PREVIS 1.0: Easy software for simulation and sizing of solar water heating system

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Abstract - *In this paper we are interested in developing new and easy software for the sizing of a solar installation of hot water production. Such installation is successful only if its determination, its conception and its realization are made with care. This software that we baptized PREVIS 1.0 supplies, for fixed operating conditions, the dimensions of each component of the installation without having to use tables of data or diagrams. PREVIS 1.0 will allow the engineers and the fitters of solar installations of hot water production to make a good sizing in a simple and precise way. Moreover, PREVIS could be coupled to TRNSYS code and this is one of its highlights. Typical university campus for a 240 students was considered as case study. The hot-water demand temperature (45°C) is controlled by a conventional fuel auxiliary heater and a tempering valve. The fluids circulate by pumps activated by electricity. Annual energy performance, in terms of solar fraction, was calculated for Tangier.*

Résumé - *Dans cet article, nous nous sommes intéressés à développer un nouveau logiciel de calcul facile pour le dimensionnement d'une installation solaire de production d'eau chaude. Une telle installation peut être réussie seulement si sa détermination, sa conception et sa réalisation sont effectuées avec soin. Ce logiciel, que nous avons baptisé PREVIS 1.0 fournit, pour des conditions de fonctionnement fixes, les dimensions de chaque composant de l'installation sans devoir employer des tables de données ou des diagrammes. PREVIS 1.0 permettra aux ingénieurs et aux assembleurs des installations solaires de production d'eau chaude de faire un bon classement par taille d'une manière simple et précise. D'ailleurs, PREVIS pourrait être couplé au code TRNSYS et, c'est l'un des points importants. Le campus universitaire pour 240 étudiants a été considéré comme une étude de cas. La demande de la température d'eau (45°C) est commandée par un réchauffeur auxiliaire de carburant conventionnel et une valve de gâchage. Les fluides circulent grâce à des pompes électriques. La performance énergétique annuelle, en termes de fraction solaire, a été calculée pour Tanger.*

Keywords: Domestic hot water - Solar fraction - Simulation - TRNSYS – PREVIS.

1. INTRODUCTION

Morocco has no natural oil resources and relies entirely on imported fuel for its energy demands. The only natural energy resource available is solar energy. Morocco has a very sunny climate with an average annual solar radiation varying from 4.7 to 5.6 $kWh/m^2 day$ (on a horizontal surface, Fig. 1), and presents fair prospects for developing the solar sector.

However, Morocco is a latecomer in the spread of solar plants both in their production and in their technological development. Recently specific financial incentives have been introduced in order to stimulate the development of the utilization of solar energy in Morocco, particularly in the north areas. These incentives are assigned for the solar water heating system in order to make solar plants economically competitive in comparison with traditional plants, not to mention the benefits coming from the reduction of CO_2 emissions.

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It should to call back that Morocco does not exceed the 40000 m^2 of solar installations. A study led by the CDER, the ONE and the SODEAN estimates the potential market in 400000 m^2 in the medium term [1].

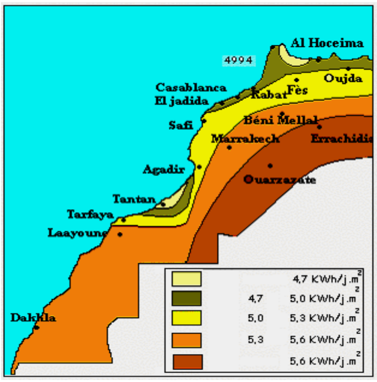

Fig. 1: Annual average daily global solar radiation in Morocco
A daily average in Wh/m² was indicated for Tangier

In this paper we attempt to develop a computational code authorizing the user to test alternative configurations of the solar water heating plant before its realization. This software, called PREVIS 1.0, is the informatics transcription of the standard used with SODEAN and of the method of estimation of the thermal performance of the solar installation, developed by the CSTB [2]. It will allow the engineers and the technicians working in the field of solar plant to simulate and to make a sizing of each component of the solar installation in a simple and precise way without having to use tables of data or diagrams. Let us note that PREVIS could be coupled to TRNSYS code and this is one of its highlights [3]. In this framework, a typical university campus for a 240 students was considered for deriving the results.

2. OPERATING CONDITIONS

The solar plant is considered to produce domestic hot water for a university campus of 240 students. The cold water temperature of the city of Tangier is given by Table 1 and the hot water demand temperature is equal to 45 °C.

Table 1: Monthly average temperature of the cold water for the city of Tangier

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
$T_{cold\ water}$ (°C)	14.6	15.3	16	15.9	17.8	21	21.4	23.5	20.7	18.6	16.3	15.6

The daily hot water consumption by student is equal to 20 l/day and the monthly occupation of the university campus is given by Table 2.

Table 2: Monthly rate of occupation of the university campus of Tangier

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Rate of occupation (%)	50	100	75	75	75	50	0	0	75	100	100	75

3. TRNSYS AND PREVIS PROGRAMS OVERVIEW

One of the objectives of this work is also the coupling of our software with the code TRNSYS to facilitate to the researchers the technical part and the sizing of each component of the solar installation.

TRNSYS is a transient system simulation program with a modular structure. Each module of TRNSYS contains a mathematical model for a system component [4]. The TRNSYS engine calls the system components based on the input file and iterates at each time-step until the system of equations is solved.

A program such as TRNSYS has the capability of interconnecting system components in any desired manner. Once all of the components of the system have been identified and a mathematical description of each component is available, an information flow diagram for the system needs to be constructed. The purpose of the information flow diagram is to facilitate identification of the components and the flow of information between them. Each component is represented as a box, which requires a number of constant PARAMETERS and time-dependent INPUTS and produces time-dependent OUTPUTS. An information flow diagram shows the manner in which all system components are interconnected. A given OUTPUT may be used as an INPUT to any number of other components. A simplified information flow diagram of the solar plant under investigation is shown in Figure 2. From the flow diagram a deck file has to be constructed containing information on all system components, weather data file and output format. Simulations generally require some components that are not ordinarily considered as part of the system. Such components are utility subroutines and output producing devices. The TYPE number of a component relates the component to a Fortran subroutine, which models that component. Each component has a unique TYPE number. The UNIT number is used to identify each component (which can be used more than once) in the deck file. Although two or more system components can have the same TYPE number, each must have a unique UNIT number.

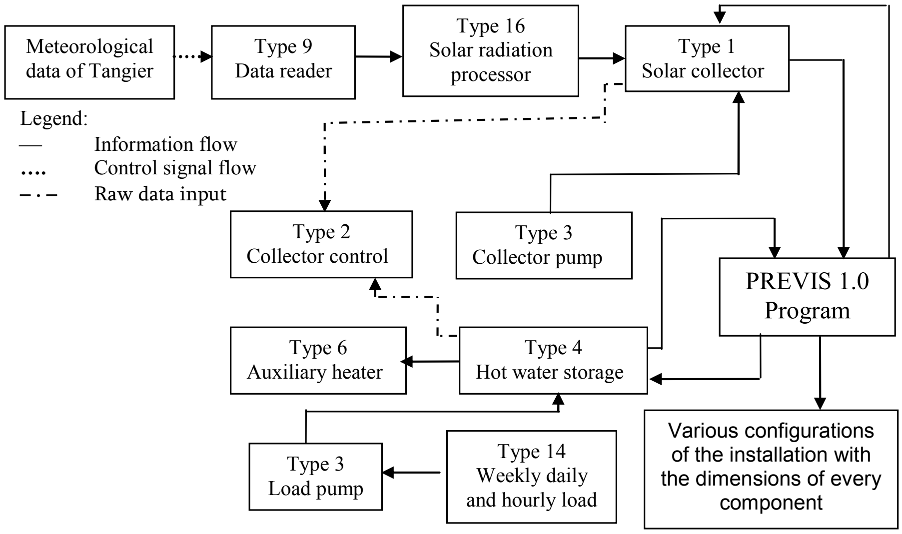

Fig. 2: Information flow diagram for the solar-system model

Weather data are needed to perform the simulation with TRNSYS and PREVIS. Because of the not availability of the meteorological data of the city of Tangier, a measures drive was realised to have the hourly solar global irradiance on horizontal surface, ambient temperature, humidity, wind speed and direction from 2001 to 2002.

The PREVIS 1.0 code is the computer transcription of standards established by SODEAN and of the ‘monthly method for estimating the thermal performances of the solar plant’, developed by the CSTB. This code is endowed with a graphic interface authorizing the user to test alternative configurations of the solar plant before its realization. PREVIS 1.0 will allow us to make a sizing of the solar installation in a simple and precise way. It has been developed at the Heat Transfer and Energetic laboratory of the Faculty of Sciences and Technologies of Tangier (Morocco) [5].

The main features of the PREVIS 1.0 simulation engine are:

- The monthly rates of solar cover
- The monthly hot water demand
- The productivity calculated monthly
- Productivity per square meter of solar collector
- Proposition of alternative configurations
- Assessment of the drop in pressure.

With PREVIS 1.0, it is for example possible to look for the best compromise between the surface of the solar collectors and the volume of stocking, to optimize productivity in the square meter while assuring a reasonable coverage of necessities.

This software was written in Pascal object by using DELPHI under its version 5; it is a powerful tool of development of Windows application.

4. RESULTS

4.1 Daily consumption of hot water

The daily consumption of hot water is a very important parameter for the choice of dimension of the solar plant. Consequently, it is necessary to grant a great importance for its quantification; although solar energy is free, the devices which transform it into hot water are not.

Maximal consumption is given by the expression:

$$C_{max}(m) = (\text{consumption/day/person}) \times (\text{number of places})$$

According to the Table 2, average occupation is of 65 %.

So the daily consumption of hot water is:

$$C(m) = 0.65 \times C_{max}(m)$$

$$C(m) = 3120 \text{ kg/day}$$

Thus, so that 65 % of the students could use 20 kg of hot water daily, we shall need of 3120 kg/day.

4.2 Monthly energy demand for hot water

The monthly energy demand for the hot water, $E_{hw}(m)$, is expressed in kWh by the following formula:

$$E_{hw}(m) = 0.00116 \times \Delta(m) \times C(m) \times N_{day}(m)$$

$N_{day}(m)$: Number of days of every month

$C(m)$: Daily consumption in (kg/jour)

$\Delta(m)$: Difference enters temperature wished for the hot water and the temperature of the cold water (K)

0.00116: Coefficient which allows to obtain $E_{hw}(m)$ in kWh [equal to 4180/(3600 x 1000)] kWh/(kg.K).

Table 3: Monthly energy demand for the hot water

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**
$E_{hw}(m)$ **kWh**	3410.73	3009.73	3253.66	3159.56	3051.71	2605.82
Month	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
$E_{hw}(m)$ **kWh**	2647.81	2413.3	2638.4	2961.95	3116.13	3298.54

4.3 Surface of the solar collectors

The international standards require that $60 < \frac{C(m)}{A} < 100$ where $C(m) = 3120\ \text{kg/day}$, we will have $31.2 < A\left(m^2\right) < 52$.

To have a symmetric distribution of the solar collectors, and to avoid an over-sizing of the installation, we chose $A = 40\,m^2$. For our study, we have used normalized collector of surface equal to 2 m^2 ($A_c = 2\ m^2$), that gives a number of collectors equal to 20.

4.4 Storage tank

The international standards require that $0.8 < \frac{V_s}{C(m)} < 1.2$. As a result, $2496\ l < V_s < 3744\ l$. We take $V_s = 3000\ l$.

Our choice is carried on two storage tanks of nominal capacity of 2000 l each.

4.5 Sizing of the hydraulic circuit

So as to size the hydraulic system, namely: piping, flow diverters, tempering valves, valves, pumps..., we need the total flow rate of the working fluid (water in our case).

The flow rate is given by the following expression:

$$Q_{total} = q_{collector} \times A$$

where $q_{collector}$ is the flow rate of the working fluid per square meter of collector. In our case, we set $q_{collector} = 50\,\text{kg/hour.m}^2$, that gives $Q_{total} = 2000\,\text{kg/hour}$.

Once flow rate is calculated, PREVIS code proposes the possible configurations of our installation. So that all the solar collectors work in the same conditions, it is necessary that the route of the water is the same for each of them. The recommended assembly is said Tickelman's buckle assembly. Its principle is illustrated on the figure 3.

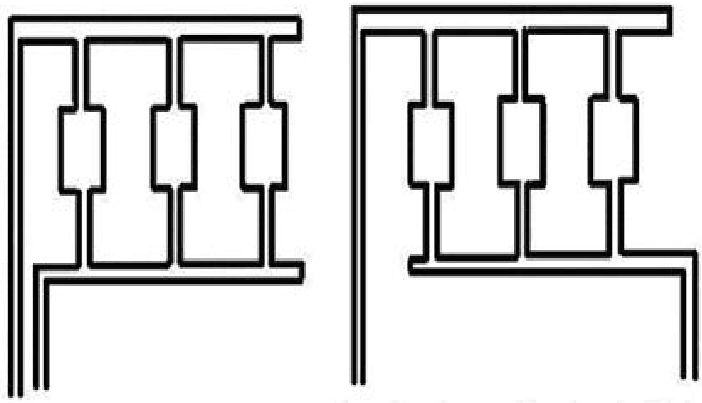

Fig. 3: Tickelman's buckle assembly (to the right)

So PREVIS 1.0 code propose the following two configurations illustrated by figures 4 and 5.

4.6 Drop in pressure in the hydraulic circuit

This calculation is very important, because it allows us to verify if chosen diameters, assure really a good installation. To do it, PREVIS divides the circuit of the figure 5 into several paths:

Path1: path ABCDEFG
Path 2: path BIJ
Path 3: path CJK
Path 4: path DKF.

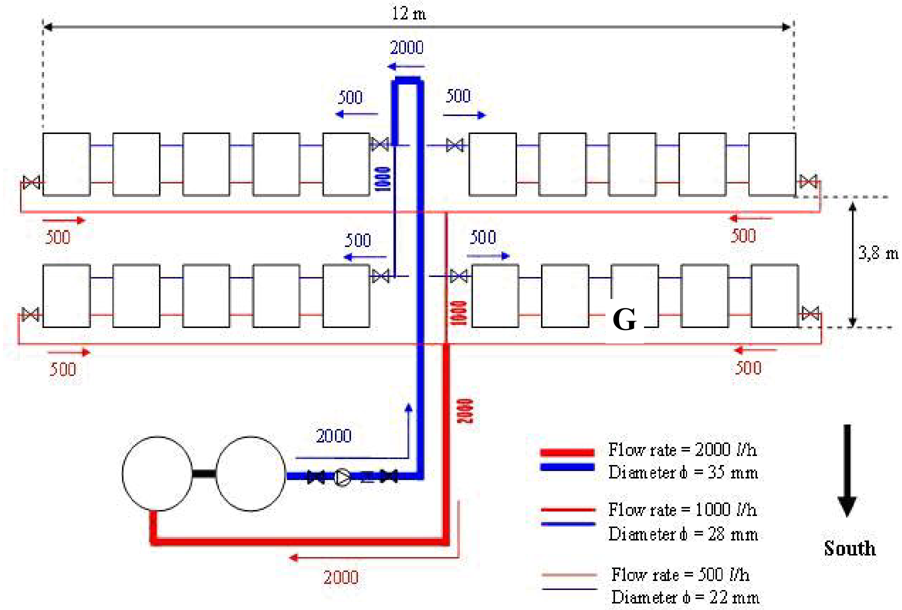

Fig. 4: Synoptic plan of our solar installation (configuration 1)
The blue and red colours represent respectively the circuits of cold and hot water

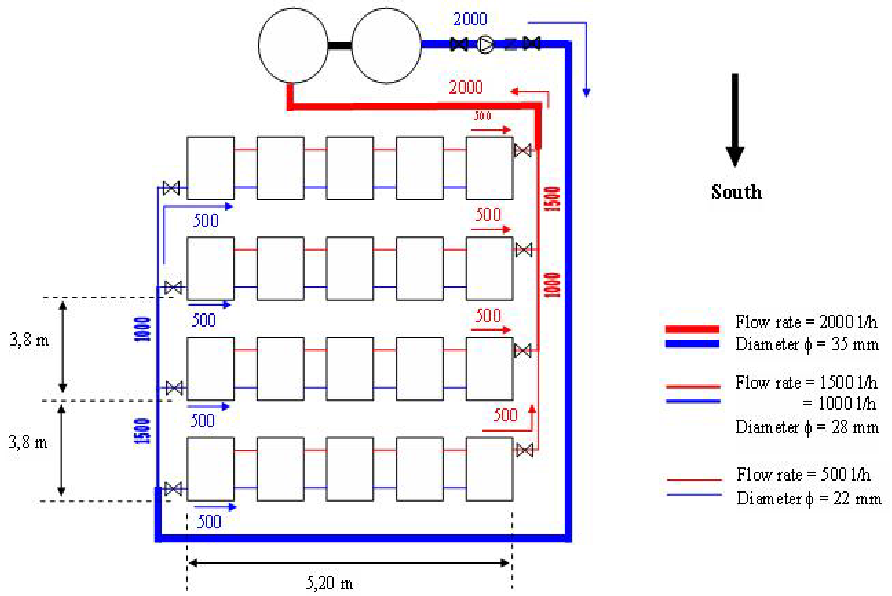

Fig. 5: Synoptic plan of the solar installation that we adopted (configuration 2)
The blue and red colours represent respectively the circuits of cold and hot water

The drop in pressure is given by the following expression:

$$\Delta P = L \times \delta P$$

where:

$$\delta P = 6819 \times \left(\frac{v}{145}\right)^{1.852} \times \left(\frac{d_{int}}{1000}\right)^{-1.167}$$

$$v = \frac{1000 \times Q}{3.1416 \times 3600 \times \left(\frac{d_{ext} - 2}{2}\right)^2}$$

$$d_{int} = 2000 \times \sqrt{\frac{Q}{v \times 3600 \times 3.1416 \times 1000}}$$

where: L : piping length; δP : drop in pressure per unit of length; d_{ext} : exterior diameter; v : flow velocity.

PREVIS chooses configuration illustrated by the figure 5 because it presents weaker drop in pressure than the configuration of the figure 4.

4.7 Monthly rate of the solar cover

System is constituted of a field of 40 m^2 of the solar collectors, which are tilted to 45° in the south direction. In fact, a previous study realized in the laboratory of the solar energy of the Faculty of Science of Rabat showed that the optimal slope, (i), of the solar collectors is given by [6]:

- $i = \varphi$ in case we would like to have a maximal energy during all year.
- $i = \varphi + 10$ (or 15) in case we would like to have a maximal energy during winter.
- $i = 0$ or $(\varphi - 15)$ in case we would like to have a maximal energy during summer.

where φ is the latitude of the considered site (in degree).

Seeing that the rate of occupation of the university campus of Tangier is more important in winter than in summer, we adopted $i = \varphi + 10 = 45°$ to favour winter season.

The monthly rate of the solar cover is given by the Table 4.

Table 4: Monthly rate of the solar cover

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
$C_{hw}(m)$ (%)	38	46	58	65	71	77	81	86	79	68	48	44

The monthly productivity of the system corresponds to the useful kWh produced (Table 5):

$$\text{Productivity}(m) = C_{hw}(m) \times E_{hw}(m)$$

Table 5: Monthly productivity

Month	Jan	Feb	Mars	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Productivity (kWh)	1296.08	1384.47	1887.1	2053.7	2166.7	2006.48	2144.7	2074.5	2084.3	2014.12	1495.7	1451.35
Productivity (kWh parm^2)	32.4	34.6	47.18	51.34	54.18	50.16	53.62	51.86	52.11	50.35	37.4	36.28

Of these results, we conclude that the adopted solar system (configuration figure 5) allows an economy of annual energy of 64 % with regard to the total need of energy which is of 35567,34 kWh/year. Also, the annually collected solar energy by 1 m^2 of sensor is of the order of 551,48 kWh /year/m^2. This value compared with the incidental solar energy which is of the order of 1791,65 kWh/year/m^2lows us to determine the average return of the solar collector which is 31 %.

5. CONCLUSION AND PERSPECTIVE

In this paper we were interested in the sizing of a solar installation of hot water production in favour of the university campus of Tangier. Such installation is successful only if its determination, its conception and its realization are made with care.

We have used the dynamic simulation code (TRNSYS) to investigate our solar plant for hot-water production and we have developed software which allows us to determine the optimal sizing of the solar installation of hot water production. This software that we baptized PREVIS 1.0 supplies, for fixed operating conditions, the dimensions of each component of the installation without having to use tables of data or diagrams. PREVIS 1.0 will allow the fitters of solar installations of hot water production to make a good sizing in a simple and precise way. In this framework, a typical university campus for a 240 students was considered.

The solar system that we adopted allows an annual economy of 64 % with regard to the total need of energy which is of the order of 35567.34kWh/year. The results of calculations of the drop in pressure on the hydraulic system, allowed us to size the diameters of the piping, flow diverter, flow mixer, tee-piece, pump, etc.

In perspective we will evaluate the economic viability of such a plant with the life cycle savings (LCS) method, considering three conventional fuels (Gas-Oil, LPG and Electricity).

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