CALCULATIONS OF COST-OPTIMAL LEVELS OF ENERGY PERFORMANCE REQUIREMENTS FOR RENOVATED BUILDINGS AND BUILDING ELEMENTS: A LATVIAN CASE

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ABSTRACT

This research work describes cost-optimal calculations for existing buildings of different categories and main building elements, as well as comparison with the existing energy requirements. Calculations are based on Directive 2010/31/EU and on the Commission Delegated Regulation (EU) No 244/2012 with the associated Guidelines. Those documents are used both – for the calculation of cost-optimal energy performance for a whole building (MWh or kWh/m^2 per year) and for the assessment of optimal *U*-value for different building elements.

The study starts with the choice of reference buildings according to the statistical data and selection of materials, constructions and systems incl. renewable energy resources, and defining of appropriate packages of energy saving measures. In the next step calculations of final heating and cooling energy, as well evaluation of total primary energy consumption (MWh) are determined have been made. Parallel to that costs of construction works are being estimated according to an actual market situation. The economic calculations are carried out, taking into account expected energy price increase, discount rate and operating costs during the calculation period.

As a main result cost-optimal values for both - *U*-values for different structures after insulation/replacement and for total energy level of overall building renovation are determined. Comparison with existing requirements has been made. In parallel with this, the sensitivity analysis of the future energy prices, operating/maintaining costs and renovation costs is performed. It is shown, that the role of mentioned assumptions may me even decisive in determining of the global costs and cost-optimal levels.

Keywords: refurbishment, cost optimum, energy efficiency, *U*-value, global costs.

INTRODUCTION

Building sector consumes up to 40% of total primary energy use [1] in the European Union (EU). The EU directive on energy performance of building (EPDB) [2] requires member states to set minimum requirements for energy performance of buildings and elements, including new and existing buildings. This directive demands for calculation of cost-optimal balance between the primary energy and the total cost during the lifespan of a building by using a comparative methodology [3].

There are some essential differences when analysing cost-optimum levels for renovations of existing buildings and for a new building construction. In case of renovation the number of used materials/structures and solutions is significantly smaller than for the newly erected building. Mostly, the increasing of building energy efficiency includes the following basic components: windows replacement; facade, roof and basement extra insulation, as well as air loss reduction of ventilation. Use of renewable energy sources reduces the energy costs, at the same time decreasing the primary energy value. In case with new buildings, it is very hard to select any static average data due to a very wide range of totally different used construction approaches, materials, technologies, technical systems and energy sources. Therefore, only refurbished buildings with limited number of energy-saving measures are included in this study.

Two types of calculations – energy and economic are needed to calculate the payback time for considered measures and find the cost-optimum in accordance with standard methodology [3]. Methods and assumptions used for each analysis type are described below. Cost-optimum measure (or group of them) is possible to find by combining both calculations in a single graph, where energy demand of each measure and corresponding total cost is plotted as a point, therefore creating the cloud of points (see Fig. 1).

In this study two types of cost-optimum analysis have been performed:

- optimum level as a package of energy saving measures (incl. ventilation and difference heating systems) for the whole building in kWh/m^2 according to EPBD defined energy performance calculation methodology [3], allowing them to be compared with minimum energy efficiency requirements and requirements of nearly zero energy building defined in Regulations Regarding the Energy Certification of Buildings [4];
- optimum *U*-values for building components such roof, wall, floor, as well for windows in and comparison with the current legislative requirements defined in Latvian Construction Standard LBN 002-15 [5]. For this type of calculation the same methodology was used, but only for one component was varied with other fixed.

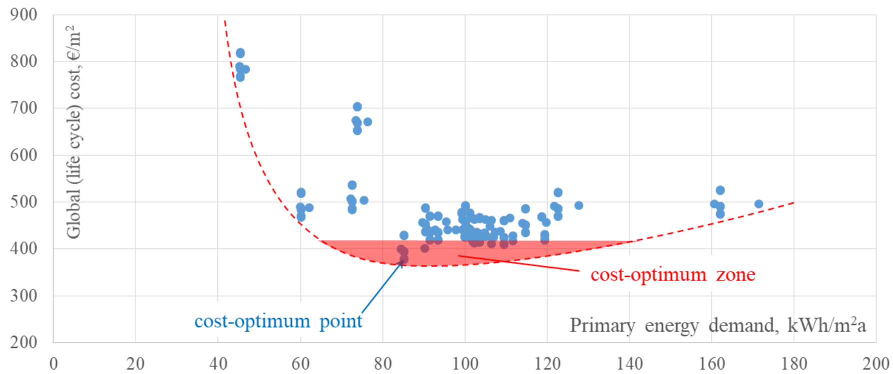

Fig. 1. Example of graphical representation of cost-optimum measures.

ASSUMPTIONS

To cover the possible wide range of existing building stock, different categories of reference buildings according to the statistical data [6] are used in calculation, including a single-family house, a multi-storey apartment building, an office building, a school building with a gym, a hospital, a supermarket, a hotel and a manufacturing building. Summary of main building parameters is shown in Table 1, models are shown in Fig. 2.

Table 1. Summary of reference existing buildings used for cost-optimum calculations.

#	Type	Floor area, m^2	Volume, m^3	No. of floors	Indoor temperature, °C	Delivered heating energy, kWh/m^2
1	single-family house	160	596	2	20	321
2		117	360	1	20	372
3	apartment building	2059	6950	5	20	157
4		1150	4062	4	20	209
5	office building	911	3705	3+1	20	220
6		416	1561	2	20	266
7	school with a gym	1071	5995	2	21	427
8		2310	13720	1, 4	21/19	287
9	hospital	397	1512	2+1	21	326
10		5148	21602	4+1	21	230
11	supermarket	1205	9641	1	20	137
12		86	324	1	20	371
13	hotel	2477	10692	5+1	21	199
14		850	3398	3	21	232
15	manufacturing building	423	2959	1	18	645
16		526	2209	1, 2	20/17	298

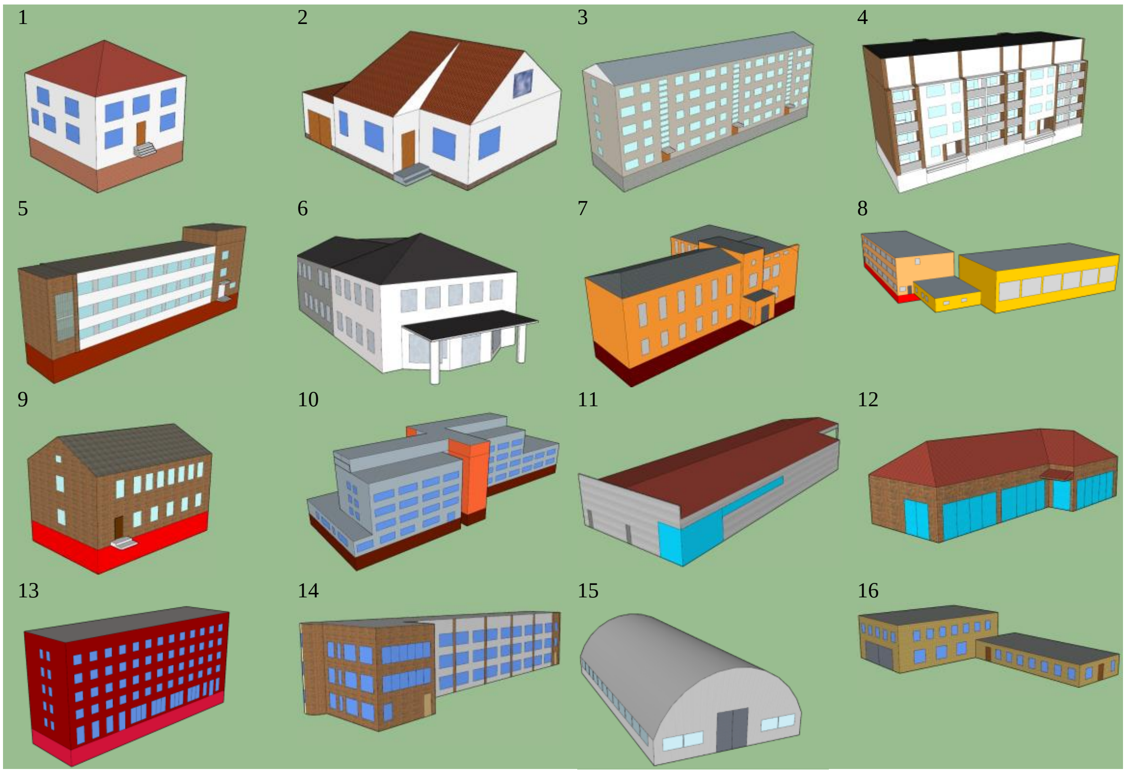

Fig. 2. Models of reference buildings (numbering corresponds to Table 1).

In the next step some more commonly used insulation materials, three types of windows (Tables 2,3) and technical systems (e.g. ventilation system, different heating energy sources and renewable energy sources, which is required for nearly zero energy buildings) are selected to be included in detailed energy and economics calculations. The thickness for each insulation material is calculated to achieve the normative *U*-value for each building [5], which is depending on building's type, indoor temperature and initial *U*-value of building construction.

One of the most important factors that have a significant impact on the results is the cost of refurbishment works for existing structures or their replacement (e.g. windows). Such costs are estimated according to an actual cost level on a market at the end of 2017 and based on detailed calculation approach including salary, materials, mechanisms and transport [7]. Refurbishment cost examples are summarized in Table 4.

Table 2. Insulation materials used for building renovation.

Insulation material	Used thermal conductivity λ (W/(m×K))				
	Rendered facade	Ventilated facade	Ceiling	Flat roof	Basement ceiling
Mineral wool	0.037	0.036		0.035	0.035
Loose mineral wool			0.049		
EPS/XPS	0.037			0.035	
Loose cellulose wool		0.049	0.049	0.049	
Polyurethane foam				0.051	
Phenolic foam	0.023			0.023	
Vacuum insulation panels	0.007				

Table 3. Windows types used for building renovation.

Glazing unit	Frame thickness	*U*-value (W/(m^2×K))
1× (4cf/16/4LowE)	70 mm	1.3
2× (4LowE/18/4cf/18/4LowE)	76 mm	1.0
2× (4LowE/18/4cf/18/4LowE)	88 mm	0.8

Table 4. Example of refurbishment costs (excl. VAT) used for the calculations.

Construction	Material	Thickness, cm	Total costs (€/m^2)
Cold ceiling insulation	Loose mineral wool	20-45	10-16
Rendered facade	Mineral wool	10-30	53-78
	EPS/XPS	10-30	48-64
	Phenolic foam	10-20	78-100
	Vacuum insulation	2-6	92-220
Ventilated facade	Mineral wool	10-35	94-122
	Loose cellulose wool	20-45	102-123
Flat roof	Mineral wool	15-35	76-101
	EPS/XPS	15-35	72-89
	Loose cellulose wool	15-40	104-129
	Polyurethane	15-35	76-106
Basement ceiling	Mineral wool	10-30	32-59
Window, *U*=1,3 W/m^2/K	-	-	113
Window, *U*=1,0 W/m^2/K	-	-	135
Window, *U*=0,8 W/m^2/K	-	-	166

METHODS

The first calculation step is the estimation of energy demand of the building after each energy-saving measure, which is combination of insulation, window/door replacement and changes in technical systems. Procedure includes calculation of the building energy demand for heating and cooling based on ISO 52016-1 standard [8], as well as calculation of the primary energy and CO_2 emissions according Latvian legislation [9].

The energy calculation for heating and cooling is based on data about required indoor temperature, internal heat gains (which differ significantly for different types of buildings), geometrical and physical properties of boundary structures (areas, *U*-values, *g*-values, etc.), ventilation heat losses and weather conditions – air temperature, solar radiation. The simplified monthly calculation principle is applied for this methodology.

The second and largest calculation block consists of financial and macroeconomics calculations and of each measure (accepted energy efficiency activity). These calculations have been made taking into account the following variables:

- expected future energy price and its changes for district heating (€/MWh), electricity (€/kWh), natural gas (€/nm^3 converted to €/MWh), pellets (€/t converted to €/MWh), mixed heating solutions (theoretical average price per mixed energy sources - €/MWh);
- financial indicators:
  - discount rates (3% as reference rate);
  - maintenance costs (as percentage of initial investments) and its increase for building structures (0…3 %/year), heating and DHW systems (1…7 %/year), ventilation systems (8 %/year) etc.;
  - operating costs (2…5 %/year depending on building type);
  - commodity prices and its increase;
  - sensitivity analysis (for financial and macroeconomics calculations):
    - Changes in discount rates (3 or 5%/year);
    - Changes in energy prices for district heating (-1/0/1 %/year);
    - Changes in energy prices for electricity (-1/0/1 %/year);
    - Changes in commodity prices (-1/0/1 %/year);
    - Changes in maintenance and operating costs (-1/0/1 %/year);
- calculation period (life cycle): 20 years for public sector, 30 – for private sector.

Differences in cost-optimal energy efficiency package (combinations of measures) may vary significantly in macroeconomics and financial calculations compared to the reference building (without any improvements) – macroeconomics calculations show more positive values (meaning more cost-effective investments), than for financial calculation approach.

RESULTS: BUILDING ENERGY PERFORMANCE

As a main result, the total costs (including investment, replacement and running costs) of chosen packages of energy-saving measure during the calculation period of 20 or 30 years can be displayed in one graph together with corresponding primary energy value. Plotting on various packages will form the data point cloud, where the minimum value of global costs means the cost-optimum package. Examples of this graph are shown in Fig. 3 – for the office building and the hotel. As it is seen, many packages give very close global cost values, at the same time primary energy demands fluctuates in a wider range. A similar situation has been observed in all the reference buildings, meaning that many refurbishment variants gives very close cost-optimum points.

In most cases, the cost-optimum zone is created by the extra insulation of boundary structures and replacement of old wooden windows. The modernization of heating system or change of energy source (incl. to satisfy the nZEB requirements) is far from the global cost minimum. In general, the rendered facade insulation with EPS/XPS and the ceiling insulation with the loose thermal insulations, as well as replacement of the windows are more cost effective than other measures (see Table 2). A comparison of the cost-optimum heating energy levels and current requirements with appropriate costs is summarized in Table 5. Comparing of both indicators allows to conclude that current heating demand requirements are stricter than the cost-optimal ones, but the difference is not large.

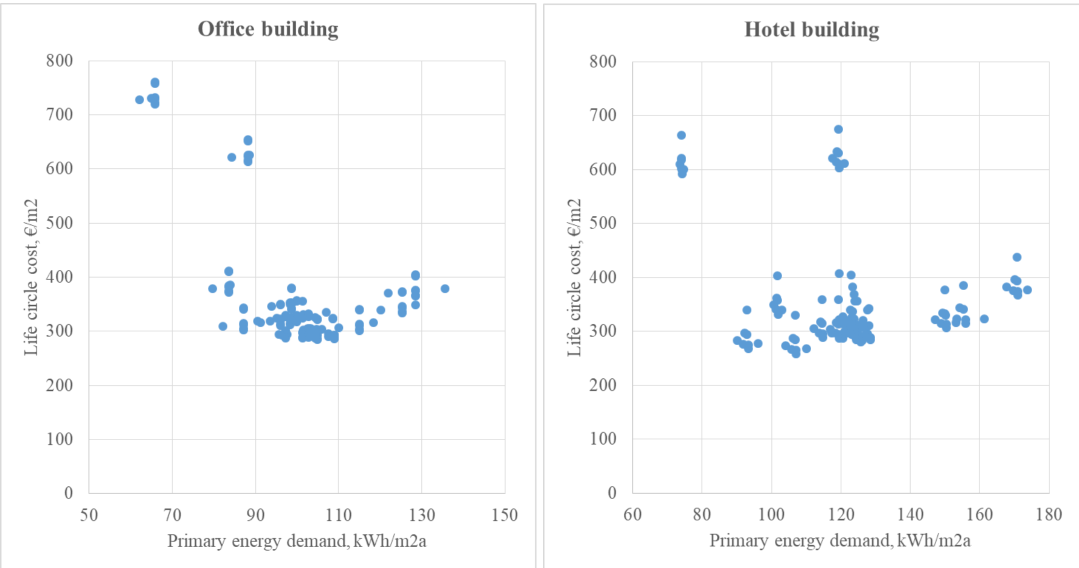

Fig. 3. Graphs of different packages of energy saving measures.

Table 5. Comparison of current requirements (**R**) and calculated cost-optimum(**O**).

#*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Heating energy, kWh/m^2																
R	37	84	61	66	49	75	112	82	46	64	70	102	59	60	175	71
O	46	92	69	79	54	75	121	82	53	67	70	102	63	60	175	70
Corresponding global costs, €/m^2																
R	390	450	340	450	300	270	430	460	450	330	590	530	290	460	365	290
O	370	430	325	420	290	280	410	400	420	320	410	435	280	370	310	250

** Building designations see in Table 1.*

RESULTS: BUILDING ELEMENTS

Using the same methodology as in the case of the whole building, cost-optimal *U*-values for a separate building structure are determined, i.e. the global cost of renovation or replacement for this structure is calculated depending on resulting primary energy need for the whole building. It should be noted that, in this case *U*-value only for analysed construction is varied, while *U*-values for all other structures are fixed according to the normative values. In case of several types of insulating materials for the same structure, they all may be combined in one graph, an examples of three facade insulation types and two types of ceiling insulation are shown in Fig. 4. As it is seen, the optimum *U*-value of 0.2 W/(m^{2}K) for refurbished facade is very close to all reviewed materials, but with different global cost estimation, the lower costs is for EPS/XPS application. In case of ceiling insulation, use of mineral or cellulose loose wools gives different optimal *U*-values – 0.16 and 0.19 W/m^{2}K and slightly different corresponding global costs.

Comparison of calculated optimum *U*-values for different building structures with normative values [10] is summarized in Table 6. Values in this table includes all the analysed building types (see Table 1) and used materials, which explains the wide range of cost-optimums. This limits the use of results, but normative *U*-values in Latvian regulations are divided into 3 categories only [5], meaning, on the other hand, more options of materials and solutions selection to achieve the cost-optimum goal.

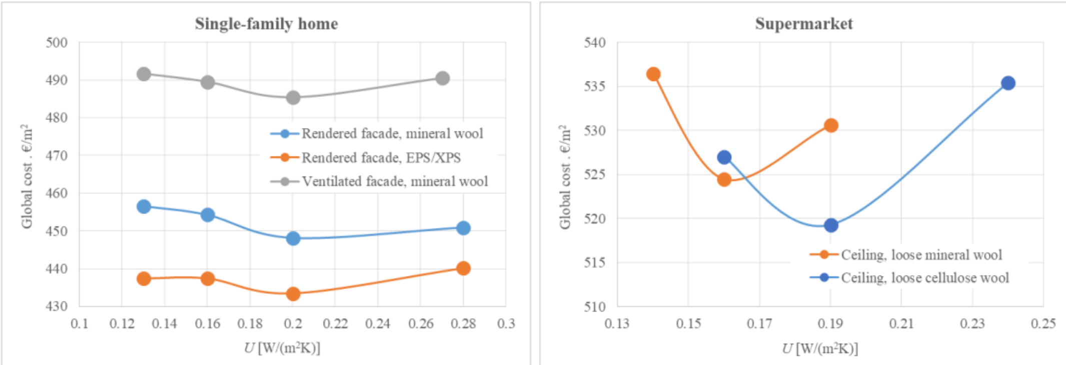

Fig. 4. Cost-optimal *U*-value for facade and ceiling insulation with different materials.

Table 6. Normative *U*-values (**N**) and calculated cost-optimum range (**O**).

Building structures	Residential buildings		Public buildings		Manufacturing buildings	
	N	**O**	**N**	**O**	**N**	**O**
Roof	0.15	0.14…0.21	0.20	0.13…0.26	0.25	0.12…0.30
Floor	0.15	0.13…0.24	0.20	0.12…0.31	0.30	0.24…0.28
Wall	0.18	0.11…0.26	0.20	0.14…0.31	0.25	0.16…0.28
Windows	1.3	1.1…1.7	1.4	0.9…1.7	1.6	1.0…1.4

CONCLUSION

The most critical assumptions used in the cost-optimal calculation methodology, which can have a significant impact on reliability of results, are identified and evaluated. The most important of these are:

- forecast of future energy prices, which are extremely unlikely in the long-term;
- operating and maintaining costs, which varies is large range and differ significantly from one building to another;
- refurbishment costs, whose forecasts are not clear in the long run;

Sensitivity analysis showed that initial building operating costs (when no improvements are made) may influence long-term cost-optimal calculation results significantly, therefore accurate initial expense audit is crucial.

Increasingly price growth in construction industry in Latvia negatively influence cost-optimal calculations in long-terms, therefore regular re-calculations must be made.

Cost-optimal calculations of *U*-values show that existing energy efficiency requirements in Latvia are within range of 15%, although requirements on roof surfaces and floor on ground are too high, showing necessary for requirement review.

Varying different energy sources, consumption of primary energy calculations significantly changes due to its factors, although absolute energy consumption stays constant.

Looking at ways to reach levels of nZEB as main restrictions can identify - high cost of ventilation system installation, existing geometry of buildings and specific operation conditions, like grocery shop with high customer turnover, open-freezers etc.

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