Reduction of Energy Consumption Through using Solar Heating and Ventilation

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ABSTRACT

Energy consumption in buildings is a large share of the world's total end use of energy. Residential and commercial buildings require approximately 35% of the end use of energy, in addition to this energy is used for buildings also in the industry. In this context the paper proposes the energetically analysis for a small scale modern station, providing solar heat to a solar building with 2 floors, located in the city of Isfahan, IRAN. The paper describes the location, size and thermal regime of the solar building; there are also presented the heating system facility and equipment components, designed for the solar building located in Isfahan Science and Technology town (ISTT). Based on the achieved simulations it is shown that compared to the ordinary control the energetically based control provides remarkable advantages and savings concerning the auxiliary heating energy. This result should be valid for any systems similar to the particular one in Isfahan .

Keywords - **thermal systems , structure Building , temperature, Solar buildings** .

I. INTRODUCTION

Energy consumption in buildings represents a large share of the world's total end use of energy. Residential and commercial buildings require approximately 35% of the end use of energy, in addition to this energy is used for buildings also in the industry. Globally, buildings account for close to 40% of total end use of energy.

Given the many possibilities to substantially reduce buildings' energy requirements, the potential savings of energy efficiency in the building sector would greatly contribute to a society wide reduction of energy consumption. By reducing buildings' energy consumption, a nation can reduce dependency on imported energy and strengthen its strategic position.

Moderation of energy end use in buildings will also reduce greenhouse gas emissions and pollution produced by the combustion of fossil fuels. This environmental benefit appears on two scales, local and global. Because much of buildings' demand for energy requires local energy combustion in individual heating systems or district heating, reduced energy demand improves air quality at the local level. In particular in developing countries a reduced demand for energy requires fewer power plants, thereby delaying or obviating the construction of new generation and grid capacity and enabling communities to devote public funds elsewhere.

Given the potential scale of energy savings across the building sector, reduced demand for energy and fossil fuels can substantially contribute to a nation's compliance with domestic or supranational targets for the reduction of greenhouse gas emissions [1].

Economic strategy of sustainable development clearly requires the promotion of energy efficiency and the rational use of energy at national level.

The specific actual situation in IRAN requires the introduction of government policy priorities, the policy of energy efficiency at wide scale. Due to the strong decline of internal hydrocarbons resources, and in the perspective of economic growth, it becomes obvious that, if we maintain the current usage of energy, energy import dependency will increase, further aggravating the external deficit, which will lead to the increase of external debt.

It is emphasized that the annual energy consumption of a building, regardless of its intended use, thermal energy for heating and hot water consumption represents the main annual energy consumption by about 75%. For the overall residential buildings in IRAN, the efficiency of the supply for heating, hot water and cooking is only 43% of the amount of heat provided by the sources; for Bucharest, it is of 63%, but still unacceptably low.

II. CALCULATION OF POTENTIAL ENERGY INCOME

During the next step the potential energy income is calculated for each grid plot. The potential energy income is output from this subroutine. For the plot with general slope β the equation (1) was used as it is described.

$$^{c}E_{b\beta} = {^{p}E_{b\beta}} + {^{d}E_{b\beta}} + {^{r}E_{b\beta}} \quad [\mathrm{W\ m^{-2}}] \qquad (1)$$

where :

$^{c}E_{b\beta}$	:	global radiation
$^{p}E_{b\beta}$	:	direct radiation
$^{d}E_{b\beta}$	:	diffuse radiation
$^{r}E_{b\beta}$	:	reflected radiation

The component of the direct radiation ${}^pE_{b\beta}$ on grid cell with slope β is calculated according (2), based on direct radiation incidence ${}^pE_{bK}$ on surface normal to sun beam

$${}^pE_{b\beta} = {}^pE_{bK}\cos(i)\ , \qquad [Wm^{-2}] \qquad (2)$$

While

$${}^pE_{bK} = E_0 \cdot \frac{\sin(h_0) - \frac{0.1T(T_m - 1)}{30}}{\sin(h_0) + 0.106T_m} \qquad [Wm^{-2}] \qquad (3)$$

$$\cos i = \cos\beta \cdot \sinh_0 + \sin\beta \cdot \cosh_0 \cdot \cos\left|A_n^s - A_0^s\right| \qquad (4)$$

Where:

${}^pE_{bK}$	:	direct radiation incident to plane normal to sun beam direction
T_m	:	Linke`s coefficient of atmospheric turbidity (mean monthly value)
E_0	:	solar constant on the upper boundary of the atmosphere (daily value)
h_0	:	Sun elevation (angle between horizontal plane and sun beam)
i	:	angle of the direct radiation incidence (spatial angle between sun beam and the normal of the given plane)
A_n^s	:	azimuth of the normal of the plane
A_0^s	:	Sun azimuth

The Sun azimuth is calculated according (5):

$$A^s_0 = \arccos[\cos\delta / \cosh_0 (\cos\varphi\ \mathrm{tg}\delta + \sin\varphi \cos(15°. H))] \qquad (5)$$

Where :

δ	:	declination
φ	:	latitude
H	:	time

The component of the diffuse radiation ${}^dE_{b\beta}$ incident to plane with slope β during cloudless conditions is expressed by (6) :

$${}^dE_{b\beta} = 0.5 \cdot {}^dE_{bH} \cdot u_2 \qquad [Wm^{-2}] \qquad (6)$$

While :

$$u_2 = \sin\beta \cdot \left(0.94 \cdot e^{\cos i} + \frac{1.84}{T_m} - 1.44\right) + 1 + \cos\beta \qquad (7)$$

$${}^dE_{bH} = k_b\left(E_0 - {}^pE_{bk}\right)\sin h_0 \qquad [Wm^{-2}] \qquad (8)$$

$$k_b = (0.22 + 0.025 \cdot T_m) \qquad (9)$$

Where :

${}^dE_{bH}$	:	diffuse radiation incident to horizontal plane
k_b	:	coefficient expressing the portion of the radiation diffused by the atmosphere

The reflected radiation ${}^rE_{b\beta}$ due to surrounding terrain is calculated for the plane with slope β>0 :

$${}^rE_{b\beta} = 0.5\alpha(1 - \cos\beta)\left({}^dE_{bH} + {}^pE_{bk} + {}^pE_{bk}\sin h_0\right) \qquad (10)$$

where α albedo. (coefficient expressing the portion of the radiation reflected by the surrounding surface).

On the plots, where direct sunshine duration (described in previous section) is equal to zero, the potential energy income is assumed to be equal only to diffuse radiation.

It is possible to change different parameters needed for energy calculations:

The most important is vegetation file, which can characterise constant as one "value" for whole basin, or for each grid plot separately, in the same shape as the input grid file. Output from this subroutine could be not only *potential energy income* to the grid plots, but *actual energy income*, too.

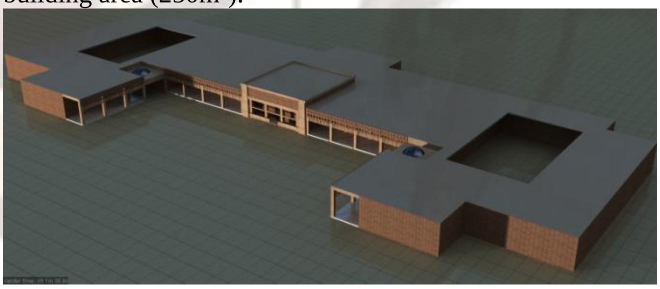
Actual energy is calculated from the potential one, based on relation to measured radiation at terrestrial control station, or based on cloudiness or relative sunshine duration from terrestrial or remote sensing observations. Input data for cloudiness could be represented from the most simple "one number" version for whole area and time range, or in time series. This time series is based on data, where cloudiness coefficient is related to date and time range. It means, if enough data are available, cloudiness coefficients for every hour could be set up and used during simulations.

The solar radiation is being calculated for each grid point (or elementary plot) with eligible time step for the selected time interval within the day. The calculated values are being summarised for the selected time interval to obtain the quantity of solar energy (irradiation) on the Earth surface. One of the possible outputs from the model are time series for the selected grid points. There are no time range limitations for the simulations.

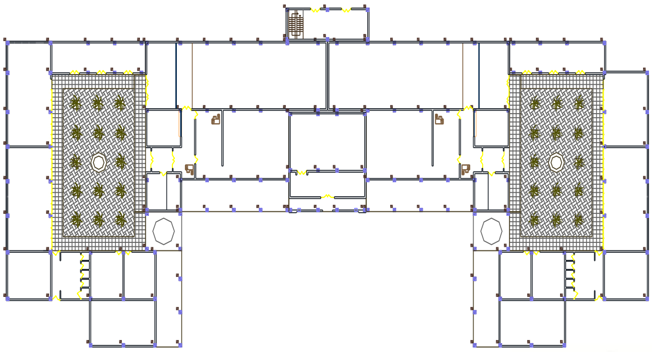
The output of the subroutine is the gridded information on potential or actual energy income integrated through the chosen time interval [W hrs m^{-2}].

III. Description About the Structure Building Case Study

The Solar building (Figure 1, built between 2008 and 2011) is a building situated on Isfahan Science and Technology town (ISTT) in Isfahan, IRAN designed to study solutions for construction high efficiency buildings. Its optimized architectural form allows the movement of the air through natural ventilation. The two heated floors (first floor 90 m^2 second floor 100 m^2) provide the thermal comfort by using passive solar radiation at low temperature for the total building area (250m^2).



a) Perspective



b) First floor

Fig. 1. Solar building in Isfahan, IRAN

The same principle is taken into account by using radiant floor. The heating box is secured by a heat pump system with a horizontal ground water type, the 10kW installed on the plateau in the vicinity. Hot water demand is supplied by a system of six flat thermal collectors and three vacuum tubes, installed on the roof. The cooling and air conditioning, in the summer, will also be provided by the solar system. The excess hot water will be used in the gym's locker room which is posted directly under the Solar building.The first floor is used as a work space, and the second floor is used for official meetings and presentations.

IV. HOW CHANGES IN WATER TEMPERATURE

For Isfahan, the monthly inlet water temperature varies from 12-15 °C in the winter and 15-20 °C in the summer.The monthly mean temperatures for Isfahan urban area are presented in Table I. The temperatures were measured with a Delta T weather station, positioned near the solar building, from October 2008 since present.

Table I. - Climate data for Isfahan

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C	20	23	27	32	37.6	41	43	42	39	33.2	25.5	21.2	43
Average high °C	9.2	12.5	17.0	22.7	28.2	34.3	36.7	35.6	31.8	25	17	11	23.42
Average low °C	−2.5	−0.4	4.1	9.3	13.7	18.5	21.0	19.1	14.7	8.9	3.2	−1	9.05
Record low °C	−19.4	−12.2	−6.2	−4	4.5	10	13	11	5	0	−8	−13	−19.4
Precipitation mm	19.9	14.2	21.7	18.9	8.7	1.2	1.7	0.3	0.1	3.9	12.5	19.7	122.8
% humidity	60	50	43	40	34	25	25	26	28	38	50	60	39.9
Avg. precipitation days	4.0	2.9	4.1	3.4	2.0	0.3	0.3	0.1	0.0	0.8	2.2	3.8	23.9
Mean monthly sunshine hours	203.6	216.8	243.7	250.0	308.7	348.3	349.4	339.7	311.3	281.5	224.2	197.0	3,274.2

In the present study, an averaged hot water consumption of 60 l/day is considered, based on a close monitoring.

The hot water consumption depends on the season of the year, time of the day and geographical parameters also of the nature of the work developed in the building [2].The hourly distribution of hot water consumption in the solar building is presented in Figure 2.

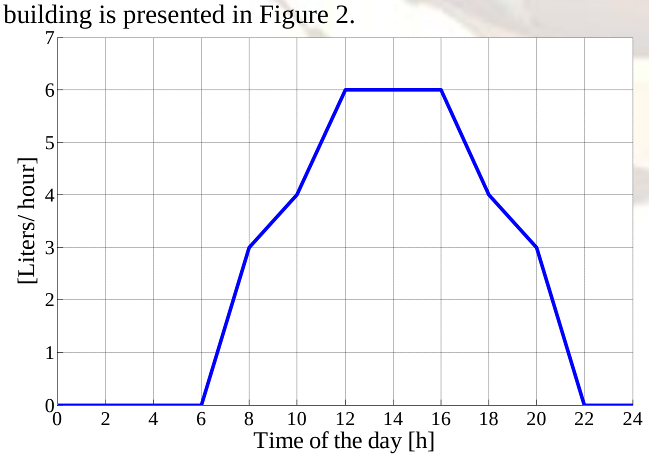


Fig. 2. Daily hot water consumption profile

V. EXPLANATION OF THE POWER GENERATION SYSTEM

HVAC systems maintain a building's comfortable indoor climate through Heating, Ventilation and Air Conditioning (Cooling). These systems profoundly influence energy consumption in buildings. Without heating, cooling and ventilation systems there would be no energy consumption in the building, since it would be totally dependent on outdoor conditions.The heat requirement of the building is acquired by a heat pump plant, operating after a bivalent scheme: radiant low temperature floor heating for rooms at level 1 and 2 of the building and domestic hot water preparation. The heat from the soil is extracted through collectors located on the platform area nearby. The capturing field is composed of 6 x 100m loops of pipe. The pitch of the loops is about 1m. It has been provided an expansion tank of 25 l and a circulation pump on the primary circuit.

The secondary part of the installation comprises a heat accumulator of 300L and two bivalent boilers of 1000L. As an auxiliary source for peak loads a wall mounted boiler of 11.8kW has been provided. The other installation characteristics are presented in Table II.

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Table II. - Characteristics of the installation

Omponents	Characteristics
Volume	2x 1000 liters
Heat pump	heating power: 10kW
Boreholes	6x 100m at 1.5 – 2 m depth
Soil	qE= 20 [W/m^2]
Heating/Cooling floor	190m^2
Total building surface	250m^2

A simple scheme of the water circulation is presented in Figure 3. During the cold period (October – March), because the intensity of the solar radiation is low, the heat pump (A) will take over also the domestic hot water preparation and the heating of the building. In the summer (April-September) the solar collector system (B) will be mainly used for the domestic hot water preparation and the heat pump will be used for cooling the building, when necessary.

Having both, heat pump and solar collectors, the use of the auxiliary heater (wall mounted boiler - C) is reduced to a minimum [3]. The auxiliary heater turns on only in the peak loads. The system produces domestic hot water stored in a bivalent tank (D) and water for space heating stored in tank (E). The heated water in the tank (E) goes to the two low temperature radiant floors.

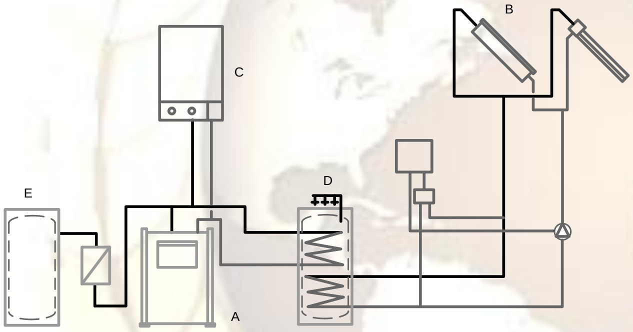

Fig. 3. Simple scheme of the installation

VI. SIMULATION OF THE SYSTEM CONDUCT

T*SOL is a complete and extensible simulation environment for the transient simulation of thermal systems including multi zone buildings. It is used by engineers and researchers around the world to validate new energy concepts, from simple domestic hot water systems to the design and simulation of buildings and their equipment, including control strategies, occupant behavior, alternative energy systems (wind, solar, photovoltaic, hydrogen systems), etc. [4].

To calculate the thermal load for heating/cooling, ventilation or air conditioning of any building, appropriate climate information of the building location are needed (e.g. the sizing of the heating systems require information on climatic parameters, which give the extreme conditions which the installation must meet) [5].

Numerical simulations were carried out using T*SOL software, one of the most important building energy simulation software, that is used by engineers and researchers around the world to validate new energy concepts, from simple solar domestic hot water systems to the design and simulation of buildings and their equipment, including control strategies, occupant behavior, alternative energy systems (wind, solar, photovoltaic, hydrogen systems), etc. The T*SOL solar building HVAC system is represented in Figure 4.

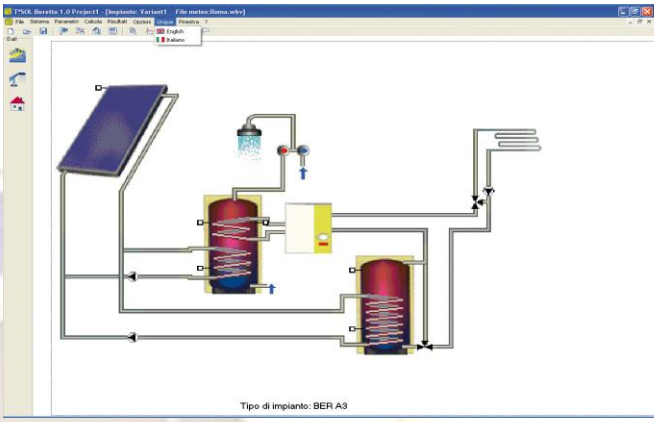

Fig. 4. T*SOL model

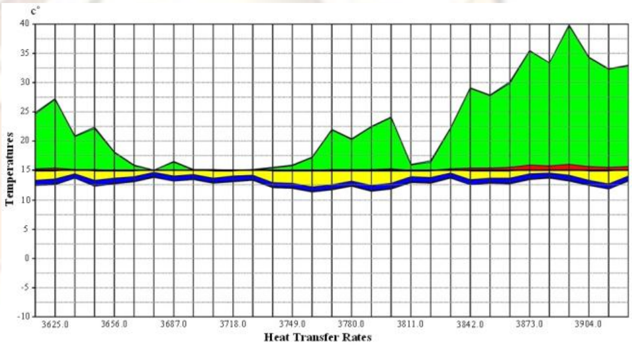

Fig. 5. Hot water production – June

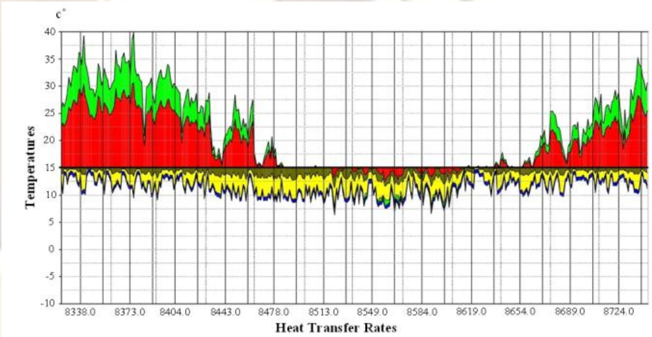

Fig. 6. Floor heating – December

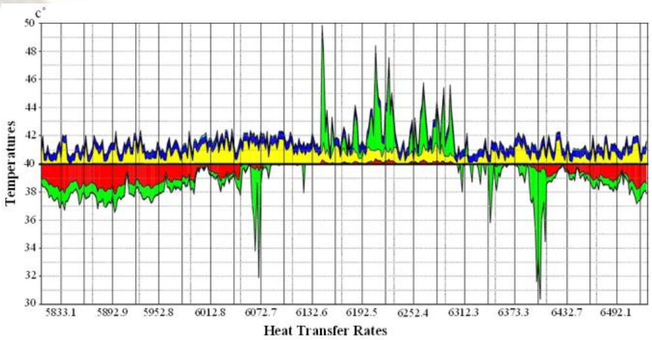

Fig. 7. Storage tank output temperatures – September

At the next stage, the physically based mathematical model of solar heating systems is proposed. The model is realized in T*SOL simulation environment which is well recognized and frequently used in scientific researches of transient thermal processes. The model is flexible and can be easily adapted to a wide range of particular solar heating systems being a good tool for analysis and development [6].
Figure 5 presents the hot water production during the first two weeks of June. The heat pump is turned off, the domestic hot water being produced by the solar collector system. It can be observed that the solar collector outlet temperature varies from 10 °C in the morning, when the solar radiation is low, to 40 °C in the noon.
The heat pump outlet temperature variation can be observed in Figure 6. The simulation was performed for two weeks in December, when the ambient temperature drops below 0 °C and space heating is necessary. The desired indoor temperature was set to 21 °C to ensure a comfortable work environment. The solar collector outlet temperature is lower, due to the decreased solar radiation.
In September, the solar system still produces hot water but the heat pump is turned on, supplementing the hot water requirement when needed (Figure 7). The output temperature of the tank is set to 50 °C.

VII. Conclusion

The combination of renewable energies such as thermal solar energy and geothermal energy in a single system should make it possible to meet a residence's heating and hot water requirements, while guaranteeing a satisfactory level of comfort. The objective of this work was to evaluate the goodness of the heating system using T*SOL and to predict the long term energy performance of the entire system. The study is not complete.

VIII. References

[1] Building Energy Software Tools Directory: Tools Listed Alphabetically. Energy Efficiency and Renewable Energy (EERE), U.S. Department of Energy (DOE) Home Page, 6 May 2010.
[2] Choudhary, R.; Augenbroe, G.; Gentry, R.; Hu, H. Simulation enhanced prototyping of an experimental solar building. *Build. Simul.* 2008, *1*, 336–355.
[3] Small Commercial Buildings Program. Sustainable Buildings Industry Council, 10 March 2010. Available online: http://www.sbicouncil.org
[4] Tankless-Water-Heater by Seisco. Tankless Order Page, 4 March 2010. Available online: http://www.seisco.com .
[5] Ahmad, M.; Culp, C.H. Uncalibrated building energy simulation modeling results. HVAC & R Research, 1 October 2006. Available online: http://www.accessmylibrary.com.
[6] High-efficiency photovoltaic module using silicon nitride multicrystalline silicon cells. BP Solar, 6802.0049 v2. May 2008; Available online: http://www.bp.com

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