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POSSIBILITIES TO REDUCE THE ENERGY DEMAND FOR MULTISTORY RESIDENTIAL BUILDINGS

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Abstract. Due to imperfect solutions on construction, architectural planning and design as well as building services in multistory residential buildings a huge amount of energy resources is being consumed. In this case, the research on reduction of the energy consumption is relevant. The world experience as well as local requirements of building regulations also solutions for architectural and structural design were analysed in this article. According to research on the consumption of energy resources in multistory dwelling houses, suggestions to increase energy efficiency of the buildings were made.

Keywords: energy efficiency, grey energy, primary energy, primary energy input, final energy.

Introduction

A comparative value of energy resources consumption in European Union housing sector amounts approximately 40% of its total demand. In directive 2006/32/EC of the European Parliament and the Council as well as in the conclusions of EU Council document 7224/07 REV1 it is told by year 2020 that it should be saved over 20 % of energy consumption in EU countries (Action Plan for Energy Efficiency: Realising the Potential COM(2006) 545).

The role of housing construction sector is one of the most important when optimising energy savings and increasing the efficiency of energy consumption. Effective energy saving is possible not just decreasing energy resources demand for heating purposes only, but by including the whole complex of building investment lifecycle. This point of view means that energy resources could be saved even at a selection of building materials stage. Different materials require different energy resources demand for the production (so called „grey energy“). Within a context of the considered problem it should be stated that smaller amounts of grey energy consumption for the material has become very important. The construction process should require as less treatment of materials as possible, this is more efficient when considering the amount of time and working power resources. During the design process, all the decisional solutions such as architectural, planning, structural, building services‘, etc. should fulfil energy requirements of energy-efficient building and allow energy-efficient technological building processes.

From this point of view, energy efficiency should be applied for building demolition and recycling processes as well as for operational period. According to this, within the frame of a project „LONGLIFE“ under „Baltic Sea Region programme 2007-2013“, the concept of energy-efficient multi-storey apartment house will be created. The concept should finally be materialised as a pilot project. Vilnius Gediminas Technical University is one of LONGLIFE project partners from Lithuanian side.

This report presents opportunities to choose construction materials for a building according to the demand of energy resources calculated in pre-design stage as well as comparative energy resources demand analysis of multi-storey apartment houses that were built at different times. Possibilities to increase energy efficiency of a building by operating different external wall models and applying „passive“ energy saving measures are presented within this report as well.

Primary energy demand

Primary energy demand within building construction process comprises the extraction of raw materials, production of details and structures, transportation, storage, utilisation of wastes, and etc. This kind of energy consumption is required at building construction, operation and demolition stages.

The “box” of a living house, according to the demand of “grey” energy, is the most recipient. Usually it is associated to buildings’ sole weight – if more light materials could be used for building structures it would probably contain less “grey” energy. For example, it is needed 1764 MJ of Primary Energy Input (PEI) to produce one cubic meter of concrete, 4098 MJ – for the reinforced concrete (2 % of reinforcement) and 600 MJ for the lightweight concrete (Hegger *et al.* 2008). It is obvious that the density of materials is not directly proportional to the PEI, for this reason, this point of view needs to be proved and requires special researches. Nevertheless, it is also clear that smaller mass of volume directly corresponds to smaller transportation and construction costs, as well as better sound insulation and thermodynamic characteristics.

Some of the building facades directly influence "grey" energy demand as well as demand of energy resources during building operational time. If the solutions of traditional architecture provide possibilities to get optimal result with minimal expenses (Keizikas and Parasonis 2009), nowadays the popular but in most regions untraditional glass facades usually fixed by aluminum structural elements (PEI_{glass} = 35000 MJ/m^3; $PEI_{aluminium}$ = 753380 MJ/m^3; Hegger *et al.* 2008), require deep research on the influences of a building energy efficiency and primary energy demand. It is relevant especially in such variable climatic conditions as Baltic Sea region, where buildings have to adapt to seasonal changes.

Usually houses of traditional architecture are the examples that built using local materials (mostly of low PEI level) and technologies based on longevous experience and local climatic conditions. The shape, size, structure of dwellings usually depends on predominant climatic zone at particular location. The zones may be summarized as polar (including ice cap and tundra), sub-arctic (cool or humid microthermal climates), continental (with humid cool summers), temperate (humid mesothermal), subtropical (coastal, humid and warm), dry (semi-arid steppe and desert), tropical (savannah and tropical rain forest zones) (Oliver 2007). It is important that within all mentioned climate zones to some extent building envelope solutions were formed leaving much less space for transparent partitions than for apparent ones: the least area of openings in dwellings can be found in coldest and warmest places and the most area of transparent external partitions can be seen in continental and temperate climate zones.

Nevertheless, glass facades used in contemporary times cannot be comparable to the quality of the old windows. Modern ones are much leak-proof, also effective for solar insulation and heat inflow in wintertime. On the other hand their thermodynamic characteristics are still insufficient and it is not possible to apply effective thermal insulation for them. Also, unfortunately, overheat of inner spaces during summertime necessitates the installation of a conditioning system which is very inefficient according to the energy consumption. All these aspects represent the fact that application to some measures of traditional architecture when solving energy efficiency of houses is still relevant.

Primary energy demand also includes building construction process. The selection of technological solutions for construction works is an important link within a chain of energy resources efficient consumption. During the soviet times construction sites looked like mounting works to erect the prefabricated details end elements. Nowadays building construction process takes a lot more operation works and expenditures on the site. The production of prefabricated details and structures requires labour expenditures and consumption of energy resources as well. However, its efficiency, quality control, waste of materials and recycling is on a higher level than the production itself in a building construction site.

Preliminary researches on the demand of energy resources show that less expenditure were experienced to erect a multi-storey apartment house made of precast concrete elements and masonry structures. According to comparable weights, the house made of precast concrete elements required 30 % less energy than the one, made out of masonry structures (Martinaitis 2001). During the operational period both buildings have a similar energy resources demand – heating and ventilation systems require the major part of energy consumption.

More thorough researches on energy consumption for the whole building lifecycle costs by operating on the comparative as well as absolute values, are needed. Within the next chapter of this paper some evaluations of energy consumption during the operation period of a building are presented.

The structure of energy resources demand and possibilities for saving during the operation time of a building

Overall annual energy demand was determined for each partner country during the realisation of LONGLIFE project. It varies within different partner countries: 120-150 KWh/m^2 in Denmark; avg. 195 KWh/m^2 in Germany and 96–420 KWh/m^2 in Lithuania. During the last period energy prices in Denmark were stabile, in Germany (during the last 10 years) it increased 40 % and in Lithuania (during last 8 years) it increased 66%. It was determined that energy consumption of apartment houses depending on different architectural and structural solutions during the hole operational period consists of 30 to 70 % of the total energy consumption. It is widely understood, that the more energy efficient house is, the less energy is demanded during the operational period.

For this reason, it means Lithuania has the highest potential to save energy resources and decrease CO_2 emissions comparing to the other partner countries.

A research on energy efficiency of three different multi-storey apartment houses with a similar proportion of effective and building envelope areas was made. Buildings were composed by different architectural and plan solutions and erected at a different period of time (see Table 1). Calculations were made according to the methodology set by STR 2.01.09:2005 „Energy Performance of Buildings. Certification of Energy Performance of Buildings“. There are many certification systems evaluating energy efficiency, sustainability or even ecological and social aspects of a house (for example, German DGNB, LEED in the USA and many others). However, the official one in Lithuania, evaluating consumption of final energy (which reaches the consumer considering the loss of transmitting and converting energy) is STR 2.01.09:2005. The houses evaluated by this methodology are defined by characteristics stated below:

Table 1. Description of researched houses

House	Year of constr.	Type of structures	Effective area, m^2	Envelope area / Effective area index	Proportions of heated volume, m: Height up to cornice/ parapet	Proportions of heated volume, m: Height up to roof-top	Width, m	Length, m	Description of compactness
No. 1	1973	Masonry, (typical proj.)	1390	1,35	- / 14,3	-	11,50	29,70	Compact, facade is with protruded elements
No. 2	2002	Masonry	1752	1,33	I volume: 15,25 II volume: 9,00	20,70 13,20	11,70 8,20	23,20 17,60	Incompact, facade is even
No. 3	2007	Masonry	1237,21	1,31	10,0	13,80	14,30	27,60	Compact, facade is even

Volumes of the houses are covered by several types of external partitions with various thermodynamic characteristics. House No.1 is formed of partitions without insulation layers, majority of windows are old, wooden and double glazed. Facades are not even (with protruded elements). U-value of the external partitions for the houses No.2 and No.3 almost fulfils nowadays regulations: house No.2 (incompact – composed out of 2 contiguous volumes) average heat transfer coefficient of external walls U_w is close to 0,21 W/(m^2K), average roof characteristic U_r is less than 0,2 W/(m^2K), floors under cellar U_c = 0,25 W/(m^2K); house No.3 U_w = 0,23 W/(m^2K), U_r = 0,18 W/(m^2K), $U_{c\ c}$= 0,20 W/(m^2K). Both houses are equipped by new wooden windows with double glazing.

After applying STR 2.01.09:2005 methodology and processing calculations using "NRG-sert" (approved by Ministry of Environment, Rep. of Lithuania) computer programme package, energy performance and qualifying index (C) values were got (Table 2):

Table 2. Qualifying index and energy performance class of evaluated houses

House	Qualifying index C value	Energy performance class
No. 1	2,18	E
No. 2	0,93	B
No. 3	0,90	B

The Fig 1 shows the presented calculated values of energy loss (Q):

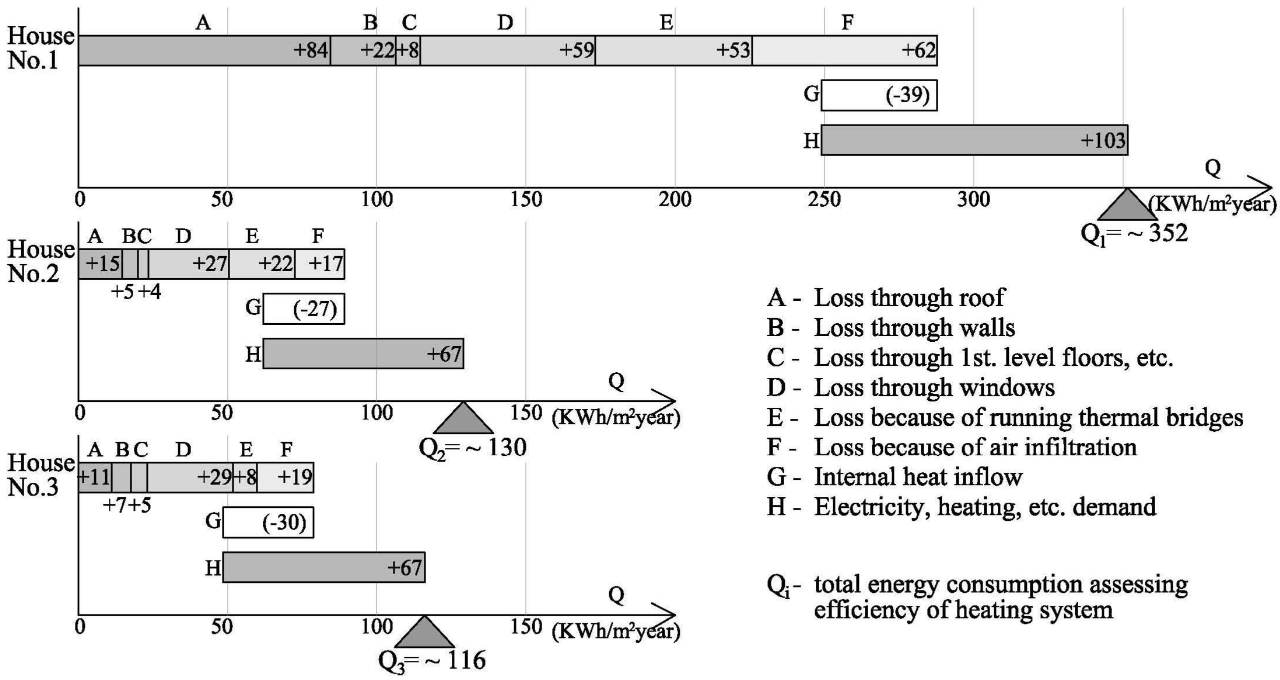

Fig 1. The diagrams of annual energy demand within different energy efficiency class of multistory apartment buildings

As it was expected, the worst results were obtained by the house No.1 – the oldest and without a thermal envelope. The best performance is obtained by a brand-new, compact house No 3. It could also be concluded from the diagrams that the better parameters of external partitions (U-value) are, the more important parameters belonging to the building exploitation (heating, ventilation, hot water preparation and control systems, etc.) get. Due to this, energy loss of the house could be divided into 2 groups, as:

1. – Dependent on the thermal characteristics of the building envelope (Fig 1, positions A-F);
2. – Intended to obtain healthy and comfortable internal microclimate (Fig 1, position H).

The enhancement of parameters belonging to the first group could be called as an application of “passive” measures to increase the energy efficiency of the building. Similarly, the enhancement of the parameters belonging to the second group (including responsive usage of electricity, hot/cold water, etc.) could be called as an “active” measures targeted to the same purpose. Loss of the second group will not to be discussed in this article. It is worth mentioning that the efficiency of heating and ventilation systems depends on the quality characteristics of external partitions. This means that by improving the mentioned above characteristics the value of the second group could also become better.

For the better interpretation of A-F loss characteristics, it is worth to evaluate every factor (forcing building energy performance) in percents and compare it to the external partition areas expressed in percents as well. It is shown in Table 3.

The percentage of external partitions of the houses No.1 and No.2 are similar. This shows that it is possible to evaluate the importance of influencing energy efficiency parameters by comparing the house performance. According to the presented results, the most effective measure to save energy is the quality of external walls and its main characteristic – heat transfer coefficient (also opposite proportion to the U-value). By changing value of the coefficient from 1,27 to 0,21 W/m^{2}K the loss drops down more than 5 times (approx. 70 KWh/(m^2 year)). Comparing the characteristics of windows, it seems that the new ones (wooden with double glazing, one selective case) influence energy performance not that much – these transparent partitions decrease energy loss of old windows approximately twice. However, after assessment of air infiltration, which is related to sealing of windows, the effect of it could be equal to the insulation of walls.

Undoubtedly, comparing old and new buildings the results of new ones should be better due to tighter regulations. Moreover, the accomplished comparison can reason economic efficiency by refurbishing the old ones. However, this comparison doesn‘t reveal the influence on energy efficiency by architectural and plan solutions of the houses. For this purpose the data of energy loss in the house No.3 is important. Its area of external partitions is different comparing to the ratio of the houses No.1 and 2. Moreover, the annual consumption of energy per square meter is 10% better than in the house No.2. This means that the increase of energy efficiency in house No.3 was influenced by better thermal characteristics of partitions or by the compactness of the building.

In order to demonstrate the influence for building energy efficiency by previously mentioned characteristics it is necessary to compare buildings by modelling their external partitions using the same structural solutions of thermal envelope. For this purpose the properties of external partitions in the house No.2 are assigned to volumes of houses No.1 and No.3. The results of the modelling are presented in the middle part of Table 3.

Considering the features of compact and regular forms to take less area of external surface in the same volume than incompact ones (Fig 2), the building No.3 is modelled to be increased in size by one floor. Ergo, width and height proportions of the house become equal and closer to compact form. Thereby, ratio of effective area and area of external partitions decrease to 1,17. The loss results through external partitions per square meter of effective area per year are shown at the bottom of the Table 3.

Table 3. Evaluation of factors forcing building energy performance comparing to external partition areas

House No.	Walls			Roof			Floors			Windows			Losses: running thermal bridges		Losses: air infiltration		Total losses, KWh / m2 year
	Losses,		Area, %	Losses,		Area, %	Losses,		Area, %	Losses,		Area, %					
	KWh/ m2 year	%		KWh/ m2 year	%		KWh/ m2 year	%		KWh/ m2 year	%		KWh/ m2 year	%	KWh/ m2 year	%	
1	84,5	29,4	48,0	22,0	7,6	18,7	8,2	2,8	16,5	58,5	20,3	16,8	52,6	18,3	62,0	21,6	287,8
2	14,6	16,4	50,4	5,4	6,1	19,9	3,5	4,9	15,0	27,0	30,4	14,7	22,0	24,7	16,5	18,5	89,0
3	11,2	13,9	35,9	6,5	8,9	25,9	5,4	6,3	22,9	28,7	36,7	15,3	8,1	10,1	18,9	24,1	78,8
After setting parameters of external partitions of house no.2 to houses no. 1 and 3:																	
2-1	14,0	12,2	48,0	5,2	4,5	18,7	3,9	3,4	16,5	30,6	26,6	16,8	37,7	32,8	23,5	20,5	114,9
2-3	10,3	16,7	35,9	7,2	5,6	25,9	6,2	4,4	22,9	28,7	30	15,3	8,1	24,4	18,9	18,9	79,4
After increasing the height of house no.3 by one floor:																	
3a	11,5	15,1	40,6	5,1	6,7	22,6	4,2	5,5	19,9	28,5	37,4	16,9	7,6	10,0	19,2	25,2	76,1

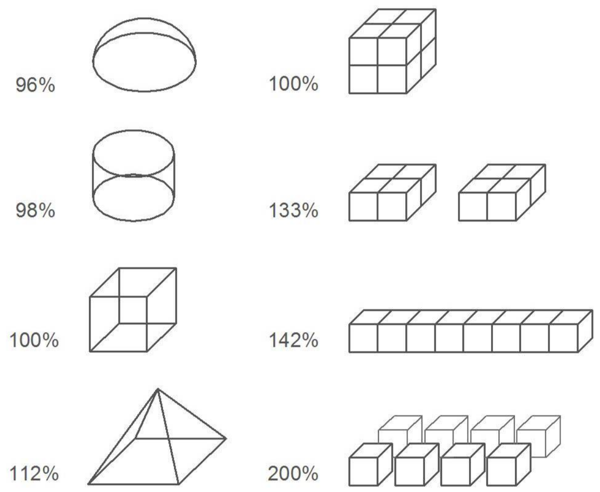

Fig 2. Transmission of heat losses of various 3D shapes with the same volume (Hegger *et al*. 2008)

The energy efficiency data of the modelled buildings revealed that one of the main factors for the house No.3 to show best energy efficiency is compact architectural solution. The influence to efficiency by partition characteristics is likely to be smaller than influence of the shape. In this case, results of energy performance changed fractionally after assignment of external partition characteristics of the house No.2 to house No.3. The facades of a house which are not even (with protruded elements) cause upspring of running thermal bridges, despite the compact volume of the building. This statement is also confirmed by the results of the old construction building which, after assigning the properties of modern buildings, became better but remained worst to that type of shape.

Unfortunately, the performed calculations are not enough to determine the maximum effect that could be achieved by architectural solution to the energy efficiency of a building. On the other hand the obtained information is a solid base for further researches on this topic.

It can be concluded that the protruded elements of the facades provide more energy loss than incompactness of the building. This is partly demonstrated by a small increase of energy efficiency of the raised building during its modelling (only 3–4 %).

Summarising the results of performed calculations, it is worth to mention the possibility to increase energy efficiency of buildings by improving quality of windowing systems. These transparent partitions take 15–16 % of total building envelope area and release approximately 30 (and more) percents of energy compared to the total consumption through external partitions. If taking into account the energy loss considering air infiltration, the total waste of energy through windows is even larger. On the other hand, after improving the sealing of windows it is important to take care about indoor microclimate.

It can be stated the negative outcomes which are leaded by protruded elements of the facades when avoiding larger impact of running thermal bridges. If protruded elements are a part of architectural solution idea they have to be formed out of lightweight materials (with better thermodynamic characteristics) or in a layer of external decoration (out of insulation layer).

Conclusions

1. In order to save energy resources in building sector the complex investment process (extraction, design, construction, operation, demolition, recycling) should be applied. For this reason consumed energy should be evaluated according to primary energy demand.
2. The majority of energy losses of typical project house built in year 1973 are conditioned by insufficient characteristics of external walls, windows and abundance of running thermal bridges, when energy losses of new-built houses are mostly influenced by windowing systems and protruded elements of the facades. The observed consumption of final energy of 1973's house is more than 2 times larger than of houses built post 2000.
3. Buildings of compact architectural solutions have ability to lose less energy than incompact ones. On the other hand facades with protruded elements lead to higher energy loss than incompactness of volume of a house.
4. Performed comparable calculations have pointed the potential of architectural, planning and structure solutions to influence the saving of energy resources.

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