Solar energy and thermal building analysis

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Abstract

Reducing energy consumption for heating purposes in buildings by means of elements to capture solar energy, for climatic conditions in Bulgaria, has been analyzed in this work. A reference single-family house has been considered for calculation and analysis of energy balance and solar energy contribution. Building simulation, from the point of view of calculating energy consumption for heating, was one of the main tools for presented study. Different passive concepts were studied by mathematical modeling, and the results of numerical experiments were compared with the corresponding results obtained from TRANSYS computer simulation model. We consider as the functional unit a whole building, which is assumed to be comfortable and healthy for occupants. Hot water supply in houses was analyzed by simulation model for solar installations, and the results were grouped for three solar zones in Bulgaria.

Appropriate design and construction of building can reduce the energy consumption and the environmental impact over their life cycle. Reducing energy consumption for heating purposes in buildings by means of elements to capture solar energy, for climatic conditions in Bulgaria, is the objective of this work. Two main approaches for solar energy utilization in buildings are applied: active and passive design Philosophy. The first approach was analyzed for hot water supply in houses, and the second – for heating purposes. A reference single-family house has been considered for calculation and analysis of energy balance and solar energy contribution.

The performance of solar systems depends upon local climatic conditions. From this point of view they are very different from conventional domestic heating system and system for hot water. Two sets of climatic data are needed to conduct analysis of the thermal solar systems. The first is the 'normals' of daily air temperature distributions for a typical day in each month of the year. These are required to calculate heat loses of a building during the heating period and the thermal loses of solar collectors in hot water solar systems. The heat loses should not be taken from tables of heating degree day figures, as they will vary according to the solar gains, wind speed, effective temperature of the sky, internal gains of the building etc.

The second set of climatic data is required to assess gains of the house or the solar collectors due to absorption of solar radiation. They are affected by such climatic factors as the amount of cloudiness and the atmospheric clarity.

I. Available meteorological data

In Bulgaria, the average annual period of sunshine is about 2100 hours. In some of its regions it may reach 2500 hours, which corresponds to 1400 ÷ 1600 kWh/m^2 annually on the horizontal surface. The assessment of long-term observations from more than 40 meteorological stations in Bulgaria has shown that the country can be divided into three "solar zones" (Fig.1).

For design purposes it is best to use a full year's data, or full seasonal data if the process is seasonal one, and if data are available for many years it is necessary to select the best set. Klain (J.A.Duffie and W.A. Beckman, 1974), suggests the concept of a design year, which using many years data, selects for every month the radiation closest to the all year average for this month. Monthly average temperatures are used as a secondary criterion where necessary.

The set of month's daily distribution of solar radiation and ambient temperature constitutes the design year data. These quantities are often estimated in hour-by-hour time period.

Radiation data are the best source of information for estimating the incident solar gain. However, the network collecting solar radiation in Bulgaria is still very scarce; complete radiation data are available only from Sofia and partially from any other places. The main concern is therefore, to use empirical relationship to estimate radiation from hours of sunshine or cloudiness. Data on average hours of sunshine are available from over 40 stations in Bulgaria. Many papers have been written on the sunshine based models to estimate solar radiation on horizontal surface (J.A.Duffie and W.A. Beckman, 1974; Halouani N. and C.T.Nguyen, 1993). Well-known Kimbal-Angstrom-Page model was used to calculate total radiation on horizontal surface through the day. Design year data for solar radiation we have received for the stations with available sunshine hours data. Temperature distribution data are available for many places in Bulgaria

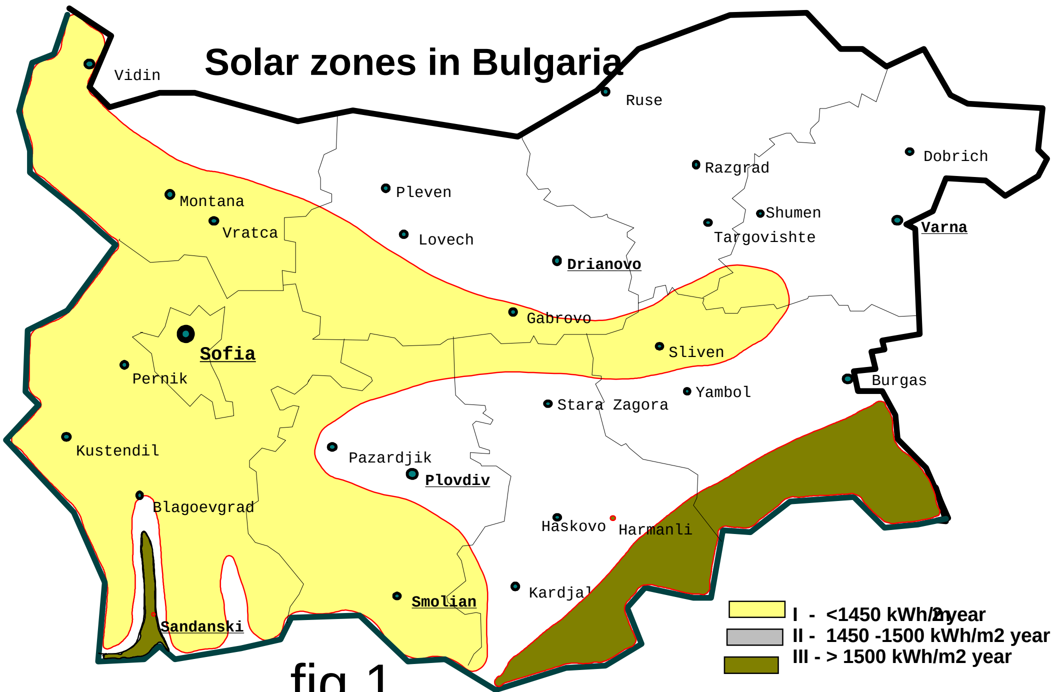

fig.1

II. Solar heating in buildings

Solar design in buildings has two approaches: active and passive solar systems. The first uses solar colleting panels, storage tanks, an energy transfer mechanism and an energy distribution system. It always employs one or more working fluids, which collect, transfer, store and distribute the collected solar energy. The working fluids are circulated by means of fans or pumps.

The second approach, passive solar design seeks to reduce the house's energy budget by close attention to orientation, insulation, window's placement and design, and the subtleties of the energy transfer properties of building materials. Since solar gains are present in every building, all buildings are passively solar heated to some extent. It is when the building has been designed to optimize the use of solar energy and when solar energy contributes substantially to the heating requirements of the building that is termed solar building. Passive solar energy systems work with the climate rather than in spite of it, as is characteristic for contemporary room conditioning technology.

There are two types of passive solar heating: direct and indirect gain systems. All other categories are subsets within these two approaches. The direct gain system uses a transparent wall to allow solar radiation to enter the space requiring heating. The energy is absorbed and stored by the areas of thermal mass it strikes. The thermal mass is isolated from the external climate by insulated envelope. The thermal mass then heats the room by radiation and convection. Movable insulation may be applied to the transparent wall to prevent excessive heat losses at night.

The indirect gain systems combine the function of collector and storage as a part of building structure. Heat is transferred from storage to the room by radiation and convection. The following subsets are included within the indirect gain category: Trombe-Michell wall, water wall, roof pond, attached sunspace, thermosyphoning collectors etc.

In order to utilize solar energy, it is essential for the planning process to know in advance what amount of energy will fall on each individual component, and accordingly, what part of it will be absorbed, and also how to control this energy. For each specific building, this depends on a great extend from the geographical region and the local factors.

1. **Direct gain systems**

There are four thermal aspects of window design in direct-gain passive solar building:

- Design to maximize the penetrating solar radiation through windows during the heated season, implying consideration of energy storage in the fabric as well as energy collection through windows during other seasons.
- Design to control condition losses through the glazing, which may be very large due to poor insulation characteristics of the windows.
- Design for the control of any excessive ventilation losses, associated with entrances and openable windows, especially important in wind areas;
-Design to control overheating in hot weather in summer caused by large heat gains through windows in building.

A successful design must balance all aspects and combine them into a workable design. Choice of window orientation is especially critical. Energy balance depends upon local climatic conditions and must be considered in any direct gain passive solar building.

Window in direct gain solar building provides the key part for radiation gain, but also tends to be key week element in overall thermal insulation. Glazing thermal performance can be characterized by two parameters, the U-value (reflecting the heat losses), and the shading-transmittance coefficient (reflecting solar gain through window).

The U-value (loss coefficient), in units W/m^2K, is the heat loss through unit area of the window, for each degree temperature difference across the window. The lower the U-value, the lower the heat loss through windows. The U-value of window depends on whether single, double or triple glazing is used. The frame also has considerable influence.

Solar radiation gains are only available between sunrise and sunset. If the window opening is well insulated during the long period of darkness, the balance between heat gains and losses through windows is radically altered. Night insulation can thus have a great effect on the overall 24-hour losses, especially in winter at high latitudes. Curtains are assistance especially with single glazing; their relative effect is somewhat less with double glazing and negligible with triple glazing.

The transmittance of glazing to short-wave solar radiation varies with angle of incidence. Energy is lost both by multiple reflection from the surfaces and by absorption in the body of the glass. These losses increase as the sun strikes the glazing more obliquely. If positive use is to be made of solar energy gains through windows, the glass thickness should not be greater than is necessary to give adequate security against high winds. Further, where economically possible, glasses of low iron contents should be used, because of better transition characteristics.

Overall light transition coefficient of window (τ) can be defined as it is made in (J.A.Duffie and W.A. Beckman, 1974). The transmittance for beam radiation varies with the solar incidence angle, and so depends on the time of day. On the other hand, following (J.A.Duffie and W.A. Beckman, 1974), diffuse sky radiation and diffuse ground radiation, which may be considered isotropic, is treated as beam radiation with angle of incidence $\Theta = 60^o$. Therefore, the different optical properties of the two components of solar radiation require separate calculation of transferred quantities of solar radiation across the windows.

The total influence of windows on energy requirements of house can be evaluated only when the losses are compared with the energy gains from solar radiation through windows. The result of these comparisons indicate, whether enlargement of window surface area and improvement of window construction have a significant influence on annual heating requirements. It is obvious, that energy balance of window depend on orientation, construction and glassing type, insulation of house, weather condition in region etc.

The window and the room in direct gain window systems are, in effect, a vertical flat plate collector with thermal capacitance. The net rate of energy transfer across window (receiver) of area $\mathbf{A_w}$ at any time can be written as:

$$\mathbf{Q_r = A_r [\alpha F_c (q_b \tau_b f_i + q_d \tau_d) - U_L F_I (T_r - T_a)]} \qquad \mathbf{(1)}$$

The effective absorbance, α of the window – room combination can be approximated by:

$$\alpha = 1 - \frac{\tau_d \rho_R A_r / A_R}{1 - \rho_R (1 - A_r / A_R)}$$

where ρ_r is the reflectance of the room surfaces, $\mathbf{A_r}$ is the receiver (window) area, $\mathbf{A_R}$ is the room surface area. $\mathbf{F_c}$ is a control function, which is unity when there is no movable insulation, covering window and zero if movable insulation is in place. $\mathbf{F_i}$ is also control function, which is unity when $\mathbf{F_c}$=1. With insulation in place $\mathbf{F_i}$ is the ratio of the loss coefficient with insulation in place to the loss coefficient without the insulation.

There are two base terms in equation (1) – the solar gain term (two radiant members in parenthesis) and the heat loss term. The first term (direct radiation) depends on window orientation, whereas second term (diffuse radiation) does not depend on orientation (to a certain extend).

2. Direct gain systems for Bulgaria's climate

Thermal performance studies of direct gain systems based on equation (1) have been carried out for territory of Bulgaria. Five locations where global solar radiation data are available have been selected for presented study. The selected locations represent specific climatic regions in Bulgaria: Sandanski – south region with maximal sunshine hours and high winter temperature; Sofia – industrial region with low-level of solar radiation and relatively low winter temperature; Smolian – south mountain region with large winter sunshine periods; Varna – coastal region in East Bulgaria and Pleven – plane region in North Bulgaria.

Energy balance for unit area of windows is presented in terms of monthly and seasonal energy quantities in units of [kWh/m^2 month] or [kWh/m^2 season]. With $\mathbf{Q_{loss}}$ is described the increase (comprisal with insulated wall) of monthly (seasonal) heat loss of unit area for windows (because of the low window insulation characteristics) and with $\mathbf{Q_{sol}}$ – monthly (seasonal) extracted solar energy by unit area of window (with assumption $\mathbf{A_r/A_R}$ = 0.2, ρ_R = 0.3 and appropriate accumulation ability of internal walls and furniture). To determine how actual thermal accumulation and internal gains affect the usable solar contributions, dynamic simulations were done for a reference single-family house (fig. 3).

The key issue for the energy balance of the window in direct gain systems is its construction. Double or triple glazing deliver about as much useful energy as the heat lost over the heating season. The window contribution in seasonal energy requirements can be estimated only on the base of seasonal energy balance in the building. The net energy, extracted from unit area of window, can be determined by comparing the energy, penetrating the glasses and the increasing of heat losses because of replacing the wall with window (with low insulation characteristics). This can be done by careful energy analysis using climatic data for reference region and construction data of walls and windows. Such analysis has been carried out for many climatic regions in Bulgaria and for different construction and orientations of windows.

The detailed energy balance for window, considering as solar gain device is illustrated for two locations in Bulgaria – Sandanski and Sofia (table 1 and 2) and graphically for Sandanski (Fig. 2). Tables present monthly solar energy gains for 1,2 an 3 – glazed windows $\mathbf{Q_{sol}}$ and increasing of heat losses $\mathbf{Q_{loss}}$ due to replacing wall surface (thermal resistance R=2.8 [m^2 K/W]) with window). It is noteworthy in tables that in December, January and February one glazed window delivers less useable solar gains after losses for south facing windows for Sandanski and in November, December, January, February and March - for Sofia. These data and other results of our researches show, that single glazed window could not be applied for direct solar gain systems in Bulgaria. Double glazed window delivers as much useful energy as the heat lost in all months in heating season for Sandanski region (it is fully energy efficient), but for Sofia, in December and January the solar gains are lower then heat losses, and seasonal efficiency must be assessed by fully seasonal energy balance for building. Our researches also show, that triple glazing windows (south-facing) are energy efficient for all regions in Bulgaria. Double-glazing windows can be used as a solar gain system for many places in Bulgaria, but after seasonal energy analysis for all building. South-east and south-west orientation are also appropriate as a solar gain system for many places, even west and east orientation can be used as a solar gain system for some places in south Bulgaria.

Table 1. Sandanski (South façade)

	$\mathbf{Q_{sol}}$ – [kWh/m^2 month]			$\mathbf{Q_{loss}}$ –[kWh/m2 month]		
	Glass number			Glass number		
Month	**N=1**	**N=2**	**N=3**	**N=1**	**N=2**	**N=3**
Oct	105.4	90.5	79.7	9.47	4.52	2.72
Nov	59.1	51.0	45.0	38.55	18.27	11.71
Dec	40.0	34.7	30.7	69.12	32.86	19.96
Jan	43.4	37.5	33.2	80.55	38.16	23.36
Feb	69.4	59.6	52.6	62.3	29.52	18.02
Mar	75.0	63.9	56.1	48.04	22.97	13.87
Apr	75.0	62.7	54.6	14.41	6.88	4.19

Table 2. Sofia (South façade)

	$\mathbf{Q_{sol}}$ – [kWh/m^2 month]			$\mathbf{Q_{loss}}$ – [kWh/m2 month]		
	Glass number			Glass number		
Month	**N=1**	**N=2**	**N=3**	**N=1**	**N=2**	**N=3**
Oct	81.84	70.37	61.69	29.86	13.46	8.45
Nov	44.1	38.10	33.60	60.29	27.19	16.99
Dec	34.1	29.14	25.73	89.97	40.57	25.47
Jan	34.72	30.07	26.35	101.1	45.66	28.56
Feb	53.76	46.20	40.60	81.15	36.65	22.95
Mar	63.55	53.94	47.43	69.10	31.20	19.50
Apr	70.80	59.40	51.90	32.33	14.63	9.13

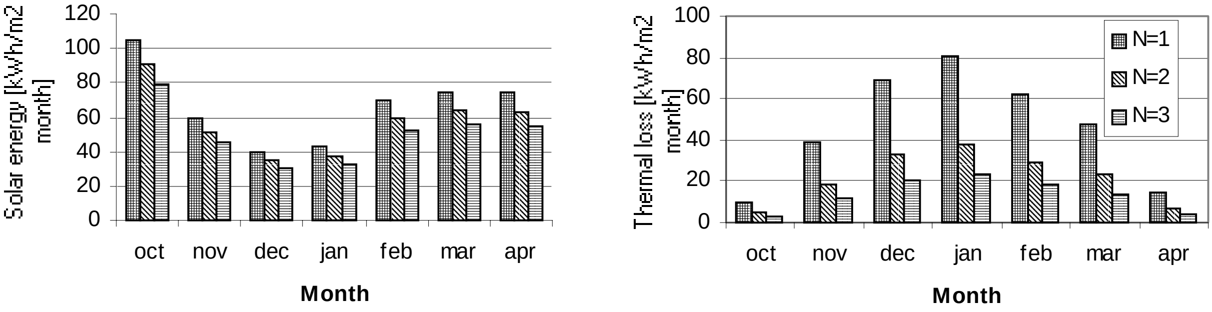

Fig. 2 Energy balance for south-facing window in Sandanski region.

3. Indirect passive solar systems – massive wall

Massive wall is most frequently designed as a combination of dark colored solid wall (stone, concrete, brick) with glazed surface in front of it and an air layer (10 to 15 cm) in between. One or two glass coverings, aiming to diminish convective and radiant heat losses, protect the wall and the dark color increases the absorbing capacity. Opening in the lower and upper part of the wall secure air circulation between the room and the air layer between the wall and its external glass covering. Solar radiation passing through the transparent coverings and absorbed by the solid surface is transformed into thermal energy, and part of it warms up the air in the space between the wall and glass. The heated air rises and enters into the internal space. Another part of the solar energy is accumulated in the solid wall and is transferred to its internal surface and is further transmitted inside the room. The third part of solar radiation covers the losses of the transparent coverings. These losses are related to the number of coverings. Some screening devices are used to reduce thermal losses.

The energy efficiency of massive wall solar heating systems can be calculated by several methods. The most important factor here is the correct choice of wall width with respect to the thermal characteristics of the used material.

The followed Table shows the results obtained by means of TROMBSYS computer programme, producing a two-dimensional non-stationary mathematical model of the massive wall system. The model and the numerical solution of equations system are presented in (Shtrakov St,2000). Calculations are made for a concrete solid wall with width 30 cm and distance of 12 cm between the wall and the glass coverings. As a useful energy in Tromb wall we consider energy contribution by natural convection and radiation to the room, and energy compensation, which the insulated wall loss if there was not Tromb system mounted.

Table 3. Solar energy utilized by Tromb wall – one end two glass covers

	Energy utilized by Tromb wall – [kWh/day m^2]							
Town	**Glasses**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
Sandanski	1	1.94	0.74	0.17	0.17	0.82	0.91	1.23
	2	1.99	0.92	0.39	0.41	1.06	1.12	1.32
Sofia	1	1.21	0.31	0	0	0.37	0.59	0.99
	2	1.38	0.54	0.21	0.18	0.64	0.79	1.14
Smolian	1	1.44	0.65	0.11	0.12	0.64	0.55	0.79
	2	1.66	0.9	0.35	0.36	0.91	0.82	0.98
Plovdiv	1	1.72	0.55	0.11	0.09	0.65	0.76	1.1
	2	1.85	0.75	0.32	0.31	0.9	0.95	1.2

Drianovo	1	1.63	0.53	0.1	0.07	0.48	0.6	1.05
	2	1.76	0.73	0.3	0.28	0.72	0.8	1.17
Varna	1	1.59	0.74	0.17	0.17	0.82	0.91	1.23
	2	1.69	0.74	0.33	0.35	0.68	0.76	1.08

Data in table 3 show, that the indirect passive solar systems are not so efficient in typical winter months (December, January), when we use it in house with good thermal insulation, because massive wall have low thermal resistance in comparison with the insulated wall, but in other months of heating season it will have significant contribution. Energy efficiency of the massive wall can be improved significantly by using thermal insulation in periods when solar radiation is not present. The overall efficiency of the massive wall system can be assessed only by energy analysis of building over year or heating season.

III. Single-family house - description

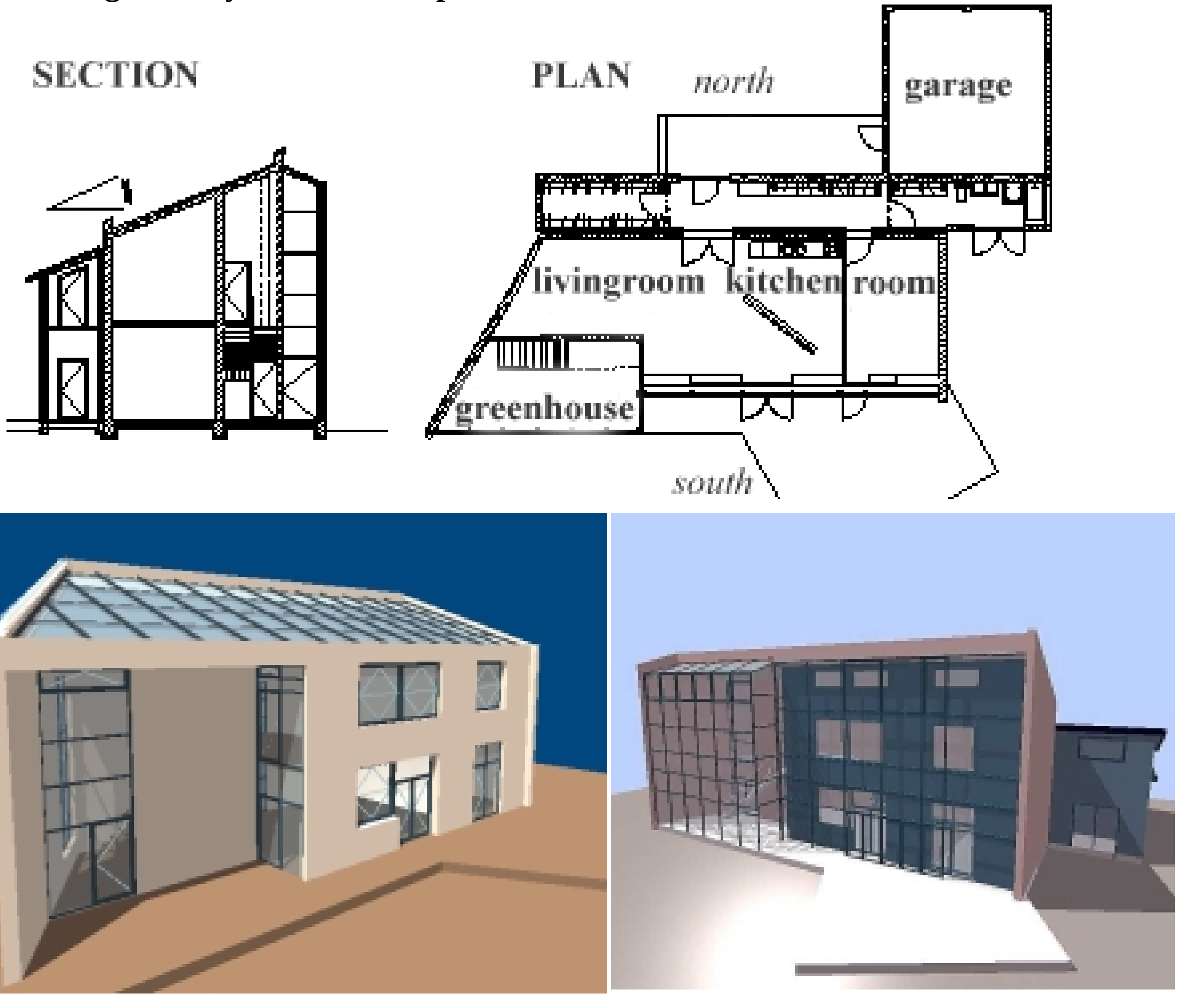

Fig.3

An example of a model exploration of energy efficiency of a house is the represented energy analysis of a modern, well-insulated house, utilizing solar radiation. Under consideration is a solar designed house, developed in 4 different variations with equal building area of outer envelope and equal volume. The difference is in arrangement of the solar design elements and their type-green house, massive wall and structural glazing, Trombe wall, solar collectors for water heating etc. The building is single family two-floor house. The floor area of living spaces is 120 m^2, of garages-36 m^2, of green house is 21 m^2. The form, size and thermophysical characteristics of the building provide optimal microclimate in the interior with minimum use of conventional energy. The building itself controls its own microclimate.The environment conditions vary according to location, climate, season and day-time. In winter the ideal energy efficient houses absorbs as much as possible solar energy and transmits minimum heat towards the cold night sky. In summer the same building reflects solar radiation and transmits maximum heat towards the sky.

In order to avoid summer overheating on West side the plan of the building is open with 30 degrees from exact South as trapezoid. Thus we avoid the crucial 2 o’clock summer afternoon overheating.

- Building materials and thermal insulation

The building materials are traditional. The structure is massive concrete. Floors-concrete, façade walls-25sm YTONG light concrete bricks+4sm FIBRAN thermal insulation, PVC fenestration, Roof-concrete 10sm+ 8sm FIBRAN thermal insulation.

-Fenestration and windows for heat gain

This house uses only south oriented windows for heating. To reduce radiation towards the cold night sky we propose AL foil between outer fenestration and massive wall. No shading device is necessary for the West facade, since it is rotated to NW.

- Heat zone house dividing

This building is divided into 3 temperature zones. The first zone contains living rooms and bedrooms. They require 20 degrees C and are designed to be in the South part. Corridors, baths and storage rooms require 16 degree C and are positioned in the North part. They are also isolating buffer for habitual spaces. The third zone is garages-require 10 degree C.

- Ventilation and heat flows in the house

The living room is 2 level spaces and in 3 of 4 variations contains the stairs. Therefore the plan is open and allows free heat flow between the 2 floors. Habitual rooms and corridors are divided by walls and air flow is controlled by doors. When house needs to be cooled these doors are open and North cold air penetrates into the rooms. East end of the corridor and bathroom increase the sucks ion effect when we exploit cold north fresh air or when we through out exhausted warm air from the living rooms. That is why entrance door and living room door are closely positioned. Green house and space between Trombe wall and fenestration also encourage suction effect. Close proximity to the existing hill is supposed to keep house from E, N-E winds, which satisfy winter condition requirements. On the other side the velocity of the north coming air between the building and the hill would produce unwilling heat suction effect-consequently we don’t use east windows.

- Transitional heat producing spaces. Passive systems

In Bulgarian traditional houses is always present a south oriented transitional space between habitual spaces and exterior ground. In its simplest form it was just projected floor and roof. Now we continue this tradition-using greenhouse. Moreover we integrate it as an indirect passive system. The other passive integrated system is the black coloured Trombe wall on South façade. One direct passive proposal is black coloured walls located close to south fenestration.

IV Energy balance for house

Energy balance for house was done by means of calculations for different solar systems used in building (described above) and for different regions in Bulgaria. Balance terms are shown in next tables and graphics. Monthly solar gains (second column) are compared with needed energy for heating (third column). If solar gains exceed the heating requirements it means that net heating energy is zero and in this period is not necessary heating by conventional source. If solar gains are less than heating requirements, heating installation must work, and monthly energy is shown in last column of the table.

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- Sandanski region

Table 4 – Energy balance [kWh/month]

Month	Solar gains	Heating energy	Net energy
Oct	5631	531	0
Nov	2589	2191	0
Dec	1270	3929	2659
Jan	1346	4579	3233
Feb	2888	3542	654
Mar	3271	2731	0
Apr	3667	819	0
	Total	18328	6546
Percent of heating by solar – 64 % (11782)			

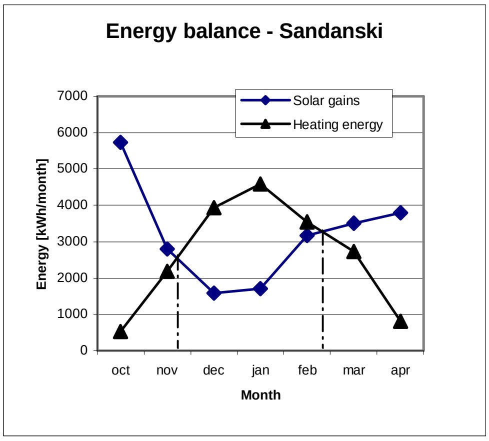

Fig. 4

- Sofia region

Table 5 – Energy balance [kWh/month]

Month	Solar gains	Heating energy	Net energy
Oct	3852	1653	0
Nov	1575	3331	1756
Dec	869	4971	4102
Jan	890	5585	4695
Feb	1853	4486	2633
Mar	2484	3818	1334
Apr	3207	1786	0
	Total	25630	14521
Percent of heating by solar – 43 % (11109 kWh]			

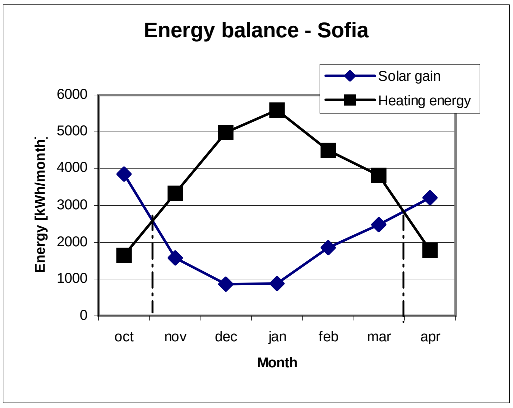

Fig.5

- Smolian region

Table 6 – Energy balance [kWh/month]

Month	Solar gains	Heating energy	Net energy
Oct	3483	2555	0
Nov	1808	3802	1944
Dec	725	5165	4440
Jan	778	5836	5058
Feb	1782	4858	3076
Mar	1735	4625	2890
Apr	2045	2855	810
	Total	29696	18268
Percent of heating by solar – 38 % (11428 kWh)			

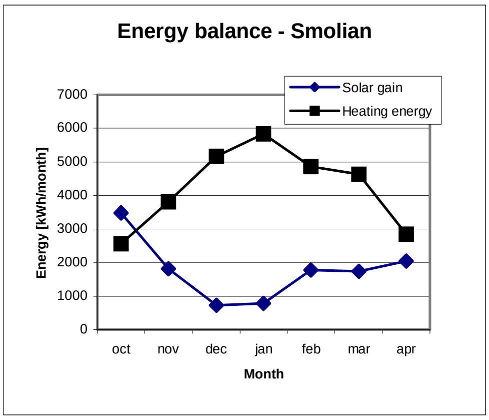

Fig.6

Results in tables and graphics show, that the energy requirements for heating vary in large interval - from 18328 kWh/season (Sandanski) to 29696 kWh/season (Smolian). Corresponding percent of energy reduction by means of solar energy utilization for heating, also vary in great extend – from 64% to 38%. This difference in energy requirements is determined by the climatic condition in regions (heat loads depends on winter temperature distribution) and different duration of the heating season for regions (shortest for Sandanski and longest for Smolian). It is worth noting, that the solar gains vary very small for regions (from 11109 to 12430 kWh/season). This results can be explained with the different duration of the heating season. In regions with hot climate (Sandanski), the solar gains are higher, but the heating season is shorter and conversely, in cold regions the solar gains are used for long time.

- Plovdiv region

Table 7 – Energy balance [kWh/month]

Month	Solar gains	Heating energy	Net energy
Oct	3780	1182	0
Nov	2019	2923	904
Dec	1436	4662	3226
Jan	1517	5220	3703
Feb	2410	4186	1776
Mar	2601	3468	867
Apr	2609	1264	0
	Total	22905	10475
Percent of heating by solar – 54 % (12430 kWh)			

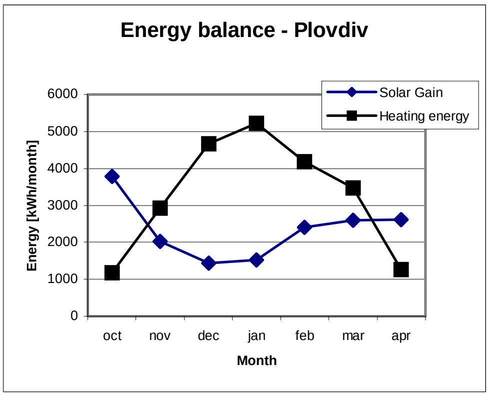

Fig. 7

- Drianovo region

Table 8 – Energy balance [kWh/month]

Month	Solar gains	Heating energy	Net energy
Oct	4923	1569	0
Nov	2109	3288	1179
Dec	1093	5145	4052
Jan	1097	5917	4820
Feb	2088	4791	2703
Mar	2470	3932	1462
Apr	3248	1691	0
	Total	26333	14216
Percent of heating by solar – 46 % (12117 kWh)			

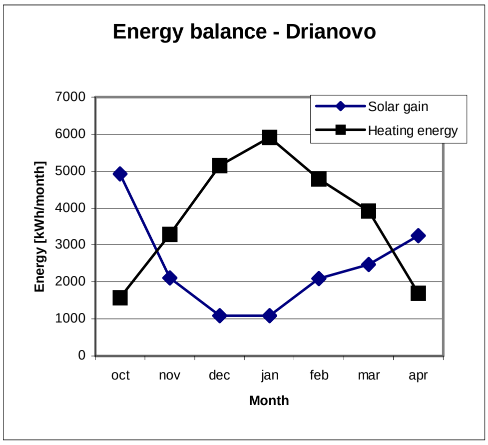

Fig.8

- Varna region

Table 9 – Energy balance [kWh/month]

Month	Solar gains	Heating energy	Net energy
Oct	4759	782	0
Nov	2094	2293	199
Dec	1130	4014	2884
Jan	1191	4695	3504
Feb	1965	4037	2072
Mar	2353	3749	1396
Apr	3009	2000	0
	Total	21570	10055
Percent of heating by solar – 53 % (11515 kWh)			

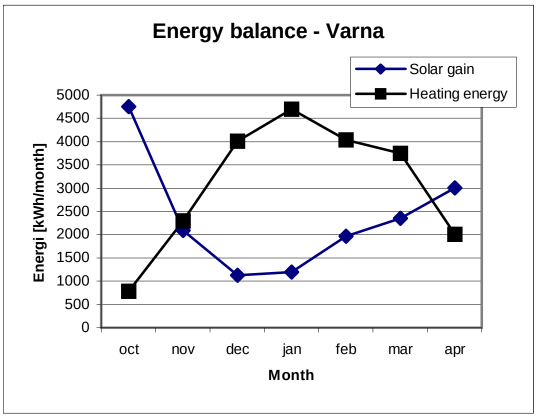

Fig.9

Our resent researches show, that this behavior of solar heating systems is present in good insulated buildings. When the house is not insulated thermally very well, the solar gains are bigger (because of longer heating season and low increase of heat loses caused by exchange the wall with the solar element) and the difference in solar incomes for regions is significant. In this case however, the percent of energy reduction is very small, because of great seasonally energy requirements for heating.

V. Solar domestic water heating systems (DWHS)

The solar part of DWHS consists of two main units – solar collectors and a heat accumulator. The collector is designed to absorb solar energy and transform it into heat, which heats the water flowing through the collector. The water, heated by the collectors, reaches the accumulator, which has the function to retain for some time the heat obtained from the sun.

In the cases when solar water systems are installed in building construction, the following initial data are necessary for the design of the solar system: number of inhabitants, in order to specify everyday hot water consumption in [***liters/day/inhabitant]***, and the building function, to define the mode of hot water consumption (daily standard for hot water consumption). When the daily water consumption is determined (liters per day), the solar collector area (for the specific location, orientation and tilt) and the accumulator volume must be calculated. This can be done by experience or by special mathematical model to research performance of solar hot water system. In this paper the simulation model based on the collector and accumulator energy balance was used for calculation. A large number of numerical examples have been carried out for the different solar zones in Bulgaria. The results were verified with experimental data. All data for domestic solar system were generalized in form of the results shown in table 3.

Because, the needed collector area for installations depend on the daily water consumption proportionally (on a great extend), in the table all data are presented for 100 liters daily hot water consumption. If there is needed other consumption, the result can be transformed proportionally for needed daily consumption. In the table is presented collector area sufficient to deliver about 60% of energy for water heating when the solar installation is used seasonally (April – October). This percent is acceptable, because in summer months (July, August), the delivered energy is 80 ÷ 90 % in average climatic day and 100% in the hottest days. If the collector area is bigger, the average solar coverage percent will increase, but in hottest summer days it will be unconsumed energy. Results for needed collector area correspond to three different fluid circulation organizations in installation: forced circulation and standard mixed accumulation; free circulations (tank is above solar collectors) and forced circulation and stratified accumulation. In this study are used standard solar collectors without selective absorbers and one glass cover. Data for needed collector area correspond to south orientation (with 20 ÷30 degree deviation from south) and favorable for Bulgaria in summer using tilt angle of 30 degree. When solar installation is used during all year, the favorable tilt angle is 45 degree (in summer it will work with low efficiency). If it is possible, seasonally regulation of collector tilt will be good decision.

Table 10

Daily amount hot water	Temp. hot water	Accum. volume	Needed energy	Solar coverage	Saved energy	Necessary collector area [m^2]		
						Forced circulation / Gravity		
l/day	^oC	Liters	KWh/ses.	%	KWh/ses	Solar zone	Standard type	Stratify accumulator
100	60	100	646	60	567	First	**2.00/ 2.25**	**1.7**
						Second	**1.70 / 2.12**	**1.50**
						Third	**1.49 / 1.86**	**1.35**

Using data in above table, one can specify approximately needed collector area for solar installation, and calculate saved solar energy for the season.

CONCLUSIONS

The present theoretical analysis for solar heating in houses is based on the modern requirements for thermal insulation of buildings. For analysis were studied different elements for solar energy utilization, suitable for climatic condition in Bulgaria. Results of theoretical investigations show that well designed building can reduce energy requirements for heating up to 40 – 60% for various regions. Saved solar energy is significant for all regions in Bulgaria.

Requirements to insulation characteristics of building vary on diverse geographical locations. In southern regions (Sandanski) double glazed windows and one glazed Trombe wall is good decision, but in mountain regions (Smolian) triple-glazed window and two-glazed Trombe wall suit better for energy balance.

The share of solar energy in overall energy balance of building depend on many factors: geographical location, thermal insulation of building, solar element type (one, two tree glasses etc.), Optimal solution could be made with considering the cost-effectivness of the solar systems.

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