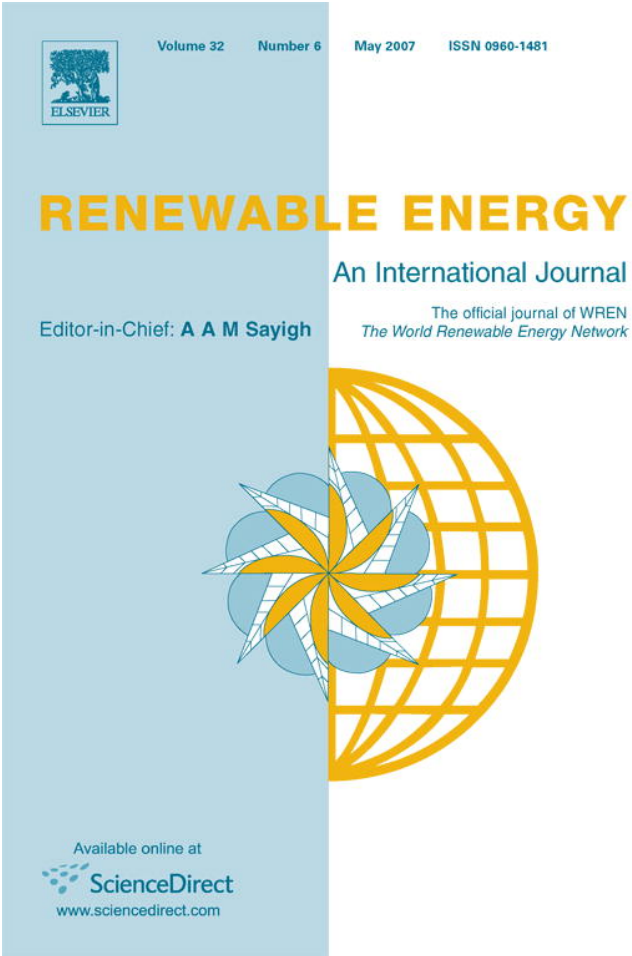
Volume 32
Number 6
May 2007
ISSN 0960-1481
ELSEVIER
RENEWABLE ENERGY
An International Journal
Editor-in-Chief: A A M Sayigh
The official journal of WREN
The World Renewable Energy Network
Available online at
ScienceDirect
www.sciencedirect.com

Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Renewable Energy 32 (2007) 1045–1058
RENEWABLE ENERGY
www.elsevier.com/locate/renene

Technical Note

Energy software programs for educational use

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Received 29 November 2005; accepted 28 August 2006
Available online 30 October 2006

Abstract

A package of six fully interactive energy software programs was developed for educational use. The first three programs can be used to simulate energy systems, while the rest three can be used to calculate some characteristic values, which can be used separately or in conjunction with the first three programs. The first one is a multimedia program for an active solar hot water system. It accounts for a large number of parameters and can be used to investigate their effect on the thermal efficiency of the system. The second program is a transient simulation for thermal behavior of a building. It can be used to predict the temperature and relative humidity inside a building along with the heating/cooling load required to keep the temperature at a preset point. The third program has been developed for sizing solar thermal systems. The fourth program is a graphical representation of the apparent motion of the sun on the celestial vault. The fifth program calculates the thermophysical properties of a number of gases and liquids for a desired temperature. The sixth program represents graphically the psychrometric chart. The above-mentioned programs, are useful tools for education in energy, suitable for high school students and Universities. It can also be used for an extensive set of exercises in the tertiary education sector.

Keywords: Solar energy; Engineering software; Education; Psychrometric chart; Thermophysical properties

1. Introduction

In the framework of educational activities of our Renewable Energy Laboratory, a number of energy software programs have been developed. The objective has been to develop fully interactive, fast, accurate, easy to use, and user friendly software programs

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doi:10.1016/j.renene.2006.08.006

for engineering education. The programs are suitable in tertiary educational sector, post secondary training institutes, and technical vocational schools. These educational tools with emphasis on the graphical representation hide the complexity of theoretical algorithms from the user and present the results of the calculations.

The simulation used is capable of providing certain kinds of useful information in a much more effective way than static text or graphs. The simulation accounts for a large number of parameters and it can be used to study analytically the behavior of the system. The user can see many situations, explore what happens in different conditions and in general see things developed on the screen as a result of her/his actions and inputs. The success of simulation in education can be attributed to its unique qualities that set it apart from other pedagogical approaches. Thus, students can approach more complex and realistic problems and they are free to repeat them. Also, they can learn about the complex interactions of a large number of variables in a short time, whereas experiments are time consuming and costly. Finally, they will have more time to test their creative skills because they will be able to place more emphasis on problem formulation and solution interpretation. The advantages that computers offer in comparison to books are fast calculation of data, mathematical modeling of actual systems, interactivity, and visual animation of real events. Also the benefits of such practice are several, being the starting point for the process of stand alone and continued education, unique capable to allow the future professional to remain itself brought up to date with the increasing development of new technologies.

The educators in engineering field have invented several new and innovative ways of teaching the subject in recent years. It should be noted that one of UNESCO's priorities in this field is the preparation of a "learning package" which consists of a textbook, multimedia products and software for self training and distance learning [1].

In the following section six energy education programs will be described briefly. In the most of them an application is presented in order to demonstrate the capabilities of each tool. The first three programs can be used to simulate energy systems, while the rest three can be used to calculate some characteristic values, which can be used separately or in conjunction with the first three programs. For example, the knowledge of the solar altitude angle at any time, from the "Solar Geometry" program, can be used to calculate the optimum tilt angle of a solar collector, and this result can be introduced in the "Multimedia application on active solar heating system" program. Also, the calculated thermophysical properties of water provided by the "Thermophysical Properties" program, can be used in conjunction with the water temperature, calculated from the "Multimedia application on active solar heating system" in order to solve heat transfer problems in solar collectors and storage tank. An other example, is the dry-bulb and relative humidity of indoor air, provided by the "OIKOSIM" program, can be used by the "Psychrometric Chart" to calculate the humidity ratio and enthalpy, of indoor air of a building.

2. Description of the programs

2.1. Multimedia application on active solar heating system

An educational software program has been developed to study the transient behavior of an active solar heating system for domestic hot water production [2]. The users can explore various cases, study what happens under different operating scenarios and examine the effects of altering conditions. In addition, simulation processes are used when a more quantitative understanding of the related subjects is needed, as they offer higher perceptual fidelity (i.e., more accurate representation of the situation being modeled). The simulation accounts for a large number of parameters and can be used to investigate their effects on the thermal efficiency of the solar collector and the system.

The operating principles and performance aspects of the different components have been considered providing a basis for understanding the components interaction and total system performance. Fig. 1 presents the main window of the program.

The program is geared to a wide range of interested persons and its aim is to be a useful tool, given the fact that it was developed to simulate not only the function of the system, but also the relevant components (solar collector, hot water storage, piping, etc.). Analytically the aim of the program is to:

- Make the function of the active solar system more descriptive, using various icons for each system component.
- Study the effect of various parameters on the thermal efficiency of the flat plate solar collector.
- Make the system more comprehensible.
- Realize exercises in very short time, avoiding the expensive experimental test facilities and the dependence from weather conditions.

The tool can also be used for an extensive set of exercises in the tertiary education sector. Some of these exercises are:

- Determination of the characteristic curve of a solar collector derived from points, calculated by the program.

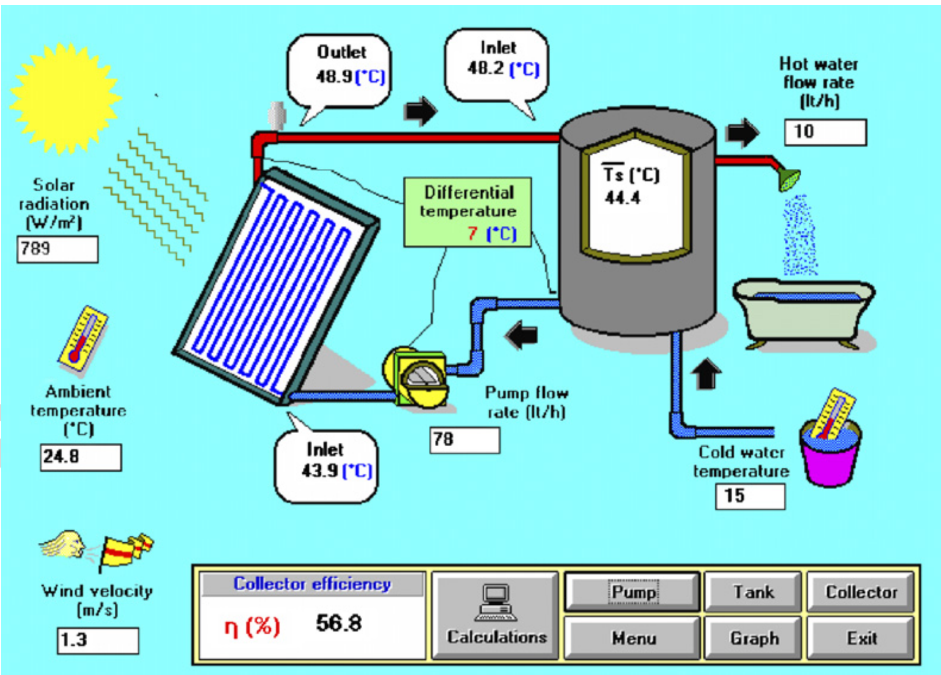

Fig. 1. Main window of the multimedia application.

- Calculation of the thermal efficiency of the heating system.
- Plot of collector efficiency versus: wind speed, ambient temperature, solar irradiance incident on the collector, fluid-flow rate, plate absorptance, plate emittance, Inlet collector temperature, thickness of back and edge insulation.

The major advantage of this program for exercises in tertiary education is the avoidance of expensive outdoor test facilities and the independence from weather conditions.

2.1.1. Model description

The collector thermal performance model is essentially the Hottel–Whillier analysis as presented in [3].

Storage tank temperature, T_s, is calculated assuming that the fluid in the tank is always well mixed and consequently at uniform temperature, varying only with time. The instantaneous time dependent energy balance of the tank can be written as:

$$\rho V c_p \frac{dT_s}{dt} = \dot{Q}_c - \dot{Q}_l - (UA)_s(T_s - T), \tag{1}$$

where ρ is the fluid density, V is tank volume, c_p is the specific heat of the collector fluid, t is the time, $\dot{Q}_c$ is the rate of energy supplied by the solar collector, $\dot{Q}_l$ is the rate of energy removed by the load, $(UA)_s$ is the product of the overall heat transfer coefficient and the surface area of the tank and T is the temperature of the storage tank environment.

It should be noted that $\dot{Q}_c$ includes the piping heat losses. Consequently, the temperature of the fluid entering the storage tank from the solar collector is the calculated outlet temperature of the fluid at the end of the pipe.

The solar system is controlled by differential thermostat, which is located between the collector outlet and the bottom of the storage tank. This thermostat controls the circulation pump and allows its operation only if the temperature difference between the two locations is greater than a value preset by the user.

2.1.2. Application

Assume a flat plate solar thermal collector with the characteristics and operating conditions given in Table 1. The effect of fluid-flow rate on the performance of the solar collector can be easily illustrated by running the program. For demonstration reasons the program was run for fluid-flow rate varying from 0 to $200\,\mathrm{l\,h^{-1}}$ and for two different inlet collector temperatures.

Results obtained are plotted in Fig. 2. It is evident that the instantaneous collector efficiency rises rapidly with the increase of the fluid flow rate for values below $70\,\mathrm{l\,h^{-1}}$, whereas it is almost steady when the fluid flow rate is greater than $70\,\mathrm{l\,h^{-1}}$. For a given fluid-flow rate the higher the inlet temperature the lower the collector efficiency, due to significant thermal losses.

Likewise to the preceding application the program can be run to explore many other cases and study the influence of many parameters on the efficiency of the solar system. Such parameters are the solar storage tank volume, the collector tilt, the characteristics of the collector and the piping length.

In addition, the program can be used to study the sensitivity of the storage tank temperature to various operating and weather conditions. Setting, for instance the solar irradiance zero, the variation of storage tank temperature can be studied during the night,

Table 1
Solar-collector characteristics and operating conditions

	Value
Solar collector characteristics	
Collector efficiency factor	0.89
Number of glass cover	1
Plate absorptance	0.96
Plate emittance	0.96
Glass emittance	0.88
Collector area (m^2)	1.7
Back insulation thickness (mm)	50
Edge insulation thickness (mm)	20
Insulation thermal conductivity ($W\,m^{-1}\,°C^{-1}$)	0.03
Refractive index of the cover	1.52
Extinction coefficient (m^{-1})	20
Cover thickness (mm)	3
Operating conditions	
Solar irradiance ($W\,m^{-2}$)	840
Ambient temperature (°C)	21
Wind velocity ($m\,s^{-1}$)	4
Collector fluid flow rate ($l\,h^{-1}$)	125
Collector tilt (°)	45
Collector azimuth angle (°)	0

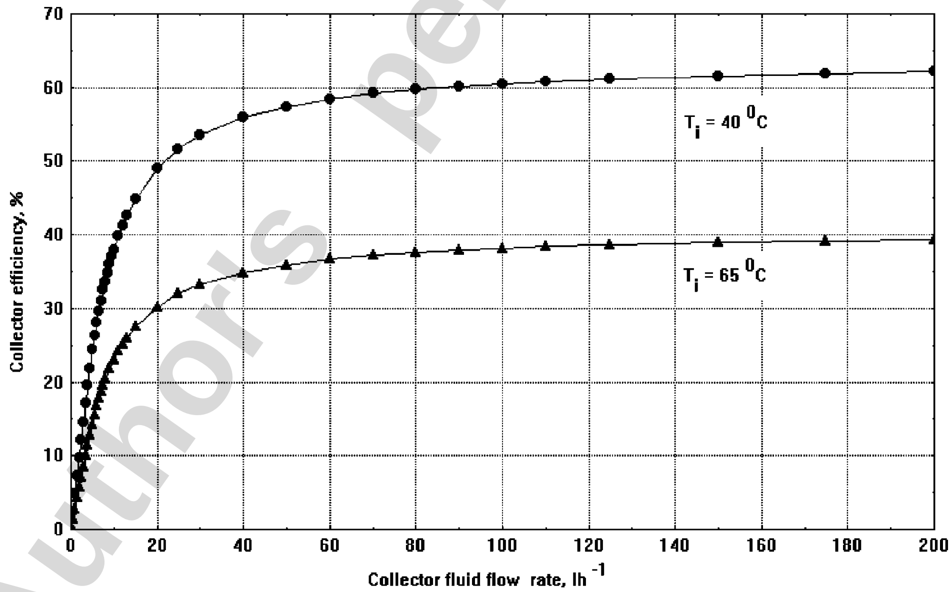

Fig. 2. Influence of solar collector fluid flow rate on solar collector efficiency for two collector inlet temperature, according to the data used in the considered application.

with or without hot water consumption using various storage tank characteristics. For a given solar system and weather conditions it is very easy to calculate the time needed for the storage tank temperature to reach a user specified value and to determine both the critical radiation level and the stagnation temperature.

2.2. OIKOSIM: a transient simulation program for the building

To thoroughly examine the dynamic thermal behavior of the buildings, a transient simulation program, was developed at the Renewable Energy Laboratory of our Institute. The simulation program simplifies the calculation procedure in order to predict the temperature and relative humidity inside a building along with the heating/cooling load required to keep the temperature at a preset point. As a result much attention was given to the speed of execution, the ease and the friendliness of the user interaction features of the program. This program is based on previous works [4,5]. The program executes, in hourly steps, using the pull down menus; data entry or corrections can be made using very few keystrokes. The program uses two input files, the parameters file and the meteorological data file. The parameters file contains information required to describe the building, as the dimensions and orientation of the walls and the type of roof, while the thermal capacitance of the building shell is automatically calculated from the data entered in the program. After supplying input data the program will create the parameters file. The meteorological file contains hourly meteorological data of a specific location. Each data file contains a set of four hourly values: total solar irradiance on a horizontal surface, outdoor air temperature, outdoor relative humidity and wind speed. The results can be shown on the screen, printed or saved in a file for further processing, and can be summarized by hourly, daily, weekly, or monthly values. The program can run on a P.C. and it is fully interactive. As regards the way that the user describes the structural elements of the building the program allows each wall to be built by a number of one to six layers and incorporates a library with structural and insulation materials for which thermal conductivity, density, and specific heat are known. Consequently, the definition of a layer within a structural element requires only the choice of the material and its thickness. The number of structural and insulation materials can be increased, adding their relevant properties in the library. Also, the library which contains meteorological data files, can be modified by the user, adding new data files from other cities. Finally the program can be used for various types of buildings, taking into account a large number of parameters.

2.2.1. Model description

The model is based on the solution of following time dependent energy and moisture balance equations for predicting dry bulb temperature and relative humidity inside the building. The building has been treated as one interior space without internal walls.

$$\sum(M_\mathrm{i}C_\mathrm{i})\frac{\mathrm{d}T_\mathrm{i}}{\mathrm{d}t} = \dot{Q}_\mathrm{b} + \dot{Q}_\mathrm{f} + \dot{Q}_\mathrm{w} + \dot{Q}_\mathrm{V} + \dot{Q}_\mathrm{inf} + \dot{Q}_\mathrm{SHG} + \dot{Q}_\mathrm{s}, \tag{2}$$

$$\rho_\mathrm{i}V_\mathrm{i}\frac{\mathrm{d}W_\mathrm{i}}{\mathrm{d}t} = \dot{m}_\mathrm{V}(W_\mathrm{V} - W_\mathrm{i}) + \dot{m}_\mathrm{inf}(W_\mathrm{o} - W_\mathrm{i}) + \dot{W}_\mathrm{s}, \tag{3}$$

where $\sum(M_\mathrm{i}C_\mathrm{i})$ is the lumped effective building capacitance, T_i the inside air temperature, t the time, $\dot{Q}_\mathrm{b}$ the sum of heat flow through the walls, the door, and the roof, $\dot{Q}_\mathrm{f}$ the heat flow through the floor, $\dot{Q}_\mathrm{w}$ the thermal heat flow through the window, $\dot{Q}_\mathrm{v}$ the heat losses due to ventilation, $\dot{Q}_\mathrm{inf}$ the heat losses due to infiltration, $\dot{Q}_\mathrm{SHG}$ the direct solar heat gain, $\dot{Q}_\mathrm{s}$ the sensible heat production, it is so called internal heat gains, ρ_i the density of inside air, V_i the volume of the inside air space, W_i the inside air humidity ratio, $\dot{m}_\mathrm{V}$ the ventilation air mass flow rate, W_V the ventilation air humidity ratio, W_o the outside air humidity ratio, and $\dot{W}_s$ the internal moisture (water vapor) production from people.

The heat flow through the building envelope $\dot{Q}_b$, is the sum of the heat fluxes entering or leaving each vertical wall, the roof, and the door. It can be expressed, using the concept of sol-air temperature as follows:

$$\dot{Q}_b = \sum_i U_{bi} A_{bi} (T_i - T_{sa,i}), \tag{4}$$

where U_{bi} is the overall heat transfer coefficient of each surface, A_{bi} is the surface area, and $T_{sa,i}$ is the sol-air temperature.

The overall heat transfer coefficient U_{bi} can be calculated applying the series thermal resistance theory, taking in account the composite layers making up the envelope components, and the interior and external surface heat transfer coefficient. The sol-air temperature is calculated for each structural element using the following equation [12]:

$$T_{sa,i} = T_o + \frac{\alpha I_{T,i}}{h_o}, \tag{5}$$

where T_o is the outside temperature, α the surface solar irradiation absorptance, $I_{T,i}$ the total solar irradiance on each envelope component surface, and h_o the external surface heat transfer coefficient. At any time step the program calculates the total solar irradiance incident upon the surface of the four differently orientated walls (i.e., south, east, north and west) and the roof. Its value depends on the orientation of each surface, the location, and the time of the year. The total solar irradiance incident on each vertical or tilted surface, is calculated based on the values of the solar irradiance on the horizontal surface, considering the isotropic sky model and using the standard formula [3].

The thermal heat flow $\dot{Q}_w$, through a window with an area A_w, and an overall heat loss coefficient U_w, can be written as:

$$\dot{Q}_w = U_w A_w (T_\alpha - T_i), \tag{6}$$

where T_α is the ambient air temperature.

For each window, the user must specify the value of overall heat loss coefficient U_w, according to different types of glazing and frame materials.

The heat losses due to ventilation ($\dot{Q}_V$), and infiltration ($\dot{Q}_{inf}$), are calculated from the following basic equations:

$$\dot{Q}_V = \dot{m}_V c_p (T_V - T_i), \tag{7}$$

$$\dot{Q}_{inf} = \dot{m}_{inf} c_p (T_\alpha - T_i), \tag{8}$$

where c_p is the specific heat of air, and T_V is the ventilation temperature.

The following equation can be used to calculate the solar heat gain $\dot{Q}_{SHG}$ through a vertical window of area A_w. This equation considers transmittance, reflectance and absorptance are function of incoming solar radiation, thickness, refractive index, and extinction coefficient of the glass material.

$$\dot{Q}_{SHG} = A_w (\tau_b I_b + \tau_d I_d)(1 - F_s), \tag{9}$$

where τ_b the transmittance of incident beam radiation, I_b the beam solar radiation incident on window, τ_d the transmittance of incident diffuse and ground reflected radiation, I_d the diffuse and ground reflected solar radiation incident on window, and F_s the fraction of window that is shaded. The user must specify the fraction F_s, for each window separately. The transmittance of incident diffuse and ground reflected radiation, can be calculated as the transmittance of beam solar radiation incident at an angle of 60°.

2.2.2. Application

A simple rectangle building located in Athens was used for hourly simulation under real climatic data, for the month of January. The building is 14 m long, 11 m wide and 4 m high with the 14 m sides facing north/south. The walls are composed of five layers (plaster 1 cm, brick 10 cm, polystyrene 5 cm, brick 10 cm, plaster 1 cm), and their external surface has a solar absorptance of 0.3 and an emissivity of 0.89. The ceiling is constructed of 14 cm concrete and 5 cm polystyrene. All glazed openings are single glazing with aluminum frame, and their distribution in each orientation is: south 10 m^2, east 4 m^2, north 2 m^2, west 4 m^2. There are no obstructions to sunlight reaching any of the facades and the infiltration rate is 0.5 air changes per hour. The auxiliary heating system is turn on when the internal temperature is less than 18 °C and turn off at 21 °C.

The program was run for the month of January and the results are shown in Figs. 3 and 4. The total heating load for January was 2399.8 kWh. The user can change any parameter used as orientation, thermal capacitance, infiltration rate, glazed area, use of movable shading, insulation level, etc., in order to analyze the thermal behavior of the building.

2.3. Sizing of solar thermal systems by simplified method using P.C.

The proper size for a solar heating system is determined by evaluating the heating performance of the system. Sizing an active solar heating system is quite an intricate task because of the many different variables that must be considered. Several methods of sizing

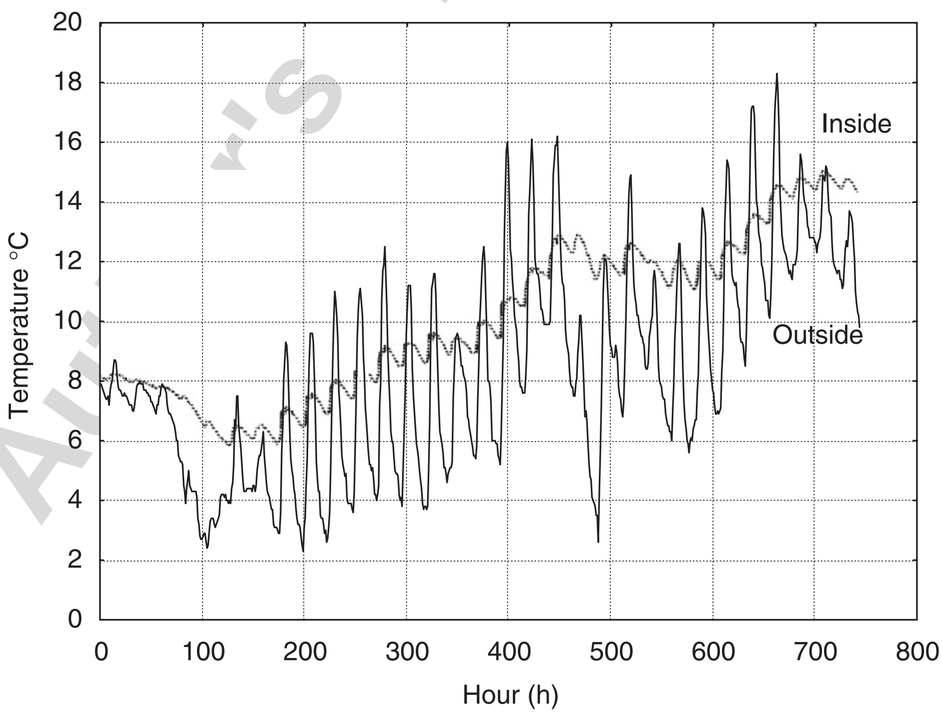

Fig. 3. Inside and outside temperature during January according to the data used in the considered application.

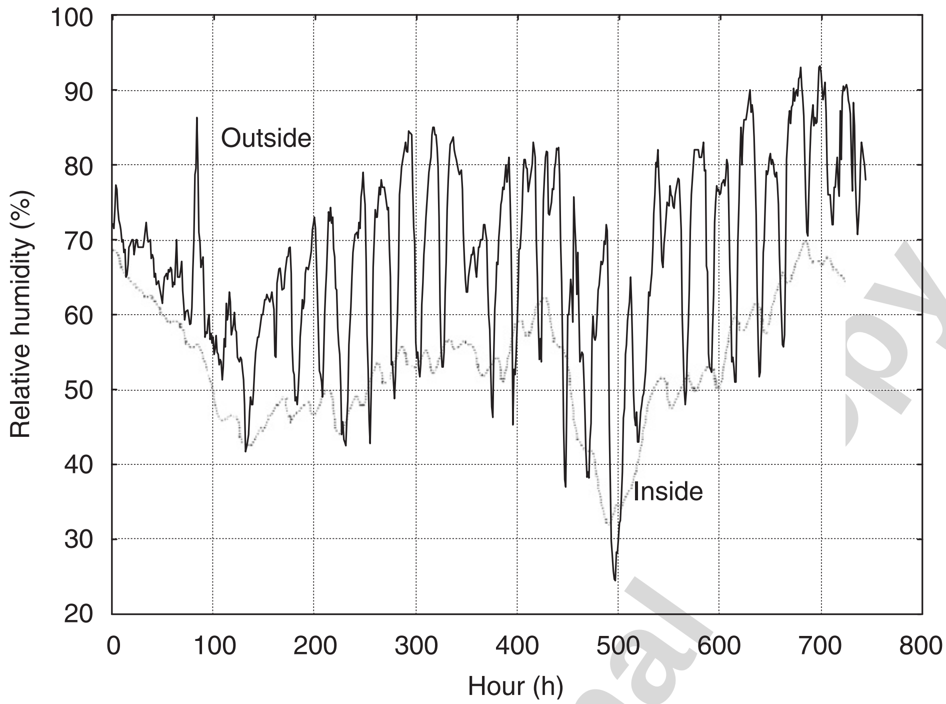

Fig. 4. Inside and outside relative humidity during January according to the data used in the considered application.

solar heating systems have been developed to varying degrees of sophistication. These methods can be classified as computer simulation methods and simplified or correlation methods. The correlation methods used have been derived from computer analysis, and most are executed manually on hand-held calculators or by use of graphs, tables, or manually solved algebraic equations.

A fully interactive computer program for P.C. has been developed for sizing of solar thermal systems by using a simplified method [6]. The program is based on *f*-chart method [7]. The *f*-chart method is one of the most comprehensive and widely used simplified method, for predicting the monthly and annual solar fraction of active solar heating systems.

The computer program uses the pull down menus technique, has on line help and disposes a library with meteorological data for many Greek and European cities. In this library, files with meteorological data from other cities can be added by the user. The program accepts values of design parameters that are only within the range of validity of the *f*-chart empirical correlations. The results are presented in tables and graphs on the screen and they can also be printed. The program can be used to predict the monthly solar fraction and hence the annual useful thermal energy delivery by solar heating systems of standard configurations, or to examine the effect of different parameters upon the performance of the solar heating system.

2.3.1. Application

In order to calculate the thermal performance of a solar hot water system installed in a building in Athens, Greece, the following specifications were used:

Daily hot water requirements of 55 l per person.
Occupants: 5.

Storage capacity: $60\,\mathrm{l\,m^{-2}}$ of solar collector area.
Flat–plate solar collector of single-glazed, non-selective.
Solar collector parameters: $F_R(U_L) = 6.5\,\mathrm{W\,m^{-2}\,{}^{\circ}C^{-1}}$, $F_R(\tau\alpha) = 0.88$.
Collector tilt: 38°.
Hot water temperature: 50 °C.
Pipe length: 15 m
Piping heat loss coefficient: $0.5\,\mathrm{W\,m^{-1}\,{}^{\circ}C^{-1}}$.

The meteorological data files for Athens contain, ambient temperature, total solar irradiance on horizontal surface, and cold water supply temperature. The program results for the above application are shown in Fig. 5. This figure shows the amount of annual useful solar thermal energy delivered per unit of collector area, together with annual solar fraction, versus solar collector area. From this figure it can be seen that the increase of solar collector area affects the useful solar energy and the solar fraction inversely. It should be noted that the amount of annual useful solar thermal energy delivered per unit of collector area, is the most important performance value relating to a solar installation.

2.4. Solar geometry

This program shows the apparent motion of the sun on the celestial vault, for each day of the year, and for a given location (Fig. 6). The position of the sun is defined by its altitude and azimuth angles and is calculated with relevant equations [3]. Also the solar altitude angle at solar noon is shown in the screen. Each time of the day, the current position of the sun with the corresponding daily trajectory can be seen, as the time progresses. Moreover the instantaneous altitude of the sun and the local times of sunrise and sunset are also shown. It should be noted that the sunrise time has been corrected due to the semi-diameter and refraction effect. The maximum and the minimum trajectory of the sun for the two characteristic days of the year are also displayed. The exact time for

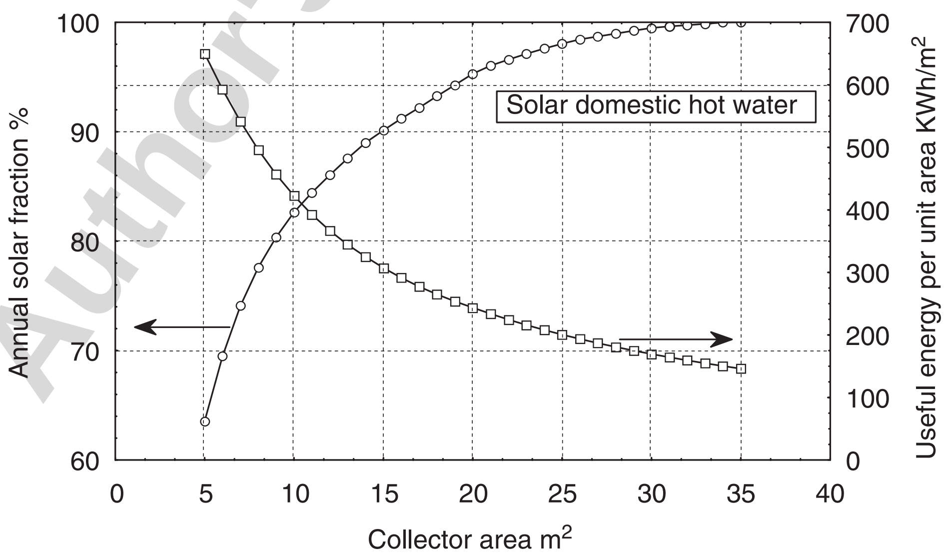

Fig. 5. The useful solar energy per unit collector area and the annual solar fraction for domestic hot water according to the data used in the considered application.

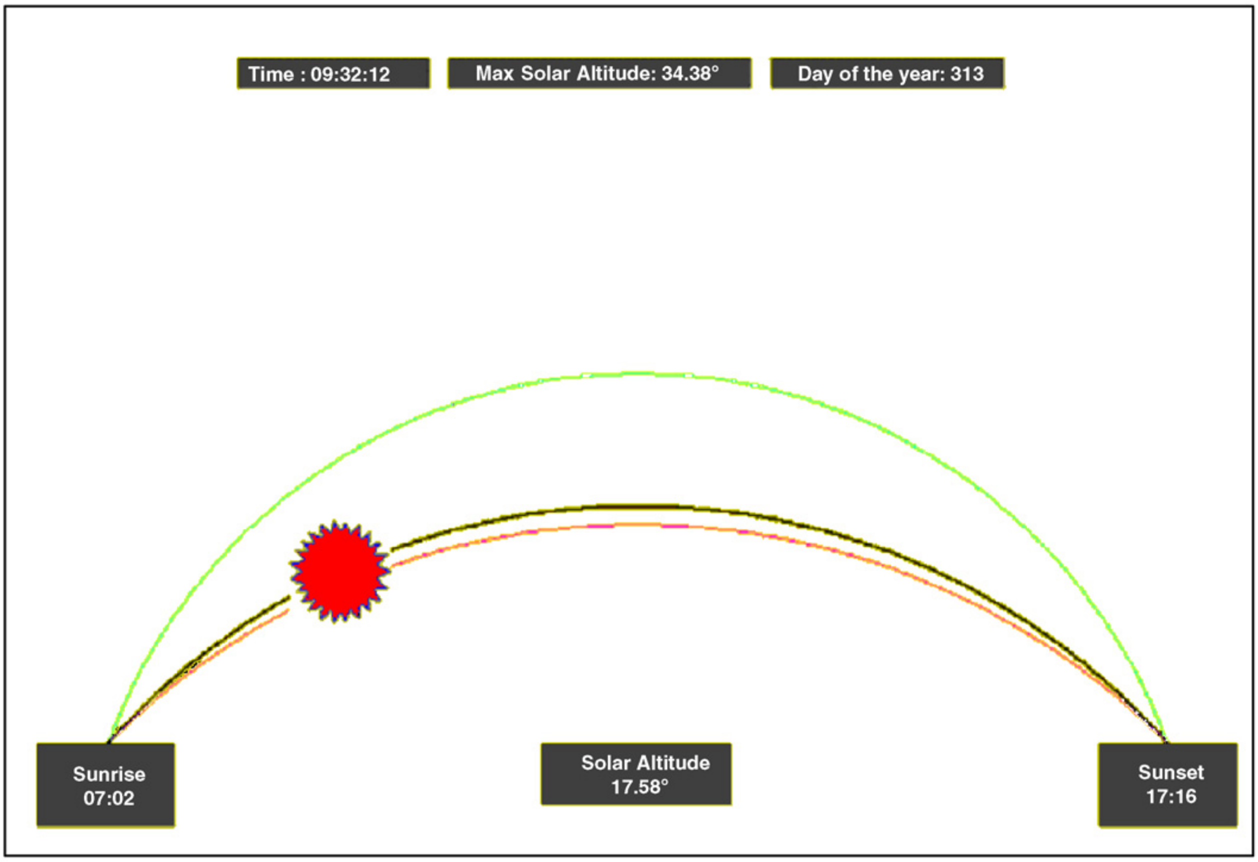

Fig. 6. Main screen of the solar geometry program.

sunrise and sunset as well as the highest daily Solar altitude for that particular day are displayed on the screen.

The sunrise and sunset times and the shape of the sun's path in the sky depend on the time of year, and the location. It is easy to calculate how the duration of the day and the maximum solar altitude angle change from winter to summer and for different latitudes. The program runs in Windows environment and is useful to all those that have an interest on the study of solar energy.

2.5. Thermophysical properties of gases and liquids using P.C.

With this program, which operates in Windows environment, the thermophysical properties of a number of liquids and gases can be calculated easily and quickly for a desired temperature. Several books have been used to find the relevant data, as [8–11]. The calculated thermophysical properties are: mass density, specific heat at constant pressure, specific heat at constant volume, dynamic viscosity, kinematic viscosity, thermal conductivity, coefficient of thermal expansion, thermal diffusivity, Prandtl number and Grashof number group. The examined liquids and gases are: Ethyl chloride, Glycerin, Ethylene glycol, Calcium chloride, Benzene, Freon 12, Freon 14, Methanol, Propane, Water and Air, vapor, Ammonia, Carbon dioxide, Carbon monoxide and Nitrogen. The results can be shown on the screen, printed or saved in a file for further processing. The information given is used in energy and heat transfer applications.

2.5.1. Application

Using this program, the thermophysical properties of water have been calculated at 72.8 °C (Fig. 7). Also for demonstration purposes the temperature dependence of the thermal diffusivity and Prandtl number for water, has been calculated and plotted in Fig. 8.

Similar computations for all thermophysical properties presented in Fig. 7 and for the aforementioned gases and liquids can be performed easily. This program is also useful for engineering applications, such as heat transfer.

2.6. The psychrometric chart using P.C.

This program represents graphically the psychrometric chart (Fig. 9). By using the mouse, the user can move the cursor to a chosen state point on the chart and immediately see the values of all properties as dry bulb, wet bulb, relative humidity, enthalpy and humidity ratio. Also it allows a direct reading of the change in enthalpy in a process between two states.

The equations used for calculating moist air properties are based on ASHRAE correlations and ideal gas laws [12]. These equations are sufficiently accurate for most engineering calculations in air conditioning applications. This software can be used for engineering calculations in air-conditioning applications. The results can be shown on the screen, printed or saved in a file for further processing.

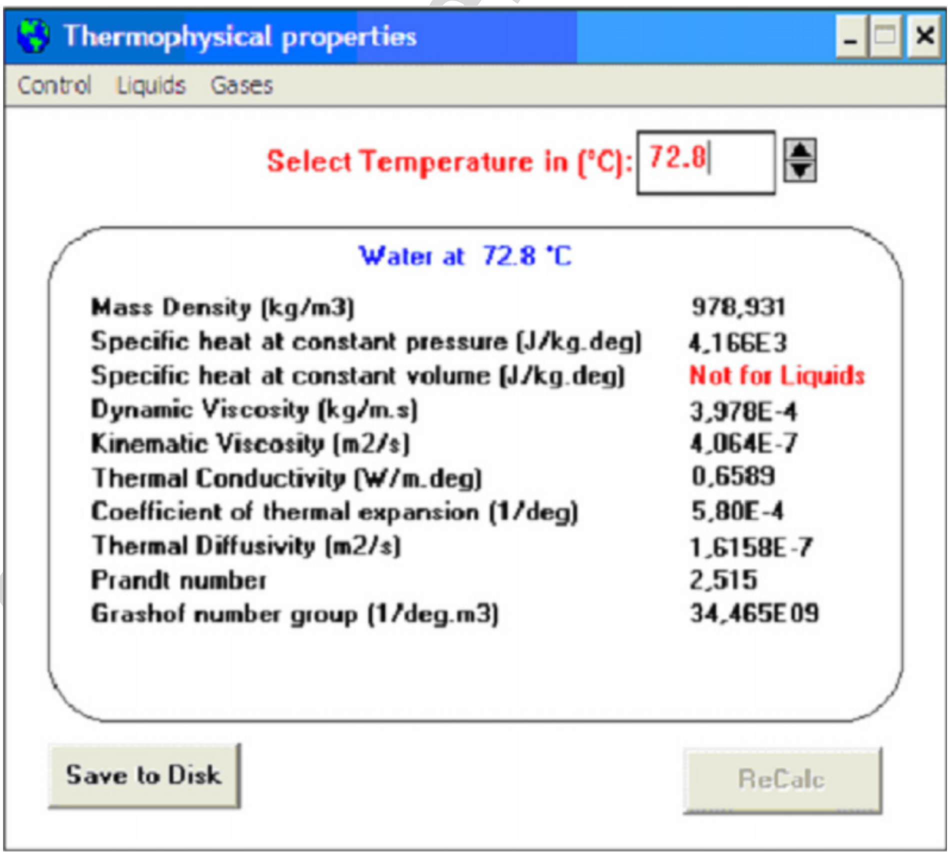

Fig. 7. Main menu of the thermophysical properties program.

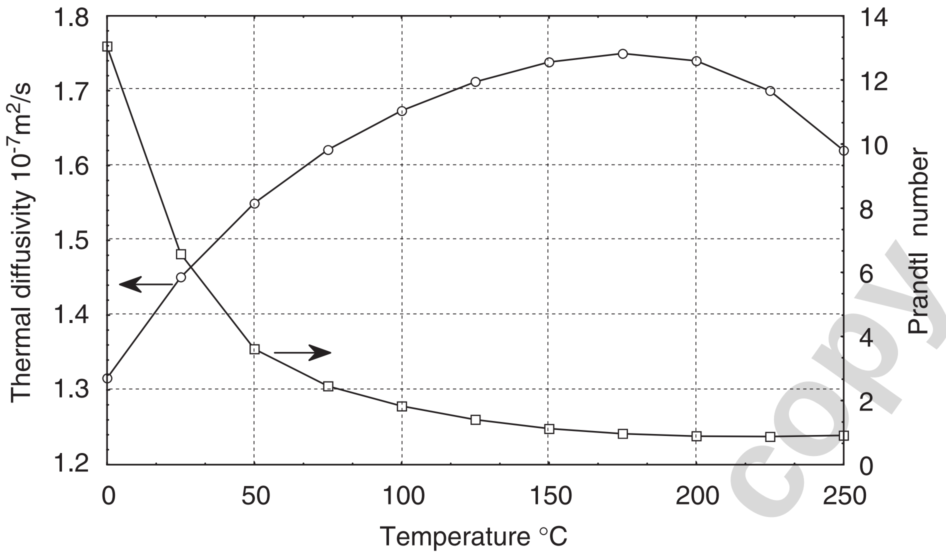

Fig. 8. Thermal diffusivity and Prandtl number for water, as a function of temperature.

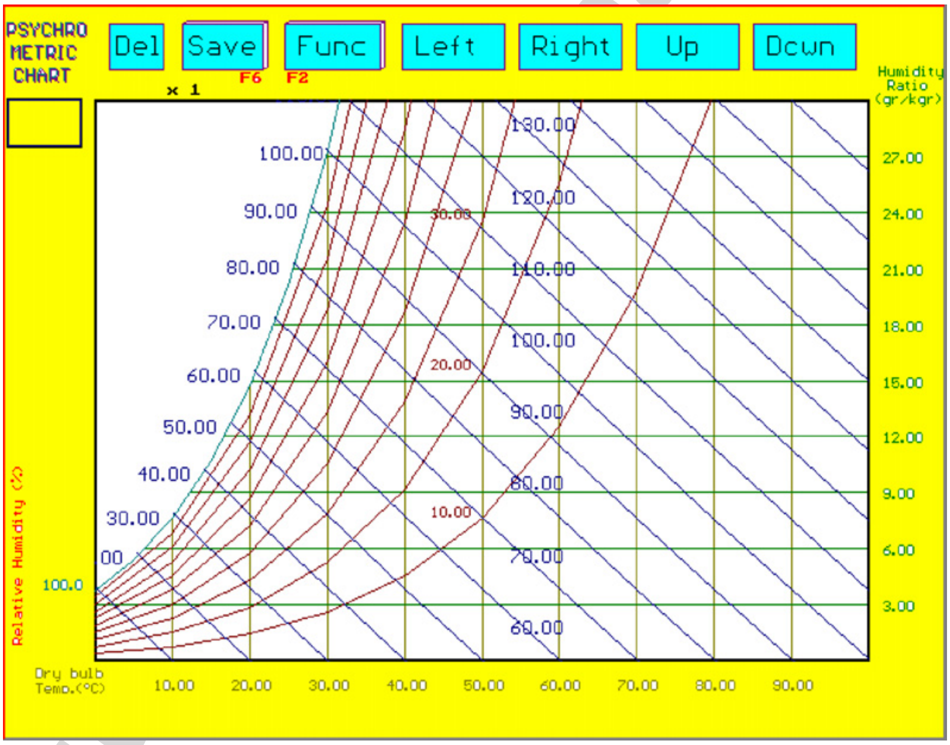

Fig. 9. Main screen of the psychrometric chart.

3. Conclusions

The above-mentioned programs, as developed, can be considered as useful energy education tools for high schools students and Universities. It can also be used for an extensive set of exercises in the tertiary education sector. Since the use of the software can decrease the necessary time for evaluations, a fairly more time can be saved, which can be used in the analysis of the results, study of parametric sensitivity, research of backing subjects, amongst other essential tasks in the modern context of energy technology.

Software availability: The aforementioned programs are free of charge and can be downloaded from our web site at http://helios.teiath.gr.

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