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Investigation of Energy Saving Possibilities in Buildings

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Buildings sector is the largest single energy end-user in the EU. There are numerous possibilities to save energy in buildings. This research deals with the analysis of the possibilities to save energy in buildings of northern latitudes by applying a passive solar energy technique. The article presents results of solar radiation monitoring in Vilnius for a 12 years period and assessment of the possibilities to save heat energy. Data could be used in designing solar houses, calculating passive solar energy gains and evaluating CO_2 emissions reduction.

Key words: *energy saving, buildings, solar energy, passive heating, solar architecture, climate change*.

1. Introduction

Buildings are affected by local climate conditions, consequently, to maintain their main function – to create comfort for residents and other users they should be heated, ventilated, lightened, cooled, etc. Residential, industrial, administrative and other buildings use 40% of primary energy in the EU and in most countries around the world (EC 2009, WBCSD 2008). In hot climates a lot of energy is used for ventilation and cooling, and this is mainly electricity, while in cold climates the most need is for heat energy.

Energy saving measures in buildings bear great importance because of climate change issues, depletion of fossil fuel resources, security of energy supply, financial resources saving, etc. There are several methods for energy saving in buildings: reduced energy needs, efficient use of energy, local renewable energy gains.

This article focuses on thermal energy saving possibilities using passive solar energy which penetrates the buildings through the south glazing. Energy saving research is based on the analysis of monitoring data of global solar radiation on the horizontal plane in Vilnius.

2. Solar energy resources

Solar energy is the resource which varies depending on geographical and weather conditions. Geographical distribution of solar energy resources is easy to calculate using solar constant and solar height over the horizon (formulas could be found in (SORENSEN 2004), also there are numerous programs available on the Internet assisting in calculation of the solar energy gains (NREL).

Weather conditions influence solar energy resources of a particular place and affect the possibilities of applying solar energy to buildings. A solar resources map for Europe (PVGIS 2008) shows that Lithuania has similar solar resources as Germany, Sweden, and more sunshine than the United Kingdom. Comparing the practices of applying solar energy to heat generation (solar hot water production) in the mentioned countries, big differences can be noticed. For example, Lithuania practically had no solar energy produced in 2007, while Germany – 580 ktoe, Sweden – 9 ktoe, the UK – 46 ktoe (EUROSTAT 2007). There is no official statistic on solar architecture applications in these countries, but examples of numerous implemented passive solar heating projects for renovation and new constructions in Germany, Sweden and the UK show (EC 2009) that solar energy application is a common practice in architecture there. In Lithuania and some other European countries there is no tradition to save energy of a building using direct solar energy gains. This situation results from the lack of awareness of solar energy resources and confusion over the outside temperature and solar energy. The outside temperature affects heat losses of buildings, but does not influence solar energy resources of a place. Thus, well-insulated houses could gain solar energy for space heating when solar architecture principles are applied to renovation or construction projects. There are several examples of solar buildings in Lithuania (MILUTIENĖ 2008), but seeking to mitigate the climate change and to save energy in a more economical way (to use direct solar energy for space heating requires knowledge, but not huge investments, mainly solar houses are not more expensive, than other type buildings) (EC 2009, MILUTIENĖ 2008, SECURE), solar architecture principles should be applied to each building whenever it is possible.

3. Global solar radiation in Vilnius

Global solar radiation monitoring was performed at Vilnius International Airport (54°45'N, 25°23'E, about 300 km from the seaside). Global radiation measurements were one of the functions of air quality management system's meteorological mast (*Airviro*) (INDIC 1993). Global solar radiation was measured at 3 m height above the ground with a typical pyranometer sensor LI200SZ (CAMPBELL 1990) measuring direct and scattered solar radiation. Pre-processing (capturing of data and primary signal processing), automatic sensor quality control and alarming in case of malfunction were carried out at the data logger near the mast. Communication via telephone link between the data logger and central computer allowed the data transfer and remote maintenance of that meteorological facility.

Global solar radiation measurements together with the other air quality management system functions started at Vilnius International Airport in mid-March, 1995. Previous analysis (MARŠALKA 2004) covered the solar radiation data from the 1st of April, 1995 till the 31st of March, 2003, over the whole eight years. Further research was carried out from the 1st of April, 2003 till the 31st of March 2007.

Global radiation measurements could be interrupted because of instrumentation failures and calibration procedures. 1995-2003 measurements were interrupted during 6% of the analyzed time period. That had caused a rather insignificant effect on the results according to the data quality objectives for the required accuracy of assessment methods (ISOa 1994). If the measurements were interrupted for more than 5 days, such monthly data were not included into calculations determining average monthly solar energy values for the 12 years period.

Airviro system stored average hourly global radiation values in its database. Using these raw data, total monthly and yearly energy values were calculated for the monitored years. The average monthly values were estimated for the 12 years period (Fig. 1).

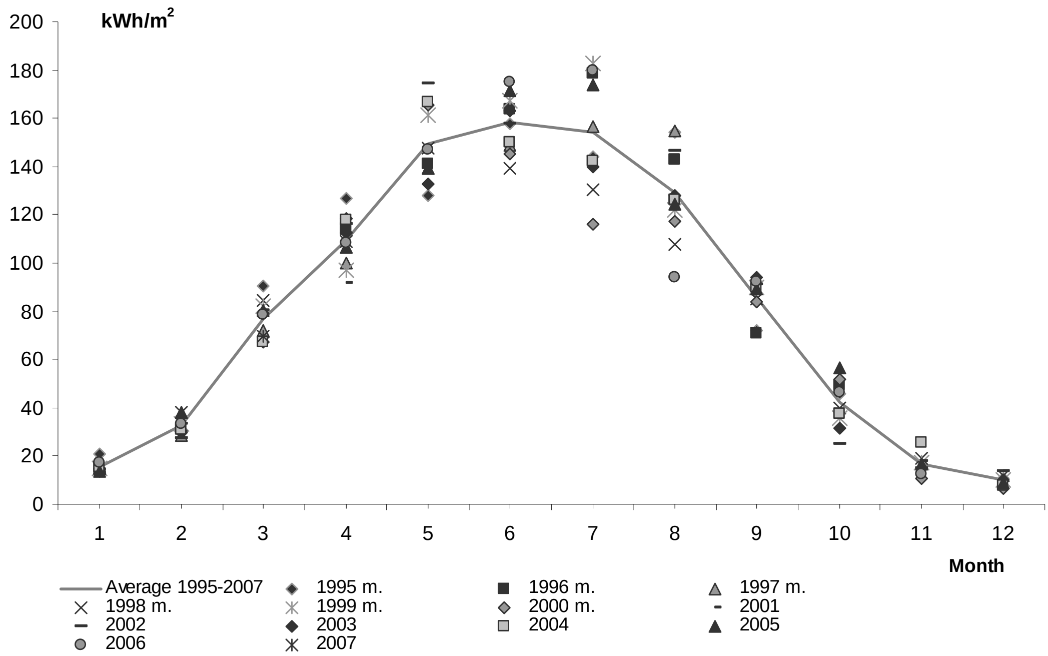

Fig.1. Average global solar radiation on the horizontal plate in Vilnius, monitoring data for 1995-2007 period

Global solar radiation varies a lot from year to year, especially in July and August (*Fig. 1*). The average solar energy amount reaching the horizontal surface during a year in Vilnius for a 12 year period is 980 kWh/m^2.

4. Solar energy amount reaching building via glazing

Passive solar gains are important during the heating season, because it could help save energy for building heating. In solar architecture, the building is like a collector, which collects, accumulates and distributes solar energy (PORTEOUS 2005). South glazing is the main "equipment" to collect solar energy efficiently (*Fig. 2*): in winter time the sun height above the horizon is low, so sunrays penetrate the building through glazing, reach indoor objects (walls, ground, furniture) and heat them. Later, these objects become secondary heat emitters. In summer time the sun is high in the horizon, and energy penetration into the building is reduced. It should be mentioned that the goal to collect solar energy during the heating season does not exclude the need to protect the house from overheating during summer time – and optimization of the energy gain is a task for solar architects and engineers.

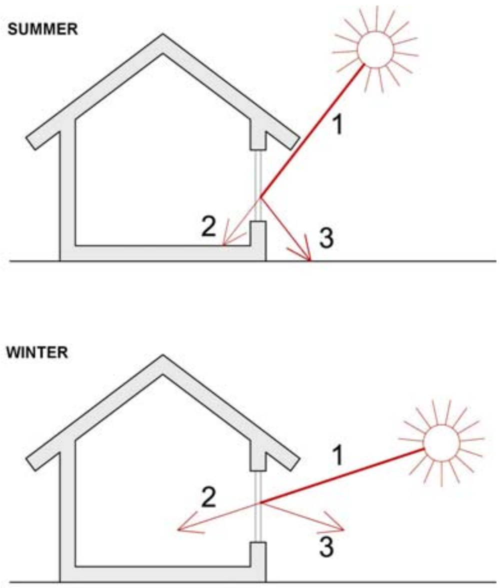

Fig. 2. Solar energy gains through south glazing depend on solar height above the horizon. 1– solar energy reaching the glazing, 2 – solar energy penetrating the building, 3 – reflected solar energy

During a year all facades of the building get energy from the sun. Because of the sun path on the horizon, the most insolated spaces are south, south east and south west facades.

To evaluate energy savings of the building when using solar energy, it is important to know solar energy flows and heat losses through glazing.

Total solar radiation to vertical surface (Q_v) is the sum of direct beam (S_v), scattered (D_v) and reflected (R_v) radiations to the vertical surface (Eq. 1) (MINISTERIJA 1995, LHMT 2002):

$$Q_v=S_v+D_v+R_v. \quad (1)$$

Conversions of global solar radiation to horizontal plane (Q_h) of each month of a year to solar energy to vertical surfaces (east, south, south west, south east, west, north east, north east and north) were done in several steps:

1. determination of direct (S_h) and scattered (D_h) solar radiation for each month, based on the global solar radiation monitoring results in Vilnius (using distribution of direct solar radiation during a year (LHMT 2002);
2. calculations of direct solar energy to the vertical plane (Eq. 2):

$$S_v=S_h \cdot K_v, \quad (2)$$

Where:
K_v - a conversion coefficient for latitude of 54° (KONDRATJEVA 1978) ;

3. calculations of scattered and reflected radiations to the vertical surfaces for each month (Eq. 3–5) (LHMT 2002):

$$D_v = D_h/2, \quad (3)$$

$$R_v= R_h/2, \quad (4)$$

$$R_h =Q_h \cdot A_t/100, \quad (5)$$

Where:
A_t - albedo of active surface, %.

Conversion results are presented in *Fig. 3*.

Direct and total radiations to the south glazing or facade are differently distributed during a year, compared to the energy flows onto all other facades (*Fig. 3*). In the middle of summer direct solar radiation to the south surface is less, than in spring or late summer. The largest amount of direct sun reaches the south surface in March and April. This is very important when planning to reduce heating days of the heating season. Less energy reaching the south facade in summer means fewer problems with overheating (but such distribution does not exclude the need to use a roof overhang to protect from surplus solar energy in summer). Distribution of total solar energy to the south facade is a little bit different from a direct energy flow, but still reaches the highest values in spring. Solar energy to south east and south west facades in spring, autumn and winter is a little bit lower compared to south, and in summer (especially in June and July) – higher. That means less energy during the heating season, and more energy, when there is no need to heat the building. East and west facades of the building also could be overheated during summer and do not provide much energy during the heating season.

Seeking to evaluate which facades could serve for energy gaining during the heating season, it is important to evaluate heat losses through glazing and solar energy gains.

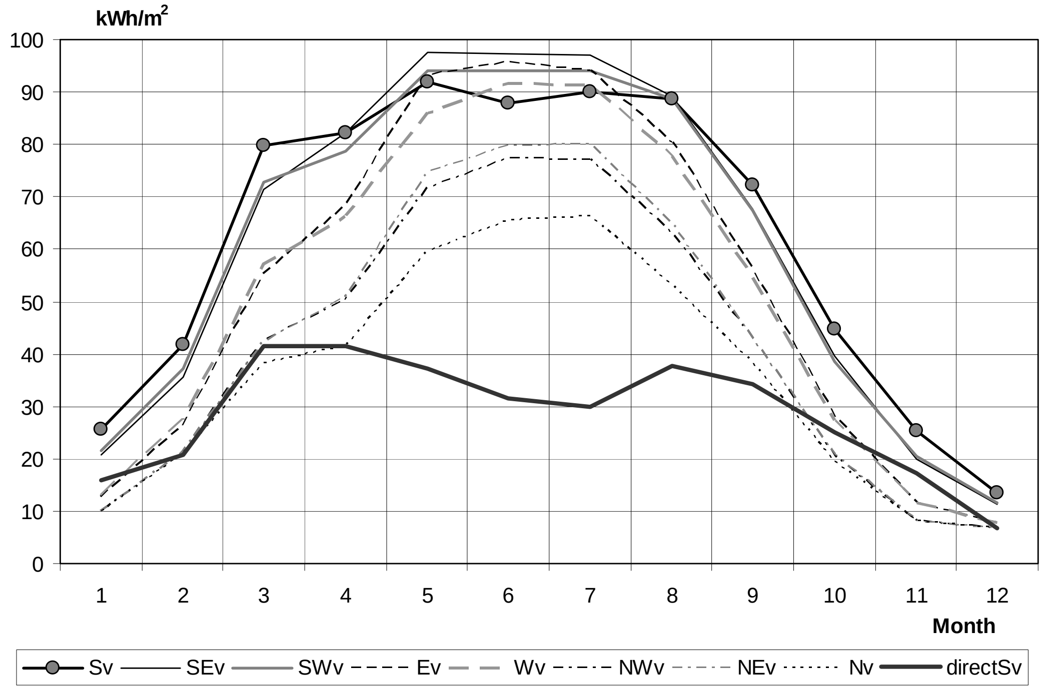

Fig 3. *Total solar radiation and direct solar radiation to different orientations of vertical plane. Sv, SEv, SWv, Ev, Wv, NWv, NEv, Nv – south, south east, south west, east, west, north west, north east and north glazing, directSv – direct solar radiation to the south glazing*

5. Solar energy penetrating the building through its glazing

Heat losses though glazing during a month (H, kWh) depend on indoor (20ºC) and mean monthly outdoor temperature differences during this month (T_m), glazing area (A, in this research – 1 m^2) and heat transmission coefficient (U, in this research – 0.7 W/m^2·K for glazing; this analysis does not evaluate the whole window, i.e. does not include window frames) (Eq. 6):

$$H=24(h) \cdot T_m \cdot N_m \cdot A \cdot U/1000, \qquad (6)$$

Where:

N_m - a number of days during a month (ISOb 1989).

Heat losses are marked with minus.

Solar energy which penetrates the building through its glazing (I, kWh) during the heating season month depends on solar energy reaching vertical surface (Q_v) during that month, glazing area, solar energy transfer rate of glazing (g, in this research – 0.52) and shading factor (r, in this research – 0.9) (Eq. 7):

$$I = Q_v \cdot g \cdot r \cdot A \text{ (ISOb 1989)}, \qquad (7)$$

Heat losses and solar energy penetrating the building have been determined for 7 months of the heating season (October – April) and in 8 orientations (east, south, south west, south east, west, north east, north east and north).

Energy balance through 1 m^2 of the glazing (E, *Fig. 4*) is the sum of solar energy gains and heat losses through it.

In December heat losses through glazing are bigger than energy gains (*Fig. 4*). At the beginning of January solar energy gains through the south glazing begin to exceed heat losses. In October, February, March and April, south, south east and south west glazing provide significant amounts of energy, and this could reduce heating season days. East and west orientated glazing could provide heat in October, March and April.

6. Possibilities to cover the building's heating demand with solar energy

A simple house model of 100 m^2 has been created with a task to evaluate whether solar energy could be used for heating purposes and thus help save heat energy generated by non-renewable sources in the climates similar to Vilnius.

The cases of a model differ in the glazing area of south, east, west and north orientation (*Table 1*).

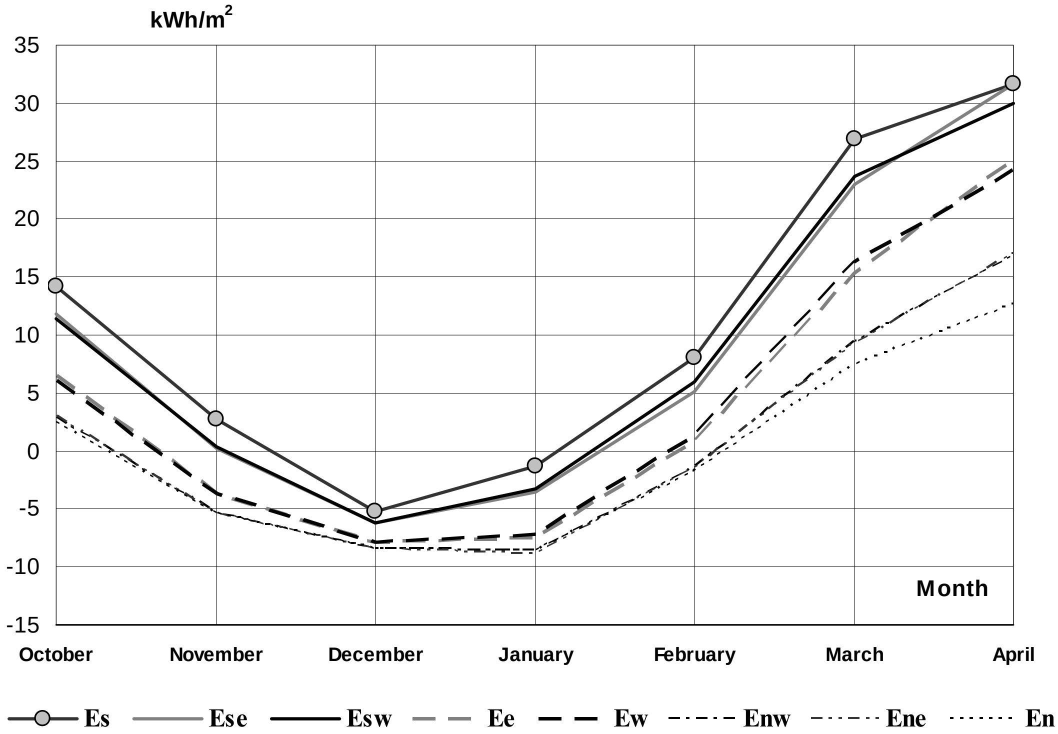

Fig. 4. *Solar energy penetrating the building through its glazing of different orientations (sum of solar energy gains and heat losses). Es, Ese, Esw, Ee, Ew, Enw, Ene, En − energy balance of south, south east, south west, east, west, north west, north east and north glazing*

Table. 1. *Total solar energy gains in 100 m² building with different glazing area*

Glazing orientation	Energy gains, kWh/m²	case 1, m²	case 1, kWh	case 2, m²	case 2, kWh	case 3, m²	case 3, kWh	case 4, m²	case 4, kWh
South	76.88	13	999.44	20	1537.60	16	1230.08	30	2306.4
East	28.78	3	86.34	0	0.00	2	57.56	0	0
West	29.03	3	87.09	0	0.00	2	58.06	0	0
North	-1.60	1	-1.60	0	0.00	0	0.00	0	0
Total	**133.09**	**20**	**1171.27**	**20**	**1537.60**	**20**	**1345.70**	**30.00**	**2306.40**

The biggest solar energy gains are in case 4, which includes only the south orientated glazing which is bigger (30 m²) than the requirements of hygiene norms. When 20 m² of glazing are distributed in 4 directions (case 1) and in 3 directions (case 3), solar energy gains are smaller by 24% and by 12% compared to case 2 (only south glazing). Whether these solar energy gains are valuable or not, it depends on building energy needs (see *Table 2*).

When the building consumes much energy (300 kWh/m² in old buildings), solar energy gains could cover less than 8% of heat needs. When the building is designed as a low energy building, i. e. energy needs for heating 1 m² are not bigger than 25 kWh, solar energy could cover more than 92% of heat needs, and this could mean that there is no need of the heating system, because some heat is provided by occupants (human body radiates heat energy to the space around) and electric devices inside the building (inner energy gains (ISOb 1989).

Table 2. *Building heat energy needs and possibilities to cover them with solar energy in different cases of 100 m² house*

Heat energy needs, kWh/m²	Possibility to cover heat energy needs with solar energy, %			
	case 1	**case 2**	**case 3**	**case 4**
300	3.90	5.13	4.49	7.69
200	5.86	7.69	6.73	11.3
100	11.71	15.38	13.46	23.06
50	23.43	30.75	26.91	46.13
25	46.85	61.50	53.83	92.26

7. Discussion

Theoretically it has been indicated that zero energy houses can be built in Vilnius with its climatic conditions. The questions concerning heat circulations, building ‘energetic behaviour’ under real conditions have not been answered yet. Further research and optionally – practical monitoring of the solar building could answer such questions.

8. Conclusions

1. Buildings are built to serve 50 years and longer, therefore energy savings are important to users. On a global scale it is also important because of the climate change, resource depletion and local economies.
2. The lack of attention to passive solar energy gains leads to energy waste and greater impact of buildings on the environment.
3. Energy saving potential of the building should be determined at early stages of its construction or renovation design, because solar architecture solutions are connected with energy efficiency of the building and they would not be expensive when included into the project before the start of construction or renovation.
4. During the heating season in Vilnius it is possible to gain 76.88 kWh/m^2 of heat energy from the sun through the south glazing, 28.78 kWh/m^2 - through the east, 29.03 kWh/m^2 – through the west glazing. Solar energy, penetrating building through its north glazing does not compensate heat losses.
5. Solar architecture solutions are very closely related to energy efficiency. Depending on building energy needs 4-92% of required heat can be covered with solar energy.

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Energijos taupymo pastatuose galimybių tyrimai

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Pastatų sektorius yra didžiausias energijos vartotojas Europos Sąjungoje. Pastatuose suvartojamą energiją galima taupyti keletu būdų. Straipsnyje analizuojamos galimybes taupyti šiluminę energiją šiaurinių platumų pastatuose naudojant pasyviojo saulės energijos vartojimo technologiją. Straipsnyje aptariami saulės intensyvumo monitoringo Vilniuje rezultatai ir galimybės taupyti šiluminę energiją pastatuose. Straipsnyje pateikti duomenys gali būti naudojami projektuojant saulės architektūros pastatus, skaičiuojant saulės energijos pritekėjimus ir vertinant šiltnamio dujų emisijų sumažėjimą, kai naudojami saulės energijos ištekliai.