Life-cycle assessment of the contemporary standardized wall systems

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Abstract. Due to the current environmental situation, the reducing of greenhouse gas emission and the saving energy is the phenomenon. The building sector is still growing and more and more energy is needed. Thermal performance of building envelope has been of great importance in the context of existing global warming issues. Buildings are responsible for 40% of energy consumption and 36% of Carbon Dioxide (CO_2) emissions in the member states of the European Union. According to the research project Heartland Green Sheets, the recommended criteria for assessments of sustainable buildings materials are low embodied energy, recyclable, use renewable resources, locally or regionally produced, energy efficient, low environmental impact, durable, minimize waste, positive social impact and affordable. The contribution focuses on life-cycle assessment (LCA) and sustainability assessment of commonly used wall systems. The multi-criteria analysis of the contemporary wall systems in term of sustainable development is presented in the paper. The contemporary commonly used wall systems are assessed in terms of labour, time and financial demands, energy and environmental performance.

1 Introduction

One of the most difficult problems in the construction industry is to take objective decisions, especially for the choice of material solutions and technologies. The decision process is complicated and time-consuming. The contribution presents a multi-criteria analysis of contemporary wall systems from the point of view of sustainable development, which should help in this decision-making process. According to the research project Heartland Green Sheets, the recommended criteria for assessments of sustainable buildings materials are low embodied energy, recyclable, use renewable resources, locally or regionally produced, energy efficient, low environmental impact, durable, minimize waste, positive social impact and affordable.

The assessed criteria (labour, time and financial demands, thermal and technical properties and environmental aspects) are assessed in relation to the results obtained on the basis of generally available technical documents issued by building materials manufacturers.

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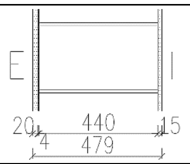
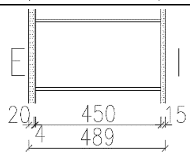
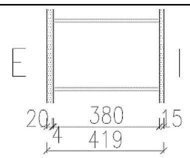
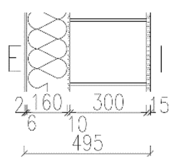
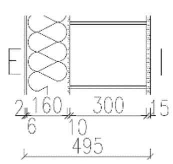
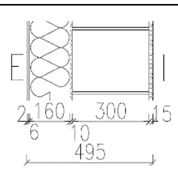
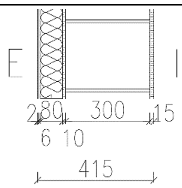
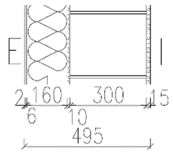
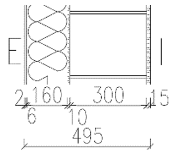
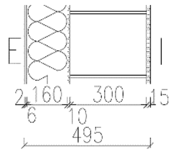
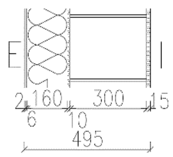
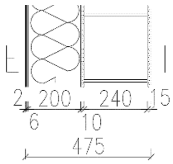
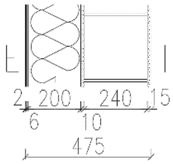
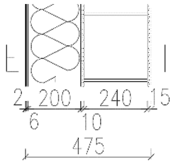
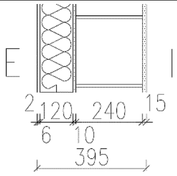
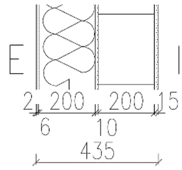
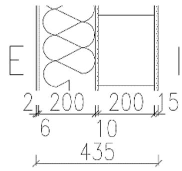
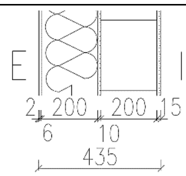
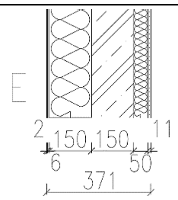
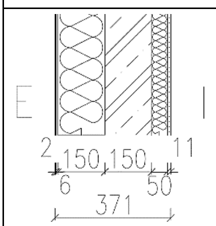
2 Contemporary standardized wall systems

Twenty different variants of wall systems are compared. The maximum wall thickness is 500 mm. The first three variants are made without additional thermal insulation only by the use of thermal insulating blocks. Variants 4 to 15 represent the use of the external thermal insulation composite system (ETICS). Variants 4 - 7 is designed made of the brick thickness of 300 mm and supplemented with thermal insulation made of white and grey polystyrene, mineral wool and phenolic foam.

Table 1. Overview of assessed standardized wall systems.

	Variant n. 1 1) One-layer lime-cement plaster with a thickness of 20 mm 2) Penetration 4 mm 3) 2in1 grinded brick 440 mm with filled the cavities of these bricks with polystyrene 4) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 2 1) One-layer lime-cement plaster with a thickness of 20 mm 2) Penetration 4 mm 3) Masonry made of aerated concrete blocks with a thickness of 450 mm 4) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 3 1) One-layer lime-cement plaster with a thickness of 20 mm 2) Penetration with a thickness of 4 mm 3) Cut brick block with mineral insulation thickness 380 mm 4) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 4 1) 1.5 mm thick silicone plaster + permeable primer coating 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Thermal insulation, white expanded polystyrene with a thickness of 160 mm 4) Adhesive cement with a thickness of 10 mm + primer 5) Grinded brick with a thickness of 300 mm 6) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 5 1) 1.5 mm thick silicone plaster + permeable primer coating 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Thermal insulation, grey expanded polystyrene with a thickness of 160 mm 4) Adhesive cement with a thickness of 10 mm + primer 5) Grinded brick with a thickness of 300 mm 6) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 6 1) 1.5 mm thick silicone plaster + permeable primer coating 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Thermal insulation, mineral wool with a thickness of 160 mm 4) Adhesive cement with a thickness of 10 mm + primer 5) Grinded brick with a thickness of 300 mm 6) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 7 1) 1.5 mm thick silicone plaster + permeable primer coating 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Thermal insulation, phenolic foam with a thickness of 80 mm 4) Adhesive cement with a thickness of 10 mm + primer 5) Grinded brick with a thickness of 300 mm 6) Interior, one-layer, lime-cement plaster with a thickness of 15 mm

	Variant n. 8 1) 1.5 mm thick silicone plaster + permeable primer coating 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Thermal insulation, white expanded polystyrene with a thickness of 160 mm 4) Adhesive cement with a thickness of 10 mm + primer 5) Aerated concrete blocks with a thickness of 300 mm 6) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 9 1) 1.5 mm thick silicone plaster + permeable primer coating 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Thermal insulation, grey expanded polystyrene with a thickness of 160 mm 4) Adhesive cement with a thickness of 10 mm + primer 5) Aerated concrete blocks with a thickness of 300 mm 6) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 10 1) 1.5 mm thick silicone plaster + permeable primer coating 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Thermal insulation, mineral wool with a thickness of 160 mm 4) Adhesive cement with a thickness of 10 mm + primer 5) Aerated concrete blocks with a thickness of 300 mm 6) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 11 1) 1.5 mm thick silicone plaster + permeable primer coating 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Thermal insulation, Calcium silicate mineral board with a thickness of 160 mm 4) Adhesive cement with a thickness of 10 mm + primer 5) Aerated concrete blocks with a thickness of 300 mm 6) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 12 1) 1.5 mm thick silicone plaster + permeable primer coating 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Thermal insulation, white expanded polystyrene with a thickness of 200 mm 4) Adhesive cement with a thickness of 10 mm + primer 5) Sand-lime bricks with a thickness of 240 mm 6) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 13 1) 1.5 mm thick silicone plaster + permeable primer coating 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Thermal insulation, grey expanded polystyrene with a thickness of 200 mm 4) Adhesive cement with a thickness of 10 mm + primer 5) Sand-lime bricks with a thickness of 240 mm 6) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 14 1) 1.5 mm thick silicone plaster + permeable primer coating 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Thermal insulation, mineral wool with a thickness of 200 mm 4) Adhesive cement with a thickness of 10 mm + primer 5) Sand-lime bricks with a thickness of 240 mm 6) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 15 1) 1.5 mm thick silicone plaster + permeable primer coating 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Thermal insulation, phenolic foam with a thickness of 120 mm 4) Adhesive cement with a thickness of 10 mm + primer 5) Sand-lime bricks with a thickness of 240 mm 6) Interior, one-layer, lime-cement plaster with a thickness of 15 mm

	Variant n. 16 1) 1.5 mm thick silicone plaster + permeable primer coating 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Thermal insulation, white expanded polystyrene with a thickness of 200 mm 4) Adhesive cement with a thickness of 10 mm + primer 5) Lost formwork and reinforced concrete with a thickness of 200 mm 6) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 17 1) 1.5 mm thick silicone plaster + permeable primer coating 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Thermal insulation, hemp fibre board with a thickness of 200 mm 4) Adhesive cement with a thickness of 10 mm + primer 5) Lost formwork and reinforced concrete with a thickness of 200 mm 6) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 18 1) 1.5 mm thick silicone plaster + permeable primer coating 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Thermal insulation, mineral wool with a thickness of 200 mm 4) Adhesive cement with a thickness of 10 mm + primer 5) Lost formwork and reinforced concrete with a thickness of 200 mm 6) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 19 1) 1.5 mm thick silicone plaster + permeable primer coating 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Thermal insulation, block of grey polystyrene with a thickness of 150 mm 4) Reinforced concrete with a thickness of 150 mm 5) Thermal insulation, block of grey polystyrene with a thickness of 50 mm 6) Polymer-cement bridge of thickness 1 mm 7) Interior, one-layer, lime-cement plaster with a thickness of 15 mm
	Variant n. 20 1) 1.5 mm thick silicone plaster 2) Backfilling layer with reinforcing glass fibre fabric of thickness 6 mm 3) Wood fibre board with a thickness of 60 mm 4) Solid Structural Timber+Thermal insulation, mineral wool with a thickness of 140 mm 5) gypsum paper board with vapour barrier with a thickness of 15 mm 6) Solid Structural Timber + Thermal insulation, mineral wool with a thickness of 60 mm 7) Gypsum board with a thickness of 15 mm 8) Interior finish - wallpaper

2 Results

2.1 Thermal-technical assessment

The thermal efficiency of building envelopes is of great importance in the context of the existing problems of global warming. Buildings account for 40% of energy consumption [1]. The main parameter is the value of the heat transfer coefficient U. It expresses how much heat escapes with a surface of 1 m^2 when the temperature difference of its surfaces is 1 K. Another important parameter is the annual balance of condensed and evaporable water vapour. If the composition of the structure is designed so that water vapour is not able to evaporate through it, thermal insulation inside the structure is degraded, the risk of mold emergence increases and the thermal insulation properties of the structure are significantly reduced. The results of the thermal-technical assessment of variants are shown in Table 2.

Table 2. Thermal-technical assessment of assessed standardized wall systems.

Var.	Heat transfer coefficient U [W/(m^{2}K)]	Amount of condensed water vapour per year $M_{c,a}$ [kg/(m^{2}a)]	The amount of evaporable water vapour per year $M_{ev,a}$ [kg/(m^{2}a)]
1	0.182	0.3234	2.7291
2	0.176	0.1490	2.7174
3	0.174	0.1216	2.7254
4	0.159	0.0101	1.0677
5	0.147	0.0136	2.4027
6	0.162	0.1179	3.5985
7	0.179	0.1220	3.6045
8	0.136	0.0242	0.7775
9	0.127	0.0252	1.5183
10	0.139	0.2075	3.5541
11	0.152	0.2059	3.5611
12	0.169	0.0029	1.2471
13	0.152	0.0057	2.4119
14	0.173	0.0765	3.6190
15	0.168	0.0815	3.6147
16	0.173	0.0009	1.4003
17	0.186	0.0067	6.8705
18	0.178	0.0107	6.8251
19	0.157	0.0021	2.5101
20	0.187	1.9370	1.9370

2.2 Labor and time consuming implementation

The time-consuming performance of construction activities is one of the important criteria. Investors and developers generally require the fastest construction process. The period of the construction implementation is related to its labor. This includes not only the construction itself but also the use of construction machinery. The modified workload equation, where t is the time required for construction, Q is the amount of material in the required unit of measure (m, m^2, m^3), and P is the labor performance in hours per worker or machine:

$$t = Q \cdot P \tag{1}$$

The resulting labor values are converted to 1 m^2 of the external wall. Calculations of the time consuming of each variant are illustrated in the following table.

Table 3. Results of the labor per 1 m^2 of building envelope.

Var.	Labor [Nh/m^2]	Var.	Labor [Nh/m^2]
1	2.000	11	2.302
2	1.505	12	2.180
3	1.770	13	2.180
4	2.640	14	2.170
5	2.640	15	2.150
6	2.630	16	2.589
7	2.610	17	2.569
8	2.395	18	2.579
9	2.395	19	2.391
10	2.385	20	3.326

2.3 Financial demands - costs

Table 4 shows the results of the financial demands (costs) of the individual variants. Price calculations are developed in EuroCALC 3 software and the price of the one square meter of the building envelope is calculated. The budgets include not only the prices of the materials, but also the wages of the workers carrying out the construction work.

Table 4. Results of the financial demands.

Var.	Costs [CZK]	Var.	Costs [CZK]
1	2 201	11	2 539
2	1 972	12	2 334
3	2 526	13	2 334
4	2 350	14	2 559
5	2 289	15	3 493
6	2 524	16	2 050
7	3 018	17	2 540
8	2 446	18	2 324
9	2 446	19	2 851
10	2 620	20	2 980

2.3 Environmental demands

Buildings account for 36% of carbon dioxide (CO_2) emissions in the Member States of the European Union [1]. The construction sector is responsible for a large number of harmful emissions, accounting for 30% of greenhouse gas emissions, because of their operation, and a further 18% indirectly caused by material abuse and transportation [2,3]. During material selection, it is necessary to pay attention not only to how much emissions the material produces after installation to the structure but also how much emissions it produces when the material is produced. The environmental assessment was carried out using the assessment methodology of SBToolCZ. Annual equivalent emissions of Carbon Dioxide and Sulfur Dioxide for each variant are determined (Table 5).

Table 5. Annual equivalent emissions of Carbon Dioxide and Sulfur Dioxide.

Var.	Annual equivalent emissions of CO_2 [(kg $CO_{2,eq}$/a)]	Annual equivalent emissions of SO_2 [(g $SO_{2,eq}$/a)]	Var.	Annual equivalent emissions of CO_2 [(kg $CO_{2,eq}$/a)]]	Annual equivalent emissions of SO_2 [(g $SO_{2,eq}$/a)]
1	1.0026	3.0506	11	1.6137	4.5826
2	1.6120	4.4734	12	1.0469	3.1894
3	1.0007	3.0235	13	1.0009	2.7894
4	0.8004	3.3366	14	1.6309	4.9174
5	0.7639	3.0166	15	2.0389	6.4614
6	1.2679	4.7190	16	2.3616	10.4148
7	1.7375	5.3046	17	2.1244	10.6702
8	1.5790	5.3474	18	2.3156	12.1422
9	1.5391	5.0274	19	1.9191	8.5577
10	2.0431	6.7298	20	0.3456	3.7380

2.4 Overall evaluation

The multi-criteria analysis is not a simple process. The overall evaluation is performed so that the values of the monitored parameters for each variant were ranked from best to worst. At the same time, points are assigned to individual variants according to the scale where 1 is the worst value and 20 is the best value. Subsequently, the points were counted and the final order was determined. The results are shown in Table 6.

Table 6. Overall evaluation.

Var.	Thermal-technical assessment		Labor		Financial demands		Environmental demands		**Overall evaluation**	
	Heat transfer coefficient U [W/(m²K)]	Points	Labor [Nh/m²]	Points	Costs [CZK]	Points	Points	Points	**Total points**	**Total rank**
1	0.182	3	2.000	18	2 201	18	7.5	8.5	**55**	**4**
2	0.176	6	1.505	20	1 972	20	5	6.5	**57.5**	**2**
3	0.174	7	1.770	19	2 526	9	8.5	9	**52.5**	**6**
4	0.159	13	2.640	2.5	2 350	13	9	7.5	**45**	**10**
5	0.147	17	2.640	2.5	2 289	17	9.5	9.5	**55.5**	**3**
6	0.162	12	2.630	4	2 524	10	6.5	5.5	**38**	**13**
7	0.179	4	2.610	5	3 018	2	3.5	4	**18.5**	**20**
8	0.136	19	2.395	9.5	2 446	11.5	5.5	3.5	**49**	**8**
9	0.127	20	2.395	9.5	2 446	11.5	6	4.5	**51.5**	**7**
10	0.139	18	2.385	12	2 620	5	2	2.5	**39.5**	**11**
11	0.152	15.5	2.302	13	2 539	8	4.5	6	**47**	**9**
12	0.169	10	2.180	14.5	2 334	14.5	7	8	**54**	**5**
13	0.152	15.5	2.180	14.5	2 334	14.5	8	10	**62.5**	**1**
14	0.173	8.5	2.170	16	2 559	6	4	5	**39.5**	**12**
15	0.168	11	2.150	17	3 493	1	2.5	3	**34.5**	**15**
16	0.173	8.5	2.589	6	2 050	19	0.5	1.5	**35.5**	**14**
17	0.186	2	2.569	8	2 540	7	1.5	1	**19.5**	**19**
18	0.178	5	2.579	7	2 324	16	1	0.5	**29.5**	**17**
19	0.157	14	2.391	11	2 851	4	3	2	**34**	**16**
20	0.187	1	3.326	1	2 980	3	10	7	**22**	**18**

4 Conclusions

Selection of the optimal wall system is not a simple and quick process. It is desirable to assess variants from all angles - criteria. Buildings are responsible for a considerable part of the consumption of primary energy. It is important to build low-energy buildings, use renewable resources, and focus on materials with low environmental impact. There is a need to reduce the energy consumption and the greenhouse gas emissions of the building sector. In total, 20 different variants of the contemporary standardized wall systems are reviewed. For this purpose, brick structures are selected either as single-layer units or as multi-layered construction in combination with a contact insulation system. Furthermore, pre-monolithic forms of lost formwork are assessed. The last variant of the external walls is the design of a wooden building. In terms of the thermal-technical point, the highest number of points reached variant n. 9. In terms of the time consuming, the shortest time is required by variant n. 2. In the case of the costs assessment of the financial difficulty, the variant 2 was the best solution. Variant n. 2 also has the lowest cost. From an environmental point of view, variant n. 5 shows the smallest amount of embodied emissions. Assuming that the significance of all criteria is the same, the variant n. 13 is best - sand-lime bricks supplemented with thermal insulation of grey polystyrene.

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2. B.V. Ventakarama Reddy, K.S. Jagadish, Energy and Buildings **35** (2),129-137 (2003)
3. C. Baglivo, P. M. Congedo, A. Fazio, Building and Environment **82**, 467-480 (2014)