6. Calculations of cost-optimal levels of building energy performance

6.1. Introduction

Calculations of cost-optimum level for buildings are very important to analyse the economic aspects of building usage during long operation period. 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 (which is needed to reach fulfil the nearly zero energy building (nZEB) requirements) 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.

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 described in Directive 2010/31/EU [6.1] and in Commission Delegated Regulation (EU) No 244/2012 with the associated Guidelines [6.2]. One 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. 6.1.1). Optimum level as a package of energy saving measures (incl. ventilation and difference heating systems) for the whole building in kWh/m^2 allows them to be compared with minimum energy efficiency requirements and requirements of nZEB defined in Regulations Regarding the Energy Certification of Buildings [6.3].

It is expected, that the nZEB case, which requires large initial investment, will form calculation point far from the cost-optimum zone (see Fig. 6.1.1). It can also be explained by relatively low energy prices in Latvia and its future forecast.

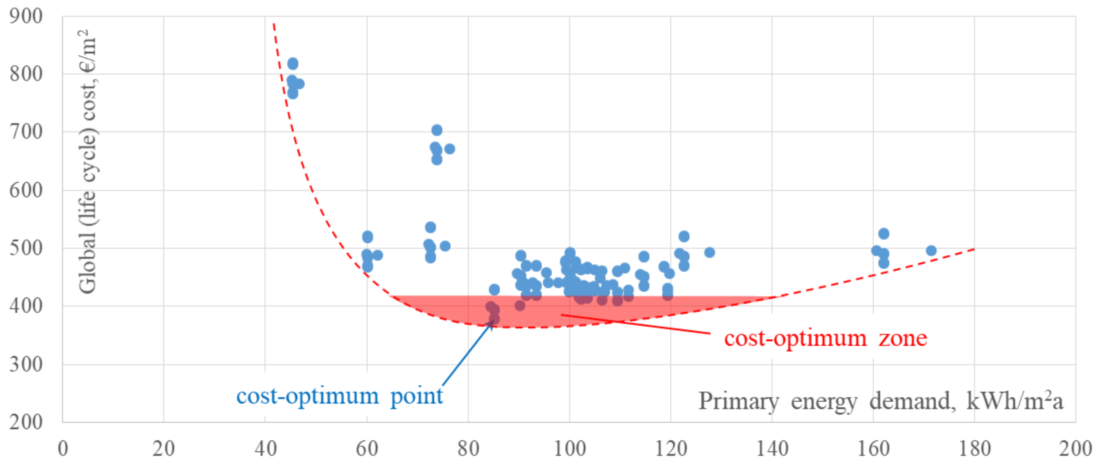


Fig. 6.1.1. *Example of graphical representation of cost-optimum measures.*

6.2. Assumptions and input data

To cover the possible wide range of existing building stock, different categories of reference buildings 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 6.2.1; models are shown in Fig. 6.2.1.

Table 6.2.1. *Summary of reference existing buildings used for cost-optimum calculations.*

#	Type	Floor area, m²	Volume, m³	No. of floors	Indoor temperature, °C	Delivered heating energy, kWh/m²
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

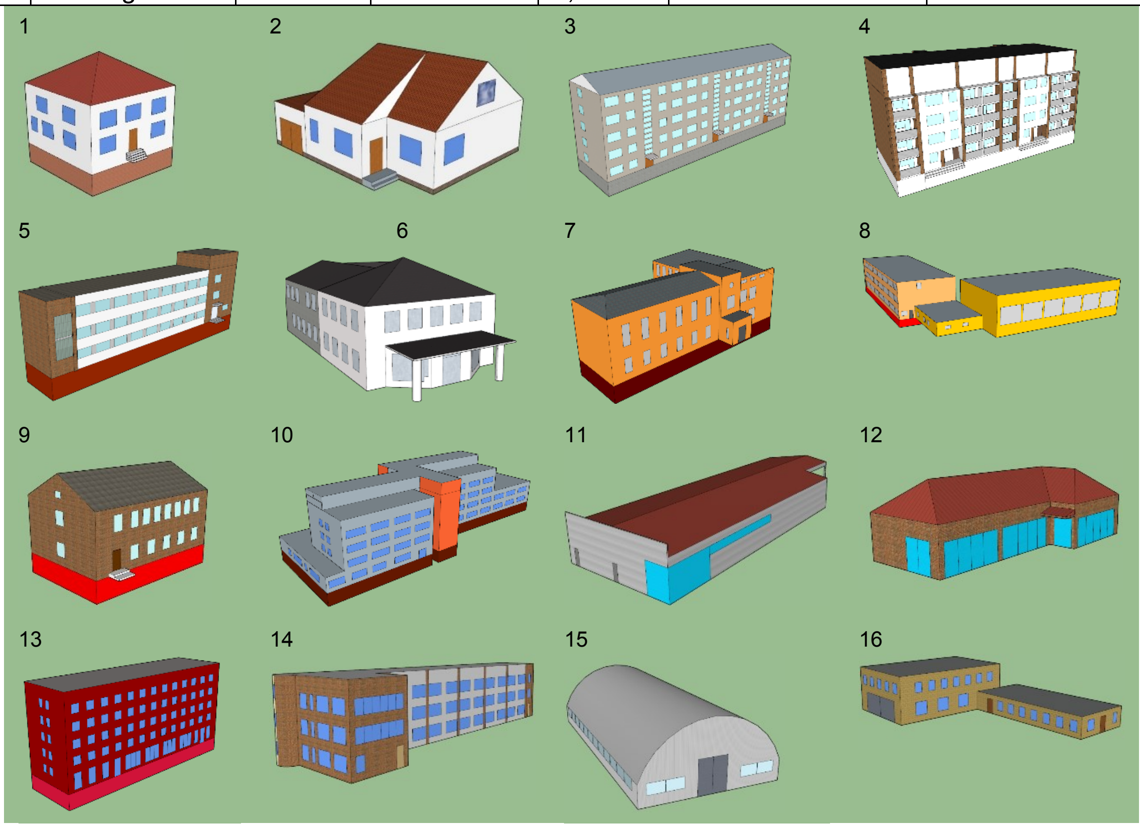


Fig. 6.2.1. *Models of reference buildings (numbering corresponds to Table 6.2.1.).*

In the next step some more commonly used insulation materials, three types of windows (Tables 6.2.2., Table 6.2.3) and technical systems (e.g. ventilation system, different heating energy sources and renewable energy sources required for nZEB) 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 [6.4], 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 building or refurbishment works. Such costs are estimated according to an actual cost level on a market at the end of 2017, they are based on detailed calculation approach including salary, materials, mechanisms and transport [6.5]. Refurbishment cost examples are summarized in Table 6.2.4.

Table 6.2.2. *Insulation materials used for calculations.*

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	
Phenolic foam	0.023			0.023	
Vacuum insulation panels	0.007				

Table 6.2.3. *Windows types used for calculations.*

Glazing unit	Frame thickness	U-value (W/(m²×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 6.2.4. *Example of refurbishment costs (excl. VAT) used for the calculations.*

Construction	Material	Thickness, cm	Total costs (€/m²)
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/m²/K	-	-	113
Window, U=1.0 W/m²/K	-	-	135
Window, U=0.8 W/m²/K	-	-	166

6.3. Calculations

The first calculation step is the estimation of energy demand of the building for each energy-saving measure, which is combination of boundary structures and technical systems. Procedure includes calculation of the building energy demand for heating and cooling based on ISO 52016-1 standard [6.6], as well as calculation of the primary energy and CO_2 emissions according Latvian legislation [6.7].

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 [6.6] is applied.

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 (€/nm³ 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.

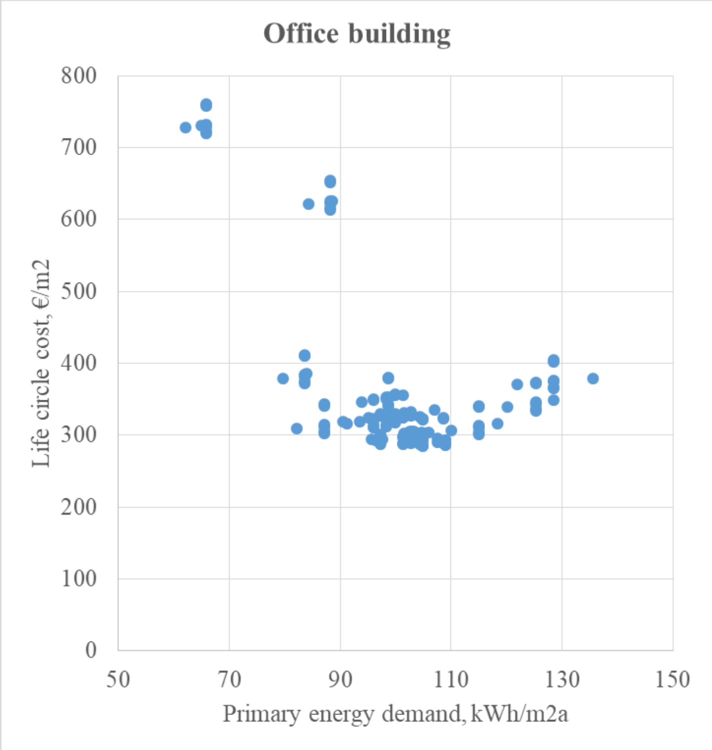
6.4. Results of calculated cost-optimal building energy performance

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 commercial, non-residential buildings) years for 30 years (for residential and public buildings) 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. Two examples of this graph are shown in Fig. 6.4.1. – for the office building and for 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 different building types, meaning that many 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.

A comprehensive comparison of the heating and primary energies for cost-optimal and nZEB cases, as well as current requirements and appropriate global costs is shown in Table 6.4.1. Comparing of calculated indicators allows to conclude that current (normative) heating demand requirements mostly are stricter than the cost-optimal ones, but the difference is not large.

Analysis of nZEB variation for different buildings show that they are far from cost-optimums values both for existing and new buildings expect supermarkets and hotels, where they are practically the same as cost-optimum ones.



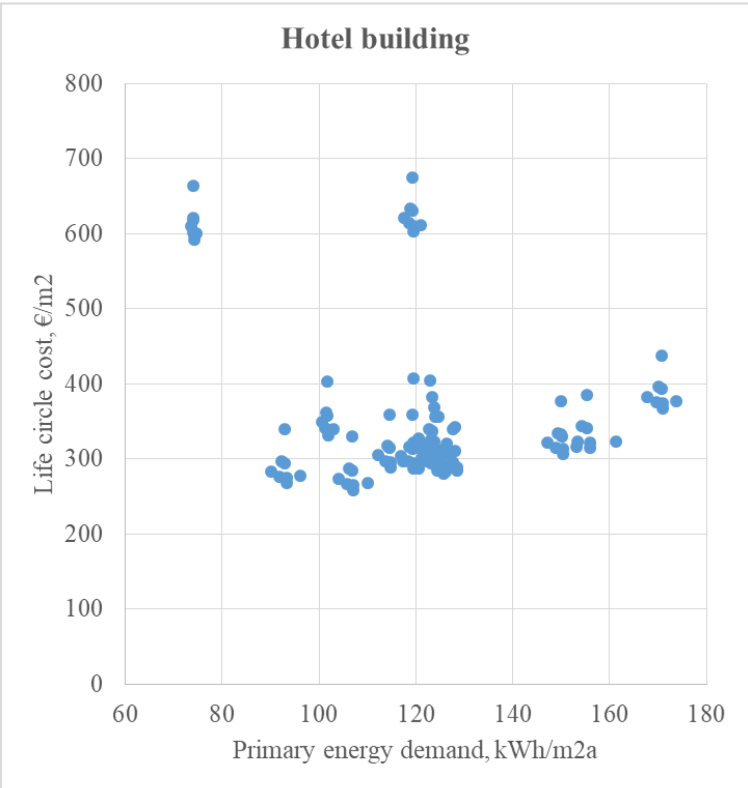


Fig. 6.4.1. *Graphs of different packages of energy saving measures.*

Table 6.4.1. *Summary of the heating energy and primary energy for cost-optimal and nZEB cases with appropriate costs.*

		Heating energy, kWh/m²			**Total primary energy, kWh/m²**			**Global costs, €/m²**		
	Building type	**Normative case***	**Cost-optimum case**	**nZEB case**	**Normative case***	**Cost-optimum case**	**nZEB case**	**Normative case***	**Cost-optimum case**	**nZEB case**
Existing buildings	single-family house	37	46	16	64	69	44	390	370	860
		84	92	48	86	90	55	450	430	1100
	apartment building	61	69	38	102	104	115	340	325	610
		66	79	40	130	132	100	450	420	770
	office building	49	54	18	103	105	65	300	290	610
		75	75	26	101	101	55	270	280	740
	school with a gym	112	121	56	104	109	45	430	410	780
		82	82	30	106	149	50	460	400	820
	hospital	46	53	24	81	85	50	450	420	650
		64	67	26	99	101	65	330	320	510
	supermarket	70	70	70	278	168	170	590	410	420
		102	102	62	205	149	150	530	435	440
	hotel	59	63	34	125	126	119	290	280	720
		60	60	54	213	162	160	460	370	380
	manufacturing building	175	175	96	143	120	70	365	310	400
		71	70	38	91	59	30	290	250	310
New buildings	single-family house	67	67	38	70	70	40	580	570	1010
	apartment building	46	40	22	90	50	55	370	290	290
	office building	34	32	22	89	88	45	370	370	710
	school with a gym	49	49	38	75	75	50	920	920	1330
	hospital	21	30	20	90	90	70	830	810	850
	supermarket	44	41**	44	220	219**	39***	890	880**	785
	hotel	29	28	28	83	67	55	630	620	625
	manufacturing building	45	34	44	82	75	55	660	650	700

** According normative requirements for boundary structures [6.4] and minimum energy performance requirements [6.3].
*** Without PV panels.
**** Lighting and cooling demand are provided by the installed PV panels.

6.5. Conclusion

Calculations of cost-optimal levels of building energy performance gives an opportunity to objectively evaluate not only the construction (initial) costs, but also the operating costs over a longer period of time. And this provides an economic reason for choosing one or the another material, structure or solution for the construction of refurbishment.

The most critical assumptions used in the cost-optimal calculation methodology, which can have a significant impact on reliability of results, 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.

Varying different energy sources, consumption of primary energy calculations significantly changes due to its factors (which may change over time in principle), 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.

Literature

[6.1] European Parliament, Directive 2010/31/EU of the European Parliament and the Council on the energy performance of buildings, Official Journal of the European Union, 2010, pp. 13-35.

[6.2] Commission Delegated Regulation (EU) No 244/2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements, Official Journal of the European Union, 2012, p. 18–36.

[6.3] Regulations Regarding Energy Certification of Buildings. Republic of Latvia, Cabinet Regulation No. 383, Adopted 9 July 2013.

[6.4] Latvian Construction Standard LBN 002-15, Thermotechnics of Building Envelopes, 2015.

[6.5] Latvian Construction Standard LBN 501-17, Procedure for Determining Construction Costs, 2017.

[6.6] International Organization for Standardization, ISO 52016-1:2017: Energy performance of buildings – Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads Part – 1: Calculation procedures, 2017.

[6.7] Latvian Cabinet of Ministers, Cabinet Regulation No. 348, Regulations Regarding the Methodology for Calculating the Energy Performance of Buildings, 2013.