Energetic and Economic Impact of Using Bioclimatic Design Technics and of Solar Water Preheating System Integration on Tertiary Building

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Abstract-In this paper, a real case study about energy efficiency improvement of the building of the Software and Services Development Companies' Space at the Technological Center of 'EL GHAZALA'is presented. On the one hand, this study aims to highlight the importance of the energetic and financial gains realized upon the respect of some bioclimatic design rules and solar water preheating system integration. Italso aims to present the Tunisian thermal regulation limits. On the other hand, it provides a method for the design of glazed surfaces and overhangs or fins while introducing the way to use the SOLO and CLIP software for the energetic and financial gains calculation. In a first step, building thermal needs were studied, using the CLIP software,for two specific cases: a first case where the building is under the most common standard conditions in Tunisia and where only glazed surfaces dimensions and orientations are optimized; and a second case where higher performance materials and overhangs and fins are used. It came out that half of the thermal energy needs could be saved and low investment payback of about nine years could be reached. Another outcome is that Tunisian thermal regulation should be updatedin order to further promote the use of more efficient building materials. Then, in a second step, the effect of solar waterpreheating system integration was studied using the SOLO software. It turned out that its integration could cover about 64% of the building's heating needs.

Keywordssolar heating, glazed surface dimensioning, bioclimatic building, energetic impact, overhang and fin dimensioning, Tunisian thermal regulation.

1. Introduction

The building's energy consumption represents between 20% and 40% of total energy consumption, particularly in developed countries [1]. This finding emphasizes the need to minimize the building's energy demand. In order to accomplish this statement, several solutions are available for designers, such as using bioclimatic design rules or the integration of renewable energy production facilities. These solutions have been the subject of several studies focusing on: their energetic and environmental impacts [2, 3, 4, 5, 6, 7, 8], their cost [8, 9], their potential [10, 11], their impact on occupant comfort [12, 13] and the policies and regulations related thereto [14, 15].

In this article, it will be presented a study on building energy efficiency improvement by following the bioclimatic design rules andsolar water heating systemintegration. This study will be conducted using two of the best known software by design offices in Tunisia: CLIP and SOLO.

CLIP software was developed by the National Agency for Energy Management (ANME) within the framework of the project of new buildings' thermal and energetic regulations implementation [15, 16]. It allows to classify a building according to its energy performance level and to determine all energy efficiency actions to introduce in order to comply with the minimum thermal regulation. Therefore, as it facilitates the design offices work during buildings' thermal performance reports preparation; it is one of the most used software in Tunisia.

SOLO software was developed by the 'Centre Scientifique et Technique du Bâtiment' (CSTB) [2]. It allows the solar thermal systems dimensioning through installation's coverage rate and productivity calculation for each configuration (collector surface, storage tank volume ...). Even if it should be used with caution, given its margin of error particularly for large flow installation [3], it remains one of the most exploited tools in Tunisia due to its simplicity.

Due to above statement,it will be interesting to present the wayto use them to quantify the energeticand economic benefits of following the bioclimatic designs rules and of solar water preheating systemintegration. As software complement, a method for the design of glazed surfaces and overhangs or fins will be exposed.Thus, this paper may serve as a basis for engineers and researchersfor future study. Moreover, this methodology will be applied during the study of the building of the Software and Services Development Companies' Space at the Technological Center of 'EL GHAZALA'. This study will show the building energy efficiency improvement limits under actual Tunisian thermal regulation.Moreover, it will highlight the importance of the energetic and financial gains realized upon the respect of some bioclimatic design rules and solar water preheating systemintegration.

In a first step, the thermal needs of the building will be studied for two specific cases using the CLIP software. The results will be compared and an economic analysis will be exposed.

The first case of study will be the building under the most common standard conditions in Tunisia. Only the sizes and the orientations of the glazed surfaces will be optimized in such a manner to minimize the heat gain during summer and the glare effects.

The second case of study will concern an improved version of the first case. More efficient materials, allowing to limit thermal exchanges with the outside and to increase the thermal inertia of the building, will be used. Overhangs and fins are also planned in order to limit heat gain during summer.

Then, in a second step, the effect of solar water preheating systemintegration will be studied using the SOLO software.

2. Presentation of the Studied Building

The studied building is a tertiary sector building. It is the Software and Services Development Companies' Space at the Technological Center of 'EL GHAZALA' (Fig.1). It consists of three blocks of three floors each. The study presented below concerns the right block, as specified in Fig. 2.

Fig.1. Building of the Software and Services Development Companies' Space at the Technological Center of 'EL GHAZALA '.

Fig.2. The studied block.

3. Building Energy Efficiency Improvement by Following the Bioclimatic Design Rules

In order to improve building energy efficiency, some bioclimatic design rules must be respected, such as [4, 17]:

- Installing more windows on eastern facade than western facade, while minimizing their size.
- Installing more windows on southern facade than northern facade.
- Using low emissivity glazing.
- Limitation of solar gains by appropriate sun protection.
- Improvement of the envelope, loft insulation.
- High thermal inertia of the building.

The effect of such rules on the building energy consumption will be studied using CLIP software. First, the building will be studied under standard conditions. Then, some modifications, following the bioclimatic design rules (cited above), will be introduced. Finally, the obtained results in the two cases will be compared. This study will evaluate the energy impact of such rules and will present Tunisian thermal regulations limits in terms of building energy demand reducing by encouraging the use of high energy performance products.

3.1. Case where the Building is under Standard Condition

In this first case, different types of building components (vertical walls, windows, roof, floor, ...) were selected according to their frequency of use in Tunisia (especially for existing buildings), such as:

- The vertical walls are air-filled double wall.

- Selected glass windows are simple and clear glass.

- The chosen roof is a horizontal uninsulated roof.

- The bottom floor is moderately heavy floor.

Given the ease of control of heat gain and glare that it offers, it is generally best to have a greater percentage of glazed areas in the south side of the building. A lower percentage should be placed in the north side of the building to minimize heat loss in winter, even if it is known by an excellent natural lighting. Glazed surfaces in the east and west facades will be minimized given the difficulty of mastering heat gain and glare effects [18]. However, implementation of these recommendations is related to building's orientation, to building's type (or to activity made inside the building), to building's interior surfaces, etc...

The studied building is oriented at 22.5 degrees from the south as the southern facade is actually south southeast. So the application of the recommendations mentioned above was carried out (as much as possible) to the nearest facade. For example, recommendations for the southern facade were applied to the south southeast façade. In order to control heat gain through the glazed surfaces, self-shading techniques, such as mass articulations or deep reveals were used.

The glazed surface necessary for adequate daylighting inside the building was calculated by the following formula [18]:

$$S = \frac{2 \times DF \times S_i \times (1 - R_i)}{VT \times \theta} \qquad (1)$$

Where:

DF: average daylight factor.

S_i: total area of interior surface (walls, floor, ceiling) (m²).

R_i: area weighted average reflectance.

VT: visible transmittance.

θ: vertical angle of sky (°). Its value varies from 0° to 90°and is equal to 90° if no obstruction.

The area weighted average reflectance is calculated by the following equation [18]:

$$R_i = \frac{S_W \times R_W}{S_T} + \frac{S_C \times R_C}{S_T} + \cdots \text{etc} \qquad (2)$$

Where:

S_w: wall area (m²).

R_w: wall reflectance.

S_c: ceiling area (m²).

R_c: ceiling reflectance.

S_T: total surface area (m²).

Total surface area of walls, ceiling, windows, floor, partition, furniture is added.

The selected glazed surfaces have horizontal shape and have been disposed in strip to avoid light/dark contrast. In order to minimize heat gain and glare, the height and width of the glazed surfacescalculation (Fig. 3) is performed as follows:

- Calculation of minimum solar altitude (at the winter solstice).

- Fixing the working plan at 0.85m from the ground (conventional value for a working plan [19]).

- Set the reference point at a distance of 0.5m from the location where task is performed (desk) and at the intersection between the wall perpendicular to the glazed surface and the work plan, as described in Figures 3 and 4.

- Calculation of window's height by the following formula:

$$h_v = \frac{d_v \times \tan \alpha_1}{\cos(\alpha_s - \alpha_2)} \qquad (3)$$

Such that:

$\alpha_1 < h$ and $\tan \alpha_1 < \frac{h_w}{d_v}$ and $(\alpha_s - \alpha_2) < \tan^{-1}\left(\frac{L_w}{d_v}\right)$

Where:

h_w: height of the wall from the working plane (m).

h: solar altitude (°).

d_v: distance between the reference point and the glazed surface (m).

α_1: angular height of the glass (°).

α_s: solar azimuth (°).

α_2: window azimuth (°).

L_w: the width of the wall where the window is located (m).

- Calculation of the width of the glass by the following formula:

$$L_v = S/h_v \qquad (4)$$

- If $L_v > L_w$ then:

$$L_v = L_w \qquad (5)$$

and

$$h_v = S/L_v \qquad (6)$$

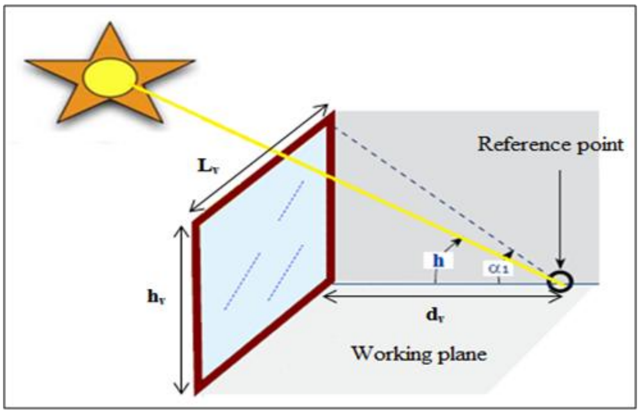


Fig.3. Windows sizing.

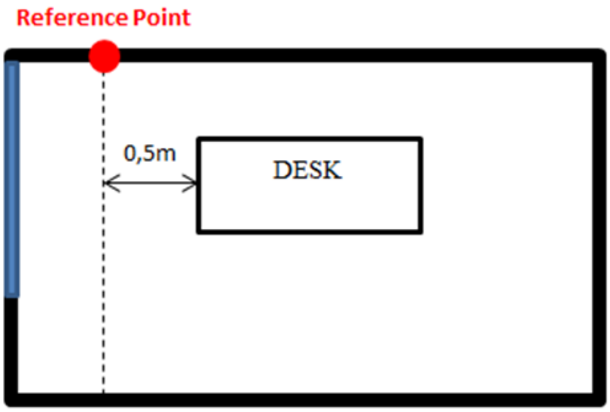


Fig.4. Reference point.

For solar altitude calculation the following formula is used [20]:

$$h = \sin^{-1}(\cos\varphi \, . \cos\delta \, . \cos\omega + \sin\varphi \sin\delta) \tag{7}$$

Where:

φ: the latitude (°).

ω: the hour angle (°).

δ: the declination (°).

The declination is determined by the following formula [20]:

$$\delta = 23{,}45 * \sin\left[\frac{360}{365} . (n - 81)\right] \tag{8}$$

Where:

n: the number of the day of the year.

The hour angle is calculated by the following formula [20]:

$$\omega = (TSV - 12) \times 15 \tag{9}$$

Where:

TSV: true solar time (h).

When calculating the dimensions of the glazed surfaces, TSV values used are 11am for the south southeast façade, 9am for the east northeast facade and 15h for the west southwest façade. These values were chosen using the sun path chart. The latter was created by a University of Oregon program [21]. An occupation of the building from 6am to 6pm (solar time) was chosen. The solar altitude at the summer solstice for those hours was read from the sun path chart. Then, by drawing a horizontal line, the corresponding time at this height at the winter solstice (the closest) was determined (Fig. 5). This technique will allow us to reduce heat gain in summer and to take advantage of it in winter. It was used for the determination of TSV for east northeast and west-southwest facades. For the south southeast façade, it was simply chosen TSV corresponding to the façade's azimuth.

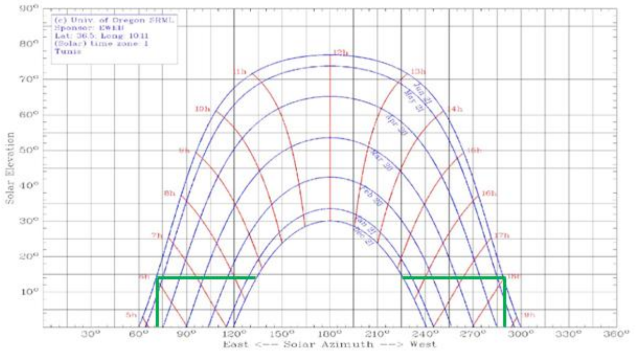
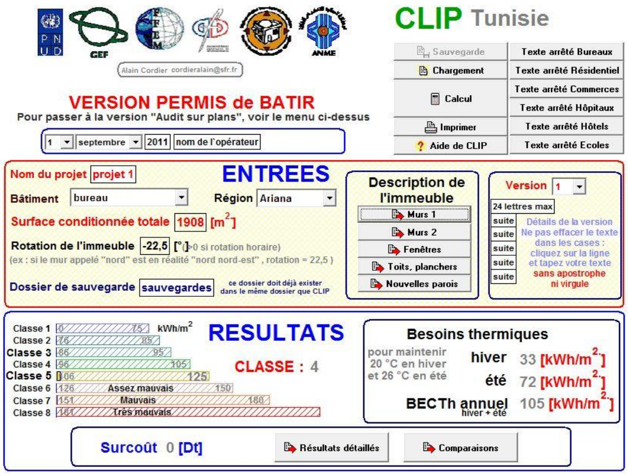


Fig.5. Determination of solar time using sun path chart.

Regarding North northwest façade, only the calculation of the area was conducted. The values of the height and the width of the glazed surface were chosen such that the width is greater than the height.

The obtained results are detailed in Fig. 6. The annual energy need related to the studied building thermal comfort is equal to 105 kWh/m². These conditions place it in class 4 of the building's thermal performance. This is in accordance with the Tunisian thermal regulation, which imposes an energetic class lower or equal to class 5 for private sector buildings [22]. Moreover, it is noteworthy that, in this first version, the only respected bioclimatic design rule is the windows size and orientation optimization. Therefore, as the use of insulation or energy efficient glazing is not always necessary to comply with the Tunisian thermal regulation, it would be obvious to argue that it does not have any motivating effect on stakeholders for using more energy efficient products.



Alain Cordier cordieralain@sfr.fr

VERSION PERMIS de BATIR
Pour passer à la version "Audit sur plans", voir le menu ci-dessus

1 septembre 2011 nom de l'opérateur

Nom du projet: projet 1
Bâtiment: bureau
Région: Ariana
Surface conditionnée totale: 1908 $[m^2]$
Rotation de l'immeuble: -22,5 [°] (>0 si rotation horaire)
(ex : si le mur appelé "nord" est en réalité "nord nord-est" , rotation = 22,5)
Dossier de sauvegarde: sauvegardes
ce dossier doit déjà exister dans le même dossier que CLIP

Version: 1
24 lettres max
suite
suite
suite
suite
suite
Détails de la version
Ne pas effacer le texte dans les cases : cliquez sur la ligne et tapez votre texte sans apostrophe ni virgule

		kWh/m²
Classe 1	0	75
Classe 2	76	85
Classe 3	86	95
Classe 4	96	105
Classe 5	106	125
Classe 6	126 Assez mauvais	150
Classe 7	151 Mauvais	180
Classe 8	181 Très mauvais	

CLASSE : 4

Besoins thermiques
pour maintenir 20 °C en hiver et 26 °C en été
hiver 33 $[kWh/m^2]$
été 72 $[kWh/m^2]$
BECTh annuel hiver + été 105 $[kWh/m^2]$

Surcoût 0 [Dt]

Fig.6. Presentation of standard case results under the CLIP software.

According to the displayed results (Fig. 6), in order to maintain the building temperature at 20°C in winter and 26°C in summer, the necessary thermal requirements are 33 kWh/m² in winter and 72 kWh/m² in summer. It may be normal, given the tropical climate of Tunisia, that summer thermal requirements are higher than winter thermal demands. However, a summer thermal requirement that constitutes more than the double of winter thermal requirement, suggests that there is a mismatch of solar gains with energy needs. Therefore, in order to limit the heat exchanges with the outside, it is proposed in the following to try to correct this mismatch by using better insulation in the building's vertical and horizontal walls and by increasing the building's thermal inertia. In addition, the glass surfaces will be replaced by others with low thermal transmission coefficients and sun visors will be provided in order to limit heat gain in summer.

3.2. Case where the Building Meets the Bioclimatic Design Rules Mentioned Above

In this second case, the various components of the building (vertical walls, windows, roof, floor ...), used previously were replaced by more energy efficient one. In addition, in order to reduce solar gain in summer, overhangs and fins have been installed. Thus, changes made are:

- The vertical walls are rock wool filled double wall. Rockwool was chosen because of its good phase shift compared to others insulation materials available in Tunisia.

- Selected glass windows are low emissivity double glazing.

- Overhangs and/or fins for each window have been planned.

- The chosen roof is a horizontal rock wool insulated roof.

- The bottom floor is moderately heavy floors.

Overhangs and fins were sized using the method explained by Duffie and Beckman [20]. This method was also presented by Alastair Robinson and Al. [18] and by ASHRAE [23].

For overhang:

$$H = \frac{D_o \times \tan h}{\cos(\alpha_s - \alpha_2)} \qquad (10)$$

For fins:

$$W = D_f \times \tan(\alpha_s - \alpha_2) \qquad (11)$$

Where:

H: height of the shadow (m).

W: width of the shadow (m).

D_o: depth of the overhang (m).

D_f : depth of the fin (m).

α_s : solar azimuth (°).

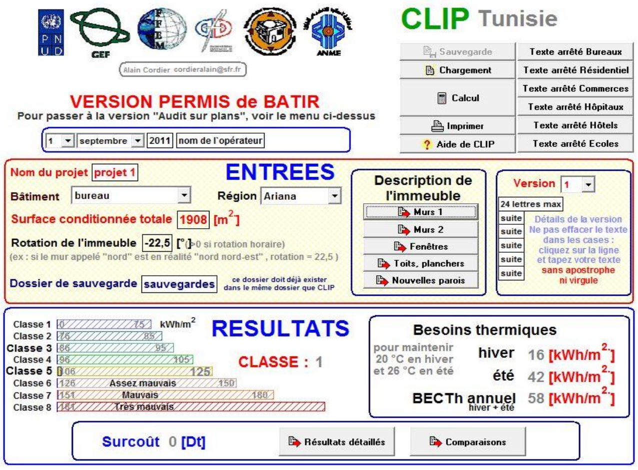
α_2 : window azimuth (°).

h: solar altitude (°).

For overhang dimensioning, α_s is fixed equal to α_2, then correspondent solar altitude is read from sun path chart for summer solstice, and finally D_0 is calculated for H equal to windows height.

For fin dimensioning, D_f is calculated for (α_s - α_2) equal to 35° and W equal to half window's width. Then the obtained value of D_f are refined according to building architecture.

The simulation results are given in Fig. 7. The annual energy need related to the studied building thermal comfort is now equal to 58 kWh/m². These conditions place it in class 1 of the building's thermal performance. In addition, the reduction of thermal needs of about half compared with the results of the initial case reflects the importance of the energy impact of building materials and overhangs and fins on building's energy demand. Also, in addition to the insulation, the role of overhangs and fins is confirmed by gap reduction between summer and winter thermal requirements.



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Nom du projet projet 1

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		kWh/m²
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Classe 5	106	125
Classe 6	126 Assez mauvais	150
Classe 7	151 Mauvais	180
Classe 8	181 Très mauvais	

CLASSE : 1

Besoins thermiques
pour maintenir 20 °C en hiver et 26 °C en été
hiver 16 [kWh/m²]
été 42 [kWh/m²]
BECTh annuel hiver + été 58 [kWh/m²]

Surcoût 0 [Dt]

Fig.7. Presentation of improved case results under CLIP software.

By analyzing the savings made, compared to the previous case, the total avoided heat demand will be of about 57240 kWh in summer and 32436 kWh in winter. If the selected conditioning system consists of heat pumps with a COP of 3.2 and an EER of 2.91 then the avoided electrical energy demand will be around 29806 kWh. For a flat rate of 167mill/kWh, the savings will be of about 4977 DT/year. However, the additional expenses expected for the second case are around 45000 dinars (Table 1). Therefore, investment payback will be of about nine years. This latter compared to building's lifetime is relatively low.

Table 1. Additional Spending for the Second Case (Grant Subtracted)

Kind of service	Supply (TND)	Workforce (TND)	Total (TND)
Rockwool + vapor barrier for wall	4961.95	4961.95	9923.9
Rockwool for roof	4564	4564	9128
Roof sealing	6278.76	7824	14102.76
Low-emissivity double glazing	8647.24		8647.24
Fins and overhangs	834.75	2504.25	3339
Total (TND)	25286.7	19854.2	45140.9

It is noteworthy that the above values (cost, investment payback…) are purely indicative. Indeed, the additional spending are subject to market fluctuations, and the investment payback is calculated in perfect operating conditions of the heat pumps (energy losses are not taken into account).

Comparing the two cases, it is clear that by following a few bioclimatic design rules, significant energy gains are achieved, contributing to environmental protection by reducing Greenhouse Gases discharges. The financial study presented above has given a magnitude of realized economy and investment payback. This will be even lower than the price of theused primary energy will be more expensive.

Notwithstanding the fact that the Tunisian state encourages stakeholders to improve the building energy efficiency through awareness and subsidies (PROMO-ISOL program) [24], it has been shown that the Tunisian thermal regulation should be updated in order to further encourage the use of more efficient building materials. Thus, this update would better respond to economic, energy and environmental future challenges.

4. Energy Intake of a Solar Water Heating System

Sometimes, to heat a building, we need a large amount of energy especially if it is not properly insulated. This amount of energy used for heating is even more important as the temperature of the cold water and the space to be heated is low. Therefore, it would be interesting to preheat the water serving as a heat transfer fluid before injecting it into the boiler. The temperature difference will be decreased and thereafter the energy consumption will be optimized.

According to the previous study, the thermal requirements for the winter period from November to March are 16 kWh/m². If we multiply this value by the total area of the building and if we divide it by the number of winter months, there will be a monthly average energy requirement of about 6105 kWh/month.

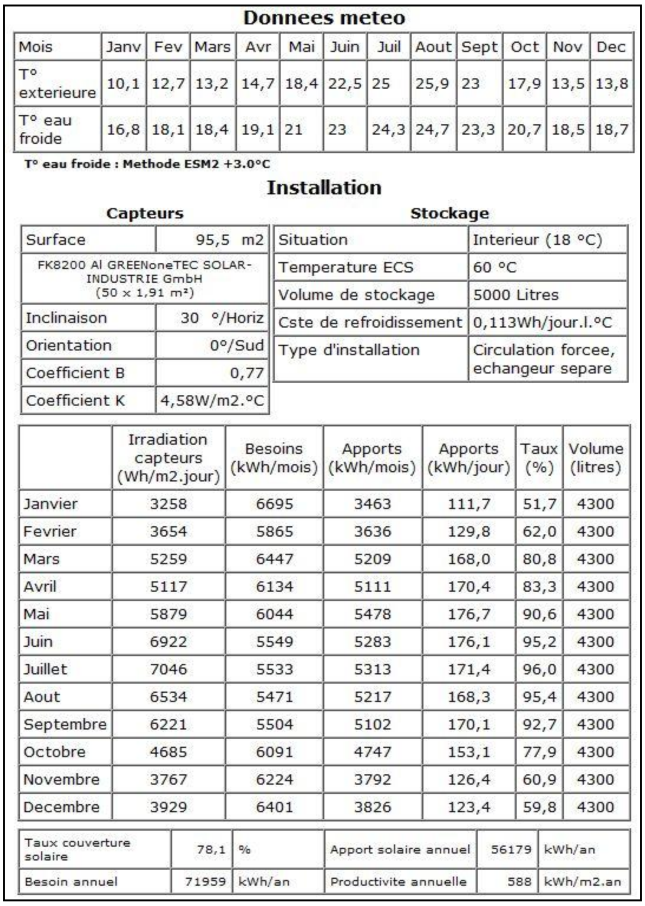
Since SOLO software calculates the required energy through the needed volume of water, it would be necessary to calculate the relative volume of water to the expected energy requirement (6105 kWh/month). To do so, the following formula was used:

$$V_u = \frac{(B_j \times 10^6)}{\left(C_P \times (T_{ec} - T_{ef})\right)} \qquad (12)$$

Where:
V_u: needed volume of water (liter/day).
B_j: daily energy needs (kWh/day).
C_p: heat capacity at constant pressure of the water (Wh/K.m^3).
T_{ec}: desired temperature of the hot water (K).
T_{ef}: average temperature of the cold water (K).

Once the volume of water calculated, SOLO software was used to determine the energy intake of a solar water heating system. Of course, since SOLO software is normally used for solar DHW installation sizing, only results for winter period months were taken into account for the calculation of energy intake.

The figure below shows the results obtained by SOLO software:



Donnees meteo

Mois	Janv	Fev	Mars	Avr	Mai	Juin	Juil	Aout	Sept	Oct	Nov	Dec
T° exterieure	10,1	12,7	13,2	14,7	18,4	22,5	25	25,9	23	17,9	13,5	13,8
T° eau froide	16,8	18,1	18,4	19,1	21	23	24,3	24,7	23,3	20,7	18,5	18,7

T° eau froide : Methode ESM2 +3.0°C

Installation

Capteurs

Surface	95,5 m2
FK8200 Al GREENoneTEC SOLAR-INDUSTRIE GmbH (50 x 1,91 m²)	
Inclinaison	30 °/Horiz
Orientation	0°/Sud
Coefficient B	0,77
Coefficient K	4,58W/m2.°C

Stockage

Situation	Interieur (18 °C)
Temperature ECS	60 °C
Volume de stockage	5000 Litres
Cste de refroidissement	0,113Wh/jour.l.°C
Type d'installation	Circulation forcee, echangeur separe

	Irradiation capteurs (Wh/m2.jour)	Besoins (kWh/mois)	Apports (kWh/mois)	Apports (kWh/jour)	Taux (%)	Volume (litres)
Janvier	3258	6695	3463	111,7	51,7	4300
Fevrier	3654	5865	3636	129,8	62,0	4300
Mars	5259	6447	5209	168,0	80,8	4300
Avril	5117	6134	5111	170,4	83,3	4300
Mai	5879	6044	5478	176,7	90,6	4300
Juin	6922	5549	5283	176,1	95,2	4300
Juillet	7046	5533	5313	171,4	96,0	4300
Aout	6534	5471	5217	168,3	95,4	4300
Septembre	6221	5504	5102	170,1	92,7	4300
Octobre	4685	6091	4747	153,1	77,9	4300
Novembre	3767	6224	3792	126,4	60,9	4300
Decembre	3929	6401	3826	123,4	59,8	4300

Taux couverture solaire	78,1	%	Apport solaire annuel	56179	kWh/an
Besoin annuel	71959	kWh/an	Productivite annuelle	588	kWh/m2.an

Fig.8. Results obtained by SOLO software.

The coverage rate for winter months (calculated for monthly needs of 6105 kWh/month) will be:

Table2. Coverage Rate for Winter Months

Month	Coverage rate (%)
January	56.7
February	59.5
March	82.3
November	62.1
December	62.6

The average value of the coverage rate will be 64.64%. Therefore almost 2/3 of the heating needs can be provided by a solar water installation (about 3946 kWh/month). If one wishes to calculate savings, simply divide the energy provided by the solar installation by the yield of the conventional heating system. For example, for a yield of conventional heating installation equal to 0.5, the savings will be equal to 7892 kWh/month.

Finally, based on the results described above, a solar water preheating system could lead to a significant energy savings and thus contribute in reducing the environmental impact due to buildings conditioning.

5. Conclusion

A real case study about energy efficiency improvement of the building of the Software and Services Development Companies' Space at the Technological Center of 'EL GHAZALA' was performed.

In a first step, building thermal needs for two specific cases were studied using CLIP software. The obtained results about the building thermal needs in the standard design case (like most of existing buildings in Tunisia) have shown that the Tunisian thermal regulation should be updated. Indeed,since the use of insulation or energy efficient windows is not always necessary to comply with the Tunisian thermal regulation, this latter does not have any motivating effect on stakeholders for using products serving to achieve greater energy efficiency.

Comparing the two cases (standard and bioclimatic cases), the importance of energy saving realized upon the use of high performance materials and the implementation of overhangs and fins was highlighted (50% of the initial thermal requirements). A financial study has given a magnitude of realized economy and investment payback. This latter, being relatively low compared to building’s lifetime, reflects the economic importance of the use of high performance materials and the implementation of overhangs and fins.

Then, in a second step, the effect of solar water preheating systemintegration has been studied using SOLO software. It was found that a solar water installation can cover about 64% of the building's heating needs.

At the end of this work, it is worth noting that this study was carried out by two of the most used software in Tunisia. The methodology for their use or for prior calculations (sizing of the glazed surfaces, overhangs and fins) was explained. Thus, this study could be the basis for future study. Another important outcome of this article is that Tunisian thermal regulation should be updated. This could be the starting point for future research on how to improve this regulation.

Finally, the encouraging energetic and economic gains obtained due to the use of some bioclimatic design technics and of solar water preheating system integration put forward the importance of using these latters. This could contribute to increase the interest in such technics or systems by the different stakeholders.

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