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Designing and Application of Solar Active Systems for Hakim Sabzevari University: A Case Study of the Dining Hall

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ABSTRACT

In this paper, on the basis of Green comprehensive Plan at Hakim Sabzevari University of Sabzevar, Iran, using of active solar systems at dining hall has been evaluated. On the basis of solar measured data and some solar models and relations, solar energy on the various surfaces and tilts are evaluated. Then electricity and thermal energy consumption are measured and new efficient lighting systems are introduced. Then photovoltaic/thermal panels and one ended evacuated tube solar collector for façade and rooftop installation are chosen. Results shows that 36683 Nm^3/year natural gas and 87.6 tone/year pollutant are reduced. Payback time of the system based on internal energy carrier and export electricity price are 21.3 and 3.9 years respectively.

1. INTRODUCTION

Energy demand is increasing due to population growth, urbanization development and consumption pattern. The application of hydrocarbon resources and combustion process has led to environmental degradation, global warming, and climate change. Therefore, the development of renewable energy substitution as an energy sector strategy in planning policies of numerous countries in the world has been taken into consideration.

Among renewable energy resources, solar energy is of considerable importance due to its universal availability, environmental friendliness and conversion to electricity, heat and cool. The latter energies are used in buildings.

Combined cycles of renewable energy are effective methods for developing resources uses. Theoretical and experimental studies on energy performance and design systems of different combined cycles have been carried out.

Many studies have been done on these issues. Matuska [1] investigated the performance and thermoeconomic analysis of hybrid pvt collectors for domestic hot water application in buildings. He compared glazed and unglazed pvt with conventional solar collectors for different area percentage ratios of pv and thermal collector. A et al. [2] studied the optimal value of solar fraction for hybrid pvt from energetic and economic point of view. From a thermoeconomic point of view, A. Behzadi; et al. [3] evaluated the hybrid pvt solar systems and absorption chillers for producing a cooling effect and hydrogen. T. Matuska and B. Sourek [4] studied solar heat pump systems with hybrid pvt Panels for residential house applications. They concluded that glazed pvt collectors had a poor thermal performance which can not be balanced by the electricity usage of heat pump system.

Furthermore thermal systems technologies based on using different refrigerants as a combined system of pvt for multiple generation of electricity, heating, and cooling have been considered. In these studies, if the outlet water from pvt does not have the desired temperature, the pvt system will be used as a preheating system.

Since the outlet fluid temperature in hybrid pvt system is lower than the desired temperature, a supplementary system for reaching the required temperature is required. Combined systems including pvt , high performance solar collectors and other renewable or fossil fuel resources can improve thermal performance of the combined cycles.

This research, considers the combined pvt system and water-in- glass evacuated tube collector for supplying electricity and hot water and proper integration into the building and thermoeconomic evaluation of the system.

Average solar irradiation in Iran is about 1800 to 2200 kwh/m^2/year [5] that can be used effectively for buildings in different climate regions.

The amount of solar radiation in any regions is the most important parameter for designing and developing various solar energy systems. Therefore, electric and thermal energy requirements for buildings can be provided by determining the amount of solar radiation on the tilted surfaces of photovoltaic panels or solar colectors.

To design thermal collectors and photovoltaic systems, it is important to provide accurate information and data of the total and diffuse solar radiation that reaches to the horizontal surfaces.

Solar radiation data can be obtained by pyranometer devices that measure the data about meteorological stations installed at different stations or can be estimated by modeling the limited number of the measured data.

Since sufficient measured solar radiation data are not available, in this research solar radiation data are obtained

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with an empirical model based on solar data measurement. In these models some climatic parameters are considered to predict the solar energy. Sunshine hours is one of the parameters whose measured data are accurate and reliable and can be used to determine the amount of solar radiation at the ground level.

One of the best suggested models for estimating the amount of solar radiation on the horizontal surface is the Angstrom model. The empirical coefficients of the Angstrom model depend on climatic parameters, geographic conditions and other meteorological characteristics of the region. With this relation, the total radiation for different parts of Iran can be estimated. Therefore by using the solar radiation data recorded in the Meteorological Organization site, the amount of total radiation for the region can be calculated.

Therefore solar radiation parameters are used to estimate the monthly average irradiance on the horizontal and tilted surfaces.

2. MATERIALS AND METHOD

This research is comprised of two main steps. In the first step data measuring, data gathering from other organization and data processing are performed. In the second step the desired systems on the basis of technological characteristics of selected systems are designed.

Therefore sunshine hours and other meteorogical data are prepared, and solar energy data on the horizontal surface are calculated by using Angstrom relation and model which are developed for Iran. Then the amount of solar energy on the collector tilted angles are calculated for vertical surface and other suitable tilted surfaces. Then it is necessary to measure the electric and hot water consumption, study the potential of energy and water saving, and consider the rational use of energy and water consumption. Since the dinning hall is closed in during the summer, the best collector tilt angle for receiving maximum solar energy irradiation and the required collector area for 9 month active time is calculated and proper solar technologies are chosen.

2.1. Available solar radiation and hot water requirements

In designing the solar hot water and photovoltaic systems, solar irradiance on the horizontal and other proper tilted surfaces for choosing the best tilted surface should be calculated. In this regard, at first, hot water and electricity consumption in dining hall are monitored, measured and calculated. Then by considering the energy management criteria included in energy management regulation and handbooks, and with choosing efficient technologies for lighting and hot water systems, the amount of hot water and lighting consumption pattern for supplying by solar energy are evaluated.

Extraterrestrial radiation on horizontal surface and monthly average daylight hours are calculated. Then, the average sunshine hours of each month are accounted on the basis of measured data and average solar irradiation obtained by using Angstrom relation and from the region meteorological organization data sheet and all the data required for designing a solar photovoltaic system are calculated by relevant equations.

Irradiation on the horizontal surface based on the sunshine hours parameter are calculated as follows [6]:

$$\overline{H}/\overline{Ho} = a + b(\overline{n}/\overline{N}) \tag{1}$$

In the above equation: $\overline{Ho}$: monthly average daily extraterresterial radiation, $\overline{H}$: monthly average daily radiation on the horizontal surface, and a, b are constants depending on location.

$\overline{n}$ Indicates the average monthly daily sunshine hour, $\overline{N}$ The average monthly maximum sunshine hours (daytime), and its value is calculated through Equation 5 [7].

$\overline{Ho}$ can be calculated through following equation:

$$\overline{H_0} = \frac{24\times3600G_{sc}}{\pi}\left(1+0.033\cos\frac{360n}{365}\right)\times\left[\cos\emptyset\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\emptyset\sin\delta\right] \tag{2}$$

G_{sc}: solar constant, $\emptyset$: latitude of the desired location, δ: declination in terms of degree, ω_s: The solar hour angle in accordance with Equation 4.

$$\delta = 23.45\left(\frac{360(248+n)}{365}\right) \tag{3}$$

$$\omega_s = \cos^{-1}(-\tan\emptyset\tan\delta) \tag{4}$$

$$\overline{N} = \frac{2}{15}\omega_s \tag{5}$$

$$\acute{\omega}_s = \min\{\omega_s, \cos^{-1}[-\tan(\emptyset-\beta)\tan\delta]\} \tag{6}$$

$$Hd/H = 1.311 - 3.22(Kt) + 3.42(Kt)^2 - 1.821(Kt)^3 \tag{7}$$

$$K_t = H/Ho \tag{8}$$

$$\overline{R}_b = \left[\cos(\emptyset-\beta)\cos\delta\sin\acute{\omega}_s + \frac{\pi}{180}\acute{\omega}_s\sin(\emptyset-\beta)\sin\delta\right] / \left[\cos\emptyset\cos\delta\sin\omega_s + \frac{\pi}{180}\omega_s\sin\emptyset\sin\delta\right] \tag{9}$$

$$R = (1 - H_d/H)R_b + \frac{H_d}{H}\left(\frac{1+\cos\beta}{2}\right) + \rho_g\left(\frac{1-\cos\beta}{2}\right) \tag{10}$$

$$H_t = \overline{R}\,\overline{H} \tag{11}$$

Hd: diffuse portion of irradiation on the horizontal surface, Kt: solar clearness index, $\overline{R}_b$: monthly average ratio of tilted to horizontal beam radiation, R: monthly average ratio of tilted to horizontal global radiation, β: tilted angle, ρ_g: ground reflectance.

Data of average hot water consumption in various months were gathered and investigated and, then compared with energy efficient pattern and technologies in the dining hall and proper hot water consumption for designing a solar hot water system for breakfast and dinner are considered.

2.2. Electricity requirements

In the second part of the study the amount of power consumption in the dining room is measured and evaluated and then the required solar cell area to provide required electricity for various angle installation is calculated and designed. This is done by calculating the daily and monthly electricity consumption of the self and then considering the efficiency of the equipment used and determining the peak solar hour of each month of the year.

$$P_{PV} = \frac{\text{Load}}{\eta_{cable}\times\eta_{reg}\times\eta_{bat}\times\eta_{inv}} \tag{12}$$

$$P_{peak} = \frac{P_{PV}}{PSH} \tag{13}$$

In the above relations, P_{PV} is the power that should be provided by the photovoltaic panel and PSH (peak solar hours) from monthly average solar radiation for the worst month of the year are found.

Then, the area required for photovoltaic panels to supply the entire electric power is calculated. The system is connected to the grid so that additional electricity could be sold, during the shut down of the dining room, and thus beneficiated.

2.3. Economy and environment

In the last part of this study, pollution reduction due to electrical and thermal part of system was evaluated by assuming that thermal energy generation in this system was substituted with natural gas consumption then, simple pay back time of the system was calculated.

Payback time = (investment)/(annual saving)

3. RESULTS AND DISCUSSION

Since the empirical coefficients of the Angstrom equation depend on the climatic conditions of the region, many researchers consider the dependence of the Angstrom coefficient on the basis of geographical and climatic parameters such as latitude, elevation, sunshine, temperature and rainfall. In this study Angstrum relation based on sun shine hours was used and coefficients “a” and “b” for several solar radiation and sun shine hours measured data are obtained.

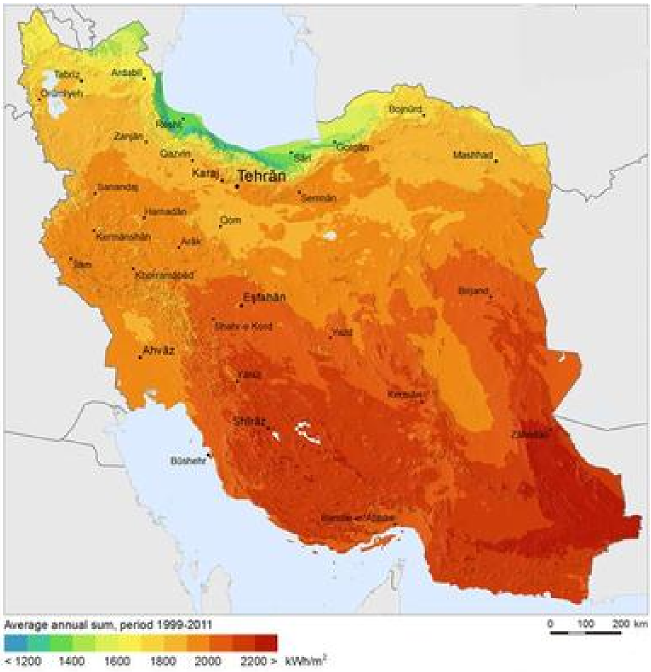

Figure 1. Solar radiation map of Iran according to solar GIS [8].

Angstrom coefficients and relation for Sabzevar region are as follows [9]:

$$\overline{H}/\overline{H0} = 0.343 + 0.347(\overline{n}/\overline{N}) \quad (14)$$

Table 1. Design parameters in different months of the year.

Month	latitude (Sabzevar)	δ (declination)	Monthly average day length (hour)	Total extraterrestrial radiation on the horizontal surface (Ho) MJ/m²
Jan.		-20.91	9.83	17.53
Feb.		-12.95	10.74	22.66
Mar.		-2.41	11.8	29.11
Apr.		9.41	12.93	35.57
May		18.79	13.91	39.93
Jun.		23.08	14.42	41.42
Jul.	36.21	21.18	14.21	40.7
Aug.		13.45	13.4	37.18
Se.p		2.21	12.32	31.39
Oct		-9.59	11.19	24.51
Nov.		-18.91	10.16	18.71
Dec.		-23.04	9.6	16.1

In this research, monthly average solar radiation energy on the surface in the selected region and the other parameters are calculated by using sun shine hours measured data, formulas, mathematical equations and average day numbers for each month.

According to the average monthly sunshine hours that were obtained from Sabzevar Weather Administration, and calculated daylight hours, solar radiation on the horizontal surface were obtained from Equation (14) and also that at the best angle for summer and winter for Sabzevar (representing the mean value of the best angle of each three month of the season) for all months of the year are also calculated. The results are shown based on Iranian calendar (Tables 2 and 3).

Energy demand for hot water load of the dining hall by specifying the number of students, the volume of hot water required for each meal, and the number of average daily meals and the other parameters were obtained (Tables 4 and 5).

Table 2. Solar radiation in different Iranian months.

Month	Monthly sunshine hour (measured)	Day length for solar months	$\bar{n}/\bar{N}$	Total radiation incident on the horizontal surface (H) M J/m^2 (Calculate according to Eq. 8)	Monthly clearness index (Kt)
Farvardin	237.3	12.54	0.623	18.65	0.559
Ordibehesht	276.9	13.59	0.664	22.21	0.589
Khordad	340	14.25	0.786	25.27	0.615
Tir	354.1	14.27	0.808	25.55	0.623
Mordad	357.2	13.62	0.84	24.32	0.634
Shahrivar	328.7	12.59	0.81	20.86	0.626
Mehr	279.1	11.44	0.75	16.23	0.605
Aban	220.6	10.40	0.69	12.02	0.582
Azar	173.9	9.75	0.58	9.23	0.544
Dey	171.1	9.76	0.56	9.45	0.539
Bahman	183.2	10.42	0.6	11.58	0.553
Esfand	188.5	11.41	0.54	15.00	0.556

Table 3. Average monthly solar radiation at different tilted angles.

Month	Total radiation on the tilted surface (21°) M J/m^2	Total radiation on the tilted surface (51°) M J/m^2	Total radiation on the tilted surface (90°) M J/m^2	Total radiation on the tilted surface (36.21°) M J/m^2
Farvardin	20.07	18.65	12.42	20.99
Ordibehesht	22.3	18.72	10.44	21.74
Khordad	23.97	18.98	9.21	22.18
Tir	24.19	19.00	8.85	21.94
Mordad	23.57	19.70	9.61	22.37
Shahrivar	22.04	20.53	11.73	21.67
Mehr	19.2	20.09	14.22	20.71
Aban	14.17	18.32	15.30	19.59
Azar	13.19	17.36	14.68	16.69
Dey	13.27	16.29	14.47	15.37
Bahman	15.36	17.65	14.72	17.25
Esfand	17.76	18.49	14.18	20.85

Table 4. Design parameters for calculating required hot water per day.

C_ρ (J/kg.°C)	ρ (kg/lit)	N (dish)	v (lit/dish)	Tw (°C)	Tm (°C)
4190	1	8800	1.5	55	18

Table 5. Hot water demand for the dining hall in different months of the year.

Month	Ndays (depending on the opening days of the hall)	Hot water demand (Gj/day)	Monthly hot water demand (GJ)
Farvardin	15	2.046	30.69
Ordibehesht	31	2.046	63.42
Khordad	31	2.046	63.42
Tir	0	2.046	-
Mordad	0	2.046	-
Shahrivar	0	2.046	-
Mehr	30	2.046	61.38
Aban	30	2.046	61.38
Azar	30	2.046	61.38
Dey	30	2.046	61.38
Bahman	30	2.046	61.38
Esfand	30	2.046	61.38

The next step is to calculate of the area of the photovoltaic panel to supply electricity to the dining salon. Power consumption was calculated by the existing dining salon meter in the 45-day period and the average monthly electricity consumption is calculated. From lighting system some new technologies for energy saving and rational use are substituted and new electricity consumption are decreased to 27.12 Kwh per day by 38 % reduction. Specification of lighting system are shown in Table 6.

Table 6. Efficient electric power requirement.

Application type	Power type	Location	Number	Power (w)	Run time	Energy/day (wh)
Lighting	AC.LED lamp	Dining room	180	12	5	10800
	AC.LED lamp	Dining room	8	12	5	4800
	AC.LED lamp	Cooking space	40	12	10	4800
	AC.LED lampt	Cooking space	56	12	10	6720
Total						27120

Solar radiation reaching to different tilted surfaces is compared, in addition, the photovoltaic thermal hybrid system for buildings facade installation and one- ended water in the glass evacuated tube collector are chosen for installation on the roof at a 51 degree tilt angle.

One part of required thermal energy is supplied by hybrid photovoltaic thermal, the rest is provided through one ended water in a glass evacuated tube solar collector. Characteristics and area required and price of evacuated tube solar collector and photovoltaic/thermal panel are shown in Tables 7 and 8.

Table 7. Specification of the one ended evacuated tube collector.

Specifications / System	Number of tubes (panel)	D (m)	L (m)	Efficiency (%)	Tilt angle	Thermal energy supply (Mwh/yr)	Price (MRls)
Evacuated tube	397	0.047	1.8	55.5	51	701	300

Table 8. specifications of PVT panel.

Specifications / System	Area of panel (m)	Number of panel	Area required (m^2)	Tilt angle	Thermal energy supply (Mwh/yr)	Price (MRls)
PVT	1.9	45	86	90	1345	1260
Exchange rate: 1 US \$ = 100,000 Rials						

The photovoltaic/thermal panels are designed with the following characteristics including an area of 85 square meters for hybrid panels which can provide the lighting power of the dining salon. Further course, in the months that the salon is closed, this power can be connected to the network and sold to the power grid. The characteristics of the water in the glass evacuated collector and photovoltaic/thermal panel are shown in Figs. 2,3,4.

Technical parameters			
Peak power for 1000 W/m^2)	Q	W	1037
Absorber's pipe	Aluminium exchanger Roll-Bond		
Aperture surface	S_n	m^2	1,86
Width	a	mm	954
Height	b	mm	1953
Collector efficiency	η	%	55,5
Electrical parameters			
Peak power (for 1000 W/m^2)	Pmax	W	300
Type of cell	Policrystalline		
Amount of cells		pcs	72
Size of a cell		mm	156 x 156
Rated current	Impp	A	8,15
Short-circuit current	Isc	A	8,78
Nominal voltage	Vmpp	V	36,82
Open-circuit voltage	Voc	V	45,31
Total peak Power (for 1000 W/m^2)	Qmax	W	1337

Figure 2. Characteristic of photovoltaic/thermal panel [10].

Figure 3. Photovoltaic/thermal panel [6].

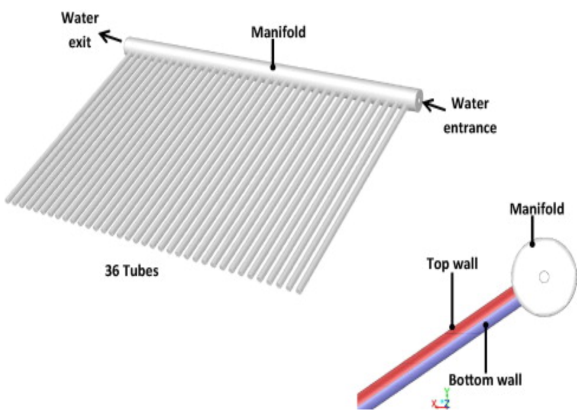

Figure 4. One-ended evacuted tube solar collector [11].

According to the statistics published by Ministry of Energy currently, for every kilowatt-hour of electricity generation from fossil fuel power plants from 1391 to 1395 on average 893.8 grams of carbon dioxide is emitted, which is the main greenhouse gas (Fig. 5). It is assumed that hot water in the usual manner is provided by natural gas in residential and commercial sector and is substitured by solar hot water and then energy saving and pollutant reduction are investigated. Results are shown in Tables 9 and 10.

If the prices of photovoltaic/thermal panel and one-ended evacuated solar water heater are 1.2 $/w and 3 $/pipe, average electric and gas tariff are 1000 rials/kwh and 1500 rials/m^3 respectively, electricity export price and social cost of environmental pollutant are 0.1 $/kwh and 285 rials/kwh$_e$ [9] and 108 rials/Kwh$_{th}$ respectively. Then payback time of using solar system is shown in Table 11.

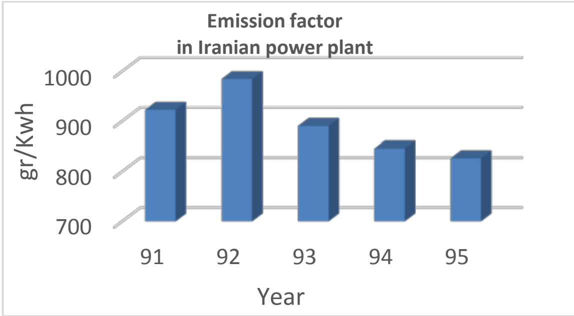

Figure 5. Yearly emission factor of Iranian power plant [12].

Table 9. Pollutant reduction due to solar systems.

Parameter / System	Pollution reduction (Tone/year)
Electric part	8.2
Thermal part	79.4

Table 10. Energy saving due to solar systems.

Energy saving system	Energy saving (Kwh/year)	Energy saving (m^3 Gas/year)
Electric part	9898.8	-
Thermal part	-	36683

Table 11. Payback time of the system considering social costs.

	Based on internal tariff	Based on electricity price export
Payback time (year)	21.3	3.9

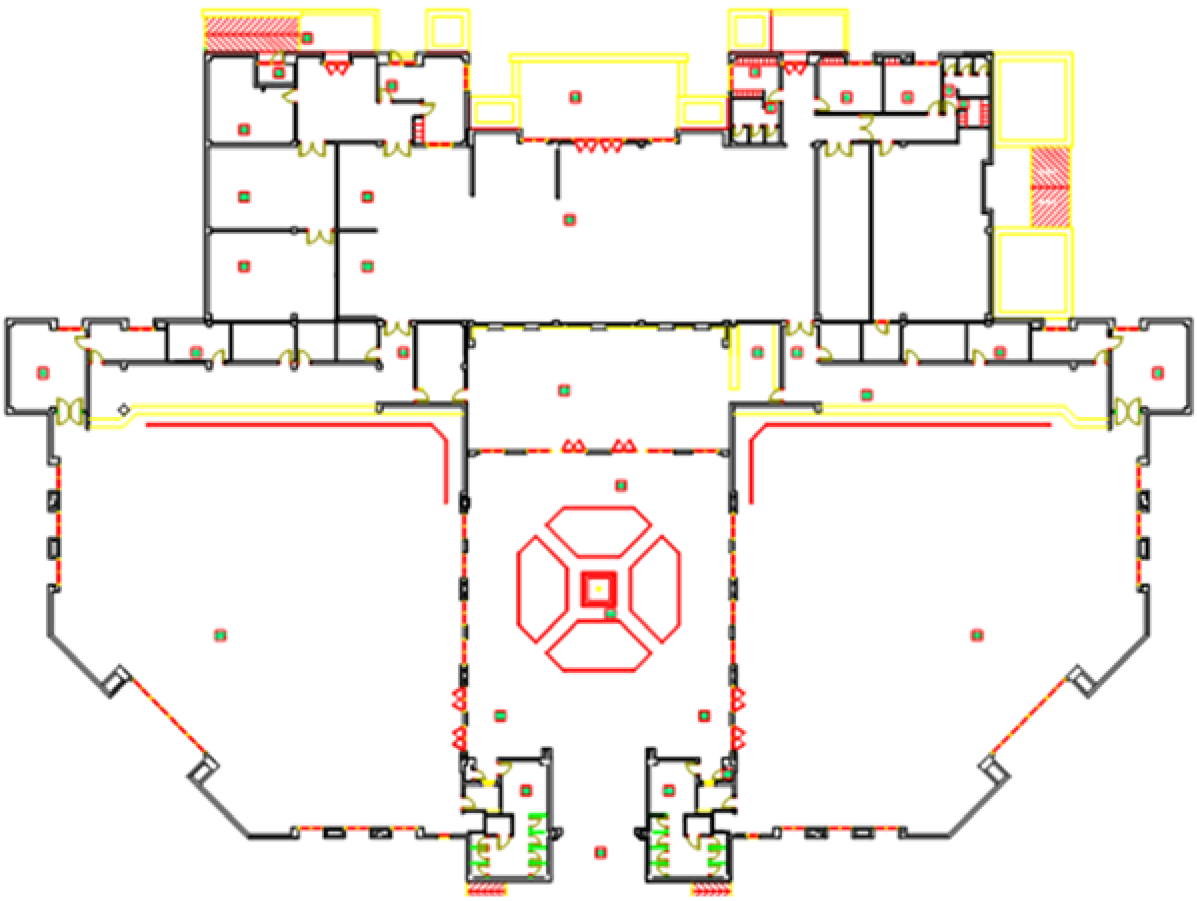

Figure 6. Plan of Sabzevar dinning hall building.

Figure 7. Image of dinning hall building.

4. CONCLUSIONS

In this research, based on measured solar data such as sunshine hours and other meteorological data, which are available, Angstrom model and mathematical equations were used for calculating amount of solar energy that reached on several proper tilt surfaces of dinning hall building. The obtained results were compared to each other and the best surfaces from architectural and structural point of view for installation solar systems were chosen. Then photovoltaic and solar water heater collectors were studied. In addition for this special application, photovoltaic/thermal panel for façade and water in the glass evacuated tube solar collector for installation on the roof at 51 tilt surfaces was selected. Power and hot water consumption are measured and optimized and the required photovoltaic/thermal panel surfaces and evacuated tube collector were calculated. Energy saving and poluttant reduction and payback time of system were presented.

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