and adaptability or control strategy)	g-value of facade system (-)

Solar shading

Solar shading is the term used to identify a number of predictor variables used to control the amount of heat and light from the sun admitted into a building. Properly designed elements reduce cooling needs during the summer months, while still taking advantage of the solar gains during the winter months (taking advantage of the different incidence angles during the year). When compared to other building typologies, cooling loads for shopping centres tend to be more important and therefore solar gains need to be properly controlled, while at the same time using daylighting to reduce the use of artificial lighting and increase visual comfort. Shading devices can be both internal (e.g. shade, blinds) and external (e.g. overhangs and vertical fins) but at least in entrance areas, the external facades are usually glazed and obstruction-free (because of the greater visibility of interior exposed to the costumer). Thus external shading is an important predictor variable.

3.2.2. Lighting, appliances and plug loads

Lighting, appliances and plug loads accounts for a significant fraction of the electricity consumption in retail buildings. Improvements of lighting should always start with optimisation of daylight harvesting and implementation of a daylight-sensitive control strategy to reduce intensity of artificial light whenever possible. Simultaneously it is necessary to limit daylight to a useful amount to prevent disturbance of sophisticated lighting design for merchandise presentation.

Major savings can be achieved by replacing outdated technology by an efficient light source like LED as well as high-quality luminaires and drivers. In the case of LED these measures come along with other advantages like a long life span, easy controllability and being UV- and IR-free to solve issues with strong product sensitivity.

Separate possibilities and the restrictions associated with these solutions will be presented here, but it is worthwhile highlighting that the best results, in term of energy savings, could be reached by mixing and merging them all in an efficient manner. The main predictor variables for lighting are:

- Daylight availability metrics, e.g. daylight factor, daylight autonomy etc., luminance value at the façade, spatial distribution of illuminance, dim status of luminaires in daylit zones.
- Luminous Efficacy (for light source), Light Output Ratio LOR (for luminaire), Driver Efficiency, Stand-By-Loss of Driver
- Illuminance distribution (vertical, horizontal)
- Amount and type of Control and monitoring variables (subdivided for window displays, general lighting, accent lighting), amount of calculated Key Performance Indicators

  Room efficiency factor, glare metrics, e.g. UGR, and good modelling properties; E_z/E_h

Average internal loads as presented in the table below serves as definition for different energy targets and a viable input variable for the simplified parametric study. The values takes into account implementation of control features (time-average), and in the case for lighting, reduced lighting levels due to daylight harvesting.

Table 9 - Most critical predictor variables for internal loads

Predictor variable	unit
Installed loads for lighting (per heated floor area)	Internal loads for lighting as average values (W/m^2) Convective and radiative parts depend on lamps and fixing solutions. In general, 100% of loads are accounted for internal gains.
Installed loads for equipment (per heated floor area)	Internal loads for equipment as average values (W/m^2) Convective and radiative parts depend on specific solutions. In general, 100% of loads are accounted for internal gains.
Installed loads for occupants (per heated floor area)	Internal loads for occupants as average values (W/m^2) Convective and radiative parts depend on calculation method. In general, 50 - 70% of loads are accounted for internal sensible gains.
Installed loads for Service Hot Water (SHW) (per heated floor area).	(Internal loads for SHW as average values (W/m^2)) In general, these loads are not accounted for internal gains depending on the location of tanks. If tanks are located in technical rooms, a decision should be made as to whether technical rooms should be included in the heated floor area or not (depends on location and calculation method).

3.2.3. HVAC System

The HVAC (heating, ventilating, and air conditioning) system is responsible for providing the thermal and hygienic needs of a shopping centre. An efficiently designed and operated building and HVAC system reduces the amount of energy needed to control hydrothermal conditions and air flow in a space. In addition to the passive solutions regarding thermal insulation, natural ventilation and solar gain controls, there are specific solutions regarding the HVAC system, that promise to lead to energy savings. To reduce the consumption associated with HVAC the focus must be on:

- energy efficient equipment
- energy flux strategy
- equipment control and management.

Energy efficient equipment and components

The current equipment could be replaced with ones with greater efficiencies.
This is especially true when the existing systems are old, inefficient or malfunctioning. Some of the main predictor variables include:

- Efficiency of the heating system (boiler, Heat pumps, Combined heat and power (co- and tri-generation, Biomass boiler or District heating)
- Efficiency of air-conditioning systems (e.g., chillers);
- Efficiency of ventilation system
- Presence and efficiency of heat recovery systems;
- Performance parameters of economisers;
- Efficiency of auxiliary devices

The type of distribution system (radiant floor or ceiling, fan coils or primary air) should be also considered as a predictor variable with special attention to the efficiency of auxiliaries (e.g., fans, motors) and to the correct size of equipment and balance systems.

Energy flux strategy and recovery

The recovery factor of the heat waste recovery system and the performance of free cooling should be considered. Thermal layout is important because it influences which thermal synergies (e.g., thermal cascade) can be exploited. For instance, the existence of interconnections and the supply and return temperatures of the refrigeration and heating/cooling duct are important predictor variables.

Equipment control and management

Building system control and management strategies in shopping centres and retail buildings are crucial to ensure correct operation. The operation should therefore be regulated by a central unit (building management system – BMS) acquiring information from the field and deciding the best strategies to deliver the required conditions for each zone and tenant. Control strategies are very powerful predictor variables (on/off set points, temperature and rate set points etc.)

Table 10 - Most critical predictor variables for building HVAC

Predictor variable	unit
Thermal efficiency of the heat recovery system	heat recovery factor (%) is typically described as annual average including thermal losses due to frost security
Efficiency of the ventilation system	specific fan power (SFP) (kW/(m³/s)) gives amount of power that is needed for the fans to ventilate with specified airflow
Amount of airflow that is needed to supply fresh air to service zones	Airflow during/outside operation (m³/(hm²))
Temperature of the supply air distributed to zones.	Supply air temperature, °C This can vary over the year with typically lower supply air temperatures during summer (cooling season) and higher temperatures during winter (heating season).
Status of actuators	Dimensionless

3.2.4. Refrigeration

Table 11 - Most critical predictor variables for building refrigeration

Predictor variable	unit
pre-cooling a product using ‘free ambient cooling’ before using a refrigeration system	refrigeration consumption time or refrigeration consumption per mass of food (kWh/kg) due to free cooling (Typically embedded in control strategy)
Remote condensers that eject the heat directly	refrigeration consumption time or refrigeration

outside the building space and not inside	consumption per mass of food (kWh/kg) due to remote condensers
Compressor should be set at the lowest condensing temperature possible and keep suction pressure only as low as is required	Compressors efficiency • energy used by compressors (kWh)
Reducing cold losses of cabinets	Air curtains and closed cabinets • energy used by compressors (kWh)

Supermarkets have the highest energy intensity within the whole commercial sector; most of their energy consumption is refrigeration. Therefore, it seems reasonable to spend some effort trying to make refrigeration in food stores and other shopping centre facilities (e.g. cool storage) more efficient.

Main predictor variables can be grouped into 3 different ways:

- Strategies to reduce heat gain
- Strategies to reduce heat load
- General setting and operation rules

3.3. *Identification of main predictor variables and performance indicators: Conclusions*

There are a large number of performance indicators, which tell us something about the state of play in shopping centres today, for example those found in building certification schemes (see BREEAM and Open House). The CommONEnergy project's primary focus is reduced energy use and many of the indicators are not directly relevant with regards to energy use. These two aspects narrow the field when considering what the key performance indicators are for shopping centres. This chapter first provides a general overview of performance indicators, and concludes with a list of performance concepts where energy use reductions may be presented in the form of quantifiable results. The key performance indicator considered is kWh energy, but it is measured, weighted, converted and applied to functional units depending on the application.

- **Energy follows function – sub dividing processes**
  - Sub metering protocols of electricity, hot tap water, or chilled water consumption within the centre complex, by organisational (authority) and functional (end-use) sub-divisions. It relates to respectively who and what is responsible for energy use within the centre and along the energy fluxes.
- **Energy follows form – design layout and linking of spaces**
  - Building performance and occupancy efficiency indexes, assigning different KPI levels as location in the centre may greatly affect energy consumption.
- **Energy follows user needs – workers & customers**
  - Comfort and other user requirements of tenants and customers that affect energy consumption and may diversify KPI's as in energy performance levels.
- **Energy follows stakeholders – decision makers**

    - Assigning design targets and system boundaries to KPI's in order to document savings by measurement and verification before and after energy retrofits.
- **Energy follows organisation – functional unit of KPI's**
    - Establishing energy related KPI's with various functional units for application in contracts between entities, or in communication to motivate change.
- **Energy follows availability – market situation**
    - Energy availability, grid interaction, tariffs and incentives in the market that may affect the relevancy of KPI's.

In general the shopping centre industry is used to key performance indicators (KPIs). Examples of KPI for a Shopping centre real estate company are: Total property return, Occupancy, Like-for-like, NRI (net rental income), and Growth in earnings per share for publicly traded companies (EPS). There may be a possibility to include energy related KPI's in contracts between entities and in communication between stakeholder groups. Tenants may also have energy related KPIs in their rental contracts, or receive reports with such indicators from the centre management on a regular basis. This shows that KPI's can be used to motivate organisational changes such as billing and metering and information distribution.

In chapter 2 four main drivers for energy use reduction in shopping centres have been defined. These are lighting, HVAC, plug-loads and refrigeration, and architecture and design and solving problems associated with these areas may be understood as direct drivers for energy retrofitting in shopping centres. The key performance indicators are associated with the suggested drivers. Drivers cause actions to take place. KPI allow measurement of what has been achieved and in turn point shopping centre management in the direction of the most effective actions. The main predictor variables may be used in a parametric study in order to assess the potential of energy savings.

4. A parametric analysis of retrofitting drivers

4.1. Aim

The aim is to assess the possible retrofitting actions with a cost-optimal vision for shopping centre managers/owners. Cost optimization will be analysed with state-of-the-art evaluation tools, taking initial, operation and maintenance into account. CommONEnergy refers to the "cost optimal methodology" defined in 2012 within the EU directive 2010/31/EU and relative applied regulation (EU) No 244/2012, where the term "global cost" is used to include all costs in the economic life cycle. A module for parametric analysis was developed and used together with simplified energy tools such as the Passive House Planning Package (PHPP), which is able to identify the most important parameters for the energy, comfort and economic performance of shopping centres.

4.2. Methodology

In the re-cast of the Energy Performance of Buildings Directive (EPBD) adopted in May 2010, a benchmarking mechanism for national energy performance requirements was introduced. The EPBD recast required the Commission to establish a comparative methodology by 30 June, 2011. Ecofys conducted a study in 2011 for European Council for an Energy Efficient Economy (eceee) to determine cost-optimal levels to be used by Member States for comparing and setting these requirements (Ecofys 2011). The report aimed to contribute to the ongoing discussion in Europe around the details of such a methodology by describing possible details on how to calculate cost optimal levels and pointing towards important factors and effects. This report gives suggestions regarding the implementation of the EU directive 2010/31/EU and disseminates the acquired information and knowledge. The revised Energy Performance in Buildings Directive (EPBD) 2010/31/EU calls for a calculation of the cost optimal energy standards and renovation standards. Cost optimal calculations can often be too short-sighted to deal with the urgent need for societal answers to the climate change challenges and can risk underestimating the potential for energy renovations in the building sector. The calculation should be informed by a long term cost effective figure of reaching a certain energy efficiency target which sufficiently contributes to mitigating climate change (EEB, 2010). Life-cycle costing based on net present value (NPV) provides a sound basis for the development of a common methodology for calculating cost-optimal levels of renovation.
It is important to include all additional benefits which can contribute to levitate the priority and scope for energy efficiency measures in shopping centres. Furthermore, other aspects including the benefits of reducing dependency of imported fossil fuels, will possibly improve energy supply security in the EU which often is addressed from a societal point of view. This also has a value, economical balance and job creation, not only in avoided payment and

reduced price pressure, but also for not having to transport and store the fossil fuels that are not needed anymore[28].

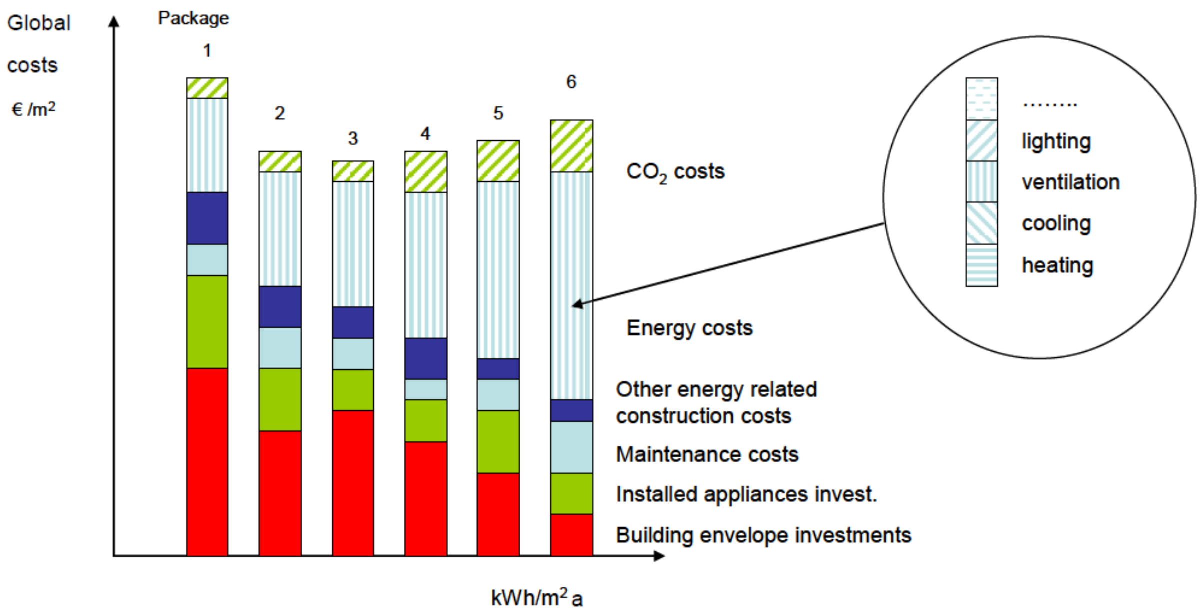


Figure 11 – Cost optimality procedure (Boermans, 2011)

To perform these kinds of calculations, it is necessary to:

- Identify the market segments and the segmentation of the current energy performance requirements (different requirements for different building types) where applicable;
- define and select a sufficient number of reference buildings that are characterised by their functionality, characteristics and regional conditions, including indoor and outdoor climate conditions;
- specify packages of energy saving- energy efficiency- and energy supply measures to be assessed;
- calculate per reference building the energy demand and energy supply for a wide number of packages representing “current practices”, “best practices” and “state of art solutions”;
- calculate the supply-related primary energy and CO_2-emissions for the combination of packages for the reference buildings;
- assess the corresponding energy-related investment costs, energy costs and other running costs of relevant packages applied to the selected reference buildings;
- from the cost curve of packages for a reference building identify the best performing package with respect to delivered energy, primary energy and CO_2-emissions; and

[28] European Union, Financing the energy renovation of buildings with cohesion policy funding, Technical guide EC – Directorate for Energy, ISBN 978-92-79-35999-6; http://ec.europa.eu/energy/efficiency/studies/doc/2014_guidance_energy_renovation_buildings.pdf

- identify the optimum energy performance requirement for a weighted average of all reference types per market segment;
- use, when appropriate, the established reference buildings and relevant packages to identify, using the same methodology, cost-optimal energy performance requirements for building elements and technical building systems.[29]

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) \times D_R(i) \right) - V_{f,\tau}(j) \right]$$

eq. (1)
with
$C_g(\tau)$ = global cost (referring to the starting year τ_0)
C_I = initial investment costs (taken from (Entranze, 2014)
$C_{a,i}(j)$ = cost during year i for energy-related component j (energy costs, operational costs, periodic or replacement costs, maintenance costs and added costs)
$D_R(i)$ = discount rate for year i, [30]
$V_{f,\tau}(j)$ = final (=residual) value of component j at the end of the calculation period (depending on lifetime of component and referring to the starting year τ_0), chosen to be zero

The discount rate D_R depends on the real interest rate R_R (market interest rate adjusted for inflation) and on the timing of the costs (number of years after the starting year).
It should be noted that not only market based interest rates[31] (EZB, 2015) but also alternative investments and/or stakeholder expectations need to be considered. This is the reason, why rates between 8-12% seem to be realistic. A deeper discussion with the shopping centre industry should be undertaken to generate a common understanding of this issue in the project.
The final or residual value $V_{f,\tau}(j)$ of a component is determined by straight-line depreciation of the initial investment until the end of the calculation period and refers to the beginning of the calculation period. Costs or benefits from disposal, if applicable, can be subtracted or added to the final value. Here, neither disposal nor residual values of components at the end of the calculation period have been considered (conservative assumptions).

For payback period a simple PBP has been used

$$PBP = \frac{C_I(j)}{C_{a,i(bc)} - C_{a,i}(j)}$$

with

[29] Ten reference buildings are far too less to make assumptions on cost-optimal levels for building components (on the overall level). But since the reference buildings were chosen according to strategic criteria it is assumed that there is a certain level to base results in a European context.
[30] DR was selected to 4% for base calculations. In the annex it is reported a sensitivity analysis to check the influence of this parameter. 4% is considered relatively low, in the SCI it is common to calculate with 8% and higher.
[31] Interest rates are currently below 2%, http://sdw.ecb.europa.eu/reports.do?node=1000004864

C_I = initial investment costs of component (j)
$C_{a,i}$ (bc) = cost during year i for base case
$C_{a,i}$ (j) = cost during year i for component (j)

Annual costs $C_{a,i}$ were calculated for base cases and for each component changing variables. The difference results in annual cost savings. Maintenance costs were not taken into consideration (for both, base case and components). After calculation for the base case, located in Vienna, different cost factors where used to transfer costs to the other countries Table 12 gives the values used.

Table 12. Different cost factors and energy prices used in the EU (BKI, 2013).

No.	country	place	cost factor (-)	electricity prices (€/kWh) 2013
1	Spain	Valladolid	0.66	0.1200
2	Norway	Trondheim	1.26	0.0865
3	Lithuania	Silute	0.55	0.1185
4	Lithuania	Klaipeda	0.55	0.1185
5	UK	London	0.87	0.1195
6	Italy	Genova	0.71	0.1750
7	Italy	Catania	0.71	0.1750
8	Austria	Vienna	1.00	0.1115
9	Belgium	Sint-Niklaas	0.79	0.1120
10	Belgium	Antwerp	0.79	0.1120

4.3. Development of a module for parametric analysis

4.3.1. Input data of reference buildings and definition of retrofit solutions

In order to propose cost optimal retrofitting packages, a thorough analysis of single sub-package variables is necessary. This is helpful for assessing which variables have the most influence on the energy savings in shopping centres. The starting point of each analysis is the definition of base cases, which represent the assumed characteristics of the performance level of the building at the time of the construction. From this, single variables were changed to reflect the possible improvement in the performance levels given by the application of newer building codes. These performance levels were named sets (from set 1 to set 3) and are chosen in order to have grades of improvement up to a level that is typical for passive-house constructions (set 3). A parametric analysis was then carried out to obtain delivered and primary energy values for each of the single variable changes (sets). Finally, a cost analysis of each single variable was performed to evaluate the cost effectiveness of each solution, according to eq. 1. In such a way, it is possible to estimate the effectiveness of different improvement sets and evaluate the beneficial effects in terms of both cost and energy savings.

The variables were chosen among those expected to have influence on the energy performance of a shopping centre, and they have been divided into six groups:

1. Variables which relate to the performance of the internal loads (such has installed power for lighting and appliances)
2. Variable which relates to the ventilation controls (such as infiltration rate and night ventilation)
3. Variables which relate to the performance of the building envelope (such as U-values of opaque and transparent surfaces, G-values of glazing)
4. Variables which relate to the performance of the HVAC system (such as heat recovery efficiency, efficiency of fans and of equipment)
5. Variables which relate to the indoor comfort (such as summer indoor comfort)
6. Variables which relate to the natural light availability (such as windows quantity and shading)

The values of the base case are shown in table 13 and are based on information gathered and based on building codes from the original construction years. The variables for which it was not possible to extract consistent information were used according to international standards (e.g. variables for which different building codes set requirements, such as the U-values of opaque surfaces).

Table 13. U-values (W/(m^{2}K)) for the base cases of some of the shopping centres.

		Norway	Lithuania	Lithuania	UK	Spain
Town		Trondheim	Silute	Klaipeda	London	Valladolid
Building		City Syd	Pamarys	Studlendas	Brent Cross	Mercado del Val
U-values ext. Walls	W/(m^{2}K)	0.40	0.30	0.25	0.60	1.61
	Ref.	TEK 85	RSN 143-92:1999	STR 2.01.09:2005	S.I. 1985/1065	Building data file
U-values roof	W/(m^{2}K)	0.14	0.25	0.20	0.61	2.15
	Ref.	TEK 85	RSN 143-92:1999	STR 2.01.09:2005	S.I. 1985/1065	Building data file
U-values floor to unheated	W/(m^{2}K)	1.33	0.31	0.31	0.60	1.19
	Ref.	TEK 85	RSN 143-92:1999	STR 2.01.09:2005	S.I. 1985/1065	Building data file
U-values partitions to unheated	W/(m^{2}K)	0.42	0.31	0.31	0.60	1.19
	Ref.	TEK 85	RSN 143-92:1999	STR 2.01.09:2005	S.I. 1985/1065	Building data file
U-values glazing	W/(m^{2}K)	2.70	1.90	1.90	2.70	5.80
	Ref.	EN ISO 10077-1	RSN 143-92:1999	STR 2.01.09:2005	EN ISO 10077-1	Building data file
U-values frame	W/(m^{2}K)	4.50	2.40	2.40	4.50	5.50
	Ref.	EN ISO 10077-1	EN ISO 10077-1	EN ISO 10077-1	EN ISO 10077-1	Building data file
g-value of glazing	W/(m^{2}K)	0.78	0.68	0.68	0.78	0.88
	Ref.	Pilkington	Pilkington	Pilkington	Pilkington	Pilkington

The values of the three improvement sets are shown in table 14 and are set in order to improve the performance level set in the base cases. The same sets have been applied for all locations irrespectively of the climate. As for the insulation levels, the base cases have different values according to the different codes and norms of each country, therefore the performance increment of the set 1 is different for different buildings. This can be seen by comparing the U-values of the set 1 with the U-values of the different building components shown in table 13.

A detailed description of the analysis variables follows here:

- Internal loads (which include both installed power for lights, general equipment and refrigeration equipment). V1 and V2 in the table. These generally represent most of the energy use in a shopping centre, both direct electricity consumption and indirect through internal gains and therefore additional cooling loads. It is therefore interesting to calculate the energy savings by reducing the installed power density for internal appliances.
- Ventilation rate (which includes both the air change rate and the additional ventilation for night cooling) V3 in the table. Shopping centres can be characterized by a very high infiltration rate due to poor air-tightness and the presence of many entrances. A lower value for infiltration rate is mainly reflected by lower energy use for space heating and cooling. Similarly, the very high cooling load in summer due to the internal heat gain can be reduced by operating night purging. This influences the energy use for cooling in summer.
- Characteristics of the building envelope (which include U-values of opaque and transparent surfaces, G-values of glazing, Psi-values of thermal bridges). V4, V5 and V6 in the table. Some shopping centres, such as the cases in London and Valladolid, have old construction elements with poor insulation levels. Higher insulation levels may reduce the energy use for space heating and cooling.
- Characteristics of the ventilation systems (which includes the efficiency of both the heat recovery systems, the fans, and the cooling unit). V7 in the table. Space heating and cooling is generally delivered through ventilation systems in shopping centres. Therefore, high efficient ventilation systems are deemed to be effective in reducing the total energy use.
- Summer comfort (which includes the summer design temperature). V8 in the table. As shopping centres are characterized by a high cooling demand due to the internal heat gains produced by users and appliances, this situation can lead to very high energy use for cooling in summer, especially if low temperatures are set (e.g., 22/23C). By increasing the indoor summer design temperature it is possible to estimate the energy savings given by this strategy.
- Geometry (which includes both the glazing area and the shading devices). V9 in the table. Shopping centres are not usually characterized by large fenestration areas, in relation to their volume. However, to achieve a very low level of energy use for internal lighting the sole use of highly efficient luminaires may not be enough.

However, this can be achieved by increasing the fenestration areas and including shading. On the other hand, large fenestration areas lead to increased energy use for space heating and cooling.

As shown in Table 14 each variable represents a group of sub-parameters. These are chosen to reflect the different areas of use of the shopping centres (such as the circulation areas and the shops), the different HVAC components (such as heat recovery systems and fans), and the different building components (such as walls, roofs, windows). A single sub-parameter analysis was not performed, as it was assumed that an intervention of energy retrofitting will change all the sub-parameters of a variable (such as the insulation level of opaque surfaces). It was therefore not assumed as significant for the analysis. This approach is also employed for the assessment of the cost analysis of the single variables.

Table 14 – Values for the variables (V1-V8) for the 3 sets (see explanation below)

Variable no	description	base case	Set 1	Set 2	Set 3	Unit
V1	CMA lights	23.68	11.84	5.92	2.96	W/m2
	OFF lights	23.90	11.95	5.97	2.99	
	SHP lights	36.17	18.08	9.04	4.52	
	OTH: auditorium lights	17.65	8.83	4.41	2.21	
	OTH: restaurant lights	28.20	14.10	7.05	3.53	
	OTH: bowling lights	25.83	12.92	6.46	3.23	
V2	ALL DHW	2.00	1.00	0.50	0.25	l day/person
	OFF equipment	10.00	5.00	2.50	1.00	W/m2
	CMA+SHP equip	10.00	5.00	2.50	1.00	
	OTH: auditorium equip	10.00	5.00	2.50	1.00	
	OTH: restaurant equip	10.00	5.00	2.50	1.00	
	OTH: bowling equip	10.00	5.00	2.50	1.00	
	Refrigeration	2.00	1.00	0.50	0.25	x current installed power
V3	Air change rate (infiltration)	6.00	4.00	1.50	0.60	1/h
	Manual night ventilation	1.00	1.50	2.00	3.00	x current summer air change rate
V4	U-values ext. Walls	From code	0.20	0.15	0.10	W/m2 K
	U-values roof	From code	0.23	0.15	0.08	
	U-values floor to unheated	From code	0.25	0.18	0.10	
	U-values partitions to unheated	From code	0.25	0.18	0.10	
V5	U-values glazing	From code	1.80	1.30	0.80	W/m2 K
	U-values frame	From code	2.20	1.40	0.60	
	G-values of glazing	From code	0.7	0.6	0.5	

V6	Thermal bridge wall-basement	0.75	0.50	0.01	0.00	W/m K
	Thermal bridge partition walls	0.75	0.50	0.01	0.00	
	Thermal bridge interior ceiling	0.75	0.50	0.01	0.00	
	thermal bridge partition walls-roof	0.75	0.50	0.01	0.00	
	thermal bridge wall-roof	0.75	0.50	0.01	0.00	
V7	Heat recovery efficiency	30	50	70	85	%
	Electric efficiency	1.50	1.11	0.69	0.42	Wh/m3
V8	T summer	25	25.5	26	26.5	C
V9	Windows quantity	1.00	1.50	2.00	3.00	x current windows quantity
	Reduction for temporary sun protection	1.00	0.75	0.50	0.25	x current shading %

CMA: common areas
OFF: office areas
OTH: other areas
DHW: Domestic hot water

The values of the variables of the base case and the three sets are chosen according to international norms, and are described per each variable as follows:

- V1 (power density for installed lighting). The values (differentiated per end users) for the Set 1 are chosen according to the ASHRAE 90.1-2010. The values for the base case are defined by doubling the values in the Set 1. The values for the Set 2 and Set 3 are defined by reduction factors of 0.5 and 0.25 times, respectively.
- V2 (power density for installed appliances). The values (differentiated per end users) for the Set 3 are defined according to the NS 3031:2007. The values for the Set 2, Set 1, and the base case are obtained by multiplying the above by 2.5, 5, and 1 times, respectively.
- V2 (hot water need). The value for the Set 1 is defined according to the EN 15316-1-3. The values for the base case, Set 2, and Set 3 are obtained by multiplying the above by 2, 0.5, and 0.25 times, respectively.
- V3 (air change rate for infiltration). The value of the Set 3 is defined according to the requirement for infiltration for a passive house. The values for the Set 2, Set 1, and the base case are obtained by multiplying the above by 2.5, 6.6, and 10.0 times, respectively.
- V3 (Manual ventilation for night cooling). The values are defined as multipliers of the summer ventilation air change rate. This is currently obtained by multiplying the winter ventilation air change rate by 1.5 times, as suggested by the PHPP, 2 an 3.
- V4 (U-values for opaque surfaces). The U-values of the constructions systems of the base case are set according to the building code issued in the same year of the corresponding building's edification, or from the descriptions in the building data files.

The U-values in the sets 1 to 3 are chosen in order to gradually get close to a passive house insulation level, as such in set 3.

- V5 (U-values of glazing, frame and G-values of glazing). The U-values of the windows (glazing and frame) of the base case are set according to the building code issued in the same year of the corresponding building's edification, or from the descriptions in the building data files. The U-values in the sets 1 to 3 are chosen in order to gradually get close to a passive house insulation level, as such in set 3. The G-values are chosen to reflect the increasing number of glass panes in the windows.
- V6 (Psi value of thermal bridges). The Psi-values of the thermal bridges are chosen between a very poor insulation level (base case) and a very high insulation level (set 3).
- V7 (efficiency of heat recovery, fans and cooling unit). Both the values chosen for the heat recovery and fans efficiencies are chosen to reflect a typical system for a passive house standard (set 3) and a very low efficient system (base case).
- V8 (comfort temperature in summer). The values are chosen as 1 °C increment from 25 °C.
- V9 (number of windows and shading levels). The values for the fenestration are chosen to fit the given smallest surface given for the case in Valladolid. The values for the shading level are chosen to represent a scale between no additional shading (base case) and high shading (set 3).

Table 15 – Technical lifetime of building components used in the calculations (Novakovic, 2007)

#	Component	Years
V1	Lighting	20
V2	Appliances	15
V3	Infiltration	40
V4	Insulation	40
V5	Windows	30
V6	Thermal bridges	40
V7	Ventilation components	20
V9	Solar shading	40

The calculation of the energy use is performed by changing each variable per time. By doing so, the influence on the total energy use of each single variable (composed of a group of related measures) can be assessed and can be used to design optimal strategies for the energy retrofitting of the shopping centres through different combinations of the most effective variables and sets. In this respect, single sub-variable parameters (such as only changing the U-value of roof) are not considered in the analysis, as it is assumed that the proposed variables (in table) include reasonable packages of building components that are upgraded in a practical retrofitting.

4.3.2. Modelling of the energy demand

To calculate final energy demand for space heating, cooling and lighting by applying the retrofit solutions defined in the previous section, the Passive House Planning Package (PHPP) is used. PHPP is the key design tool used when planning a Passive House and as such, serves as the basis for verification for the Passive House Standard. Based on the large part on European norms, the PHPP makes use of numerous tested and approved calculations to yield a building's heating, cooling and primary energy demand, as well as its tendency to overheat in the warmer months. While the PHPP was developed specifically for Passive Houses (with a large focus on heating demand reduction), it is a design tool that may also be used for other buildings[32]. The flow of information for simulation is shown in figure 11.

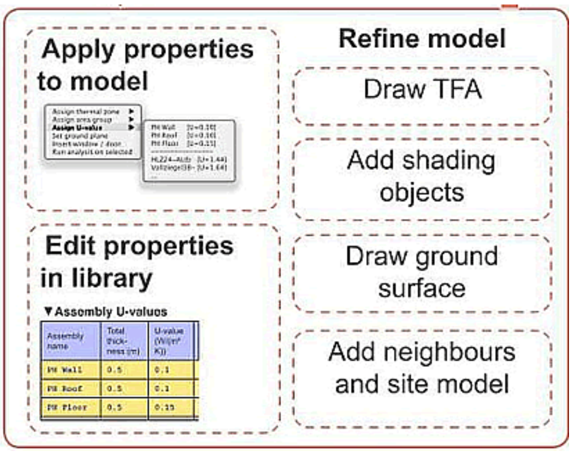


Figure 12 – How to use PHPP (from www.passiv.de)

4.3.3. Assumptions and limitations in the base case

Several assumptions and limitations are considered for the analysis. These are partly due to the limitations given by the software used, PHPP v. 8.5, and partly due to lack of information.

Due to the limitations for the description of the building geometry in the PHPP v. 8.5, a geometrical division (zoning) of the different areas (such as shops, circulation areas, and restaurants) in the shopping centre is not possible. Therefore, the energy flows between the different areas of the building are not considered. These are only considered for the whole building. However, the utilization (i.e., occupancy schedule and density) and settings (e.g., lighting density) were specified for different areas of the buildings. Similarly, this applies to the influence of different ventilation rates used in adjacent zones. Although the ventilation rate was calculated for each use (such as shops, restaurants, and circulation areas), it is not possible to analyse the mutual influence of different rates and different air temperatures in adjacent zones as it is assume to be one zone (well mixed) by the tool. In addition, buildings with complex geometry (such as curved shapes and abutting volumes) were described by a simplified shape with the closest approximation as possible (same volume). As detailed

[32] See also Passivhaus Institute for further information on concepts and tools (www.passiv.de)

drawings of the facades of the shopping centres were often not accessible, the geometrical description of the fenestration areas was assumed from photos and paper drawings. This ensured the largest fitting to available information because a simplified building geometry can lead to a poor representation of the energy flows through the building envelope. However, it is expected that this would not noticeably influence the calculated energy uses for space heating and cooling. In addition these are expected to be significantly lower than the electricity use for internal appliances.

U-values of opaque surfaces and windows and g-values of glazing were extracted from the building description data files when possible. When these were not present, values were assumed from national building codes and ISO standards. Similarly, values of ventilation rates for winter and summer design conditions were assumed from standards (i.e., EN 15251). The ration between the building surface and volume for a typical shopping centre is typically quite good (compact building form) and thus the U-values and g-values of the thermal envelope are not expected to significantly influence the final energy use. However, precise information on the ventilation rate and the efficiency of the fans can be critical for an accurate calculation of the final energy use in the shopping centres, as the indoor comfort temperature is often achieved through air-based systems.

Regarding type of systems for the ventilation, as well as heating and cooling units, it was decided to use the PHPP default ventilation system and air-water heat pump (HP). The seasonal coefficient of performance (COP) of the HP varies as it is influenced by the external air temperature. The base efficiency of the cooling unit is 2.5.

Internal heat gains from people were set to 10 W/m^2, according to the NS 3701:2012. Ventilation rates for the different uses in the shopping centres are set according to the EN 15251:2007. The value for the domestic hot water (DHW) use in the base case is set according to the EN15316-3-1:2007.

4.4. Results from the parametric analysis: energy

4.4.1. Results from the parametric study: City Syd in Trondheim

The current section gives an in-depth overview of the energy and cost savings given by the application of the different options in the City Syd shopping centre. According to the results given by the energy calculation using the PHPP, the most energy saving options are given by the Variables 1, 2, 3, and 7, as shown in Figure 13 and 14. Both the V1 and V2 reduce the energy use for plug loads. This has a consequence on the internal heat gains, which decreases when the installed power density of lights and appliances decreases. In such a perspective, the heating demand increases and partially compensates the achieved electricity savings.

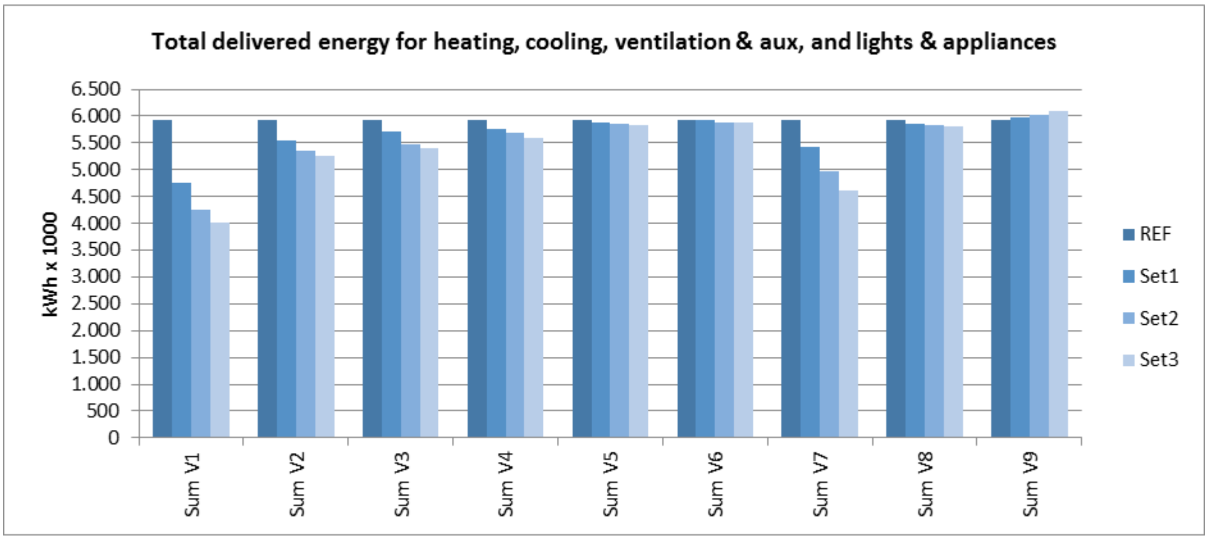


Figure 13. Total delivered energy for the different options applied to the City Syd shopping centre in Trondheim.

The option "infiltration + night ventilation" mostly influences the building heating and cooling needs. This is due to the way the heating and cooling systems are designed. However, since the initial cooling need is very low, the resulting effect is barely visible. The V7 option influences the heating and cooling needs and the electricity use for ventilation. As shown in Figure 14, this option reduces the heating need and the electricity for ventilation but, similarly to the previous case, the abatement of the cooling need is barely appreciable.

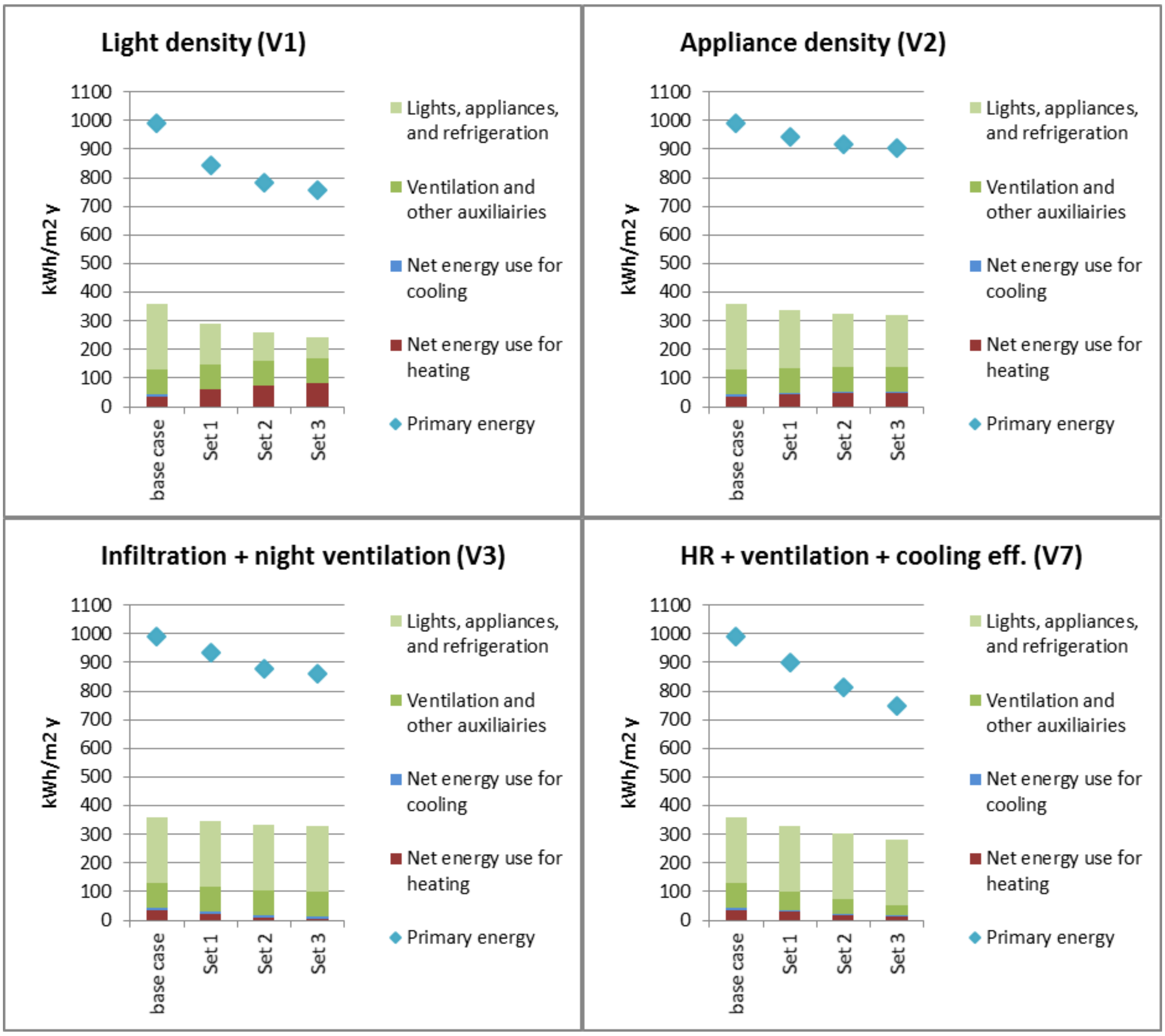


Figure 14. Energy uses for the options V1, V2, V3, and V7 applied to the City Syd shopping centre in Trondheim.

Figure 15 shows the investment, maintenance and annual operational energy cost of the different energy saving strategies. Options V2 and V3 are given by zero initial investment cost. Similarly, investment costs for the options V6 (thermal bridging) and V8 (indoor operative summer temperature) were set to zero. These are due to several reasons:

1. Regarding the investment cost for more efficient appliances there are many different possibilities which make it difficult to specify one single investment. It consists of DHW, equipment (office, CMA+SHP, auditorium, restaurant, bowling) and refrigeration.
2. A lower infiltration rate has been assumed to be done in combination with other measures: Either additional insulation or changing windows will have to be done in combination with improving infiltration.

3. Regarding the thermal bridging, it was not possible to find reliable cost information. However, the energy saving given by this strategy is very little, with the exception of the shopping centre in Valladolid.
4. The change of the set-point temperature was not associated with investment cost.

Option V7 (increasing the efficiency of the HR, ventilation, and cooling systems) shows high energy cost savings. However, the investment cost counterbalances these savings in such a way that the NPV is lower than that of the option V1, as shown in Figure 18 and Figure 19.

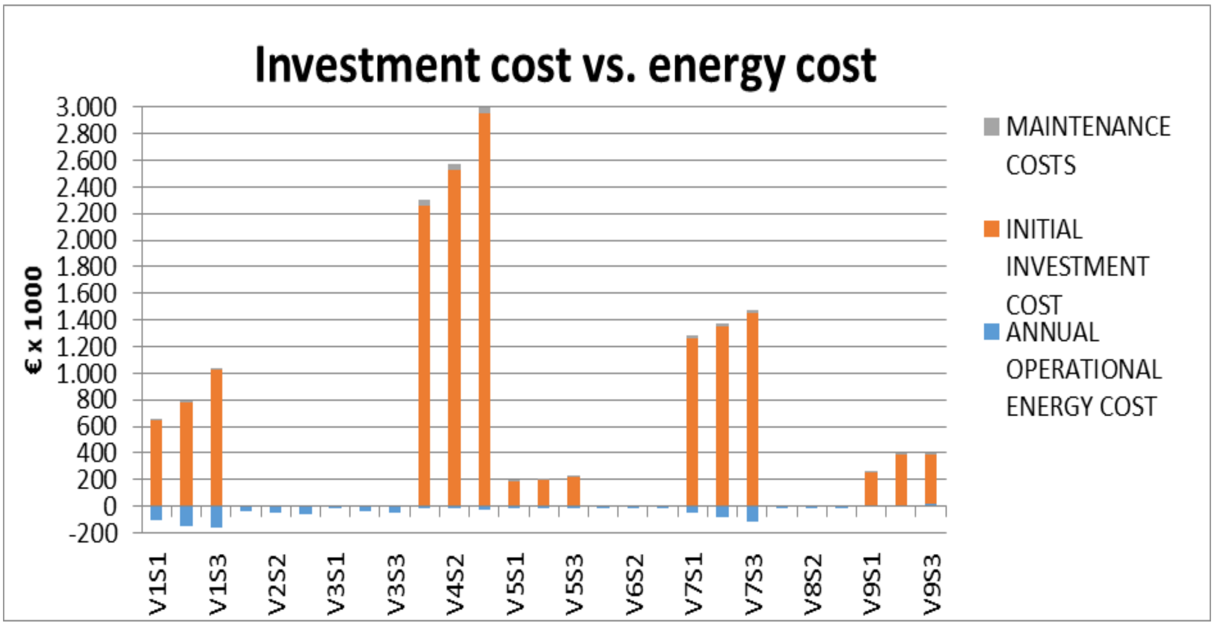


Figure 15. Investment, maintenance, and annual operational energy costs of the different options applied to the City Syd shopping centre in Trondheim.

4.4.2. Results of parametric study: other shopping centres

Figures 12 and 13 show the results of the primary energy (henceforth abbreviated as PE) calculation of the selected shopping centres. This includes the energy use for HVAC, lighting, appliances, DHW, and auxiliaries. The primary energy values are expressed as the ratio between the PE of each case between the PE of the base case for each combination of variables and sets. Both figures give an overview of the most and least efficient options for reducing the PE. As a general trend, most options shown in Table 14 give a PE reduction of lower than 20% compared to the base case. Some options, however, give energy savings of 40% and more.

The reduction of the installed power density of lights (V1 in Table 14) is the option that gives the highest energy savings. These are as high as 44% and 49% for the Set 3 applied to the shopping centres in London and Genova, respectively. For the shopping centre in London, these savings consist of a reduction by 80% of the energy use for cooling, a reduction by 8% of the energy use for ventilation and auxiliaries, and a reduction by 67% of the energy use for lighting. These are partially compensated by an increase of the energy use for heating by 10 times. The smallest saving in PE use is given in the shopping centre in Valladolid (11%), and the median value of the PE reduction for the Set 3 for all buildings is 31%. It must be noted that such an extreme reduction of the installed power density of lights is only achievable by sensibly reducing the amount of lighting appliances. In such a perspective, to deliver an adequate indoor illuminance level, wider fenestration areas should be considered. The calculation of the options with wider fenestration areas give PE values that in almost all the cases lies between 0% and +4%. This is because the surface of the glazed area is very small in comparison to the enclosed volume, even when this area is 3 times larger. As a consequence, the increasing of the PE due to the larger areas is negligible. However, this does not apply to the shopping centre in Valladolid, which, due to the very large initial fenestration area and the very poor insulating values of the glazing, shows a PE that increases by 50%. Notwithstanding the high PE of the shopping centre in Valladolid, a combination of reduced installed power density for lighting and increased glazed area gives the highest energy savings.

The increase of the efficiency of the heat recovery system, the ventilation system, and the cooling system (V7 in Table 14) is the second most effective option. When the systems efficiencies are increased to the Set 3 levels, the calculated PE savings are between 11% in the shopping centre in Genova and 36% in the shopping centre in Klaipeda. For the shopping centre in Klaipeda, these savings consist of a reduction by 76% of the energy use for heating, and a reduction by 40% of the energy use for ventilation and auxiliaries. Since the heating and the cooling systems deliver heat through the ventilation system, an increase of their efficiency has a large influence on the total PE.

Similarly to the installed power density of lighting, the reduction of the installed power density of appliances (such as refrigerators and other plug loads) is quite effective as an energy saving measure. The highest potential is given by the Set 3 applied to the shopping centre in Catania, where the PE reduction is 25%.

All other measures, such as a lower infiltration rate, lower U-values of the components of the building envelope, lower Psi-value of the thermal bridges, and increased indoor summer operative temperature do not give PE savings exceeding 14% of the PE of the base case. A lower infiltration rate is effective in cold climates, as shown by the examples of the shopping centres in Trondheim and Vienna, with PE reductions of 13% and 14%, respectively due to lower heating loads. The increase of the indoor operative summer temperature is effective in Vienna, where the PE saving is up to 8%, due to the extremely low base case summer indoor temperature setting

The energy performance of the shopping centre in Valladolid is unique compared to the other reference buildings. The building has a very poorly insulated envelope, a high glazing ratio, and a high surface-to-volume ratio. Given these conditions, the measures that increase the insulation value of the glazing and reduce the infiltration rate show higher energy savings than those in the other shopping centres. When the Set 3 is applied to the variables 3 and 5 (infiltration and U-value of windows), the given energy savings are up to 25%. On the other hand, when the glazing area is increased to the Set 3 levels, the PE increases by 50%. Also the reduction of the Psi-value of the thermal bridges has a small effect on the reduction of the PE (3%), whereas this measure does not give any energy saving and has not been applied to all buildings.

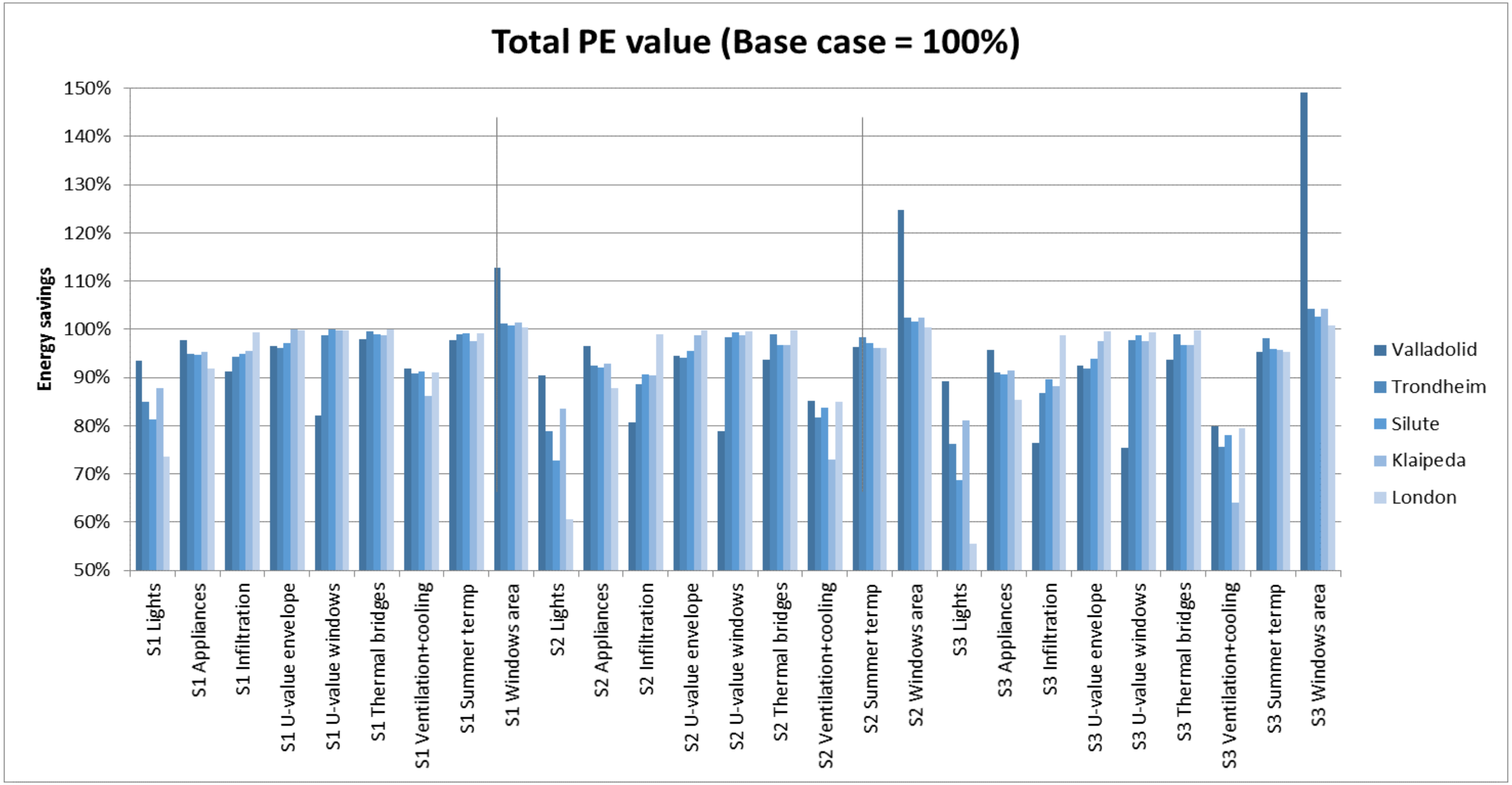


Figure 16. Total Primary Energy (PE) of all combinations of variables and sets. Values are expressed in relation to the PE of the base case.

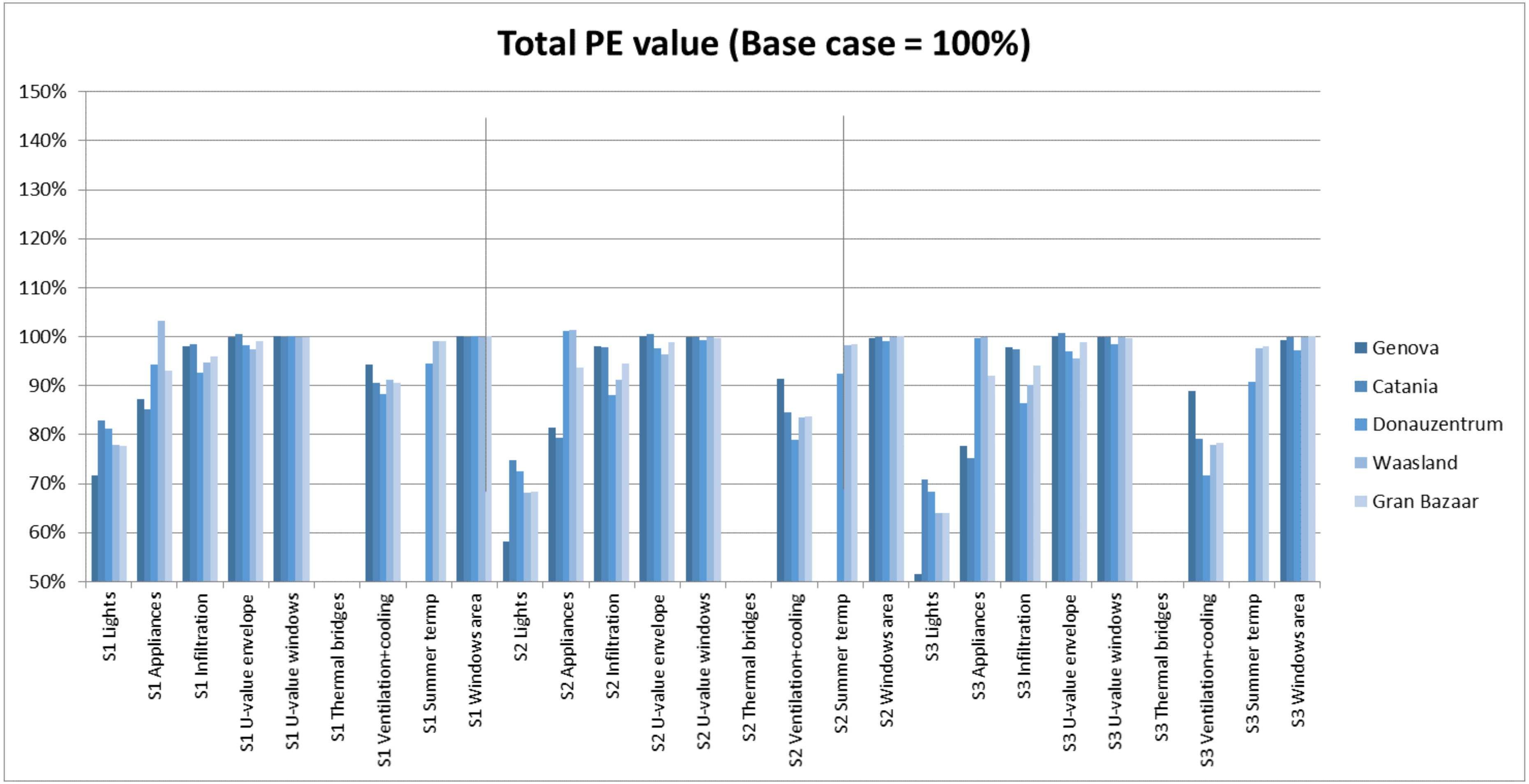


Figure 17. Total Primary Energy (PE) of all combinations of variables and sets. Values are expressed in relation to the PE of the base case (Thermal bridges were not calculated for these buildings).

4.5. Results of the parametric analysis: cost

The cost calculations were based on the energy calculations. In the following section an example is shown for the City Syd shopping centre in Trondheim. The results for PE and NPV for the other shopping centres are given in the Appendix. A summary is presented in chapter 4.5.2.

4.5.1. Net present value results

Figures 17 and 18 show the results of the net present value (henceforth abbreviated as NPV) calculation of the selected retrofit solutions applied to the reference shopping centres. The NPV is expressed as absolute cost in Euro for each combination of variables and sets. Both figures give an overview of the most and least cost saving options with a global cost perspective, where positive values represent actual savings and negative values represent actual losses (i.e., where the investment cost is higher than the energy cost saving). All options are also summarized in Table 16. Differently from the results given from the calculation of the total PE values, the options that give positive NPVs are limited to reducing the installed power density of lights, the infiltration rate, and increasing the indoor operative temperature in summer seasons (because this has zero investment cost).

The reduction of the installed power density of lights (V1 in table 3) is the option that gives the highest NPVs, regardless of each building volume. The highest NPV found in the Brent Cross shopping centre are due to its large area (and therefore greatest impact of lighting consumption). In addition, the reduced internal heat gains decreases the energy use for cooling (and associated energy cost), and this is beneficial in those cities with greater cooling needs such as Catania and Genova. The London, two Belgian and Vienna buildings show high positive NPVs for the option "Summer Temperature", which consists in increasing the indoor operative temperature. This is due to their very high energy use for cooling (due to lower set-points for temperature). The Vienna and Gran Bazaar buildings also show high positive NPVs for the option "infiltration", which consists in decreasing the air change rate for infiltration. The option "ventilation + cooling" is effective for the shopping centres in Catania and in Klaipeda, while it shows negative NPVs for almost all the other buildings.

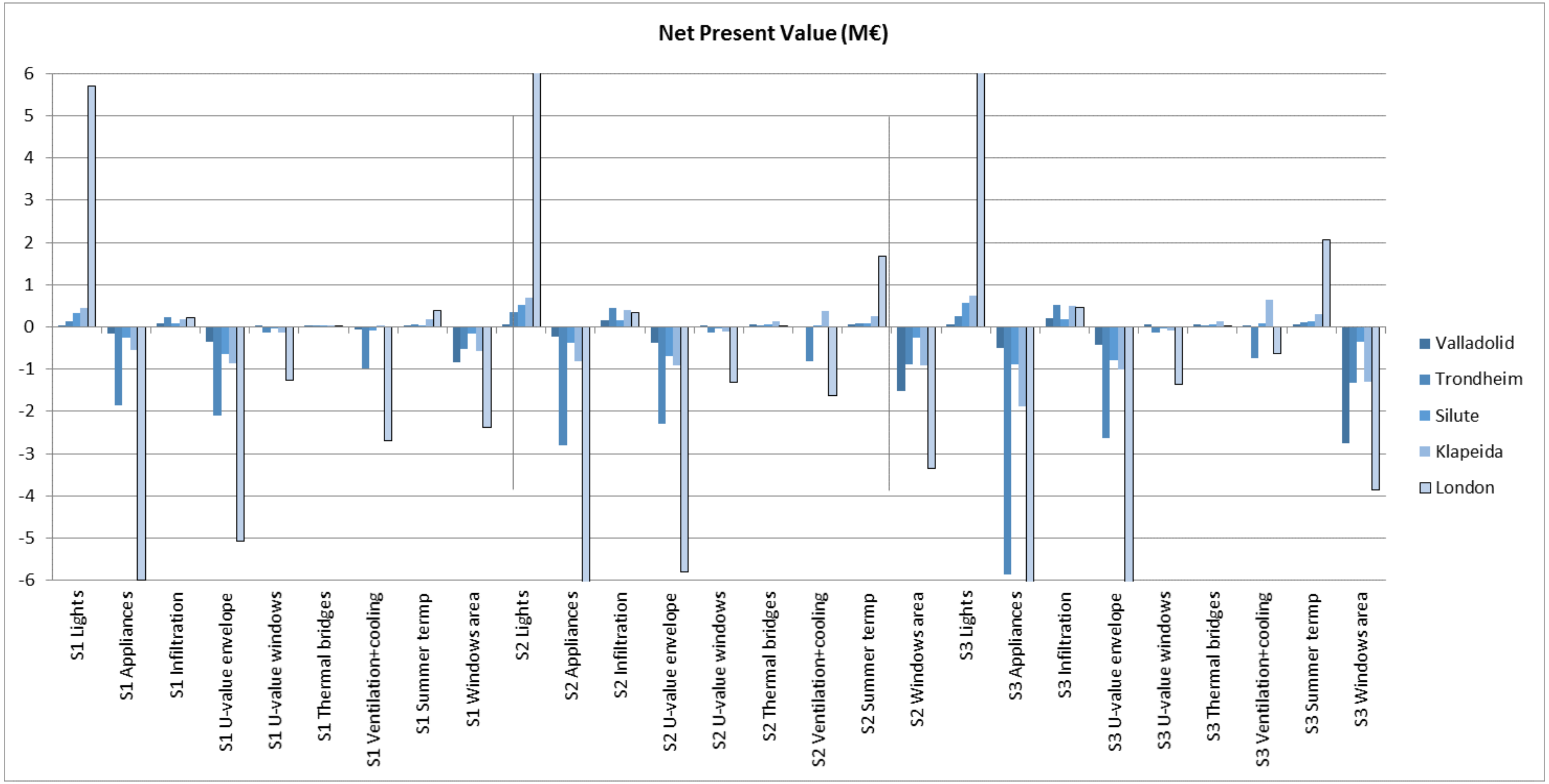


Figure 18. Total Net Present Value (NPV) of all combinations of variables and sets. Values are expressed as absolute cost values in Euros of the selected cases.

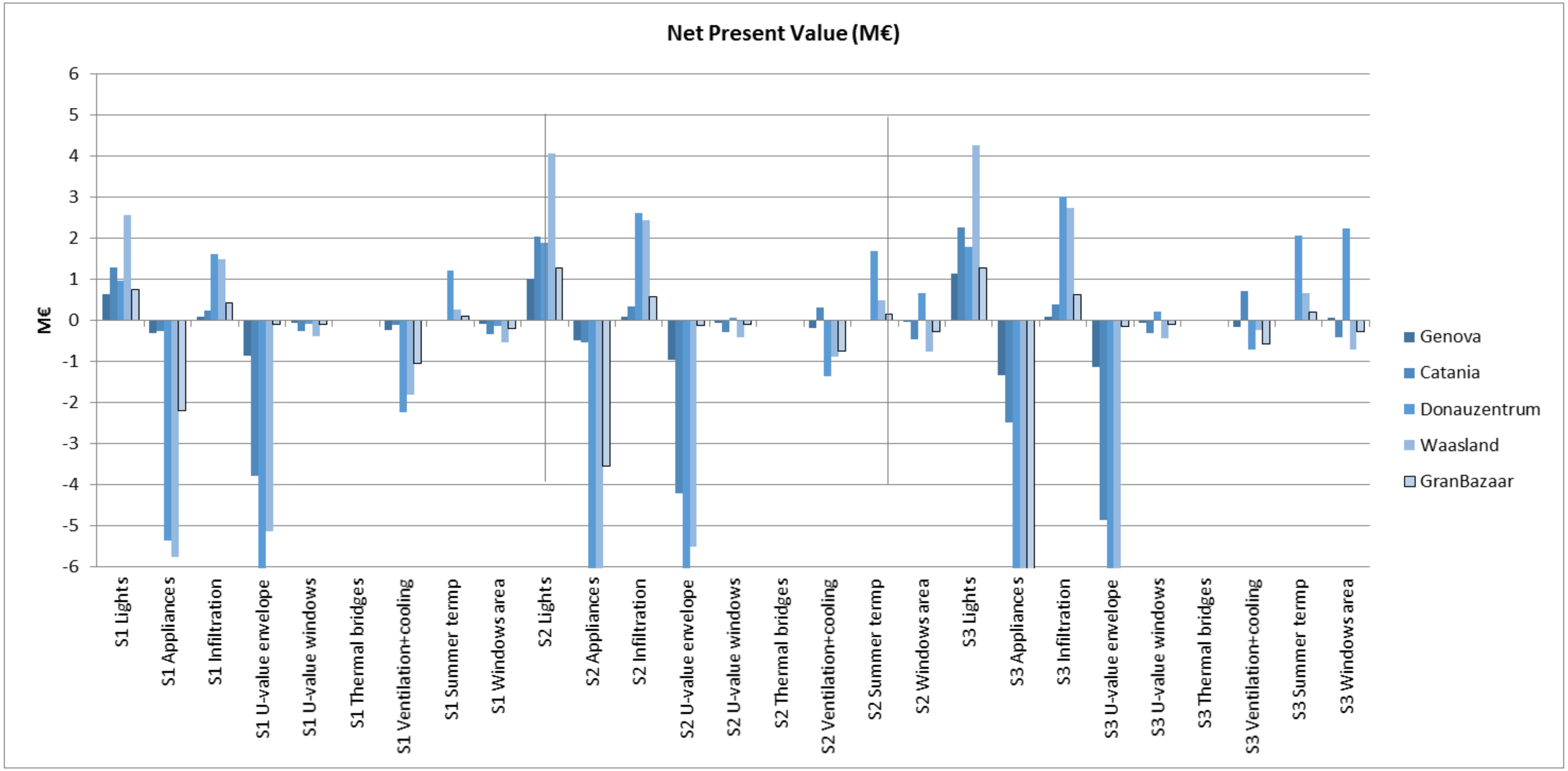


Figure 19. Total Net Present Value (NPV) of all combinations of variables and sets. Values are expressed as absolute cost values in Euros of the selected cases.

The most negative NPVs are given by increasing the efficiency of the installed appliances and increasing the thickness of the insulation of the building envelope. The increase of the window U-value shows negative NPVs for all shopping centres except for those in Valladolid and Vienna. The increase of the window area shows positive NPVs for both buildings in Vienna and Genova.

Some comments coming from Table 16 in the following.

- The options that have negative NPVs for the Valladolid building are the increasing of the window area (up to -2.76 Mil€ for the Set 3), the increasing thickness of the building insulation (up to -0.43 Mil€ for the Set 3), and the reduction of the installed power density of appliances (up to -0.51 Mil€ for the Set 3). On the other hand, the options that give positive high NVPs are limited to the reduction of the infiltration rate (up to 0.21 Mil€), and to the increasing of the indoor operative summer temperature (up to 0.07 Mil€).
- When considering the shopping centre in Trondheim, the two options with the highest positive NPVs are the reduction of the infiltration rate (up to 0.53 Mil€), and the reduction of the installed power density of lighting (up to 0.27 Mil€). On the other hand, the reduction of the installed power density of appliances and the increase in insulation value of the opaque envelope give the highest negative NPVs, and both these options show similar negative results in all the other buildings.
- The decreasing of the installed power density of lighting and the increasing of the indoor operative summer temperature are both very effective in giving high positive NPVs in building in London (up to 10.2 Mil€).
- The Vienna building achieves very high positive NPVs if either the lighting efficiency, or the summer operative temperature, or the window area increase, or the infiltration rate decreases.
- Differently from the other buildings, the Vienna shopping centre is the only one to show very high positive NPVs (up to 2.2 Mil€) when the windows increase. This is due to the fact that the U-value of the currently installed windows is very low, and, consequently, when the glazing area increases the solar gains increases too, thus reducing the need for winter heating. The same building also shows very high positive NPVs when the options "summer temperature" or "infiltration" are considered (up to 3.0 Mil€). Also, this is the only building that shows a better NPV due to the reduction of the infiltration rate than the NPV given from the increasing of lighting efficiency.

Table 16. Total Net Present Value (NPV) of all combinations of variables and sets. Values are expressed as absolute cost values in Euros of the selected cases.

	Valladolid	Trondheim	Silute	Klapeida	London	Genova	Catania	Vienna	Sint-Niklaas	Antwerp
V1S1 Lights	28 171	135 234	324 824	453 391	5 696 806	643 345	1 286 201	949 688	2 568 229	756 719
V2S1 Appliances	-159 326	-1 865 163	-257 304	-539 006	-5 989 848	-315 260	-263 939	-5 355 283	-5 771 537	-2 208 554
V3S1 Infiltration	76 822	222 792	89 684	182 480	212 520	87 733	230 837	1 607 043	1 481 414	410 721
V4S1 U-value envelope	-355 945	-2 108 572	-640 640	-858 587	-5 082 960	-871 198	-3 798 707	-11 876 808	-5 134 702	-94 487
V5S1 U-value windows	23 432	-141 767	-40 541	-142 054	-1 250 559	-56 943	-266 072	-85 703	-379 558	-105 091
V6S1 Thermal bridges	17 050	12 876	19 169	45 955	10 115					
V7S1 Ventilation+cooling	-51 093	-980 472	-83 055	8 960	-2 699 357	-241 906	-123 188	-2 242 535	-1 825 532	-1 043 105
V8S1 Summer temp	31 596	61 483	25 777	168 987	399 044			1 212 024	270 756	89 035
V9S1 Windows area	-834 470	-525 439	-150 269	-566 067	-2 385 565	-80 347	-333 249	-140 062	-529 291	-199 046
V1S2 Lights	56 150	351 814	514 984	684 803	9 395 117	1 009 125	2 032 552	1 889 360	4 066 394	1 266 523
V2S2 Appliances	-239 086	-2 798 875	-387 069	-804 232	-9 000 537	-482 566	-546 771	-9 237 325	-8 124 446	-3 546 506
V3S2 Infiltration	165 478	447 270	166 607	397 104	334 087	83 069	328 120	2 617 136	2 433 720	569 784
V4S2 U-value envelope	-382 999	-2 294 358	-693 116	-904 335	-5 803 310	-972 268	-4 210 657	-13 099 668	-5 515 829	-118 110
V5S2 U-value windows	41 505	-139 554	-35 042	-114 703	-1 308 698	-56 652	-290 182	64 141	-413 087	-106 112
V6S2 Thermal bridges	51 526	37 927	54 396	134 120	27 692					
V7S2 Ventilation+cooling	-12 826	-822 061	3 826	377 381	-1 620 146	-198 848	307 844	-1 359 994	-893 185	-761 994
V8S2 Summer temp	51 686	95 886	85 646	260 815	1 671 871			1 677 858	488 907	156 725
V9S2 Windows area	-1 510 398	-893 690	-251 723	-908 559	-3 354 030	-51 438	-476 255	646 545	-764 178	-276 392
V1S3 Lights	53 338	263 646	576 214	742 314	10 186 737	1 131 895	2 260 605	1 793 344	4 258 850	1 261 577
V2S3 Appliances	-507 446	-5 850 652	-891 691	-1 872 501	-20 463 384	-1 329 033	-2 489 391	-18 165 552	-15 815 837	-7 355 593
V3S3 Infiltration	205 837	526 963	186 356	505 504	459 613	89 507	375 395	3 016 315	2 733 505	612 489
V4S3 U-value envelope	-430 978	-2 631 756	-795 291	-1 005 839	-7 248 101	-1 131 645	-4 858 862	-15 078 888	-6 276 779	-146 610
V5S3 U-value windows	59 897	-137 478	-29 687	-87 788	-1 368 828	-56 378	-312 844	213 573	-446 616	-107 181
V6S3 Thermal bridges	52 240	38 431	55 073	135 872	28 017					
V7S3 Ventilation+cooling	16 887	-730 338	72 352	647 623	-635 811	-167 483	705 487	-726 587	-239 216	-567 556
V8S3 Summer temp	68 275	109 766	121 201	293 146	2 068 068			2 051 471	667 856	207 784
V9S3 Windows area	-2 756 779	-1 321 494	-355 729	-1 294 049	-3 857 367	54 678	-411 734	2 226 790	-719 685	-272 040

A clear recommendation for each reference building is given below. More detailed results can be found in the appendix.

Table 17. Recommendations for each reference shopping centre

Valladolid

Cost effective measures (positive NPV):

- Lighting (V1, all sets with high interest rate),
- Equipment (V2, all sets), Infiltration (V3, all sets),
- Thermal bridges (V4, all sets),
- Setpoint temperature (V8, all sets)

Trondheim

Cost effective measures (positive NPV):

- Lighting (V1, all sets with high interest rate),
- Equipment (V2, all sets),
- Infiltration (V3, all sets),
- Thermal bridges (V6, all sets),
- Setpoint temperature (V8, all sets)

Silute

Cost effective measures (positive NPV):

- Lighting (V1, all sets),
- Equipment (V2, all sets),
- Infiltration (V3, all sets),
- Thermal bridges (V6, all sets),
- Ventilation (V7, set 2 and set 3 with high interest rate),
- Setpoint temperature (V8, all sets)

Klapeida

Cost effective measures (positive NPV):

- Lighting (V1, all sets),
- Equipment (V2, all sets),
- Infiltration (V3, all sets),
- Thermal bridges (V6, all sets),
- Ventilation (V7, set 1 with high interest rate, set and set 3),
- Setpoint temperature (V8, all sets)

London

Cost effective measures (positive NPV):

- Lighting (V1, all sets),
- Equipment (V2, all sets),
- Infiltration (V3, all sets),
- Ventilation (V7, set 2 and set 3; with high interest rate),
- Setpoint temperature (V8, all sets)

Genova

Cost effective measures (positive NPV):

- Lighting (V1, all sets),
- Equipment (V2, all sets),
- Infiltration (V3, all sets)

Catania

Cost effective measures (positive NPV):

- Lighting (V1, all sets),
- Equipment (V2, all sets),
- Infiltration (V3, all sets),
- Ventilation (V7, set 1 and set 2; with high interest rate, set 3)

Vienna

Cost effective measures (positive NPV)

- Lighting (V1, all sets),
- Infiltration (V3, all sets),
- Windows (V5, set 3),
- Ventilation (V7, set 3; high interest rate),
- Window area (V9, set 3)

Sint-Niklaas

Cost effective measures (positive NPV):

- Lighting (V1, all sets),
- Infiltration (V3, all sets),
- Ventilation (V7, set 2 and set 3; with high interest rate),
- Setpoint temperature (V8, all sets)

Antwerp

Cost effective measures (positive NPV):

- Lighting (V1, all sets),
- Equipment (V2, all sets),
- Infiltration (V3, all sets),
- Ventilation (V7, set 3; with high interest rate),
- Setpoint temperature (V8, all sets)

4.5.2. Payback period results

Payback period calculation results show three different groups of results, components with:

- Positive PBP
- Zero PBP
- No value (due to negative cost savings)

The three components with positive PBP are lighting, windows and ventilation components (V1, V5, V7). Components that did not have investment costs (and thus PBP results in zero) are equipment, infiltration, thermal bridges, and set-point temperatures (V2, V3, V6, V8).
The third group of components includes insulation and solar gains (V4 and V9). Both variables demonstrate not being feasible.

The PBP calculations have to be seen in comparison with the expected lifetime of the technologies. Table 19 shows this comparison for those components with a positive PBP.

- The PBP for lighting (with a lifetime of 20 years) is in the range between 1.5 and 7.6 years. The values vary also for the three sets (set1 to set 3) with a range of PBP for set 1 between 1.9 and 7.6 years, for set 2 between 1.5 and 6.1 years, and set 3 between 1.8 and 7.2 years.
- The PBP for improvements of windows (with a lifetime of 30 years) is in the range between 3 and 116 years and depends on the climate and building design. But only four buildings show positive PBP with two buildings only having a positive PBP for set 3 (Silute and Klapeida). The best PBP provided by the shopping centre in Vienna (PBP=6.2 years for set 2 and 3.1 years for set 3).
- The ventilation components (with a lifetime of 20 years) provide PBP between 3 and 35 years. The results depend more on the specific building than on the chosen sets. For set 1 PBP range between 7.3 and 35 years, for set 2 PBP ranges between 4 and 26 years and for set 3 PBP ranges between 3 and 18 years.

Table 18. Payback period (PBP) compared to lifetime of components

#	Components	Lifetime (years)	PBP Min (years)	Max (years)
V1	Lighting	20	1.5	7.6
V5	Windows	30	3	116
V7	Ventilation components	20	3	35

4.6. A parametric analysis of retrofitting drivers: Conclusions

A list of analysis variables has been chosen for assessing the energy reduction of different shopping centres in Europe with different climatic conditions. These have been grouped according to different level of efficacy (here known as sets) to define several energy saving measures. The primary energy and the energy uses for heating, cooling and electricity use have been calculated. The calculation of the total PE of the selected shopping centres showed that the measures for reduction of the installed power density of lighting and infiltration are most effective.

A cost analysis has been performed and the results show positive NPV for lighting, infiltration, thermal bridges allowing an increase in summer temperatures. Net present value results can be used to inform the stakeholders about investing in energy refurbishment. However, in the analysis only single measures have been considered.

Some parameters as e.g. infiltration do not have separate investment costs. It can be assumed that infiltration can be improved when either insulating the facade and the roof or when changing the windows. Investment costs for improving plug loads were not considered.

- The primary energy and the energy uses for heating, cooling and electricity use have been calculated using the PHPP. The calculation of the total PE of the selected shopping centres showed that the measures for the reduction of the installed power density of lighting and appliances, has the largest PE savings.
- Since costs associated with retrofitting may be barriers it was set in a net present value evaluation. In this way ensuring that the cost of implementing energy efficient measures do not outweigh the costs achieved by energy use reductions.
- A list of variables has been developed for assessing the energy reduction of different shopping centres in Europe. These have been grouped to define several energy saving measures which have been evaluated.

Recommendations for further work

It is recommended to analyse in detail investment costs for improving lighting and plug loads. Other measures such as improvement on infiltration have to be seen in combination with other measures (either windows and/or insulation). Additional costs for the improvements of entrance areas need also to be included. A sensitivity analysis of the discount rate in the NPV calculation is recommended for further work since the results showed that NPV is extremely sensitive to discount rates and assumed lifetimes.

More advanced solution sets can now be developed that take this first evaluation of energy drivers into account and which need to be adjusted to each specific building. Investment costs were calculated for all countries but specific components might show different cost levels (due to different levels of market development for those components). More detailed analysis with focus on technologies should be done in CommONEnergy Work Package 4 - Solutions for enhancing energy efficiency.

5. Conclusions

The majority of European shopping centres are already built, but there is still huge potential for energy savings due to the practice of regular rehabilitation and redesign of shopping centres. Efforts to improve energy efficiency and provide sustainable solutions for shopping centres must take this tendency into account. This state of constant flux offers the advantage of regular opportunities to improve the technical systems, such as lighting and ventilation, or the building envelope and monitoring systems. The consideration of these aspects along with the other drivers has the potential to achieve significant energy reductions and IEQ improvement. There are, however a number of issues associated with barriers and drivers which can hinder efforts to achieve the desired energy reductions.

The report has identified three different kinds of drivers: Direct drivers, indirect drivers and potential drivers.

Direct drivers for energy retrofits actually cause a phenomenon for example a deep energy retrofit to happen: Their influence is direct and they may be seen as actively influencing energy use reductions in shopping centres today. However there is more than one side to direct drivers, and they may not always have a positive effect on energy. This because if the consequences are not correctly understood they may in some cases function as barriers to energy use reductions, this may be clearly seen for example in the cases of knowledge and cost. Examples of direct drivers are presented below:

- The need to reduce energy use in shopping centres is in itself a driver based on the needs to reduce operational costs and overhead costs.
- Thermal and visual comfort issues and potential improvement could be drivers to improve lighting and thermal aspects related mainly to the envelope, HVAC system and lighting devices
- The need to have systems that are easier to control and maintain is a driver especially regarding the greater management and flexibility that could in turn lead to economic benefits such as taking advantage of building-grid interaction aspects
- Lack of knowledge among stakeholder levels is a barrier to energy use reductions. On the other hand, increasing knowledge about energy use in shopping centres on all stakeholder levels is a potential driver for energy efficient upgrades. Increasing user awareness might for example be achieved through use of certification systems. It is important that certification systems measure improvements and can account for the changes in the building and its operation which occur much more frequently in shopping centres than in other building types.
- Costs associated with retrofitting may both drivers and barriers. Reducing overheads and operational costs may be considered a driver for energy retrofitting among stakeholders. However if the costs of implementing energy efficient measures outweigh the costs achieved by energy use reductions then the measures will not be implemented.

Indirect drivers provide support or background for direct drivers. For example changing shopping habits and user behaviour influences the non-energy related retrofitting activity. These retrofitting actions may affect energy use in shopping centres and they have the potential to be associated with energy retrofits. Customers are not demanding energy use reductions in shopping centres and as long as there is no direct demand then shopping habits cannot be considered a driver. The lack of demand may potentially be a hindrance to owners, managers and tenants. They are not be pushed by customer demand to take direct actions and as long as their profits remain stable or continue to increase this will not change. However consumer awareness is increasing. Increasing knowledge about the implications of their actions in shopping centres may put pressure on the industry to increase their actions aimed at energy use reductions.

Size does have an effect on energy use and changes in user behaviour are influencing shopping centre size and may affect the kind of shopping centres built, but this kind of user behaviour cannot be said to be a direct driver for energy use reductions. Existing shopping centres are not expected to decrease in size due to the aforementioned trend. Some shopping centres are increasing in size based on changing shopping habits. Shopping centres are increasing providing for a wider range of activities, eating, meeting, sports and cinemas are all leisure activities, they all require more space and potentially affect shopping centre energy use. Customer behaviour can be seen to influence the kind of shopping centres being built or rebuilt, but it is only an indirect driver for energy use or energy use reductions.

Potential drivers are drivers which are not actually causing an effect at the moment, but with the correct set of circumstances in place they have the potential to become direct drivers. It is not always easy to separate indirect drivers and potential drivers from each other, because they could both affect energy actions. The difference between them is that indirect drivers are already in place, and they are having an effect on the physical structure in shopping centres, for example user behaviour, but they are not the main reason for actions to reduce energy use. Potential drivers are not at the moment in place, but if they were in place they could have a great impact on the amount of energy used in shopping centres. An example of a potential driver is tenant knowledge. Tenants know little about in-store energy use and have a lack of engagement about energy issues. Owners and managers see a potential for reducing energy use in shopping centres through collaboration with tenants. This is due to two main factors, firstly tenants are the major cause of energy use in shopping centres, and secondly tenants have a high degree of independent control over their in-store energy use. By supplying tenants with knowledge about how lighting, ventilation and building design (all direct drivers for energy use reduction) affect their in-store energy use (energy bills), owners and managers will encourage tenants to instigate actions to reduce energy use. Without this knowledge tenants will remain unengaged. It is proposed here by establishing potential drivers as direct drivers shopping centres will increase their efforts to reduce energy use.

Social aspects such as customer satisfaction, tenant knowledge or retail profits and organisational structures have, as shown above, major implications for shopping centre retrofitting, and may operate as drivers or barrier for energy use reductions. However it is within the technical challenges that the major drivers for energy use reductions are found. Shopping centres are complex buildings, which are subject to regular change, have complicated layouts, sophisticated utility plants and a high concentration of customer and workers. Four main areas of energy use inefficiencies were identified: lighting, HVAC measures, plug-loads and refrigeration, and lastly architecture and design, which includes issues such as ergonomics and safety. The need to achieve energy use reductions within these four areas may be considered major drivers for energy retrofitting in shopping centres.

In the scope of this analysis both indicators and requirements with a direct or an indirect effect on energy consumption in shopping centres were identified. When defining the relevance of performance indicators; legal requirements (i.e. for work environment), ownership or authority over parts of the centre, and cultural context also come into play. Six performance concepts were identified which have contextual relevance to energy use and supply of energy in shopping centres:

- Energy follows function
- Energy follows form
- Energy follows user needs
- Energy follows stakeholders
- Energy follows organization
- Energy follows availability

As a result of the underlining complexity of performance requirements in shopping centres, it may also be useful to distinguish between causes of energy use within a functional sub-division, meaning energy divided by the functions which it is used (by end use or supply system), and organizational sub-divisions of energy use distinguished by who pays for the energy and thus is related to billing practice, tenant agreements, and contracts with energy supply carrier companies.
Conversions to primary energy, or CO_2 equivalents are typically performed on the supply side according to the type of energy carriers. This has been followed in the economic evaluation and a list of analysis variables has been developed for assessing the energy reduction of different shopping centres in Europe. These have been grouped according to different level of efficacy (here known as sets) to define several energy saving measures. The primary energy and the energy uses for heating, cooling and electricity use have been calculated. The calculation of the total PE of the selected shopping centres showed that the measures for reduction of the installed power density of lighting and infiltration are most effective.

- Since costs associated with retrofitting may be barriers it was set in a net present value evaluation. In this way ensuring that costs of implementing energy efficient measures do not outweigh the costs achieved by energy use reductions.

- The primary energy and the energy uses for heating, cooling and electricity use have been calculated. The calculation of the total primary energy (PE) of the selected shopping centres showed that the measures of reduction of the installed power density of lighting and appliances, has the largest PE savings.
- A cost analysis has been performed and the results show positive NPV for lighting, infiltration, thermal bridges and allowing increase in summer temperatures. Net present value results can be used to inform the stakeholders about investing in energy refurbishment. However, in the analysis only single measures have been considered.

Recommendations for further work

- An effort should be put on increasing knowledge among stakeholder which will potentially function as a driver for implementing actions to achieve energy use reductions.
- An integrated design process should be further developed that allows for assessing multiple variables changing simultaneously.
- It is recommended to perform more detailed simulations of such complex buildings. Especially a number of control strategies for lighting and HVAC have considerable potential for optimized operation (i.e. maximum comfort with minimum energy use). For that analysis advanced building simulation tools are recommended to use.
- A possible task for the next phases could be to identify if and how relevant energy performance indicators can be incorporated in contracts, or other forms of agreements between the stakeholders.
- A considerable effort should therefore be put on developing models that can give detailed answers to KPIs. The implications of both indicators and requirements with a direct or an indirect effect on energy consumption in shopping centres revealed the relevance for legal requirements (i.e. for work environment), ownership or authority over parts of the centre, and cultural context to energy use and supply of energy in SC.
- The residual of investment in comfort improvements have not been taken into consideration. Thus, there is room for further analysing the specific residual benefits of investing in specific technologies. The shopping centre with refurbished equipment or building envelope has potentially a higher value. This aspect should be followed up.
- Net present value results can be used to inform the stakeholders about investing in energy refurbishment. However, in the analysis only single measures have been considered. In the following project progress considerable effort should be put on demonstrating the benefits of applying solution sets. Some efforts and costs can be simply added but others are interacting with each other. E.g. investing in energy efficient lighting will not only reduce electricity consumption but also reduce cooling loads and increase heating loads. The energy consumption should be sub-metered in shopping centres and performance indicator should be expressed according to functional units (energy use per tenant, per facade meter, per leased floor area, per

heated floor area etc. (i.e. kWh/m2)). Energy use and associated costs should also be weighted by sub-metering of processes (i.e. tenants hot water, or cold water consumption). Then meaningful conversions to CO_2 equivalents can be performed on the demand side according to the type of function (shop etc.)

- As a result of the underlining complexity of performance requirements in SC, it may also be useful to distinguish between causes of energy use within a functional sub-division, meaning energy divided by the functions which it is used (by end use or supply system), and organizational sub-divisions of energy use distinguished by who pays for the energy and thus is related to billing practice, tenant agreements, and contracts with energy supply carrier companies.
- A possible task for the future could be to identify if and how relevant energy performance indicators can be incorporated in contracts, or other forms of agreements between the stakeholders.

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Appendix

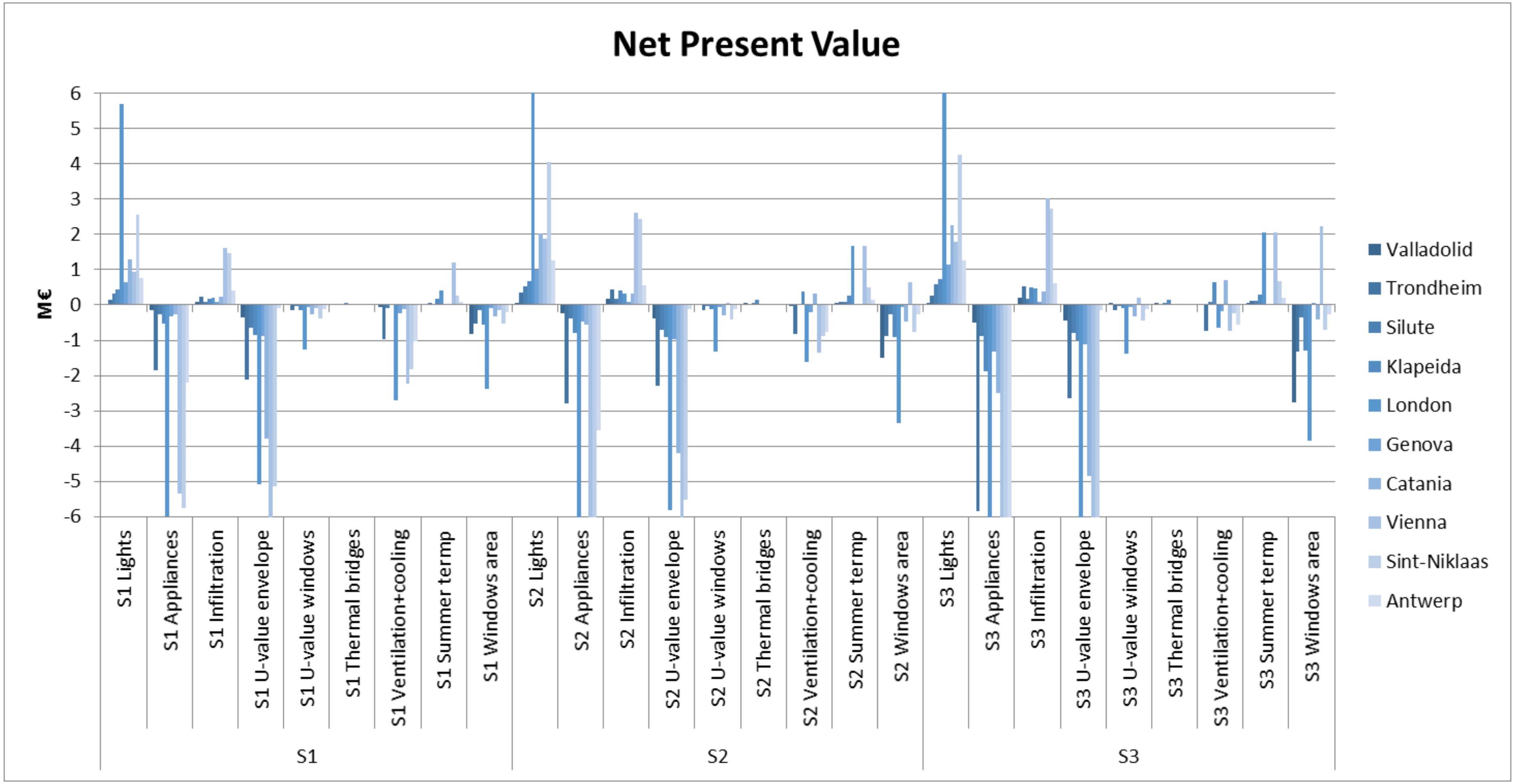


Figure 20. Total Net Present Value (NPV) of all combinations of variables and sets. Values are expressed as absolute cost values in Euros

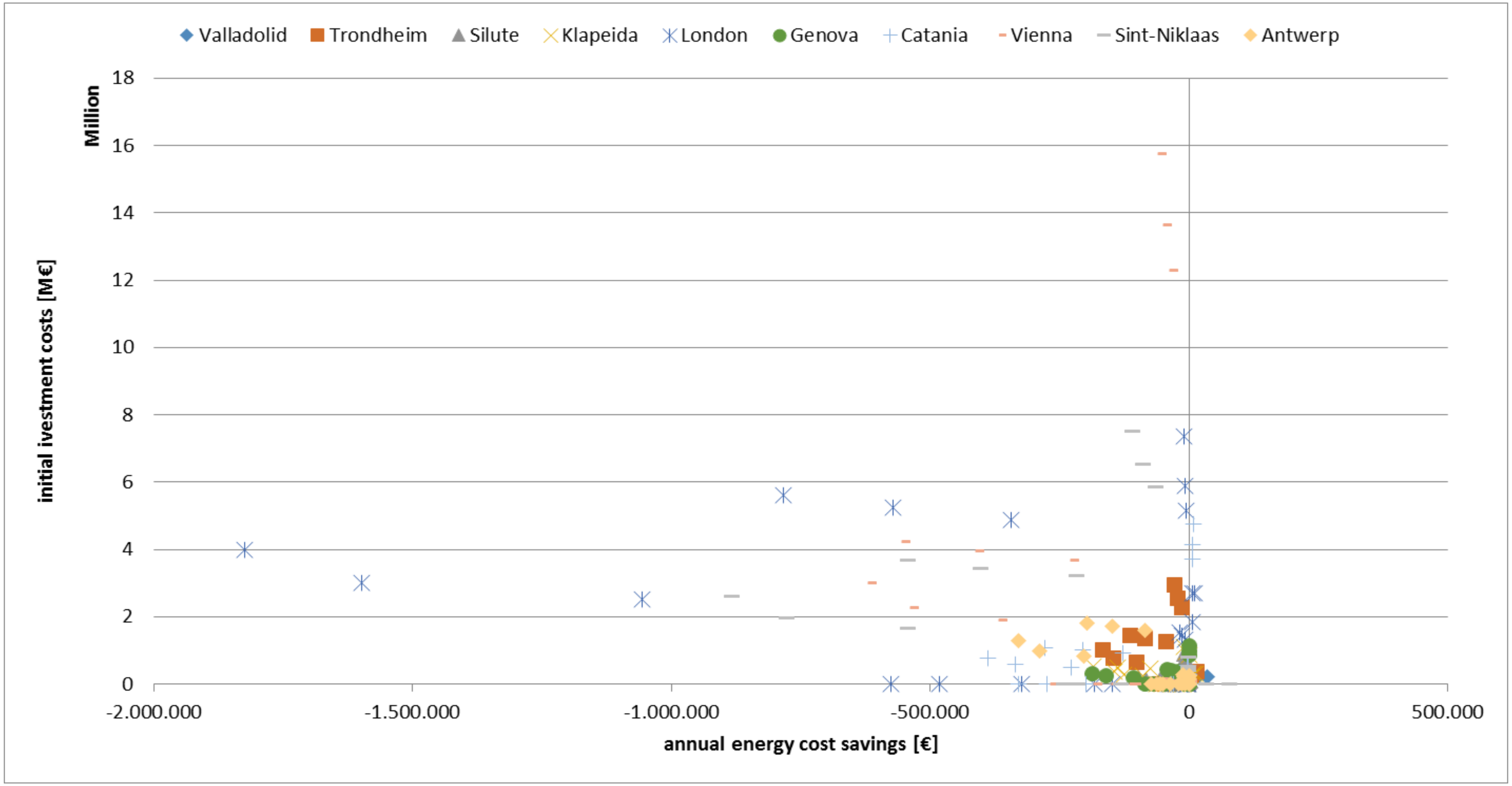


Figure 21. Initial investment costs over annual energy saving costs of all combinations of variables and sets. Values are in Euros

Table 19. Investment costs of all combinations of variables and sets. Values are expressed as absolute cost values in Euros of the selected cases.

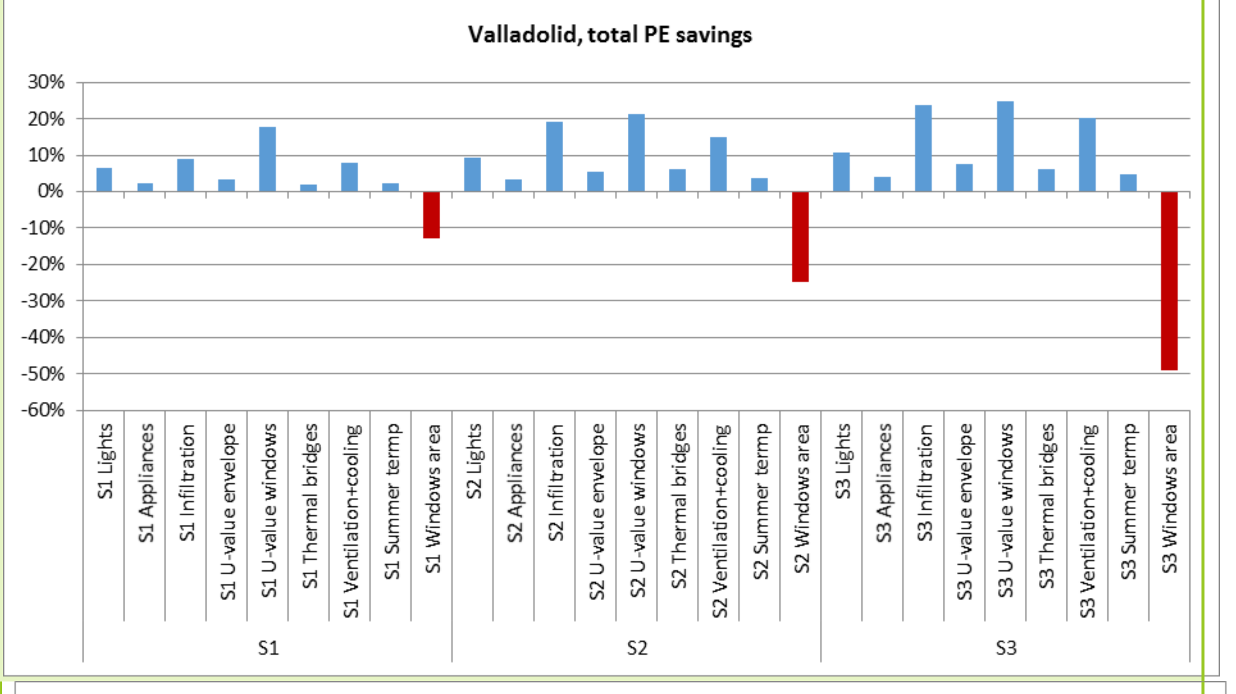
NPV (€)		Valladolid	Trondheim	Silute	Klapeida	London	Genova	Catania	Vienna	Sint-Niklaas	Antwerp
V1 Lighting	Set 1	57 328	647 508	110 950	235 778	2 508 133	194 605	476 713	1 893 996	1 645 106	812 817
	Set 2	68 794	777 010	133 139	282 934	3 009 759	233 526	572 055	2 272 795	1 974 127	975 381
	Set 3	90 843	1 026 051	175 812	373 618	3 974 426	308 374	755 406	3 001 255	2 606 860	1 288 002
V2 Equipment	Set 1	0	0	0	0	0	0	0	0	0	0
	Set 2	0	0	0	0	0	0	0	0	0	0
	Set 3	0	0	0	0	0	0	0	0	0	0
V3 Infiltration	Set 1	0	0	0	0	0	0	0	0	0	0
	Set 2	0	0	0	0	0	0	0	0	0	0
	Set 3	0	0	0	0	0	0	0	0	0	0
V4 Insulation	Set 1	385 284	2 264 710	692 676	854 868	5 138 500	871 198	3 713 959	12 287 333	5 863 867	200 574
	Set 2	429 539	2 529 615	774 206	953 372	5 882 767	971 957	4 128 513	13 643 784	6 519 114	229 594
	Set 3	495 176	2 950 380	904 029	1 109 365	7 348 717	1 130 105	4 762 089	15 740 995	7 519 399	263 337
V5 Windows	Set 1	111 581	183 265	42 115	150 065	1 315 694	52 270	267 093	70 031	385 753	120 040
	Set 2	121 279	199 193	45 776	163 108	1 430 051	56 813	290 308	76 118	419 282	130 474
	Set 3	130 978	215 122	49 437	176 151	1 544 408	61 356	313 523	82 205	452 810	140 907
V6 Thermal bridges	Set 1	0	0	0	0	0	0	0	0	0	0
	Set 2	0	0	0	0	0	0	0	0	0	0
	Set 3	0	0	0	0	0	0	0	0	0	0
V7 Ventilation	Set 1	111 663	1 261 210	216 106	459 247	4 885 318	379 050	928 537	3 689 108	3 204 323	1 583 198
	Set 2	120 030	1 355 716	232 300	493 660	5 251 388	407 453	998 115	3 965 543	3 444 431	1 701 831
	Set 3	128 398	1 450 222	248 493	528 072	5 617 457	435 856	1 067 692	4 241 977	3 684 539	1 820 464
V8 Setpoint TH	Set 1	0	0	0	0	0	0	0	0	0	0
	Set 2	0	0	0	0	0	0	0	0	0	0
	Set 3	0	0	0	0	0	0	0	0	0	0
V9 Solar gains	Set 1	154 805	254 257	58 430	208 197	1 825 365	72 518	370 559	97 160	535 185	166 541
	Set 2	229 202	376 449	86 511	308 253	2 702 608	107 370	548 644	143 853	792 387	246 578
	Set 3	229 202	376 449	86 511	308 253	2 702 608	107 370	548 644	143 853	792 387	246 578

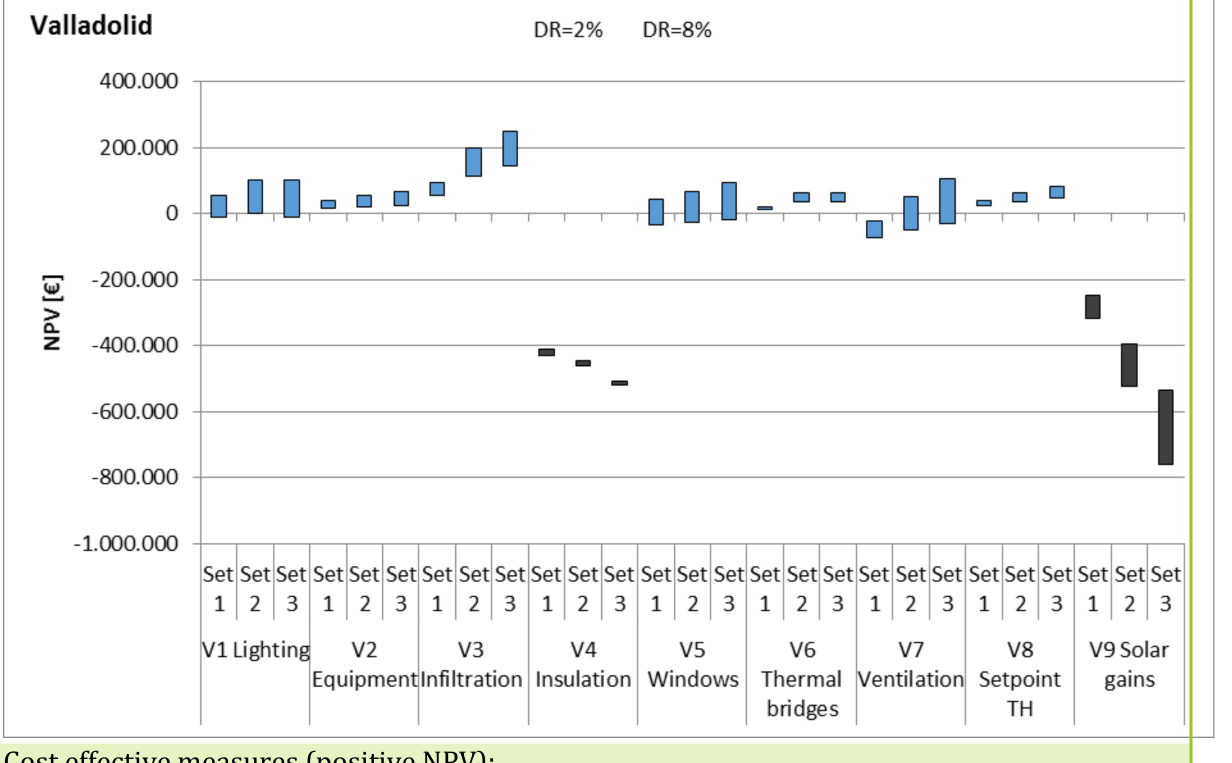
Table 20. Payback period (PBP) of all combinations of variables and sets. Values are expressed in years. Zeros indicate no investment costs, while no result indicates no positive payback period.

PBP (a)		Valladolid	Trondheim	Silute	Klapeida	London	Genova	Catania	Vienna	Sint-Niklaas	Antwerp
V1 Lighting	Set 1	6.0	7.6	2.1	2.9	2.5	1.9	2.2	5.9	3.3	4.5
	Set 2	4.8	6.1	1.7	2.4	2.0	1.5	1.8	4.7	2.7	3.7
	Set 3	5.6	7.2	1.9	2.8	2.3	1.8	2.1	5.5	3.2	4.4
V2 Equipment	Set 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Set 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Set 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
V3 Infiltration	Set 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Set 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Set 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
V4 Insulation	Set 1										49.3
	Set 2										68.4
	Set 3										
V5 Windows	Set 1	10.1									
	Set 2	8.9							6.2		
	Set 3	8.1		115.8	39.5				3.0		
V6 Thermal bridges	Set 1	0.0	0.0	0.0	0.0	0.0					
	Set 2	0.0	0.0	0.0	0.0	0.0					
	Set 3	0.0	0.0	0.0	0.0	0.0					
V7 Ventilation	Set 1	16.1		13.6	7.3	21.4	30.9	8.8	26.6	22.8	34.8
	Set 2	8.5	26.4	7.3	4.0	11.7	17.5	5.5	12.5	10.7	15.7
	Set 3	6.5	18.3	5.6	3.1	8.6	13.6	4.2	9.3	8.1	11.8
V8 Setpoint TH	Set 1	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0
	Set 2	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0
	Set 3	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0
V9 Solar gains	Set 1										
	Set 2								9.8		
	Set 3								2.9		

In the following results for primary energy (PE) savings and net present value (NPV) for all reference buildings is given. In addition, a sensitivity analysis of the discount rate (D_R) was performed using DR bewteen 2% and 8%. The results are shown in bars that indicate the range.

Valladolid

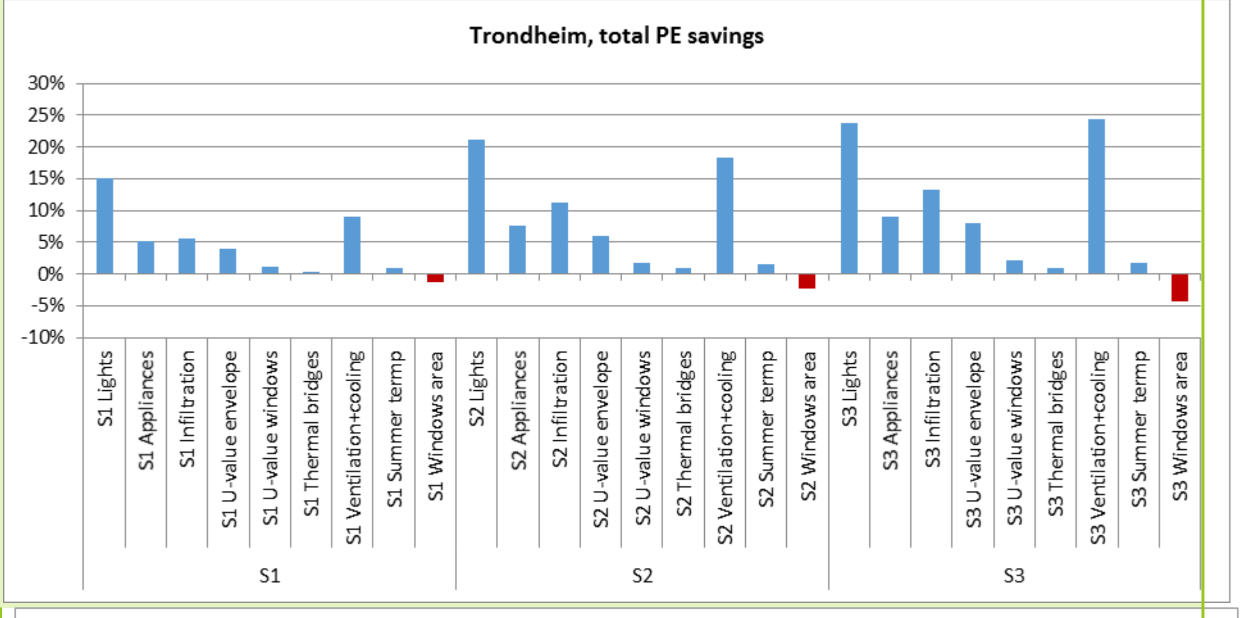


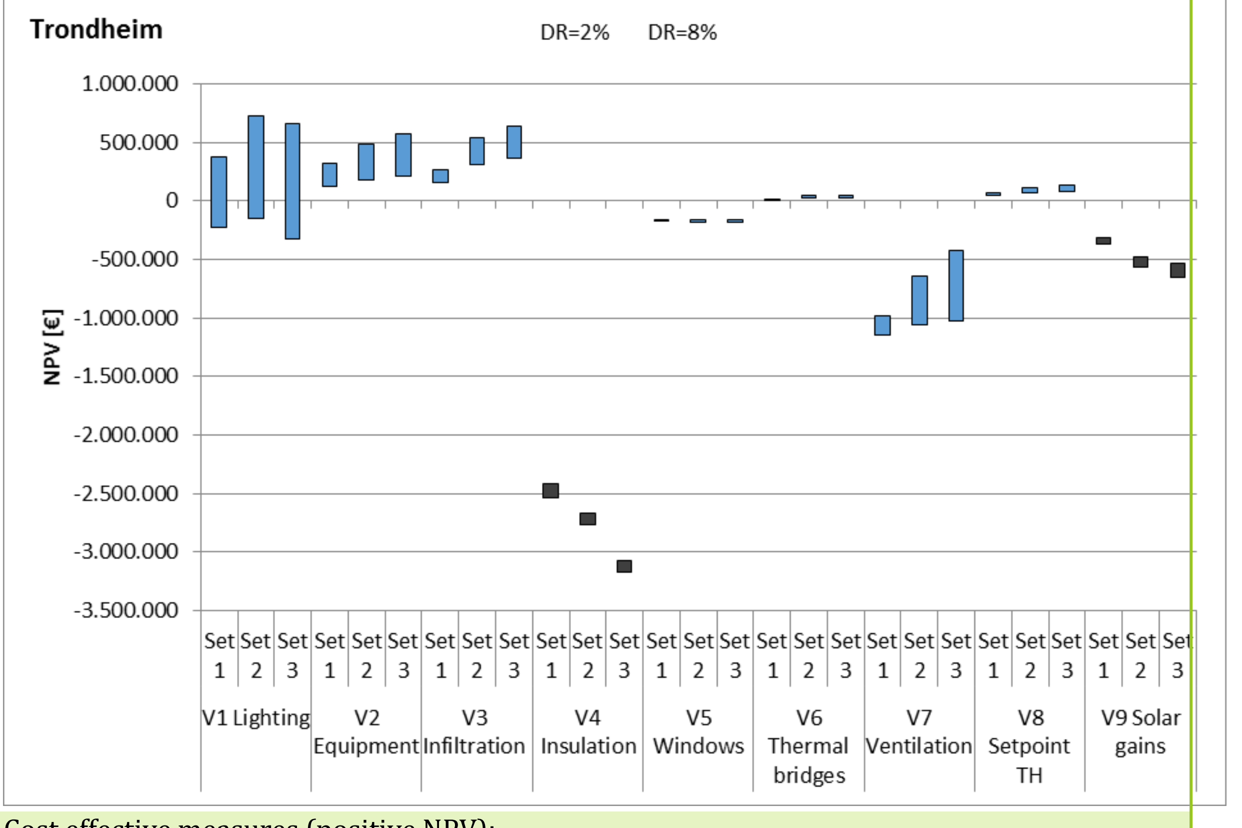


Cost effective measures (positive NPV):

Lighting (V1, all sets with high interest rate), Equipment (V2, all sets), Infiltration (V3, all sets), Thermal bridges (V6, all sets), setpoint temperature (V8, all sets)

Trondheim

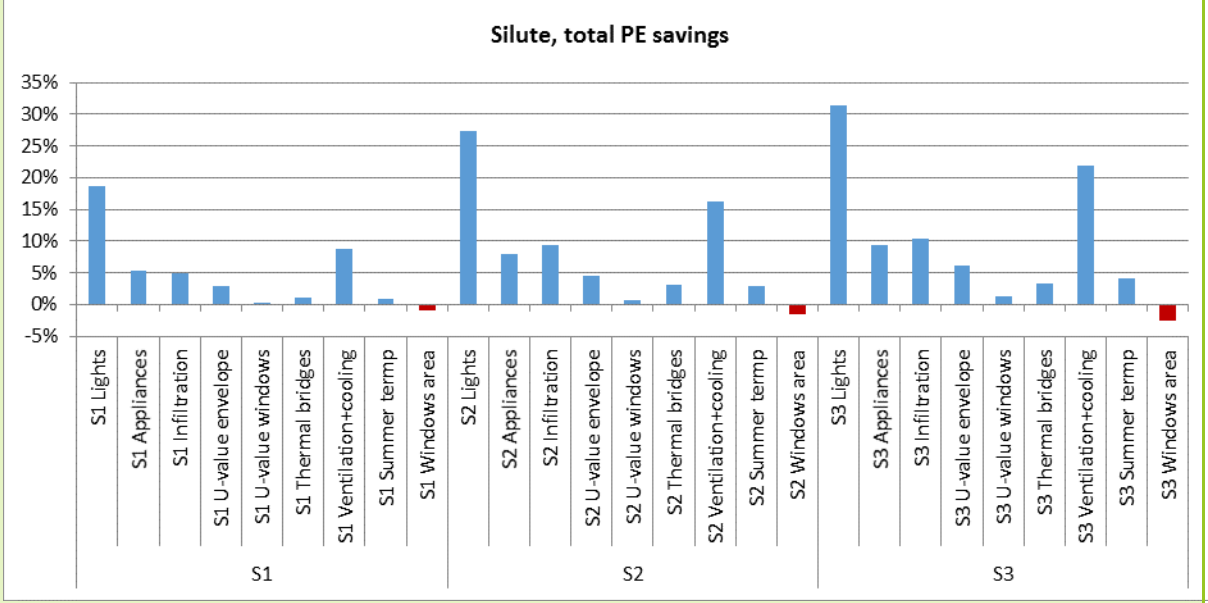


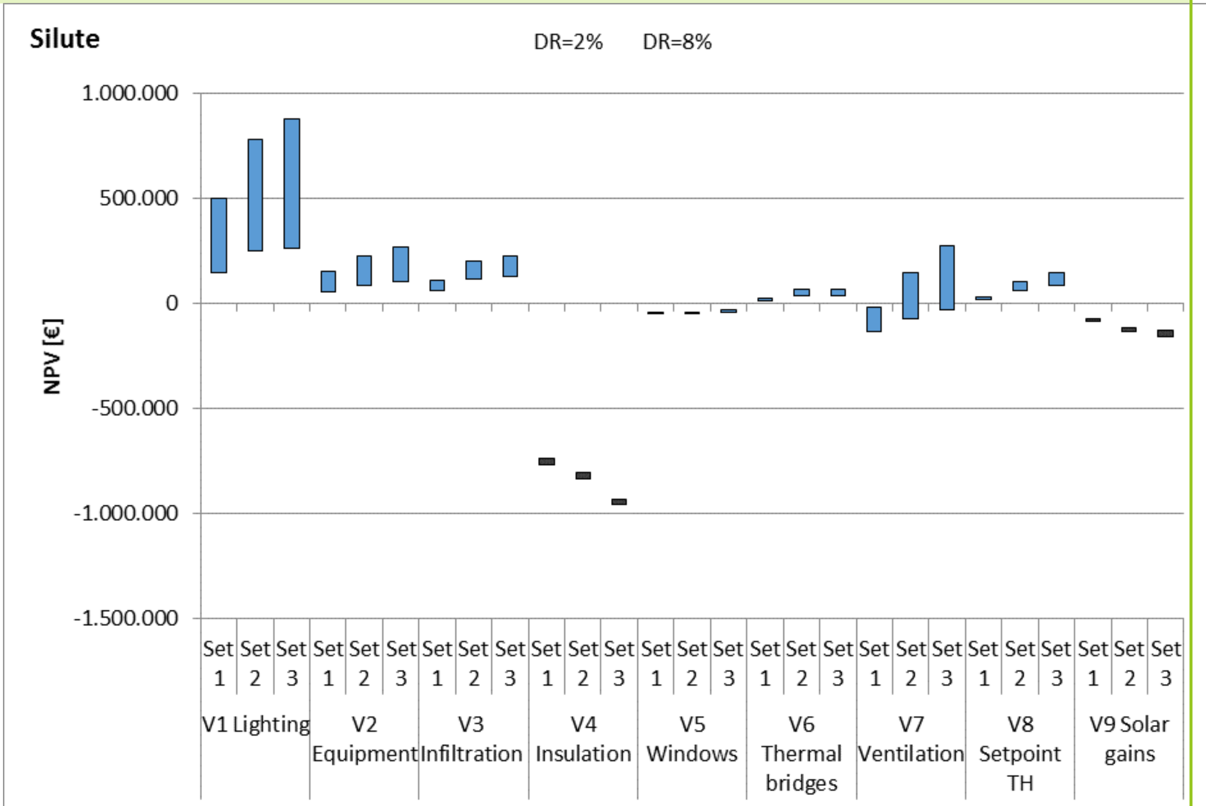


Cost effective measures (positive NPV):

Lighting (V1, all sets with high interest rate), Equipment (V2, all sets), Infiltration (V3, all sets), Thermal bridges (V6, all sets), setpoint temperature (V8, all sets)

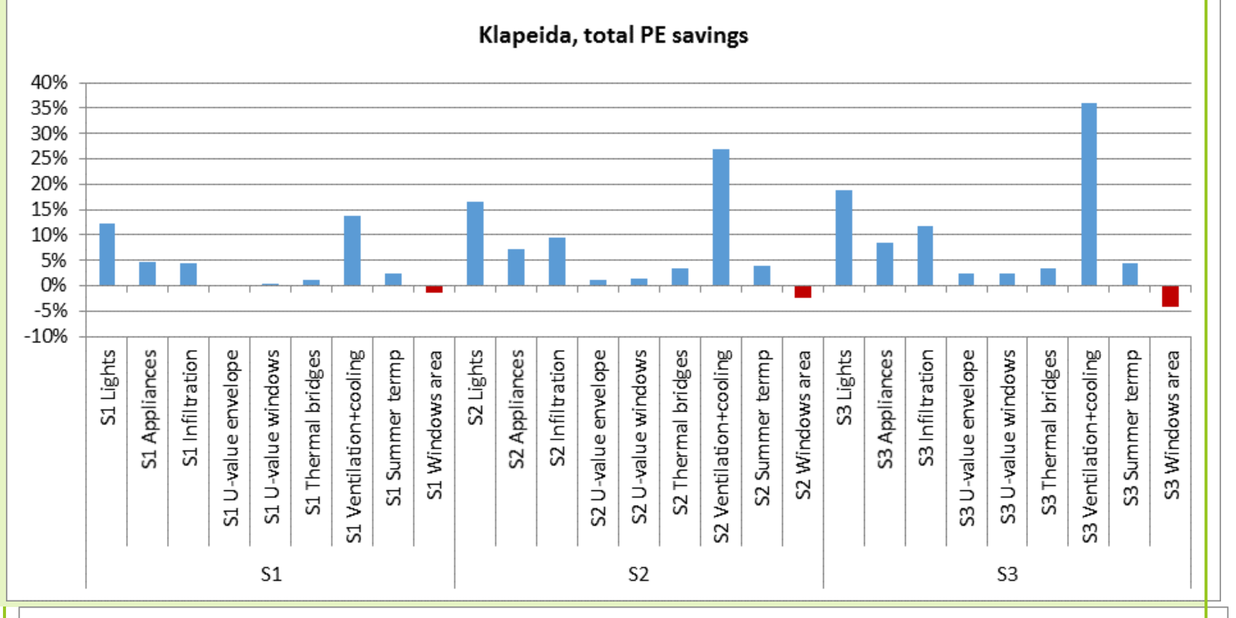
Silute

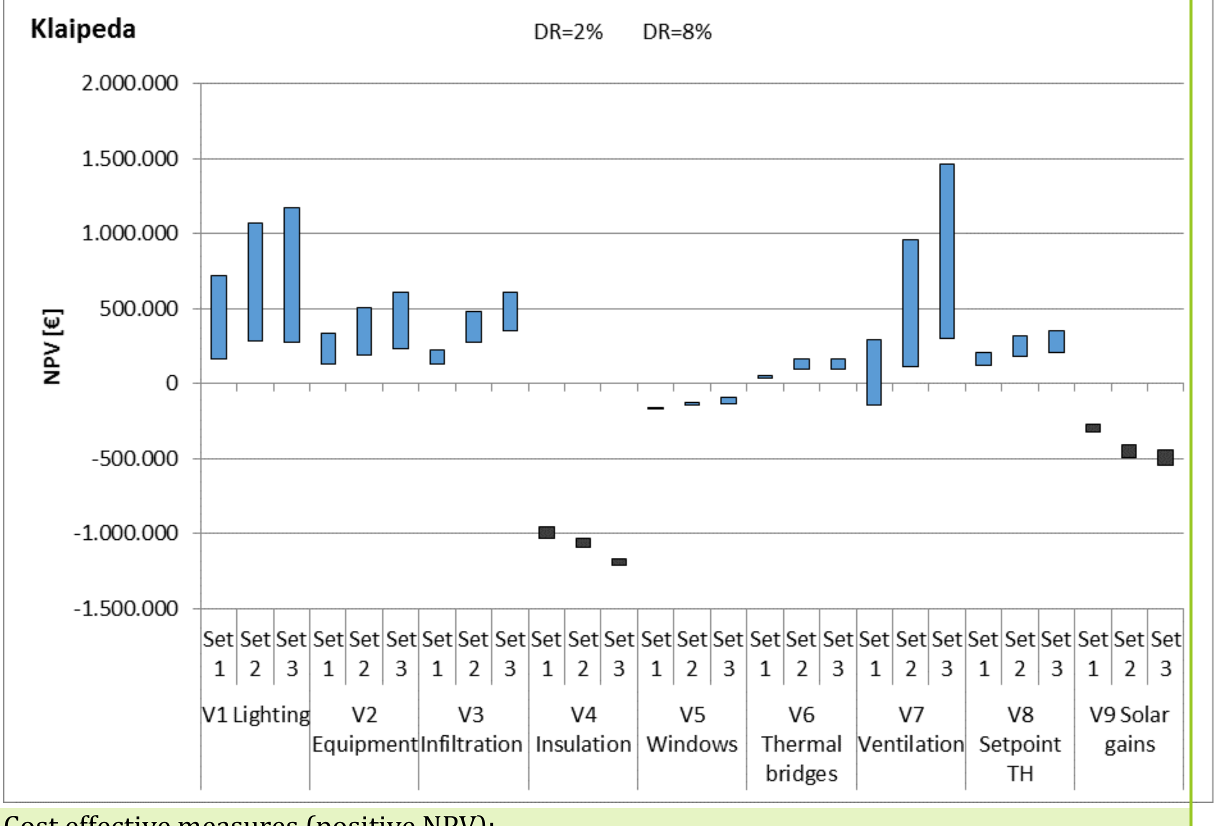




Cost effective measures (positive NPV):
Lighting (V1, all sets), Equipment (V2, all sets), Infiltration (V3, all sets), Thermal bridges (V6, all sets), Ventilation (V7, set 2 and set 3 with high interest rate), setpoint temperature (V8, all sets)

Klapeida

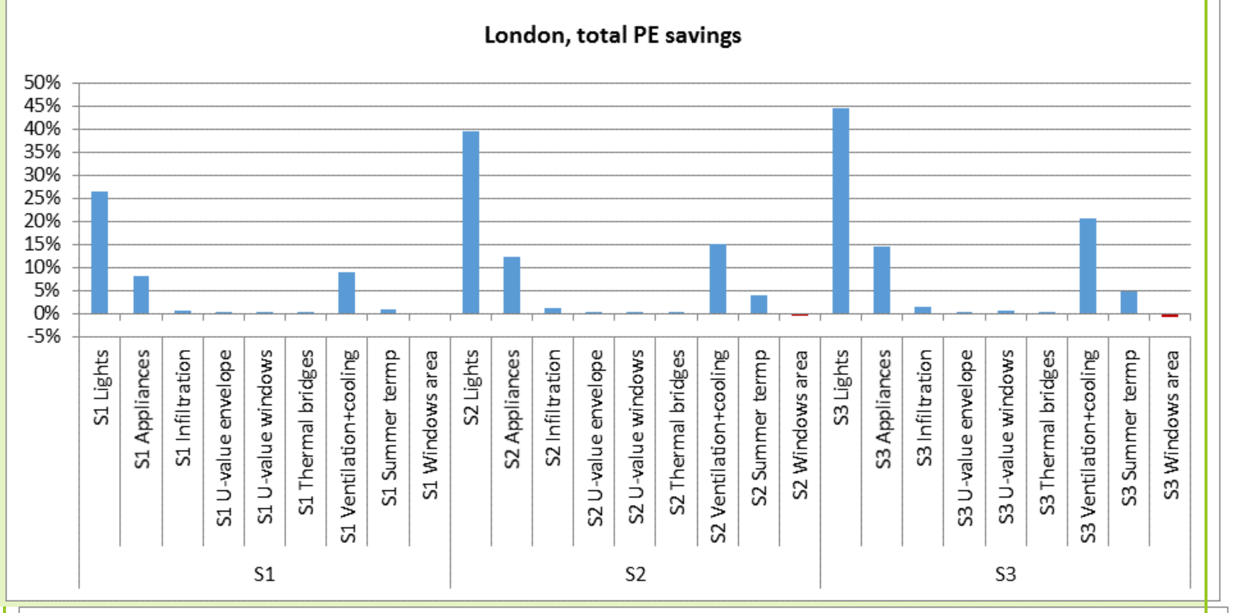


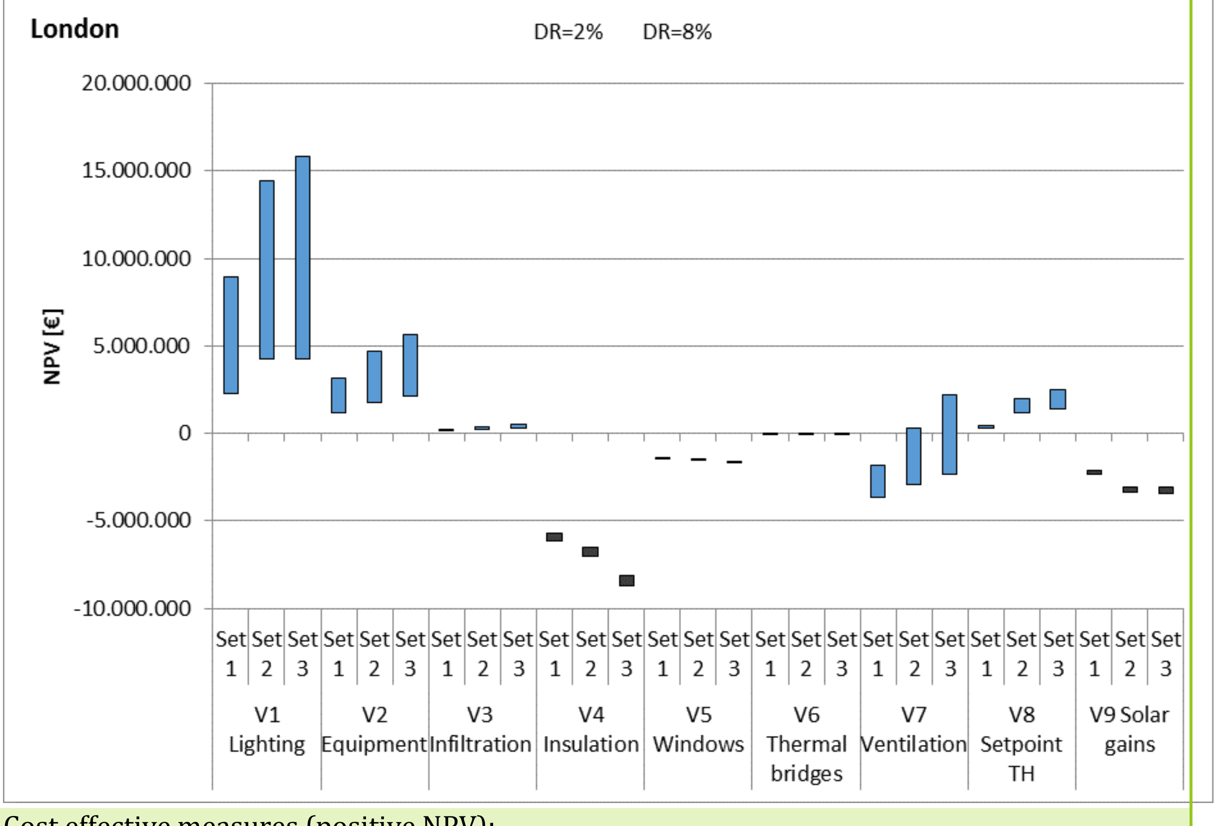


Cost effective measures (positive NPV):

Lighting (V1, all sets), Equipment (V2, all sets), Infiltration (V3, all sets), Thermal bridges (V6, all sets), Ventilation (V7, set 1 with high interest rate, set and set 3), setpoint temperature (V8, all sets)

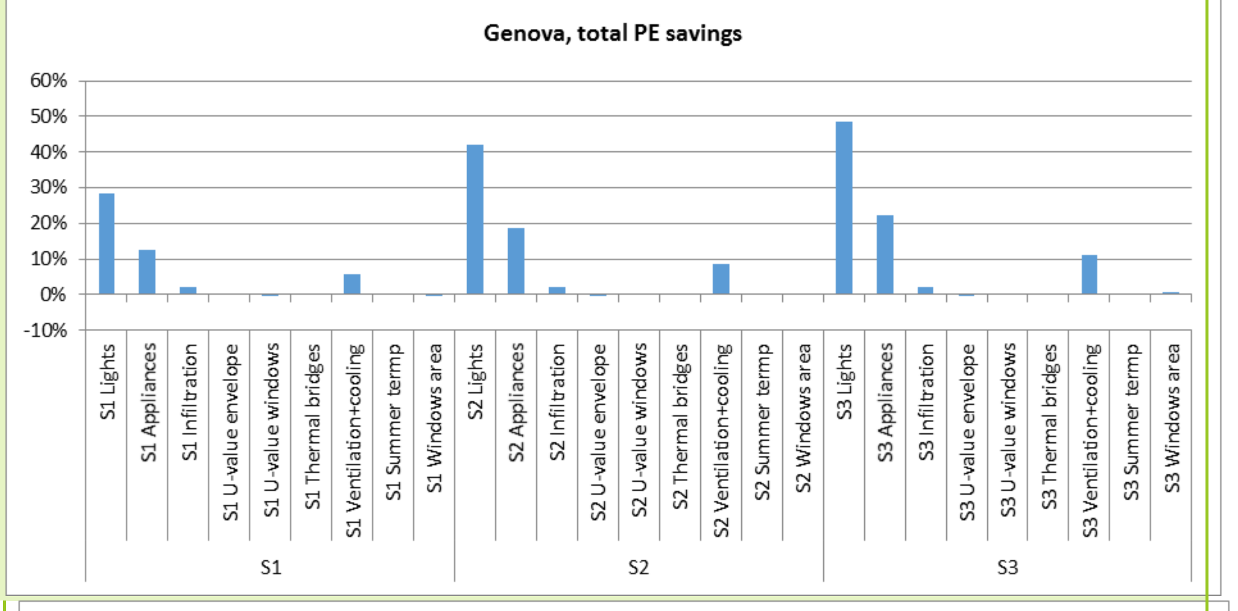
London

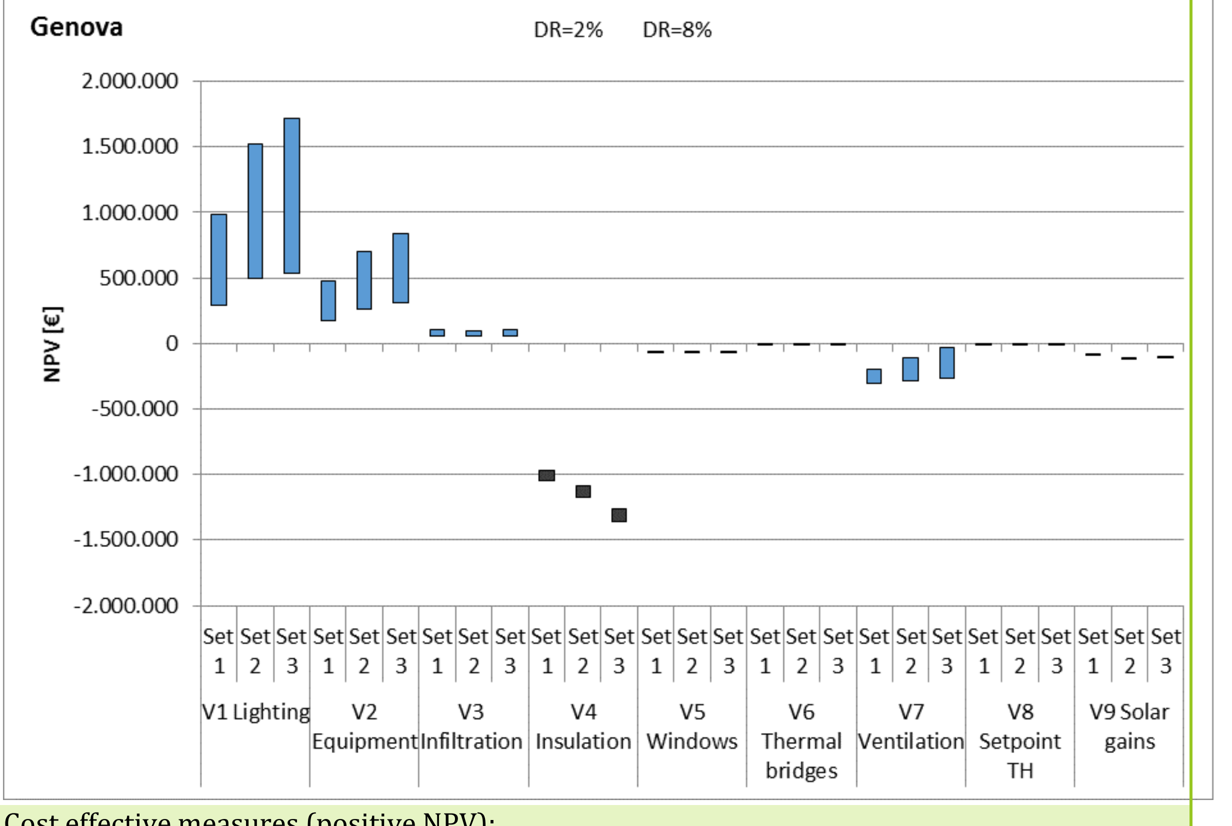




Cost effective measures (positive NPV):
Lighting (V1, all sets), Equipment (V2, all sets), Infiltration (V3, all sets), Ventilation (V7, set 2 and set 3; with high interest rate), set point temperature (V8, all sets)

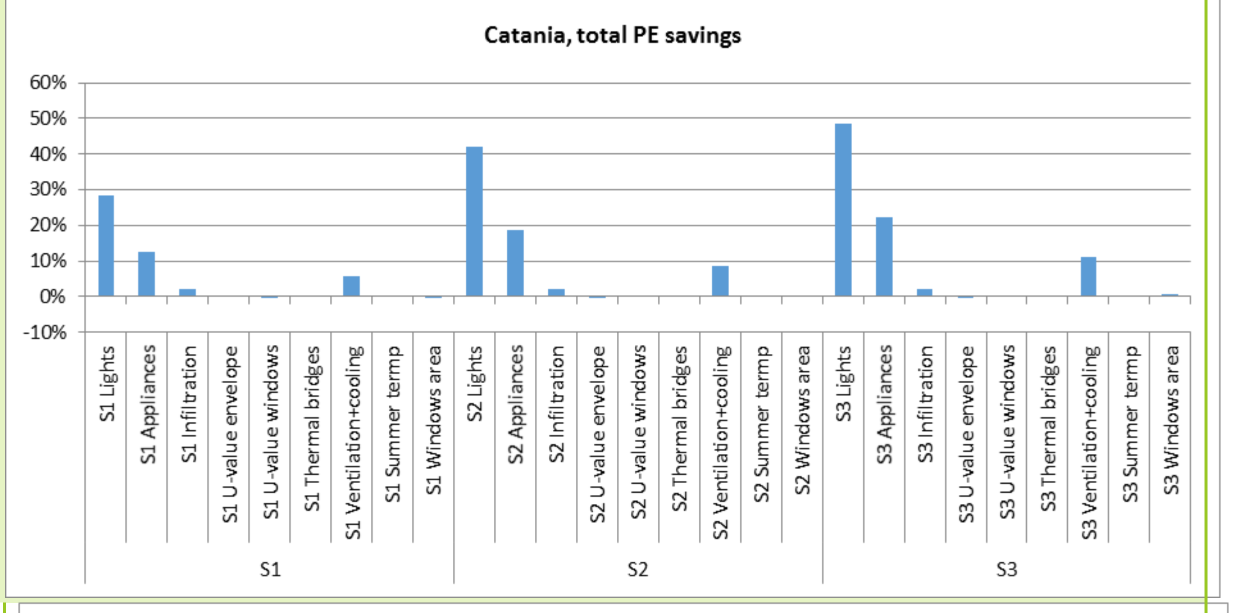
Genova

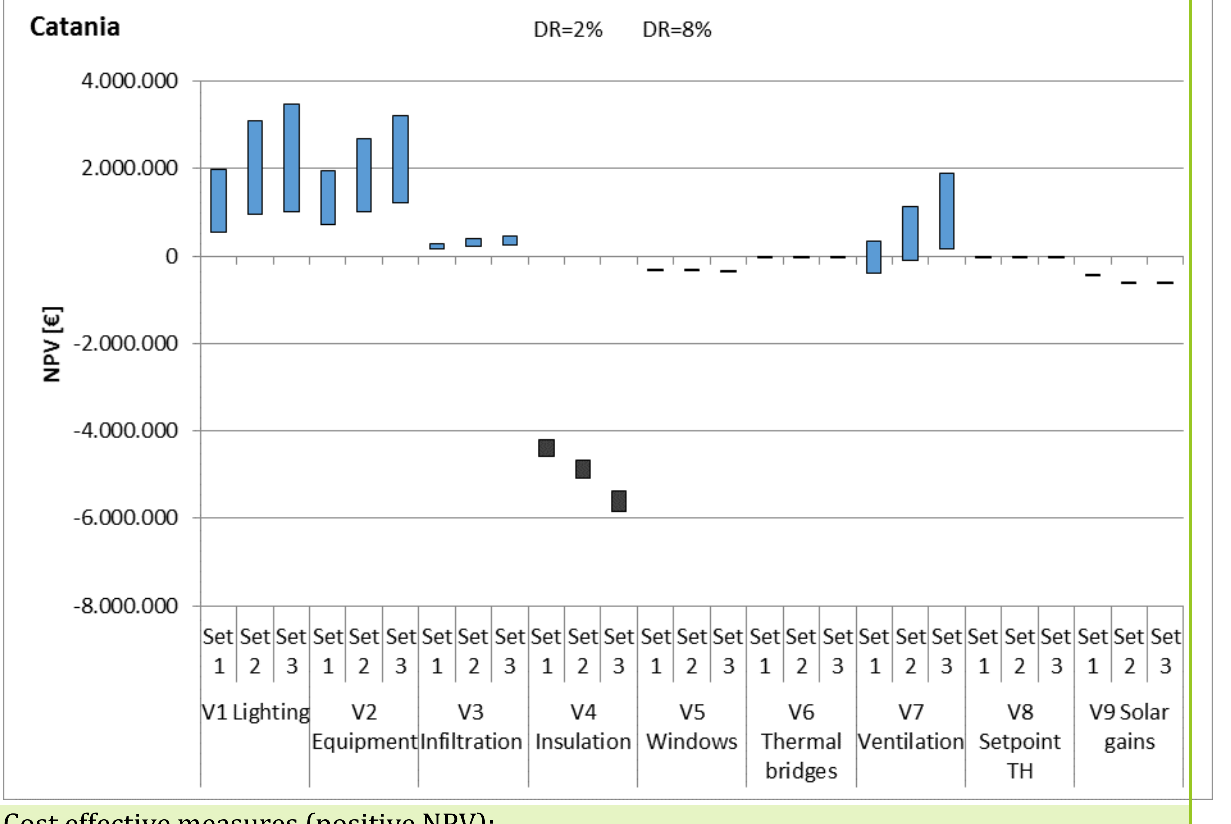




Cost effective measures (positive NPV):
Lighting (V1, all sets), Equipment (V2, all sets), Infiltration (V3, all sets)

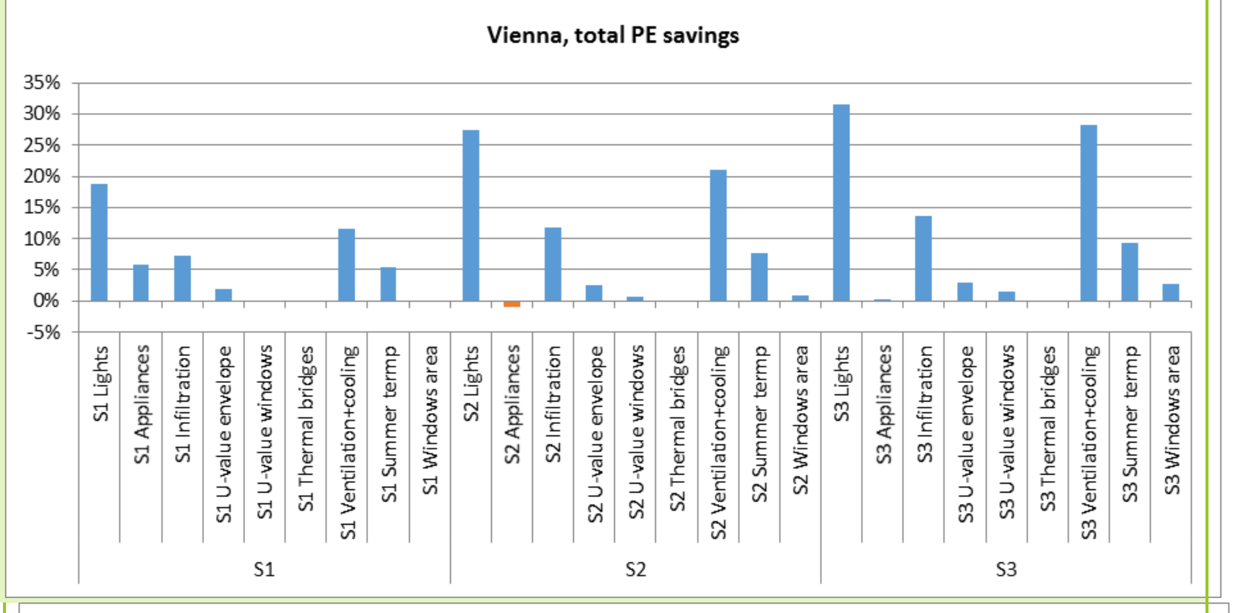
Catania

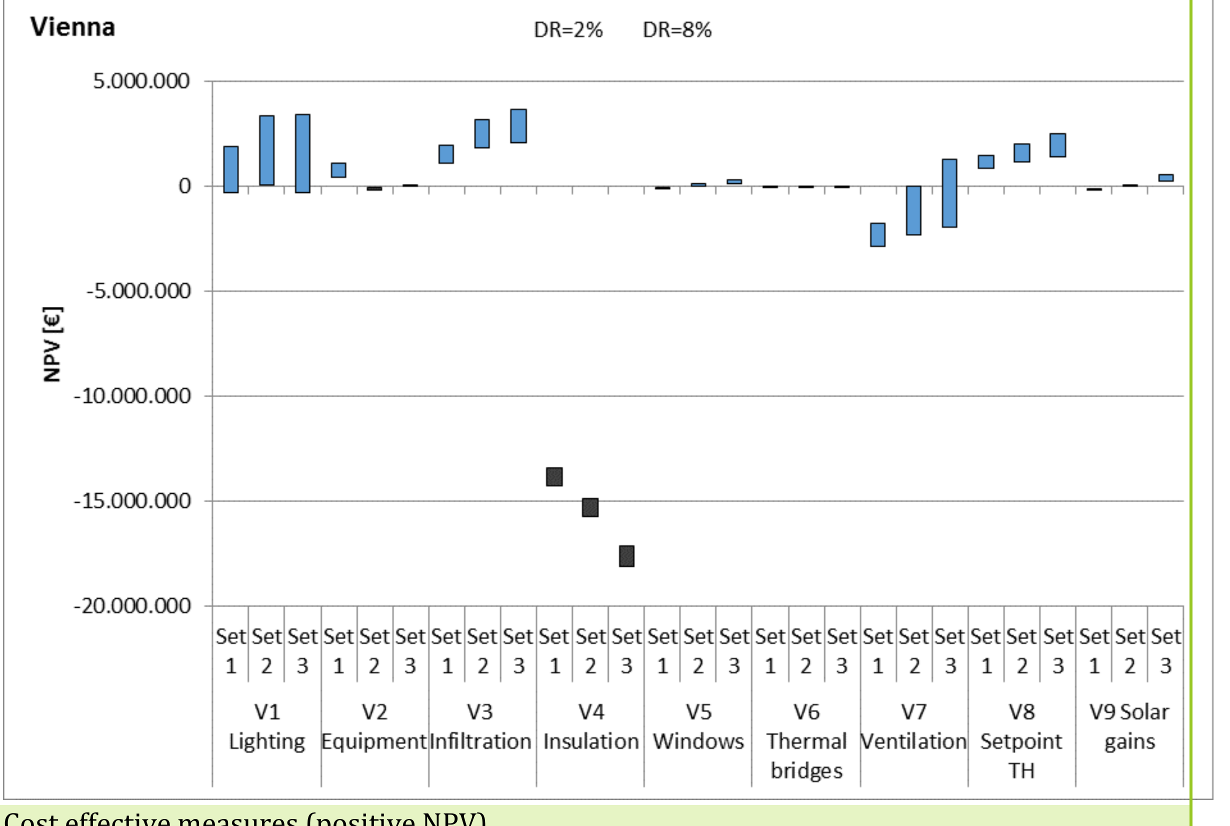




Cost effective measures (positive NPV):
Lighting (V1, all sets), Equipment (V2, all sets), Infiltration (V3, all sets), Ventilation (V7, set 1 and set 2; with high interest rate, set 3)

Vienna

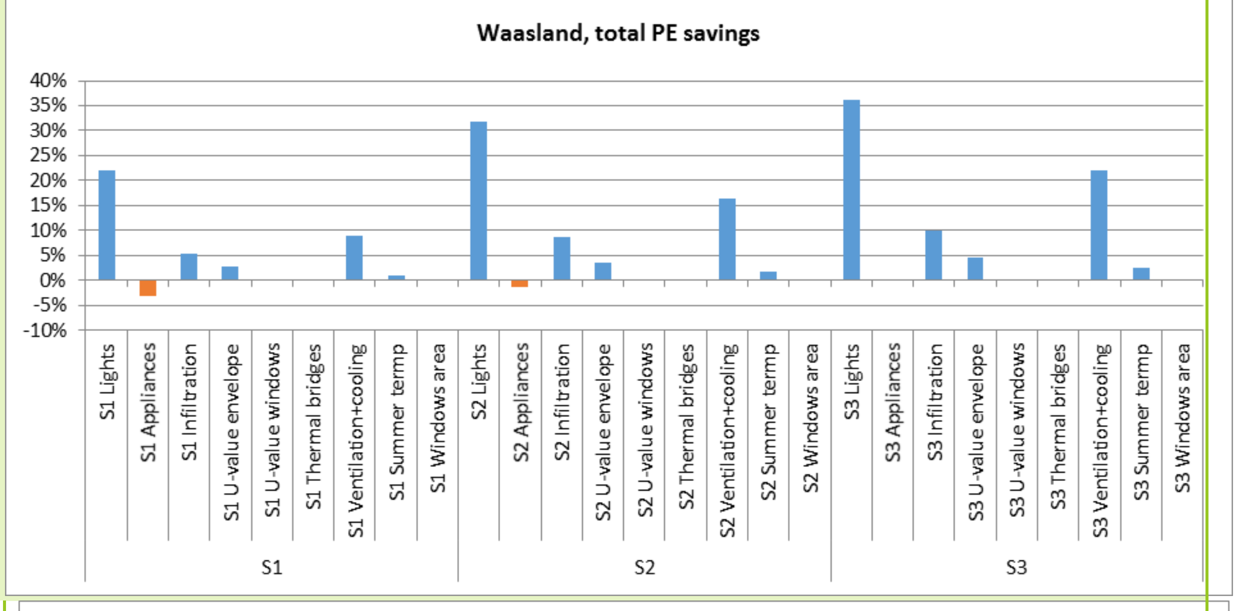


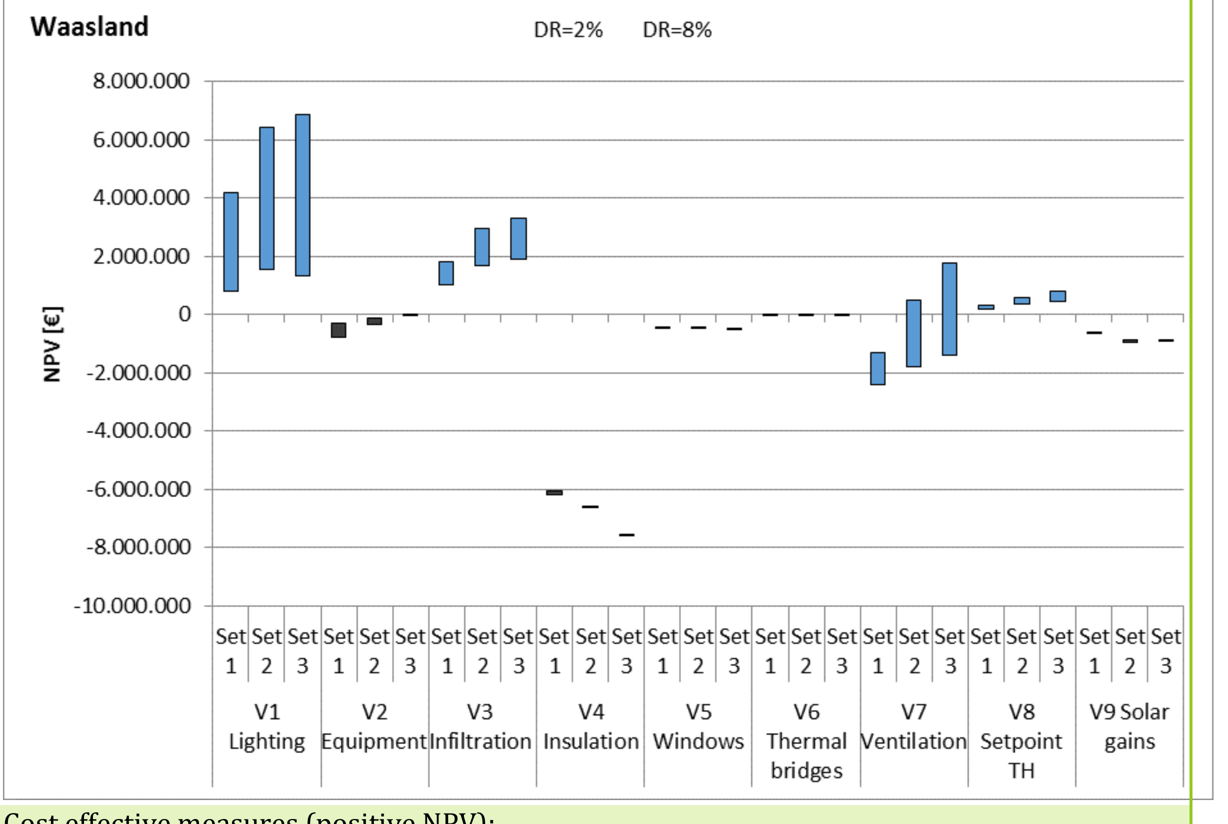


Cost effective measures (positive NPV)

Lighting (V1, all sets), Infiltration (V3, all sets), Windows (V5, set 3), Ventilation (V7, set 3; high interest rate), Window area (V9, set 3)

Waasland

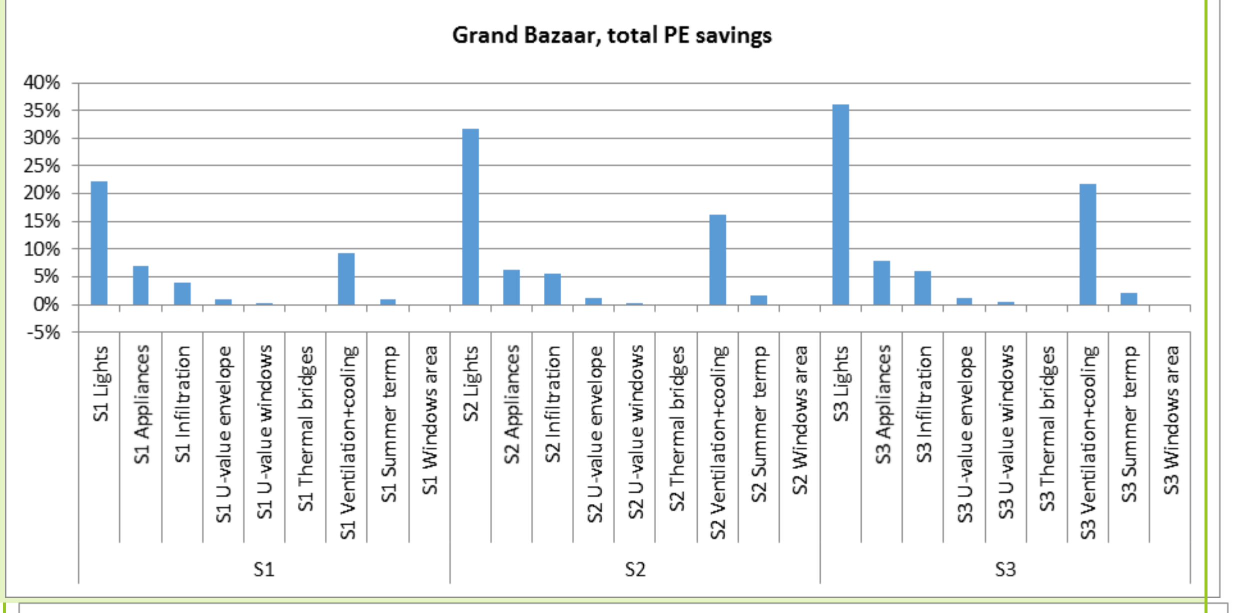


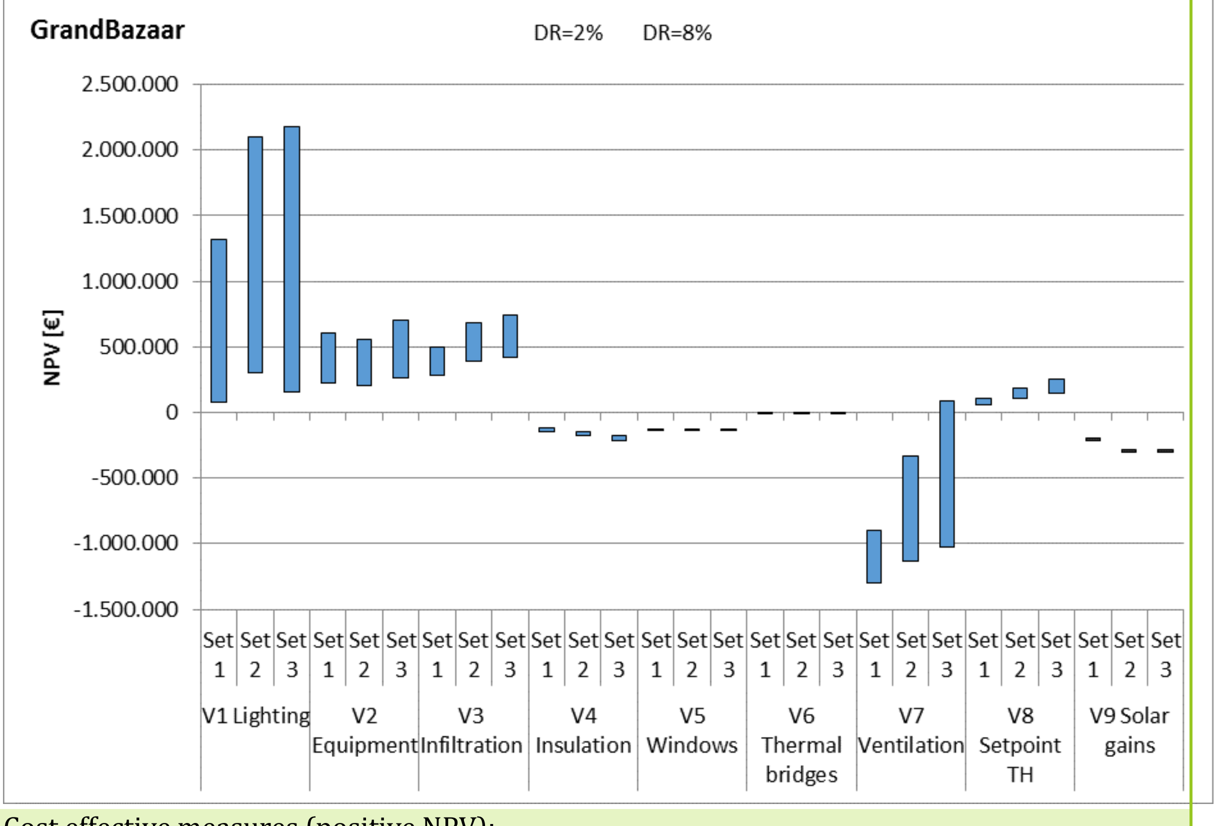


Cost effective measures (positive NPV):

Lighting (V1, all sets), Infiltration (V3, all sets), Ventilation (V7, set 2 and set 3; with high interest rate), setpoint temperature (V8, all sets)

Grand Bazaar

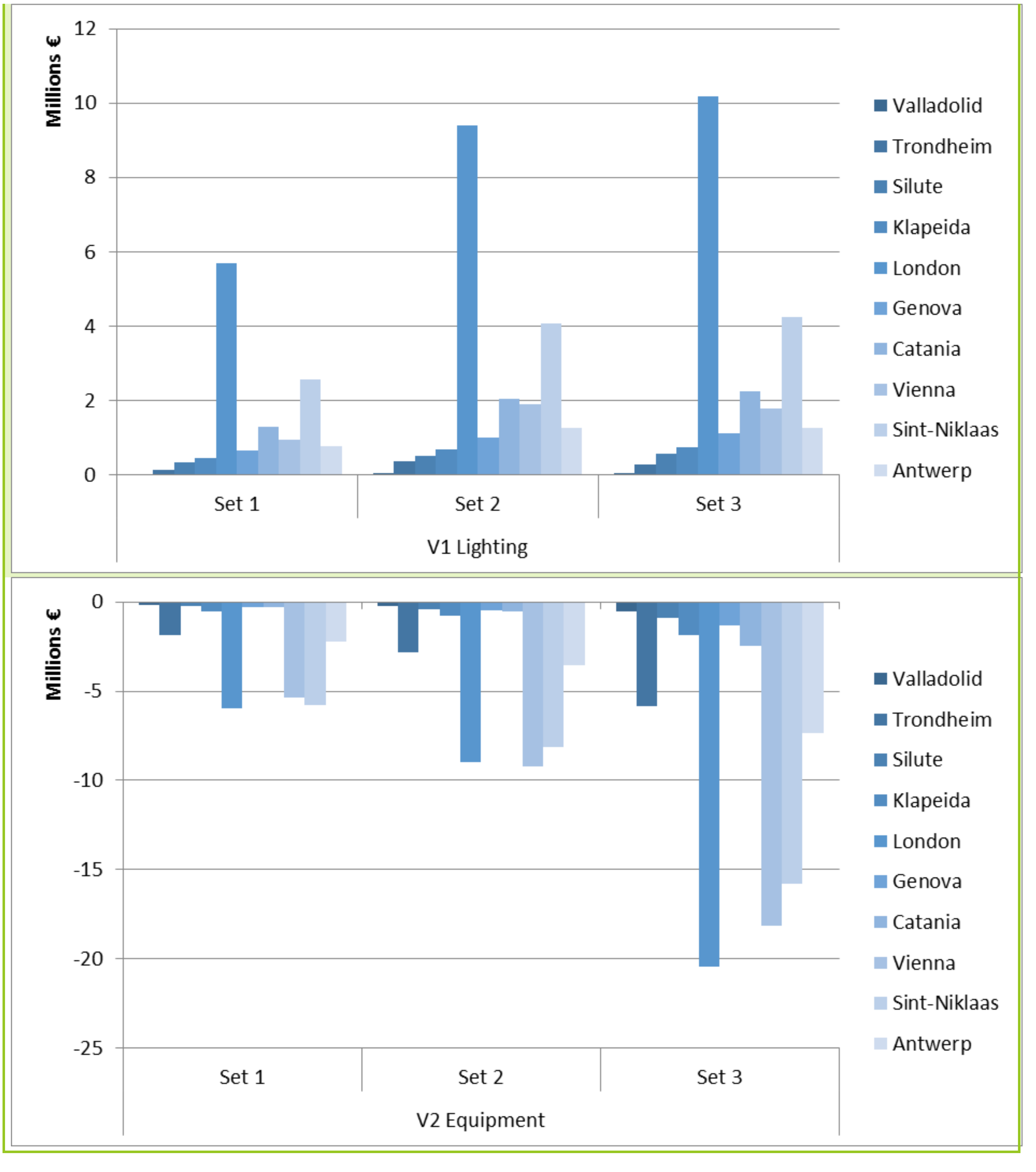


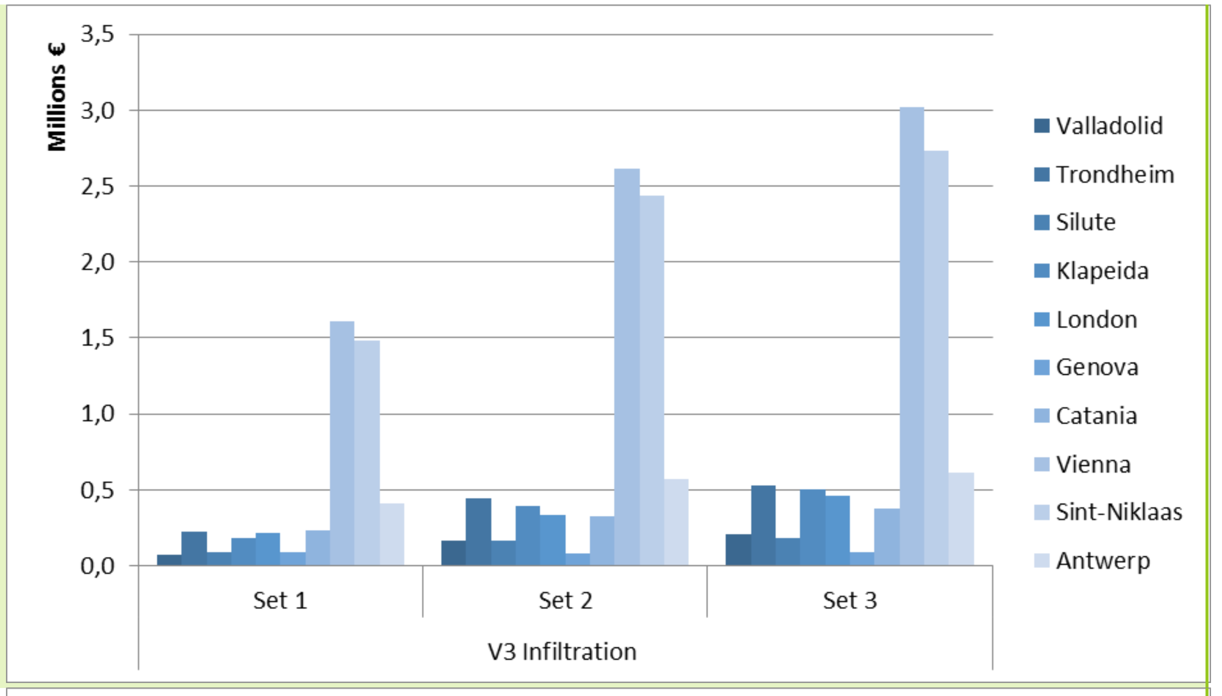


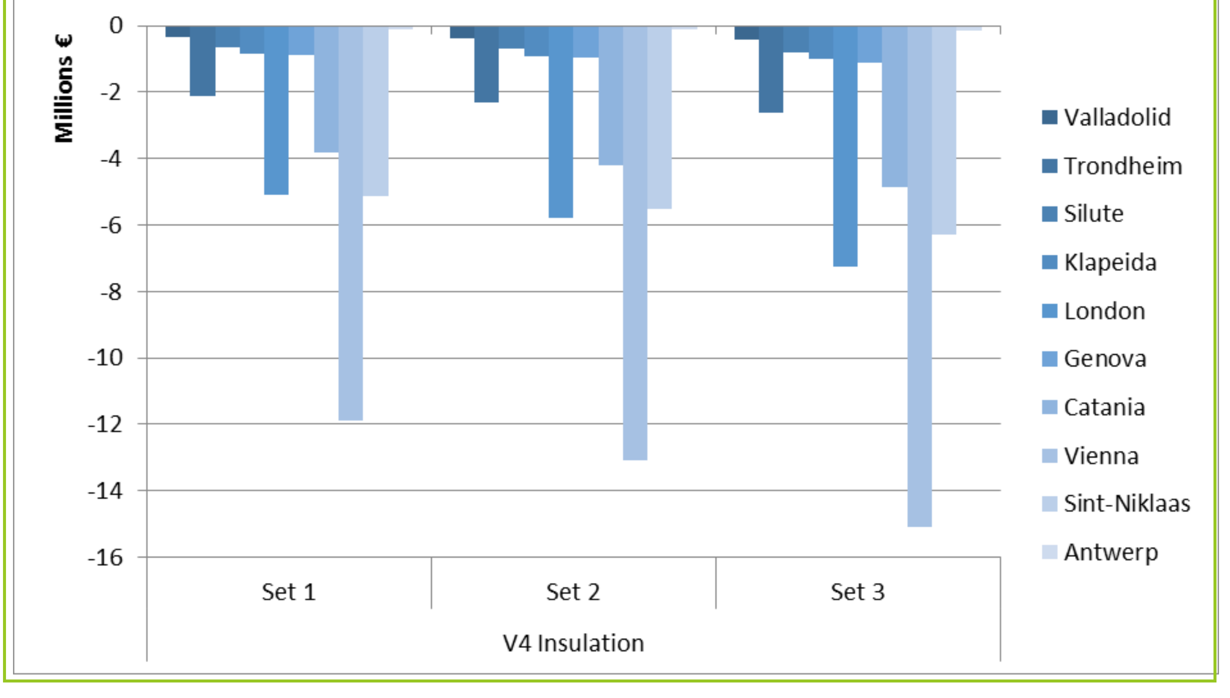
Cost effective measures (positive NPV):

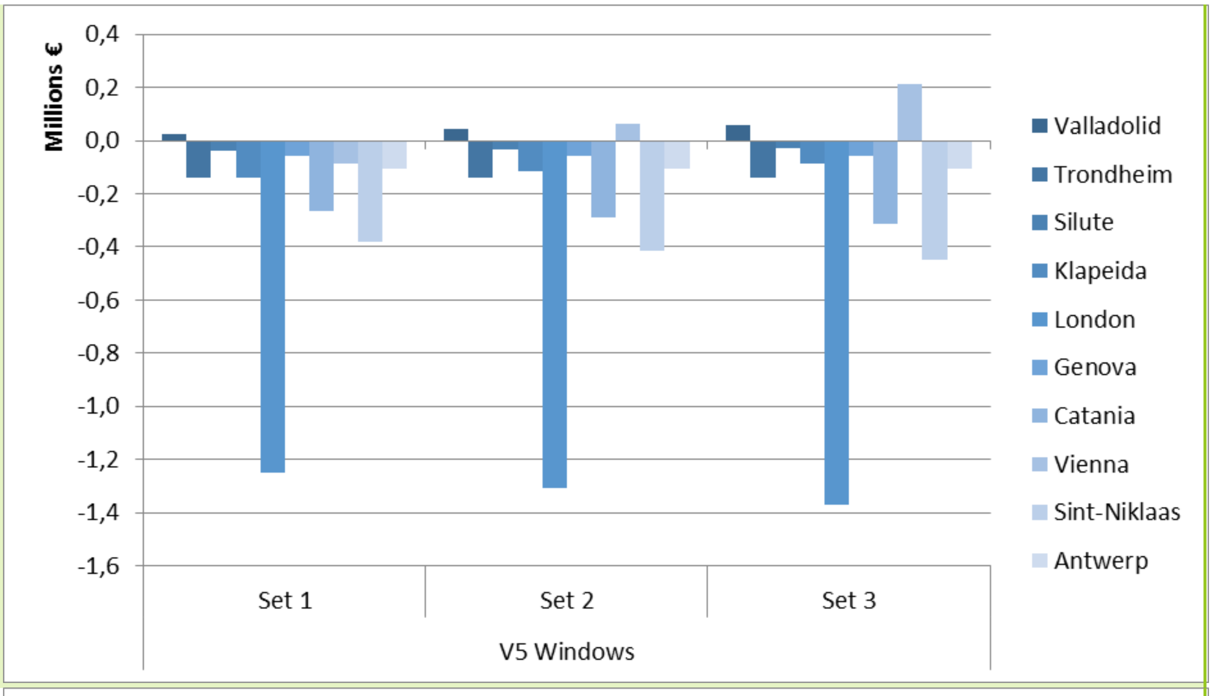
Lighting (V1, all sets), Equipment (V2, all sets), Infiltration (V3, all sets), Ventilation (V7, set 3; with high interest rate),setpoint temperature (V8, all sets)

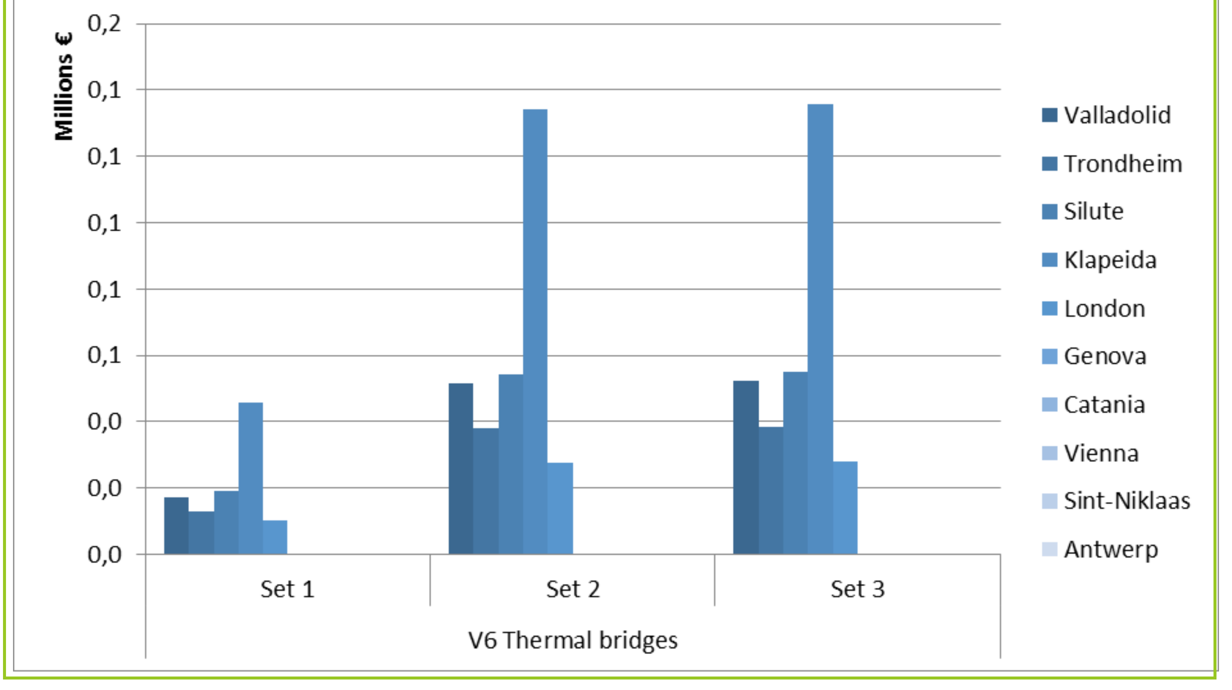
NPV for different variables

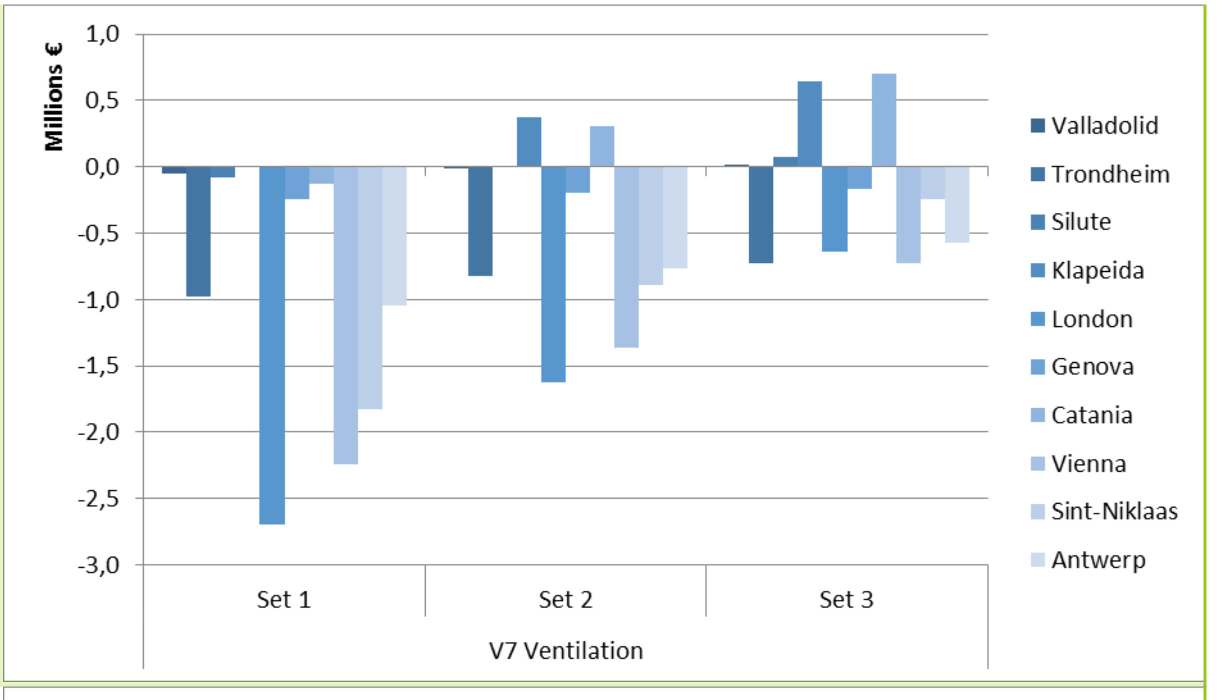

Millions €
12
10
8
6
4
2
0
Set 1
Set 2
Set 3
V1 Lighting
Valladolid
Trondheim
Silute
Klapeida
London
Genova
Catania
Vienna
Sint-Niklaas
Antwerp
Millions €
0
-5
-10
-15
-20
-25
Set 1
Set 2
Set 3
V2 Equipment
Valladolid
Trondheim
Silute
Klapeida
London
Genova
Catania
Vienna
Sint-Niklaas
Antwerp

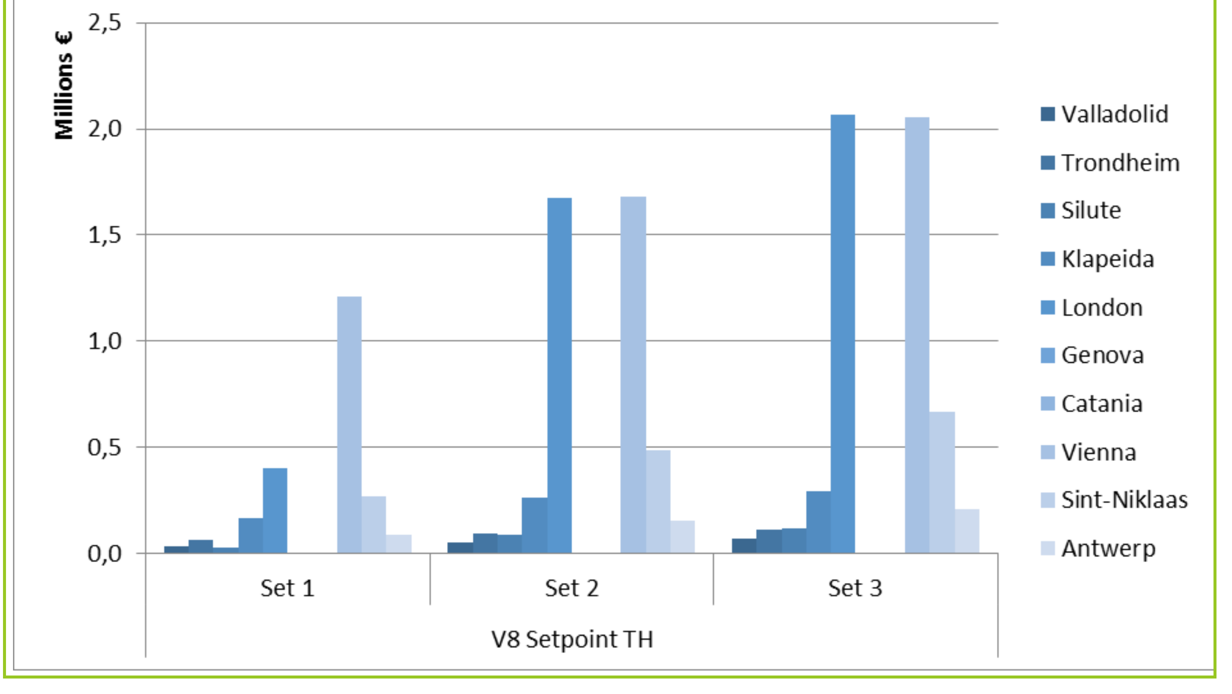

Millions €
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
Set 1
Set 2
Set 3
V3 Infiltration
Valladolid
Trondheim
Silute
Klapeida
London
Genova
Catania
Vienna
Sint-Niklaas
Antwerp

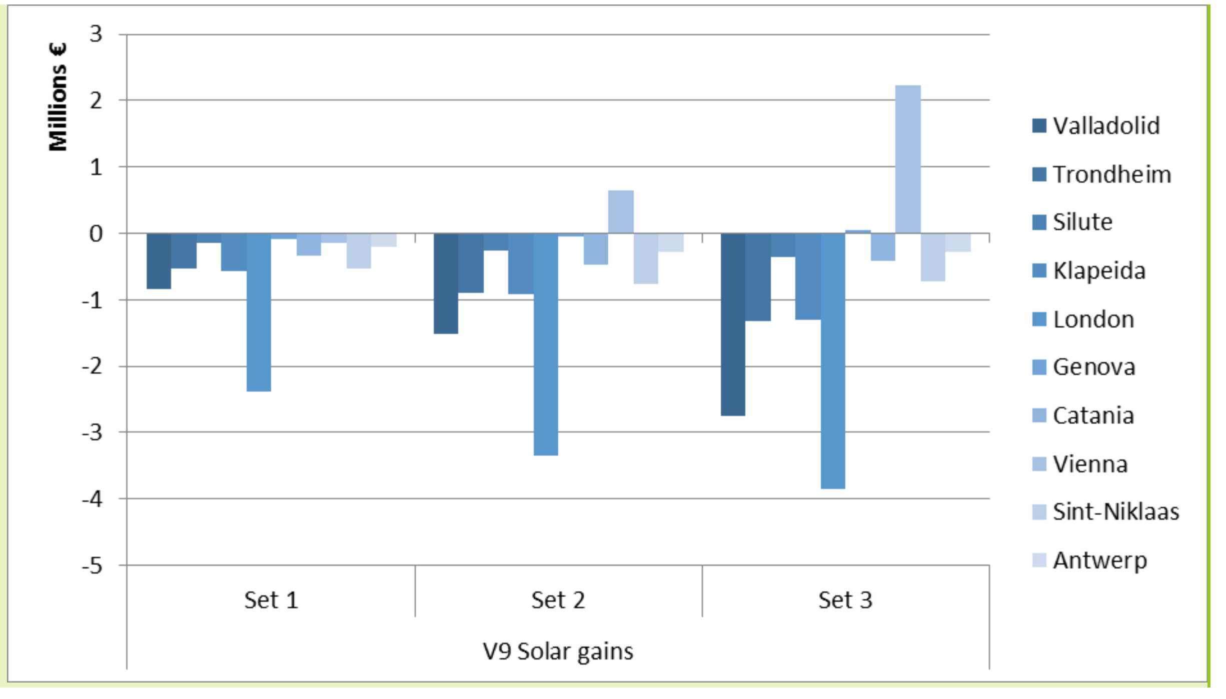

Millions €
0
-2
-4
-6
-8
-10
-12
-14
-16
Set 1
Set 2
Set 3
V4 Insulation
Valladolid
Trondheim
Silute
Klapeida
London
Genova
Catania
Vienna
Sint-Niklaas
Antwerp


Millions €
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
-1,0
-1,2
-1,4
-1,6
Set 1
Set 2
Set 3
V5 Windows
Valladolid
Trondheim
Silute
Klapeida
London
Genova
Catania
Vienna
Sint-Niklaas
Antwerp


Millions €
0,2
0,1
0,1
0,1
0,1
0,1
0,0
0,0
0,0
Set 1
Set 2
Set 3
V6 Thermal bridges
Valladolid
Trondheim
Silute
Klapeida
London
Genova
Catania
Vienna
Sint-Niklaas
Antwerp


Millions €
1,0
0,5
0,0
-0,5
-1,0
-1,5
-2,0
-2,5
-3,0
Set 1
Set 2
Set 3
V7 Ventilation
Valladolid
Trondheim
Silute
Klapeida
London
Genova
Catania
Vienna
Sint-Niklaas
Antwerp


Millions €
2,5
2,0
1,5
1,0
0,5
0,0
Set 1
Set 2
Set 3
V8 Setpoint TH
Valladolid
Trondheim
Silute
Klapeida
London
Genova
Catania
Vienna
Sint-Niklaas
Antwerp


Millions €
3
2
1
0
-1
-2
-3
-4
-5
Set 1
Set 2
Set 3
V9 Solar gains
Valladolid
Trondheim
Silute
Klapeida
London
Genova
Catania
Vienna
Sint-Niklaas
Antwerp