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Theoretical Investigation of Consumption Patterns Effect on Optimal Orientation of Collector in Solar Water Heating System

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ABSTRACT

One of the subjects in solar water heater design is considering distribution of hot water consumption during the day. For example, each of the household, commercial, office, school, and industrial consumptions has a particular distribution of hot water consumption named pattern in this article. In solar computation principles, the effect of longitude, latitude, and altitude on collector angle has been clearly presented. However, the effect of consumption pattern especially on the collector orientation has been rarely investigated. The aim of the current study is to survey the effect of various consumption patterns on the collector's orientation and tilt angle and so calculation of related energy saving. So, five common patterns including office building, commercial building, afternoon and morning shift high school and a 15-unit apartment have been studied and optimal surface azimuth angle and tilt angle are determined. It was observed that 11 to 14 % energy saving can be archived by selecting the optimal angles with respect to hot water consumption pattern in comparison to a state that collectors are orientated for maximum reception of solar energy. Also the effect of solar fraction, storage volume and amount of hot water consumption are studied and discussed.

1. INTRODUCTION

Solar water heater (SWH) systems are good choices for replacement of conventional water heaters that consume electricity or fossil fuel. Hot water consumption is extremely variable for various applications. It depends on the geographical situation, people's habits, time of the year, and of course on the type of the building usage [1]. There are many studies on evaluation of SWH performance through simulation and optimization programs. Some of these studies are about the effect of the hot water consumption pattern on the solar water heater efficiency and design parameters. For instance, different profiles of domestic hot water usage were employed for the testing of domestic hot water storages [2]. Jordan and Vajen [3] applied household hot water profiles for solar water heater (SWH) in various time scales for the testing of storages. Spur et al. [4] observed the effect of the domestic hot water daily draw-off profile on the performance of hot water storage. In their investigation, some hot water consumption profiles were employed and their effects on the performance of domestic hot water storage were analyzed. Results indicated the importance of the number, type and time of occurrence of the draw-offs in the profile, on the performance of the thermal storage. Rodriguez-Hidalgo et al. [1] investigated the effect of domestic hot water consumption in Spain on the storage tank volume. In their research, a transient simulation program is developed and validated with a detailed measurement campaign in an experimental facility. Finally, the optimum size for the storage tank is proposed.

In the recent decade, many studies have also been conducted regarding the optimization context of SWH systems in order to achieve the optimized design parameters. For instance, some studies focus on the optimization of design parameters using the TRNSYS software [5-9]. Moreover, linear and nonlinear mathematical programming methods are used [10, 11], or the genetic algorithm method is applied to optimize the system [6-8]. Various objective functions may be applied in the optimization of solar water heating systems. For example, solar fraction [5, 9], annualized life cycle cost [7, 10, 12-16], annual efficiency [9, 11], weighted sum of the two contributions consisting of overall thermal efficiency, and outlet temperature of the water [17] are used in different studies. Therefore, the selection of the objective function is very important for achieving the best design parameters with respect to hot

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*Corresponding Author's Email: abbasnejad@shahroodut.ac.ir (A. AbbasNejad) water consumption patterns. For example, Lima et al. [18] first simulated one thermosyphone system and then by using the economic terms, optimized this system by selecting the minimum cost as the objective function in life cycle for different fuel prices. They concluded that a system design based on maximum reception of solar energy through the year is better than a system design based on maximum reception of solar energy in winter; because in the first case, the primary cost of system is high and consumers are not willing to use it. However, in the second case, fuel cost of the auxiliary system through the year rises slightly but the primary cost of system is lower. The ratio of storage tank volume to collector area and storage tank dimensions are optimized for a natural circulation two phase closed thermosyphon flat plate SWH by Hussein [19]. Kulkarni et al. [14] proposed an innovative and partly comprehensive method for optimizing the direct SWH system that obtained good results and optimized the solar water heating system by choosing annualized life cycle cost as the objective function and by using a particular domestic hot water consumption pattern. They specified one design space for recognition of all of the possible ways by tracing constant solar fraction lines on the diagram of collector area vs. volume of storage. In this study, it has been observed that there exists a minimum as well as a maximum storage volume for a given solar fraction and collector area. Furthermore, existence of a minimum and maximum collector area is also observed for a fixed solar fraction and storage volume. The final applicable result in this study shows that in points near the optimal point, with decrease or increase of about 10% of solar fraction, the final cost varies only 2%. This allows the designer to select different arrangements by taking certain issues into consideration, such as investment costs and system reliability. Kulkarni et al. [14] also did not consider the collector angles in their study. Maybe their point of view was that the collector optimal angles can first be determined based on geographic conditions and climate and these angles are considered as constant parameters in the optimization of SWH system. Hobbi and Siddiqui [9] simulated an indirect forced circulation SWH system for a residential unit in cold climate using TRNSYS. They achieved optimal effective design parameters to reach the maximum solar fraction with variation of these parameters and by using a hot water consumption pattern for the given residential unit. Hobbi and Siddiqui [9] investigated many parameters including tank volume-to-collector area ratio (V_c/A_c), tank height, glycol percentage in solution, collector mass flow rate, absorber plate material and thickness, number of riser tube and riser tube diameter, heat exchanger effectiveness and the results were considerable for some parameters. However, although they investigated some parameters with low effect, they ignored one of the most important effective parameters, i.e. collector's angles and assumed that the collector tilt angle is constant and equal to location latitude. The optimum tilt angle and orientation of solar collectors are determined in order to reach the maximum solar radiation without considering consumption pattern in several former investigations [20-25]. Also, Kim et al. [16] presented a thermal analysis and performance optimization of a solar hot water plant (SHWP) by choosing the payback period as the objective function. The main objective of this study was to optimize the long-term performance of an existing active –indirect solar hot water plant, using a micro genetic algorithm based on the measured data. In order to achieve this objective in this problem, one typical hourly distribution of hot water consumption fraction for a day of the SHWP is presented in which three different consumptions of 80, 100, and 120 (m^3/day) are distributed during a day. The optimization is carried out for total collector area of the plant, storage volume, and three daily thermal demands. By comparing the existing plant and a slightly modified plant, it turned out that the modified plant had better thermal and economic performances. Also in the study by Kim et al. [16], collector's angles were not considered in the optimization of SWH system, similar to the two previous papers.

In this paper, the effect of time shifting of a sample hot water consumption pattern on the solar collector angles consisting of surface azimuth angle (γ), tilt angle (β), will be at first evaluated in a fixed storage volume in order to achieve a given solar fraction. Then, the effect of some practical hot water consumption patterns on the design parameters of an SWH system is analyzed and the optimal collector's orientation and tilt angle for any especial hot water consumption pattern are determined.

2. MATHEMATICAL MODEL

2.1. Solar radiation model

In the first part of this section, the intensity of solar radiation with respect to the geographic location in any time of the day will be simulated. So, total radiations consist of beam radiation, diffuse radiation, and ground reflected radiation. Diffuse radiation is an important parameter in calculation of the total radiation value, and the effect of surface azimuth angle (solar collector orientation) is shown in diffuse radiation. Diffuse radiation is composed of three parts. The first is an isotropic part, received uniformly from the entire sky dome. The second is circumsolar diffuse, resulting from forward scattering of solar radiation and concentrated on the part of the sky around the sun. The third, referred to as horizon brightening, is concentrated near the horizon, and is most pronounced in clear skies [26].

Sky models are the mathematical representations of the diffuse radiation. Therefore, the diffuse radiation can be written as:

$$I_{T,d} = I_{T,d,iso} + I_{T,d,cs} + I_{T,d,hz} \tag{1}$$

In various models, the isotropic diffuse model is a very simple model that has been developed by Liu and Jordan [27]. However, improved models have been developed which take into account the circumsolar diffuse and/or horizon brightening components on a tilt surface. Hay and Davies [28] took into account only the circumsolar component; they did not treat horizon brightening. Reindl et al. [29] added a horizon brightening term to the Hay and Davis model, as proposed by Klucher [30], giving a model to be referred to as the HDKR model. Perez et al. [31] presented a model that is based on a more detailed analysis of the three diffuse components (isotropic, circumsolar, and horizon brightening). The Perez model is more complex to use and generally predicts slightly higher total radiation on the tilt surface; it is thus the least conservative of the three methods (isotropic model, HDKR model, and Perez model). The Perez model is suggested for calculating solar intensity on surfaces with surface azimuth angles (γ) far from 0° in the northern hemisphere or far from 180° in the southern hemisphere [26]. In the present work, the effect of hot water consumption patterns on γ has been studied. Therefore, the Perez model has been selected as the best choice for calculating the intensity of solar radiation. Solar collector angles (γ and β) are shown in Fig. 1.

The total radiation on the tilt surface in the Perez model includes five terms: the beam, the isotropic diffuse, the circumsolar, the diffuse from the horizon, and the ground reflected term:

$$I_T = I_b R_b + I_d (1-F_1)\left(\frac{1+\cos\beta}{2}\right) + I_d F_1 \frac{a}{b} + I F_2 \sin\beta + I \rho_g \left(\frac{1-\cos\beta}{2}\right) \tag{2}$$

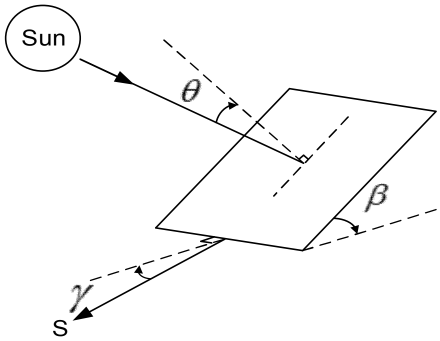

Figure 1. Orientation and tilt angles for solar collector

where the geometric factor $R_b = \cos\theta / \cos\theta_z$ is the ratio of beam radiation on the tilt surface to that on a horizontal surface at any time. F_1 and F_2 are circumsolar and horizon brightness coefficients; a, and b are terms that account for the angles of incidence of the cone of circumsolar radiation on the tilt surface and horizontal surface. The circumsolar radiation is considered to be from a point source at the sun. The terms a and b are:

$$a = \max[0, \cos\theta]$$
$$b = \max[\cos 85, \cos\theta_z] \tag{3}$$

TABLE 1. Brightness Coefficient for Perez et al. [26]

Range of ε	f_{11}	f_{12}	f_{13}	f_{21}	f_{22}	f_{23}
0-1.065	-0.196	1.084	-0.006	-0.114	0.180	-0.019
1.065-1.230	0.236	0.519	-0.180	-0.011	0.020	-0.038
1.230-1.500	0.454	0.321	-0.255	0.072	-0.098	-0.046
1.500-1.950	0.866	-0.381	-0.375	0.203	-0.403	-0.049
1.950-2.800	1.026	-0.711	-0.426	0.273	-0.602	-0.061
2.800-4.500	0.978	-0.986	-0.350	0.280	-0.915	-0.024
4.500-6.200	0.748	-0.913	-0.236	0.173	-1.0450	0.065
6.200-	0.318	-0.757	0.103	0.062	-1.698	0.236

The brightness coefficients F_1 and F_2 are functions of three parameters that describe the sky conditions, the zenith angle θ_z, a clearness ε, and a brightness Δ, where ε is a function of hour's diffuse radiation I_d and normal incidence beam radiation I_n. It is given by [26]:

$$\varepsilon = \frac{\dfrac{I_d + I_n}{I_d} + 5.535\times10^{-6}\theta_z^{\,3}}{1 + 5.535\times10^{-6}\theta_z^{\,3}} \tag{4}$$

where, $I_n = \dfrac{I_b}{\cos\theta_z}$ and θ_z is in degrees, and

$$\Delta = m\frac{I_d}{I_{on}} \tag{5}$$

where, $m = \dfrac{1}{\cos\theta_Z}$ and

$$I_{on} = G_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right)\times 3600. \tag{6}$$

$$F_1 = \max[0,(f_{11} + f_{12}\Delta + \frac{\pi\theta_z}{180} f_{13})] \tag{7}$$

$$F_2 = (f_{21} + f_{22}\Delta + \frac{\pi\theta_z}{180} f_{23}) \tag{8}$$

F_1 and F_2 are functions of statistically derived coefficient for range of values of ε; recommended set of these coefficients is shown in Table 1 [26]. A solar power meter TES 1333R is used in Tehran in order to validate the calculated results. The comparison showed very good agreement with the real experimental data.

2.1. Solar water heater modeling

A solar water heater is a combination of a solar collector array, an energy transfer system, and a storage tank. Solar collector array absorbs the radiation and converts it to heat. This heat is then absorbed by a heat transfer fluid (water, non-freezing liquid, or air) that passes through the collector. This heat can then be stored or used directly [32].

The schematic diagram of a solar water heating system is shown in Fig. 2. In this system, water and ethylene glycol mixture are circulated in a closed cycle through the collector tubes, and absorbed heat in the absorber plate is transferred to the water in the storage tank. With a logical assumption, the storage tank is always full. The transferred useful energy to the collector fluid may be calculated as follows:

$$\dot{q}_{gain} = \dot{m}_{col} C_{col} \left(T_{co} - T_{ci}\right) \tag{9}$$

On the other hand,

$$\frac{dq_{gain}}{dt} = \dot{q}_{gain} = \eta_{col} A_C G_T \tag{10}$$

The collector thermal efficiency (η_{col}) can be calculated through a linear equation as:

$$\eta_{col} = F_R(\tau\alpha) - F_R U_L \frac{(T_{ci} - T_{amb})}{G_T} \tag{11}$$

where, T_{amb} is the five years average of meteorological records that has been provided from the meteorological organization data.

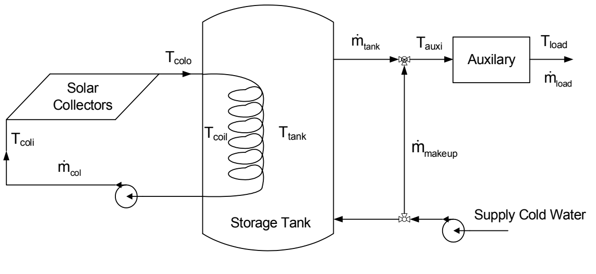

Figure 2. Schematic of solar water heating system

Combining Eq. (10) with Eq. (9), $\dot{q}_{gain}$ may be expressed as:

$$\dot{q}_{gain} = A_c[F_R(\tau\alpha)G_t - F_R U_L(T_{ci} - T_{amb})] \tag{12}$$

T_{co}, can be estimated by setting Eq. (8) equal to Eq. (12). The heat transfer to the storage tank can be estimated considering the effectiveness coefficient (Eff_{HX}).

$$\dot{q}_{trans} = Eff_{HX} \times \dot{q}_{gain} \tag{13}$$

Energy balance equation of the tank can be expressed as:

$$\rho V_{\tan k} C_{P_w} \frac{dT_{\tan k}}{dt} = \dot{q}_{trans} - \dot{q}_{use} - \dot{q}_{loss} \tag{14}$$

where,

$$\dot{q}_{use} = \dot{m}_{use} C_{P_w} (T_{\tan k} - T_{\sup}) \tag{15}$$

$$\dot{q}_{loss} = U_{\tan k} A_{\tan k} \left(T_{\tan k} - T_{amb}\right) \tag{16}$$

The recommended $U_{\tan k}$ value is ≈ 0.16 W/(m^{2}K) [32]. Energy balance for the calculation of T_{ci} can be expressed as:

$$M_{col} C_{P_{col}} \frac{dT_{ci}}{dt} = \dot{q}_{gain} - \dot{q}_{trans} \tag{20}$$

If $\dot{q}_{use}$ is less than the required thermal load at any moment, the residual thermal energy is provided via auxiliary energy, and it is given by the following formula:

$$\dot{q}_{auxilliary} = \dot{m}_{load} C_{P_w} (T_{load} - T_{aux}) \tag{21}$$

where T_{aux} is the temperature of inlet water to the auxiliary system, and is equal to $T_{\tan k}$ for conditions in which the tank temperature is not more than T_{load}. However, if $T_{\tan k}$ is more than the required temperature for consumption at that moment, i.e.T_{load}, some cold water is mixed with it. For the mixture of these two flows, two thermal and mass balance equations can be expressed as follows:

$$\dot{m}_{\tan k} + \dot{m}_{makeup} = \dot{m}_{load} \tag{19}$$

$$\dot{m}_{\tan k} T_{\tan k} + \dot{m}_{makeup} T_{\sup} = \dot{m}_{load} T_{aux} \tag{20}$$

The solar fraction may be calculated as:

$$\dot{q}_{load} = \dot{q}_{use} + \dot{q}_{aux}$$

$$SF = \frac{\dot{q}_{load} - \dot{q}_{aux}}{\dot{q}_{load}} = 1 - \frac{\dot{q}_{aux}}{\dot{q}_{load}} \quad (21)$$

Based on the presented equations in this section, the SWH system can be simulated and the effects of various parameters can be analyzed. In order to investigate the effect of consumption pattern on the optimum orientation & tilt angle of solar collectors, the effect of time shifting of a sample pattern on optimum angles of solar collector will be firstly considered. Next, the optimal orientation & tilt angle for different applications such as household, commercial, and so on will be determined.

3. MODELING RESULTS

In the optimization process, various parameters and input data are given in Table 2. The specific solution procedure is used for the optimization of the objective function. First, the model was written on VBA and then a specific or actually exotic engine that was an optimization engine coupled with Excel, was installed (that engine was bought from an American OR institution) that solved the nonlinear optimization problem.

TABLE 2. Input data for SWH at Tehran, Iran

Location	Latitude, ϕ (°North)	35.7
	Longitude, L_{loc} (°East)	54.1
	Altitude in kilometer	1.149
Load	Hot water demand temperature, °C	60
Collector	Mass flow rate per unit area of collector, (kg/m^2s)	0.02
	$F_R(\tau\alpha)_n$	0.84
	) $\frac{W}{m\,^{\circ}C}$ (, $F_R U_L$	4.64
	Specific heat of ethylene-glycol in water, ($\frac{J}{kgK}$)	4022
Storage	Cylindrical, with $(h/d) = 2$	2
	) $\frac{W}{m\,^{\circ}C}$ (Heat loss coefficient , U	0.16
	(l/m^2) Storage tank volume, $\frac{V_c}{A_c}$	50

For validation of the obtained results, a complementary program in VB was used that generated all feasible space and compared all responses and gave the best objective function. There were close affinity between two results that showed high reliability of the results.

With respect to input data for storage tank volume in Table 2, it can be said that a general rule to follow is that the storage tank volume should be between 35 and 70 (Lit/m^2) of collector area, while the most widely used size is 50 (Lit/m^2) [32].

3.1. Time shifting of a sample pattern

In order to understand the effect of hot water consumption pattern on the design parameters, especially surface azimuth angle, a sample pattern with a 4-hour constant demand of hot water is supposed whose hourly consumption is equal to 200 Lit (totally 800 Lit).

Then, the effect of time shifting of this pattern is evaluated in various time intervals. Time intervals are shown in Table 3. The effect of time shifting of this sample pattern on the surface azimuth angle and tilt angle is studied.

The objective function has been considered to be the minimization of auxiliary energy required for a given solar fraction. Optimal gamma angle for different time intervals is shown in Fig. 3. As shown in this figure, surface azimuth angle (γ) will change with time shifting of the pattern. Surface azimuth angle (γ) values are changed from -29.9 to 5.6 degrees. Fig. 4 depicts the optimal tilt angle for various time intervals. It is observed that the lowest measured tilt angle is 37.03 at the second time interval (10 AM – 2 PM), whilst the highest tilt angle is found at the fourth time interval (2 – 6 PM) and has a value of 40.26.

In the next step, for comparing the results obtained in the previous step, maximization of the received solar energy through the year is considered as the objective function. If this objective function is used, results will be independent from the type of system and hot water consumption and they will only be dependent on geographical situations. In order to maximize the received solar energy for the given location (Tehran), the tilt angle (β) is equal to 33.2° and the surface azimuth angle (γ) is almost equal to 0 °. This state is the assumed base state and the results obtained are compared to the results of this state. The base state results in this study have a good agreement with the proposed results by Moghadam et al. [33].

Determination of the optimal orientation based on the proposed modeling in this paper leads to energy saving which is shown in Fig. 5. A comparison between optimal angles and energy saving value shows that if hot water consumption is before noon (morning) or afternoon and before sunset, the optimal surface azimuth angle would be far from the base state angle and if consumption is in mid-day hours or after sunset, the optimal surface azimuth angle would be near to the base state. As seen in Fig. 3, if hot water consumption is at morning hours, the surface azimuth angle would be negative, namely collectors are inclined toward the east. But this angle is positive for the afternoon hours and the orientation of collectors will be toward the west. The tilt angle of the collectors in each time interval is almost constant and the difference between the optimal tilt angle with respect to consumption and the tilt angle for absorbing the maximum solar radiation shows the effect of hot water consumption on design angles.

Fig. 5 shows the amount of saved energy when the surface azimuth angle has been altered from 0 to the value obtained from the optimization process.

TABLE 3. Time intervals of hot water consumption shift

Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Time intervals	8-12A.M.	10A.M.-2P.M.	12-4P.M.	2-6P.M.	4-8P.M.	6-10P.M.	8-12P.M.

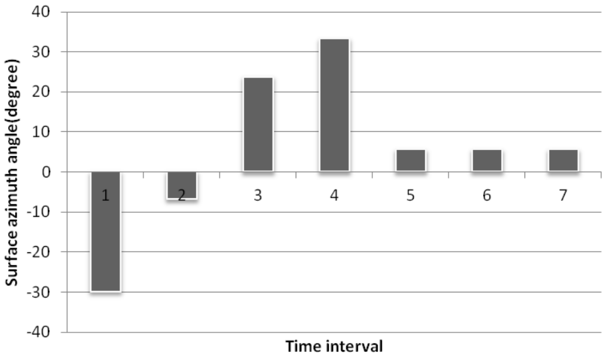

Figure 3. Optimal gamma angle for various time intervals

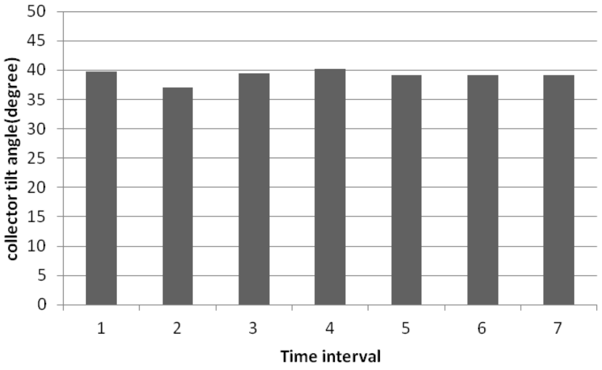

Figure 4. Optimal tilt angle for various time intervals

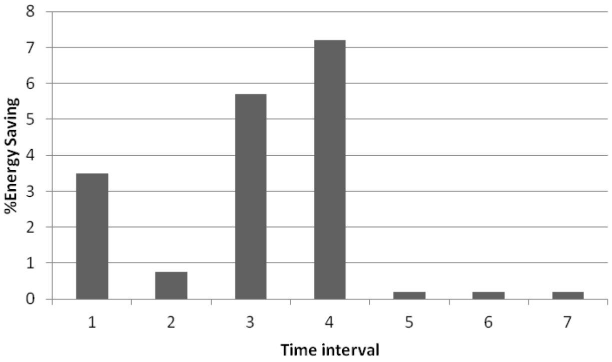

Figure 5. Energy saving percent for optimal collector angles state

In order to investigate the problem deeply, the effect of variation of angles on the tank temperature and collector efficiency has been studied. When hot water is consumed, the tank temperature will be reduced even in the sunny hours. For example, Fig. 6 shows the tank temperature when the hot water is consumed based on interval 1 (from 8 to 12). As shown in this figure, despite the solar radiation, temperature of the tank reduces due to hot water consumption, and consequently the heat transfer efficiency in coil (heat exchanger) will be enhanced. Moreover, the temperature of the working fluid of the collector will decrease and collector efficiency that depends on the inlet water temperature will increase. Fig. 7 represents daily collector's efficiency for optimal orientation and collector's orientation in the base state.

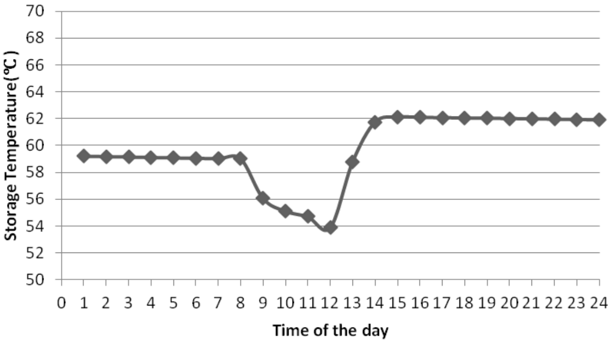

Figure 6. Storage temperature profile for optimal orientation

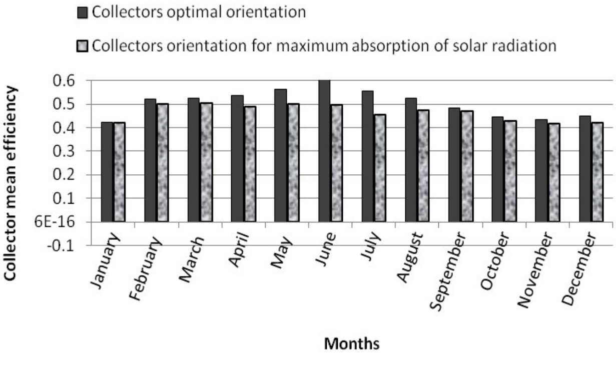

Figure 7. Monthly collector's efficiency for collectors' orientation at two states

3.2. The effect of practical hot water consumption pattern (HWCP) on design parameters

For more investigation, five specific hot water consumption patterns have been taken into account by using the proposed method. The five patterns include hot water consumption pattern for the usages of office building, commercial building, afternoon and morning shift high school and a 15-unit apartment. The hot water consumption value at various hours of the day has been shown for different applications in Fig. 8.

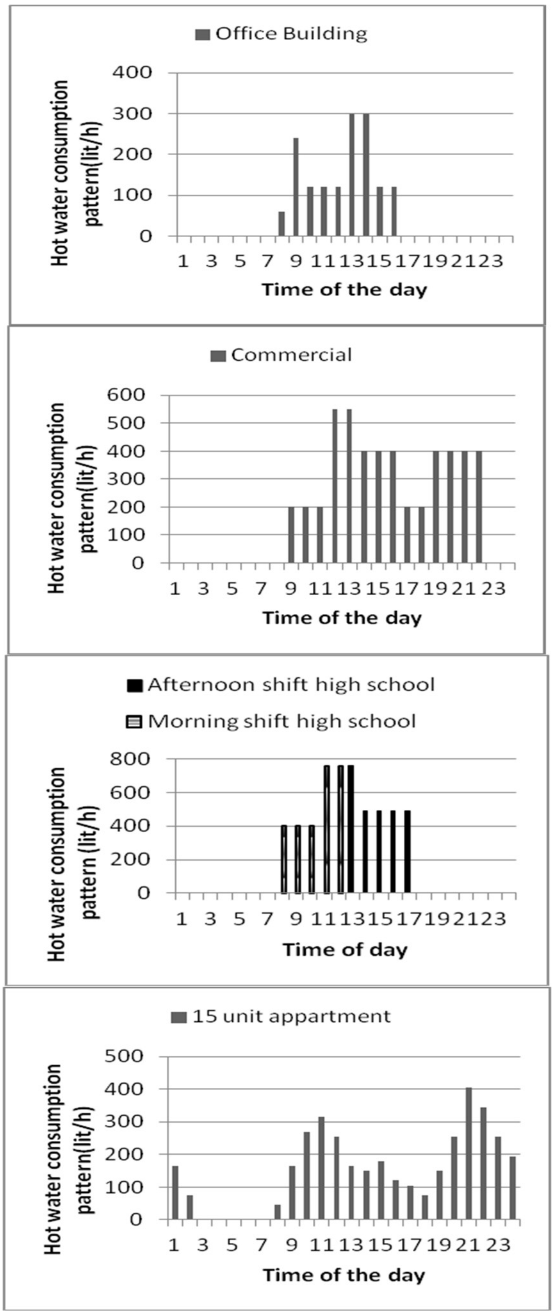

Figure 8. Hot water Consumption Pattern (HWCP) for different applications.

Optimal design parameters for the five hot water consumption patterns are given in Table 3. The surface azimuth angle for apartment, commercial, high school (P.M.), and office consumptions are positive, it means that the collectors should be inclined to west, and for high school (A.M.) the collectors should be directed toward east as shown in Table 4.

In office, commercial and particularly high school (P.M.) patterns, collectors incline toward the west because consumption is in the afternoon and hot water consumption is simultaneous with receiving solar radiation, whereas in the high school (A.M.) pattern collectors should rotate due east, because consumption is in the morning and it is simultaneous with absorption.

Fig. 9 shows the energy saving percentage through optimizing the collector angles for various hot water consumption patterns in comparison to the base state (β=33.2, γ=0 [33]). As seen in this figure, high school (P.M.) has the maximum energy saving, whilst high school (A.M.) has the minimum energy saving. Similar to Fig. 5, in consumption patterns where collectors are inclined toward west, more energy saving is achieved than the consumption patterns with collectors due east, and it is through the greater increase of storage temperature.

Values of the tilt angles in various consumption patterns and tilt angle in the base state are different, and it is through the effect of hot water consumptions. The difference between optimum angles (γ and β) in Table 3 and optimal angles in the base state lead to additional energy saving.

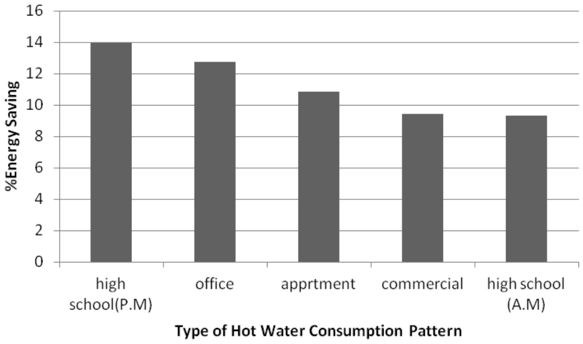

Figure 9. Energy saving percent for optimal β and γ angles state.

3.3. Variation of Optimal Angles with Various Solar fractions

Given optimal angles (γ, β) exist for achieving each given solar fraction. Fig. 10 shows the variation of surface azimuth angle with solar fraction for various HWCPs. It has been observed that the optimal γ is almost constant. It shows that in order to minimize the Q_{aux} and achieve a given solar fraction simultaneously, the orientation of the collectors does not have important effect on the storage temperature and the collector's area is an effective parameter. Fig. 11 depicts the variation of tilt angle with solar fraction. As it can be seen in Fig. 11, this variation is very similar to the γ angle variation. Generally, solar fraction does not affect the optimal orientation of the solar collectors significantly.

TABLE 4. Optimal design parameter for type of hot water consumption pattern

	Type of Hot Water Consumption Pattern				
Parameters	**Apartment**	**Office**	**High School (P.M.)**	**High School (A.M.)**	**Commercial**
γ (degree)	7	12.76	14.6	-9.6	10.8
β (degree)	44.08	44.31	50.19	48.36	43.77
Ac(m^2)	106.328	41.83	83.312	80.51	136.548

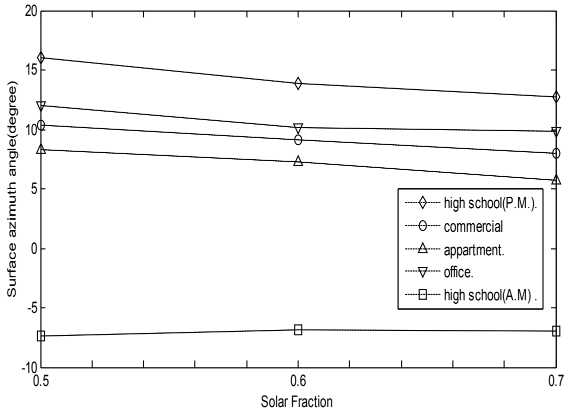

Figure 10. Variation of surface azimuth angle with solar fraction.

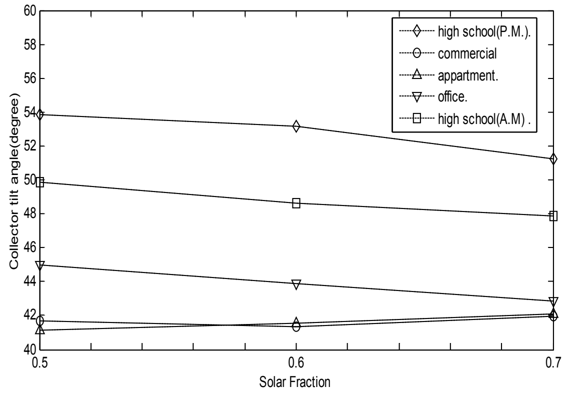

Figure 11. Variation of collector tilt angle with solar fraction

3.4. The Effect of Storage Volume on the Optimal Angles (γ, β)

In order to investigate the effect of storage volume, five values for volume per collector area (V_c/A_c) including 35, 40, 50, 60, and 70 (Lit/m^2) are studied. Fig. 12 shows the effect of storage volume on the surface azimuth angle. For high school (P.M.), office, and commercial patterns which have higher consumptions in the afternoon, the surface azimuth angle decreases by increasing the volume and turns from the west to the south as shown in Fig. 12. This angle for apartment and high school (A.M.) pattern increases and so it is turned from the west to the south. With the increase of storage volume, required collector area increases. Therefore, with the increase of storage volume, the effect of surface azimuth angle reduces, i.e. collectors are orientated due south.

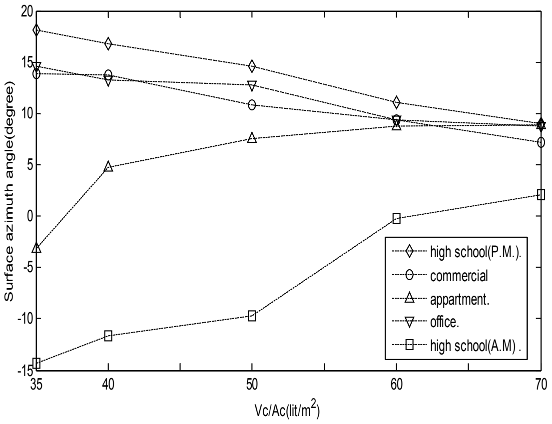

Figure 12. Variation of storage volume on surface azimuth angle.

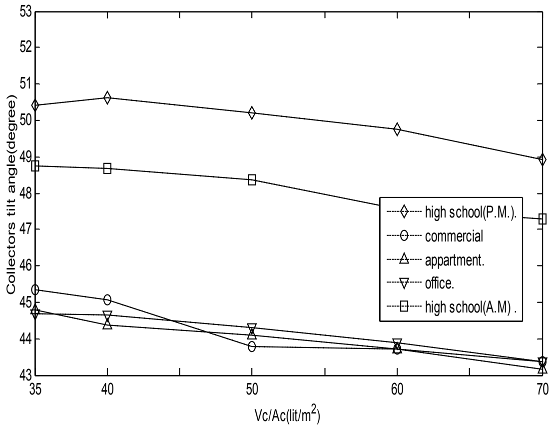

Figure 13. Variation of storage volume on the collector tilt angle.

Fig. 13 shows the variation of the tilt angle with the storage volume. With respect to Fig. 13, the collector tilt angle is almost constant with the variation of the storage volume. For high schools pattern that consumption is only in the afternoon or before noon, the tilt angle is greater than the tilt angle of the collectors for HWCPs so that their consumptions are scattered throughout the day. Therefore, the storage volume is also an effective parameter in the optimum collector's angles.

In our optimization model, more investigation on water consumption shows that decreasing or increasing of water consumption do not affect the optimal angles and just leads to decrease or increase in collector's area, respectively.

6. CONCLUSIONS

1. The effect of hot water consumption pattern (HWCP) on the design parameters, particularly collector's angles including collector's orientation (γ) and tilt angle (β) is presented in this paper. An indirect forced circulation solar water heating system with a flat plate collector is modeled. In addition, in order to study the variation of γ angle, the Perez model was used for solar radiation modeling.
2. By studying the time shifting of a sample pattern, it has been observed that for the first (8-12 A.M.), the third (12-4 P.M.), and the fourth (2-6 P.M.) intervals in which solar energy absorption and hot water consumption are simultaneous, the collectors have been directed more toward the south, i.e. at the first intervals, collectors are orientated toward the east, and at the third and fourth intervals, collectors are oriented toward the west. Moreover, for mid-day hours or after sunset, the optimal surface azimuth angle will be near to γ angle for receiving the maximum solar energy. Collector's tilt angle in each time interval is almost constant.
3. Optimal angles for the five practical hot water consumption patterns including office building, commercial building, high school (P.M.) or (A.M.), and 15-unit apartment in Tehran, Iran have been obtained. With comparison to annual energy consumption between this state and when collectors are located in the situation of receiving the maximum solar energy (base state), the effect of consumption on the value of optimal angles (γ, β) is clarified. Results shown that 9 to 14% energy saving can be obtained by changing the orientation of the collectors in various pattern. This amount of energy saving might be considered as insignificant especially in some countries with high level of accessibility of sun like Iran, but the aim of this research is making a major push to attract the attention of other students about some different aspects of the solar energy context, especially solar water heater owing to the great importance of renewable energy, particularly solar energy in future lives of human being.
4. For minimization of $Q_{auxiliary}$ and achieving a given solar fraction simultaneously, collector's area is the most effective parameter and γ, β angles are constant parameters.
5. It has been observed that storage volume is a significant parameter in the optimization of SWH system. However when it increases optimal angles of collectors will be almost near together for various patterns.
6. Increase or decrease of hot water consumption quantity only leads to increase or decrease of collector's area, respectively. These variations do not have much impact on the optimal angles (γ, β).

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