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Cost Optimal Retrofitting Of Shopping Malls In Europe

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Abstract

The aim of this study was to assess the possible retrofitting actions with a cost-optimal vision for shopping mall managers. Cost optimization was analysed with state-of-the-art evaluation tools, taking initial, operational and maintenance into account. Costs of retrofitting measures were collected and with energy saving measures correlated.

For each building the energy demand and primary energy (PE) savings for a wide number of packages representing "current practices", "best practices" and "state of art solutions" were calculated. From the results for all reference buildings the best performing parameters with respect to primary energy savings and net present values were identified.

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Keywords: energy retrofitting; cost optimal; performance simulation

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1. Introduction

In the re-cast 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 [1]. 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.

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With this report a clear explanations and suggestions regarding the methodology and can distribute knowledge and information was provided. The revised Energy Performance in Buildings Directive (EPBD) 2008/0223 calls for a calculation of the cost optimal energy standards and renovation standards [2]. Cost optimal calculations can often be too short-sighted to deal with the urgent need for societal answers to the climate change challenge 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 the fight on climate change [3]. Life-cycle costing based on net present values 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 as the benefits 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.

2. Objectives

The aim was to assess the possible retrofitting actions with a cost-optimal vision for shopping mall managers. Cost optimization was analysed with state-of-the-art evaluation tools, taking initial, operational and maintenance into account. It is referred to the “cost optimal methodology” defined in 2012 within the EU directive 2010/31 and relative applied regulation 244/2012, where the term “global cost” is used to include all costs in the economic life cycle [2]. A module for parametric analysis was developed and used together with a simplified energy tool which is able to identify most important parameter for energy, comfort and economic shopping mall performances [4]. Costs of retrofitting measures were collected and with energy saving measures correlated. Cost optimal measure curves were developed.

3. Methodology

To perform these kinds of calculations, it was necessary to identify the market segments and the segmentation of the current energy performance requirements (different requirements for different building types). Then a sufficient number of reference buildings that are characterised by their functionality, characteristics and regional conditions, including indoor and outdoor climate conditions was define and 10 buildings around Europe were selected. For space limitation reasons only five buildings are presented in this paper. Specific packages of energy saving- energy efficiency- and energy supply measures were assessed. For that 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” were calculated. Then the corresponding energy-related investment costs, energy costs and other running costs of relevant packages applied to the selected reference buildings were assessed. From the cost curve of packages for a reference building the best performing package with respect to delivered energy, primary energy and CO2-emissions and the optimum energy performance requirement for a weighted average of all reference types per market segment were identified.

In order to propose cost optimal retrofitting packages, a thorough analysis of single sub-package variables is necessary. This is helpful for assessing which are the variables that have the most influence in the energy savings of shopping malls. 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 are changed to reflect the possible improvement in the performance levels given by the application of newer building codes. These performance levels are named sets (from set 1 to set 3) and are chosen in order to have grades of improvements up to a level that is typical for passive-house constructions (set 3). A parametric analysis is then carried out to obtain delivered and primary energy values for each of the single variables changes (sets). Finally, a cost analysis of each single variable is performed to evaluate the cost effectiveness of each solution. 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 have been chosen among those which have expected influence on the energy performance of a shopping mall, 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 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 ventilation system (such as heat recovery efficiency and efficiency of fans)
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)

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 [4].

Due to the limitations of 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) of the shopping mall 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. 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. In addition, buildings with complex geometry (such as curved shapes and abutting volumes) were described by a simplified shape with the closest volume. As detailed drawings of the facades of the shopping malls were often not accessible, the geometrical description of the fenestration areas was assumed from pictures. 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, as 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. Due to the low ration between the building surface and volume for a typical shopping mall, a poor description of the U-values and G-values of the thermal envelope is 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 of the shopping malls, as the indoor comfort temperature is achieved through air-based systems.

As no information on the type of systems for the ventilation, the heating, and the cooling units, it was decided to use the PHPP default ventilation system, an air-air HP with a COP of 2.5, and an air cooling unit with a COP of 2.5.

Internal heat gains from people were set to 10 W/m2, according to the NS 3701:2012. Ventilation rates for the different uses in the shopping malls are set according to the EN 15251:2007. The value for the DHW use in the base case is set according to the EN15316-3-1:2007.

4. Results

Each variable represent a group of sub-parameters chosen to reflect the different areas of use of the shopping malls (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. The values of the base case are shown in **Error! Reference source not found.** and are used for those variables for which different building codes set requirements, such as the U-values of opaque surfaces. The variables for which it was not possible to extract consistent information from the building codes were set according to international standards.

The values of the three improvement sets are set in order to improve the performance level set in the base cases. As for the insulation levels the base cases have different values, the performance increment of the set 1 is different for different buildings.

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 can be assessed and can be used for designing optimal strategies for the energy retrofitting of the shopping malls by 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.

4.1. Primary energy

Figures 1 shows the results of the primary energy (PE) calculation of the selected shopping malls. 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 of the options shown in table 3 give a reduction of PE less than 20% of the PE of the base case. Some options, however, gives energy savings of 40% and more.

The reduction of the installed power density of lights (V1 in table 3) is the option that gives the highest energy savings. These are up to 44% and 49% for the Set 3 applied to the shopping malls in London. However, 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 mall 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 mall in Valladolid, a combination of reduced installed power density of lighting and increased glazed area gives the highest PE savings.

The increasing of the efficiency of the heat recovery system, the ventilation system, and the cooling system (V7 in table 2) is the second most effective option. When the systems efficiencies are increased to the Set 3 levels, the calculated PE savings are between 20% in the shopping mall in London and 36% in the shopping mall in Klaipeda. Since the heating and the cooling systems deliver heat through the ventilation system, an increasing 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 mall in Catania, where the PE reduction is 13%.

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 which exceed 14% of the PE of the base case. A lower infiltration rate is effective in cold climates, as shown by the example of the shopping malls in Trondheim. It results in PE reductions of 13%. The increasing of the indoors operative summer temperature is not very effective. A separate explanation is required for understanding the energy behaviour of the shopping mall in Valladolid. 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 malls. When the Set 3 is applied to the variables V3 and V5 (infiltration and U-value of windows), the given energy savings are up to 25%. On the other hand, when the glazing are 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 when applied to the other buildings.

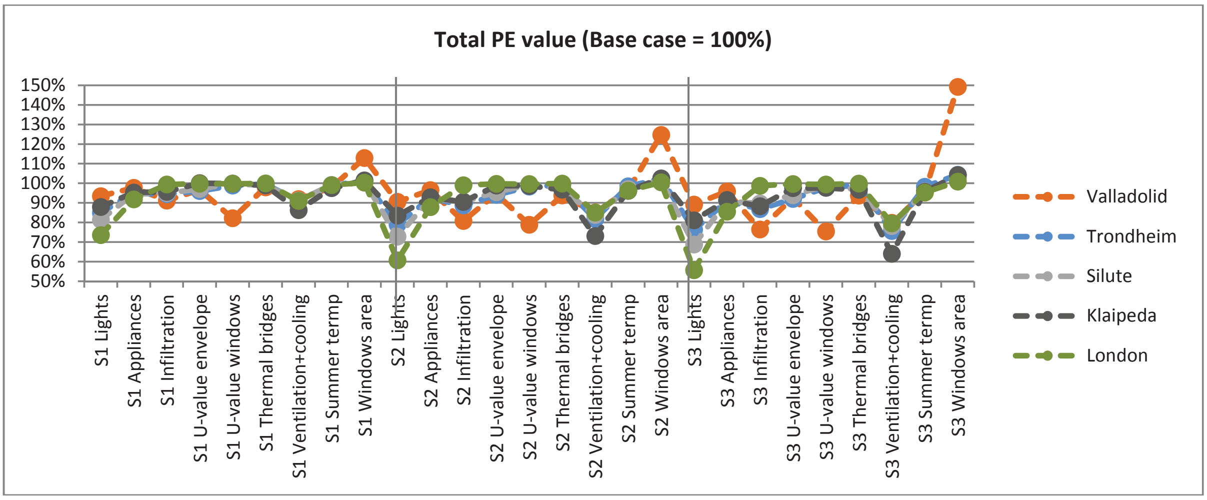


Figure 1. Total Primary Energy (PE) of all combinations of variables and sets. Values are expressed as the ratio between the PE of the selected cases and the PE of the base case.

4.2. Cost calculations

Total cost evaluation is based on [1]

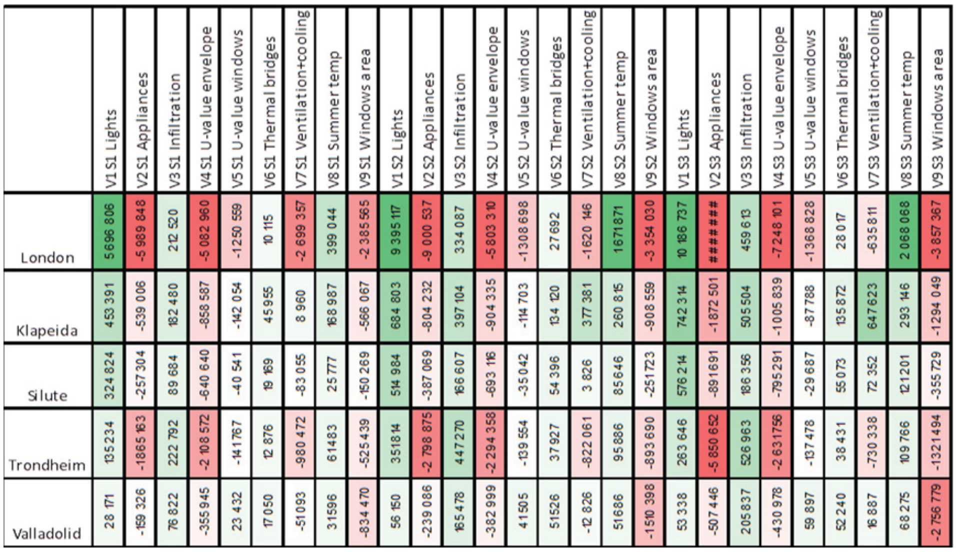
$$C_g(\tau) = C_I + \sum_{j} \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) \times R_d(i) \right) - V_{f,\tau}(j) \right]$$

with
$C_g(\tau)$ = global cost (referring to the starting year τ_0)
C_I = initial investment costs
$C_{a,i}(j)$ = cost during year i for energy-related component j (energy costs, operational costs, periodic or replacement costs, maintenance costs and added costs)
$R_d(i)$ = discount rate for year i
$V_{f,\tau}(j)$ = final (=residual) value of component j at the end of the calculation period (referring to starting year τ_0)

4.3. NPV and payback period

Table 1 shows the results of the net present value (NPV) calculation of the selected shopping malls. The net present value is expressed as absolute cost value in Euro for each combination of variables and sets. 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 to increasing the indoor operative temperature in summer seasons. The reduction of the installed power density of lights (V1 in table 2) is the option that gives the highest NPVs, regardless of each building volume. The highest peaks of the London shopping mall are due to its large area. 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 mild climates, such as London. The London building shows 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. All 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 mall in Klaipeda, while it shows negative NPVs for almost all the other buildings. The highest negative NPVs are given by increasing the efficiency of the installed appliances and increasing the thickness of the insulation of the building envelope. The increasing of the windows U-value shows negative NPVs for all the buildings but the Valla*dolid mall. The increasing of the window area does not show positive NPVs.*

Table 1. 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.



	V1 S1 Lights	V2 S1 Appliances	V3 S1 Infiltration	V4 S1 U-value envelope	V5 S1 U-value windows	V6 S1 Thermal bridges	V7 S1 Ventilation+cooling	V8 S1 Summer temp	V9 S1 Windows area
London	5 696 806	-5 989 848	212 520	-5 082 960	-1250 559	10 115	-2 699 357	399 044	-2 385 565
Klapeida	453 391	-539 006	182 480	-858 587	-142 054	45 955	8 960	168 987	-566 067
Silute	324 824	-257 304	89 684	-640 640	-40 541	19 169	-83 055	25 777	-150 269
Trondheim	135234	-1865 163	222 792	-2 108 572	-141 767	12 876	-980 472	61483	-525 439
Valladolid	28 171	-159 326	76 822	-355 945	23 432	17 050	-51093	31596	-834 470

	V1 S2 Lights	V2 S2 Appliances	V3 S2 Infiltration	V4 S2 U-value envelope	V5 S2 U-value windows	V6 S2 Thermal bridges	V7 S2 Ventilation+cooling	V8 S2 Summer temp	V9 S2 Windows area
London	9 395 117	-9 000 537	334 087	-5 803 310	-1308 698	27692	-1620 146	1671871	-3 354 030
Klapeida	684 803	-804 232	397 104	-904 335	-114 703	134 120	377 381	260 815	-908 559
Silute	514 984	-387 069	166 607	-693 116	-35 042	54 396	3 826	85646	-251723
Trondheim	351814	-2 798 875	447270	-2 294 358	-139 554	37 927	-822 061	95886	-893 690
Valladolid	56 150	-239 086	165 478	-382 999	41505	51526	-12 826	51686	-1510 398

	V1 S3 Lights	V2 S3 Appliances	V3 S3 Infiltration	V4 S3 U-value envelope	V5 S3 U-value windows	V6 S3 Thermal bridges	V7 S3 Ventilation+cooling	V8 S3 Summer temp	V9 S3 Windows area
London	10 186 737	#######	459 613	-7 248 101	-1368 828	28 017	-635 811	2 068 068	-3 857 367
Klapeida	742 314	-1872 501	505 504	-1005 839	-87 788	135 872	647623	293 146	-1294 049
Silute	576 214	-891691	186 356	-795 291	-29 687	55 073	72 352	121201	-355 729
Trondheim	263 646	-5 850 652	526 963	-2 631756	-137 478	38 431	-730 338	109 766	-1321494
Valladolid	53 338	-507 446	205 837	-430 978	59 897	52 240	16 887	68 275	-2 756 779

5. Conclusions

A list of analysis variables has been chosen for assessing the energy reduction of different shopping malls 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 malls in European regions with different climatic conditions (from Mediterranean climates to Continental and Sub-Polar climates). 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 malls 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.

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