ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

PROGRAM FOR SOLAR WATER HEATING SYSTEMS BASED ON THE F-CHART METHOD

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Abstract. *This paper aims at presenting an application developed in JAVA for optimizing the design of centralized solar water heating systems with forced circulation, based on the f-chart method. The program uses data from the Brazilian Solar Atlas, performance data of flat plate collectors and thermal reservoirs from the standardized tests run within the Brazilian Labeling Program, and values of water consumption of appliances defined by the ABNT. The program finds the inclination of the collector that maximizes the annual solar fraction, or for the winter, and enables the use of arrays in series and parallel collectors. From the investment costs and O & M of solar heating systems, the program carries out economical analysis using classical parameters as net present value, discounted payback and internal rate of return. The program was validated through examples from the book of Duffie & Beckman(2006) and also by comparison with the results from a project developed at UFRGS that obtained good agreement.*

Keywords: solar water heating, f-chart method, solar collectors, software

1. INTRODUCTION

In Brazil the widespread use of electrical showerheads that provide hot water for domestic consumption contributes to a load curve that peaks in the early evening, imposing a considerable burden to generation, transmission, and distribution utilities. On average, over 73% of Brazilian households use these 3–8 kW electrical resistance showerheads.

In some of the more temperate climate regions in the south of the country, where most of the Brazilian population is concentrated, electrical showers are present in over 90% of residential buildings. For the residential consumer, while these high-power heating devices are the least-cost alternative investment, they lead to high running energy costs.

Furthermore, due to their very low load factor (typically below 2%), each of these high-power showerheads results in considerably low return on the high investment costs in terms of infrastructure for the electricity sector (Helena F.Naspolini, 2010).

Additionally, typical utilization times coincide with and contribute to, the electrical power demand peaks in Brazil, rendering these low-cost, high-power electrical devices a high-cost consumer for the electrical system to cater for (Helena F.Naspolini, 2011).

According to the national utility ELETROBRA´S (EPE, 2009), electrical showers are responsible for 60% of the residential electrical load at peak load hours (Helena F.Naspolini, 2010).

The solar water heating is the most attractive option for shaving this electrical load peak. The Brazilian solar radiation resource is one of the largest in the world (Tiba, 2000) that is available all over the country throughout all seasons. But the wide-spread of solar water heating systems is limited by high investment costs and the lack of knowledge of economical performance. Computational tools that allow predicting the thermal performance of solar water heating systems are potential way to proportionate conditions to the designers to precisely estimate the payback period, contributing to increase the usage of the solar water heating (P.A. Lisboa and M.A. Fonseca-Costa, 2012).

This paper presents a software for optimizing the design of solar water heating systems developed based on a previous work (Souza, 2009 and 2011). The main advantage of the current proposal is that the software carries out thermal and economical analysis using technical data from equipments commercially available in Brazil. Additionally, typical Brazilian domestic hot water consumption data are taken into account, including design specifications from Brazilian standards.

Only water heating systems with forced circulation using flat plate solar collectors can be designed. All the constraints from the f-chart method were considered during software development and must be known by the software users.

The f-Chart method offers an crucial advantages for the designers and field engineers, but it has many limitations, such as the specific design configuration, system size and design parameter restrictions, as well as the lack of flexibility

ISSN 2176-5480

to cover any hourly load demand profile (P. Tsilingiris, 1996). But the Brazilian domestic hot water consumption profiles adjust well to these constraints, since the consumption is concentrated in the early evening.

2. COMPUTATIONAL TOOLS FOR SOLAR HEATING SYSTEM PERFORMANCE SIMULATION AND DESIGN

It is widely recognized that the most accurate and complete solar design tool currently available is the TRNSYS computer simulation model, developed by Klein,*et al.*(1975). This tool has been very much enriched and refined and its validity and accuracy has been repeatedly confirmed since then. It is very appropriate as an analysis and research tool and there are many TRNSYS simulation of solar water heating systems available in literature (Mohammed,*et al.***,** 2011; Bae, e*t al.,* 2006). Although it is very appropriate for researching purposes, its complexity and required expertise make it difficult to be used by the field engineers.

The f-Chart is a simplified design method of solar space and water heating systems for residences (Klein, *et al*.,1976). It is a simple graphical method requiring only monthly average meteorological data for estimating the long-term thermal performance of solar heating systems, suitable for engineers and architects.

The Solar Advisor Model (SAM) (www.**nrel**.gov/docs/fy12osti/49150.pdf), developed by the National Renewable Energy Laboratory (NREL), is a program for calculating and comparing cost and performance of solar power systems. It is a framework that contains some modules TRNSYS responsible for calculations and a graphical interface where the systems are configured to be calculated in a more simplified way than in TRNSYS.

RETScreen 4 is an Excel-based clean energy project analysis software tool that helps decision makers quickly and inexpensively determine the technical and financial viability of potential renewable energy, energy efficiency and cogeneration projects. RETScreen Plus is a Windows-based energy management software tool that allows project owners to easily verify the ongoing energy performance of their facilities (www.retscreen.net, 2005). Both computational tools encompass solar energy projects.

In the University of the State of Rio de Janeiro, it was developed a thermal performance simulation program of solar water heating systems (P.A. Lisboa, 2012, P.A. Lisboa and M.A. Fonseca-Costa, 2012). The implemented model computes the mass and energy balances in the thermal tank in each time step along a simulation interval, typically an hour throughout a year. Its input data are values from a typical meteorological year of a chosen location and the hot water load. The system components are the hot water storage tank and the solar collector. It was validated through comparisons with results from TRNSYS simulations.

3. SOLAR RADIATION MODEL

The solar radiation is split in the beam and diffuses components. Sky models are mathematical representation of the diffuse radiation. The current software uses the isotropic diffuse sky model developed by Liu and Jordan (1963) (Duffie and Beckman, 2006). The radiation on the tilted surface is considered to include three components: the beam radiation (I_b), the isotropic diffuse radiation from the sky (I_d), and solar radiation reflected diffusively by the ground ($I_{\rho g}$). One tilted surface with inclination β to the horizontal has a view factor to the sky $F_{c-s} = (1 + \cos\beta)/2$ and a view factor to ground $F_{c-g} = (1 - \cos\beta)/2$. The total incident radiation can be written as (Duffie and Beckman, 2006):

$$I_T = I_b.R_b + I_d.\left(\frac{1+\cos\beta}{2}\right) + I_{\rho g}.\left(\frac{1-\cos\beta}{2}\right) \quad (1)$$

where R_b is the ratio of beam radiation on the tilted surface to that on a horizontal surface and is defined as:

$$R_b = \frac{\cos\theta}{\cos\theta_z} \quad (2)$$

where θ is the angle of incidence and θ_z is the zenith angle.

The software utilizes an optimization routine for encountering the inclination angle (β) that maximizes the solar radiation incident on the collector surface taking into account all months or optionally only the winter months, through maximizing R_b in Eq.3.

$$R_B = \frac{\left(\frac{\pi}{180}\right).\omega_S^{'}.sen\,(\phi+\beta).sen\delta + sen\,\omega_S^{'}.\cos\delta.\cos(\phi+\beta)}{\cos\phi.\cos\delta.sen\,\omega_S + \left(\frac{\pi}{180}\right).\omega_S.sen\phi.sen\delta} \quad \text{where} \quad \omega_S^{'} = \min\begin{bmatrix}\cos^{-1}(-\tan\phi\cdot\tan\delta) \\ \cos^{-1}(-\tan(\phi+\beta)\cdot\tan\delta)\end{bmatrix} \quad (3)$$

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δ, ϕ and ω_s are the solar declination angle, the latitude and the sunset (or sunrise) hour angle, respectively.

The Eq. (3) is valid for surfaces in the southern hemisphere sloped toward the equator. For sites in the northern hemisphere, the equation is similar and it was omitted here due to space limitation. The numerator of this equation is the extraterrestrial radiation on the tilted surface and the denominator is that on the horizontal surface.

The monthly average integrated daily extraterrestrial radiation $\overline{H_0}$ is calculated by Eq.4:

$$\bar{H}_o = \frac{24 \cdot 3600 \cdot G_{SC}}{\pi} \cdot \left(1 + 0{,}033 \cdot \cos\left(\frac{2.\pi.d}{365}\right)\right)\left(\cos\phi \cdot \cos\delta \cdot sen\omega_s + \omega_s \cdot sen\phi \cdot sen\delta\right) \tag{4}$$

where G_{SC} is the solar constant and d day of the year, from 1 to 365. For latitudes in the range +60 to -60, $\overline{H_0}$ can be calculated using n and δ for the "mean day" of the month, as described in (Duffie and Beckman, 2006).

The clearness index (K_T) takes into account the atmospheric attenuation of the extraterrestrial solar radiation. The software utilizes monthly average values of the clearness index $\overline{K_T}$, which are read from the Brazilian Solar Atlas (Tiba, 2000).

$$\bar{K}_T = \frac{\bar{H}}{\bar{H}_0} \tag{5}$$

The software requires monthly average values of the integrated daily radiation on the tilted surface $\overline{H_T}$. They are calculated by Eq.6 through a summation procedure similar to Eq. (1), where $\overline{H}$ is the total radiation and the subscripts d and ρg refer to the diffuse and ground-reflected components, respectively.

$$\bar{H}_T = \bar{H}\left(1 - \frac{\bar{H}_d}{\bar{H}}\right)R_B + \bar{H}_d\left(\frac{1+\cos\beta}{2}\right) + \bar{H}_{\rho g}\left(\frac{1-\cos\beta}{2}\right) \tag{6}$$

The diffuse component is related with the total radiation as proposed by Collares-Pereira & Rabl (1979) (Duffie and Beckman, 2006):

$$\frac{\bar{H}_d}{\bar{H}} = 0{,}775 + 0{,}00606 \cdot (\omega_s - 90) - [0{,}505 + 0{,}00455 \cdot (\omega_s - 90)] \cdot \cos\left(115\bar{K}_T - 103\right) \tag{7}$$

4. COMPONENT PHYSICAL MODELS

The model assumptions are:

- The thermal tank containing the stored hot water is treated by the fully-mixed sensible heat model, i.e. there is no internal thermal stratification;
- There is a controller that turns the pump on only if there is a minimum temperature difference and a useful energy output from the collector to justify it.
- The solar collector model uses a linear form of the collector efficiency and does not include incidence angle modifier for correction of the inclination angle.
- There is no intermediate heat exchanger since the water that circulates in the solar collector is the same that is stored and consumed.

The useful output heat flux from the solar collector is the difference between the thermal power absorbed by the collector plate and heat losses to the environment, expressed based on the Hottel-Williers equation as described in (Duffie and Beckman, 2006):

$$Q_u = A_c.F_R.[G_T.(\tau.\alpha) - U_L.(T_i - T_a)] \tag{8}$$

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where F_R is the heat removal factor defined as the ratio between the actual useful energy gain of a collector and the useful gain if the whole collector surface were at the fluid inlet temperature. ($\tau\ \alpha$) is the product of the coverage transmittance by the collector plate absorbance, G_T is the incident irradiance on the collector. U_L is the overall heat loss coefficient, which includes all losses from the collector. Ti and Ta are the water temperature at collector inlet and the environment temperature, respectively. A_c is the total area of the collector.

As above mentioned, operation of a forced-circulation collector will not be carried out when Qu < 0. The values of F_R.(τ α) and $F_R.U_L$ express the collector efficiency linear behavior and are obtained from standardized tests (ABNT NBR ISO 15747 (NBR ISO, 2009), ASHRAE 93 (ASHRAE, 2009), available in Brazil from the Brazilian Labeling Program (PBE) coordinated by the National Institute of Metrology, Standardization and Industrial Quality (INMETRO). The software adjusts the values of these parameters when the actual flow rate is within the range between 25% above and 25% below the flow rate of the standardized test.

The software allows both series and parallel connections in the solar collector arrays. In series arrays, the decrease in thermal performance of the second (and subsequent) module is considered as described in (Duffie and Beckman, 2006):

$$F_R\,(\tau\alpha) = F_{R1}(\tau\alpha)_1\left[\frac{1-(1-K)^N}{NK}\right] \quad \text{and} \quad F_R\,U_L = F_{R1}U_{L1}\left[\frac{1-(1-K)^N}{NK}\right] \tag{9}$$

where N is the number of collectors in series and K is given by:

$$K = \frac{AF_R U_L}{\dot{m}C_P} \tag{10}$$

The heat loss through the storage tank walls is written by:

$$L_P = (U.A).(T - T_a) \tag{11}$$

where A is the corresponding area, T_a is the environment temperature and U is the global heat transfer coefficient, which includes all thermal losses. This last parameter is obtained from standardized tests prescribed by the ABNT NBR10185 (NBR 10185, 1988), also within the PBE.

The storage tank volume is calculated from the hot water consumption through the summation of the products of number of users, usage flow rate and utilization time. Since thermal reservoirs are standardized, the software indicates the standardized volume immediately above. Both the adopted appliance usage flow rates and utilization times are those from the Brazilian standards.

The heat losses through the pipeline are calculated from the correlation proposed by Churchill and Benstein (1977) for forced convective heat transfer with Peclet number greater than 0.2:

$$Nu = 0,3 + \frac{0,62\,\mathrm{Re}^{1/2}\,\mathrm{Pr}^{1/3}}{\left[1+\left(0,4/\mathrm{Pr}\right)^{2/3}\right]^{C1}}\left[1+\left(D\right)^{A}\right]^{B} \tag{12}$$

where the coefficients A, B, C1 and D are related to Reynolds number (Re) ranges and Pr is the Prandtl number.

Holman (1998) suggested that the natural convection is the predominant heat transfer mechanism when the Grashof (Gr) number divided by the square of the Reynolds number is greater than 1,0. In this case, the software uses the correlation proposed by Churchill and Chu (Holman, 1998), valid for 10^{-5} < Gr and Pr < 10^{12}.

$$Nu = \sqrt{0,60 + 0,387\left(\frac{Gr\,.\,\mathrm{Pr}}{\left(1+\left(0,559/\mathrm{Pr}\right)^{9/16}\right)^{16/9}}\right)^{1/6}} \tag{13}$$

The pipe surface temperature (T(x)) varies with the position (x) along the pipe length (l) and can be expressed as (Arruda, 2004):

$$T_{(x)} = T_{air} + \left(T_{(x0)} - T_{air}\right).e^{\frac{-4x}{\rho.c.v_w.\pi.di^2.l.R_{Tot}}} \tag{14}$$

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where T_{air}, d_i, v_w, ρ, c, R_{Tot}, x_0 are the air temperature, the pipe inside diameter, the water velocity, water density, water specific heat and a pipe location where the surface temperature is known, respectively. The total pipeline heat losses (q_{pipe}) are determined by the summation:

$$q_{pipe} = \sum_{x=0}^{x=L} h_c.A.(T_{(x)} - T_{air}) \tag{15}$$

6. CLIMATIC DATA AND OTHER CALCULATIONS

Monthly average daily temperatures are obtained from the Brazilian Meteorological Station Data by the considered site available in the web.

The monthly average water mains temperatures (Tmains) are approached by a fixed amount of degrees Celsius below the correspondent environmental temperature.

The mensal hot water load (L) is calculated by Eq. (16) considering the bath water temperature (T_{bath}):

$$L = \rho V c\left(T_{bath} - T_{mains}\right) \tag{16}$$

from the investment and O & M costs of solar heating systems, the program carries out economical analysis using classical parameters as net present value, discounted payback and internal rate of return. To detail the economical analysis is out of the scope of this paper.

7. THE F-CHART METHOD

The f-chart method has the following configuration constraints:

- The water consumption is carried out only at evening;
- The ratio of the collector area (m^2) to the storage tank volume (liters) must be within the range from 37.5 to 300;
- The ranges of the design parameters are shown in Table 1 (Duffie and Beckman, 2006).

Table 1. Ranges of Design Parameters Used in the Development of the f-Chart for Liquid Systems

0.6	<	$(\tau\alpha)_n$	<	0.9
5	<	$F_R{}^A{}_c$	<	120 m^2
2.1	<	U_L	<	8,3W/m^2C
30	<	β	<	90^0
83	<	(UA)h	<	0.9

The solar fraction (f) of the monthly total load supplied by the solar water heating system is given as a function of two parameters (X and Y) as described by Duffie and Beckman, (2006):

$$f = 1.029\,Y - 0.065\,X - 0.245\,Y^2 + 0.0018\,X^2 + 0.0215\,Y^3$$

$$X = \frac{AcF'_R U_L (Tref - \overline{T}a)\Delta t}{L} \tag{17}$$

$$Y = \frac{AcF'R(\tau\alpha)\overline{H}_T N}{L} \tag{18}$$

where Ac is the collecton area (m^2), Δt is the total number of seconds in the month, T_a is the monthly average ambient temperature (C), T_{ref} is an empirically derived reference temperature (100°C), L is the monthly total hot water load (J), H_T = monthly average daily radiation incident on the collector surface per unit area (J/m^2), N = days in month, $(\tau\alpha)$ = monthly average transmittance-absorptance.

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8. SOFTWARE DESCRIPTION

8.1 Conceptual Modeling Software

The conceptual model helps the programmer in the representation of the problem domain and consequently the functions of the software illustrating their associations, compositions, specializations and attributes through abstraction and decomposition of the problem domain. In this work, specifically, three diagrams were built: 1- Use Case Diagrams and 2- Sequence Diagram of Activities in Fig.1 and Class Diagram in Fig. 2. These Diagrams are sufficient to model the problem and represent the problem domain.

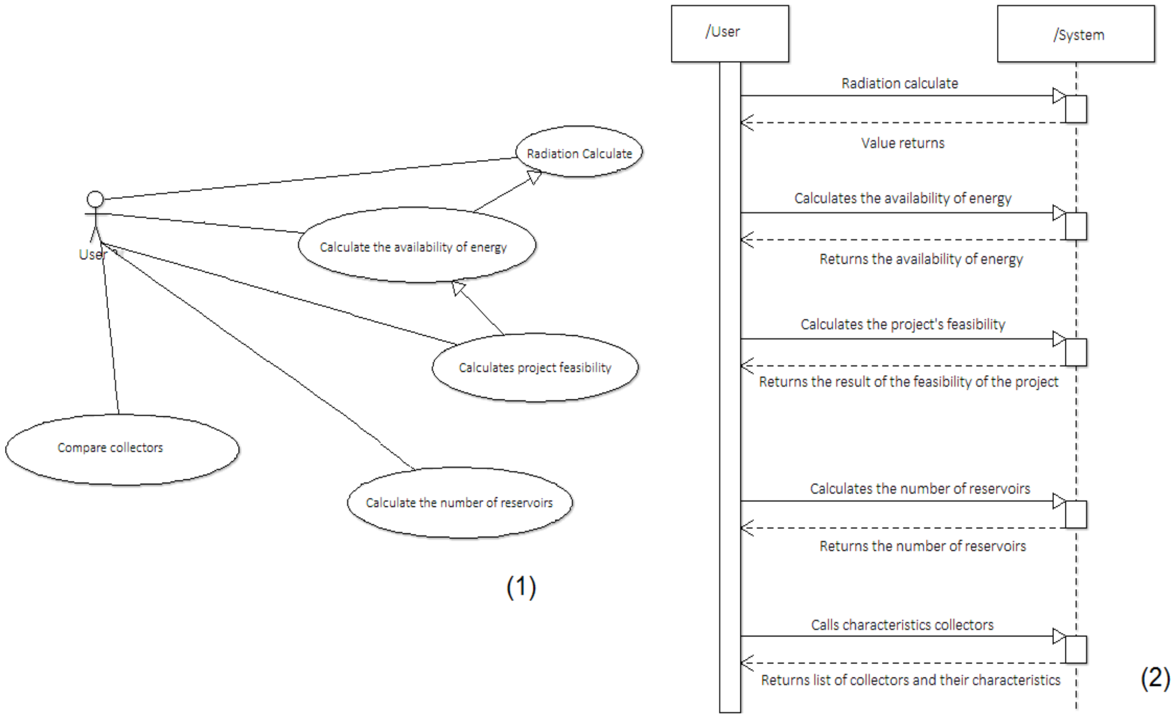

Figure1. Use Case Diagram

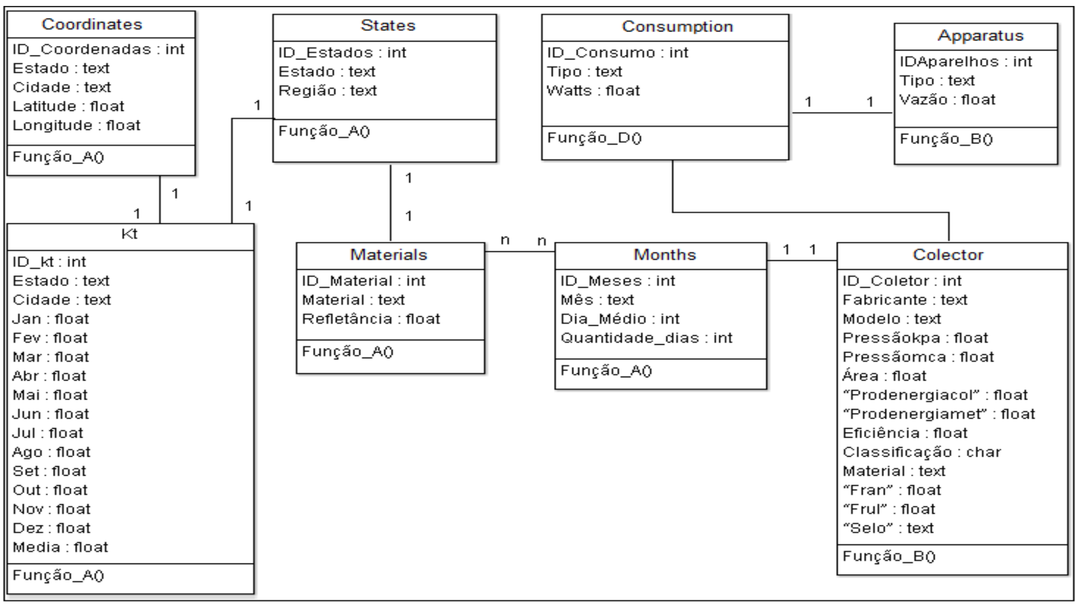

Figure 2. Class Diagram

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8.2 Conceptual Model of the Database

The database is a computational environment used not only for storage, but also for extraction and analysis including statistics of all stored data in the repository. The DBDesign and the MySQL were used as a tool for data modeling and as a repository, respectively. The option for this tool is justified by the fact that both DBDesign and MySQL are free and also they are fully integrated. The model shown in Fig. 3 represents the set of tables and their relationships in the database. Each table has an own set of attributes that will index the data stored.

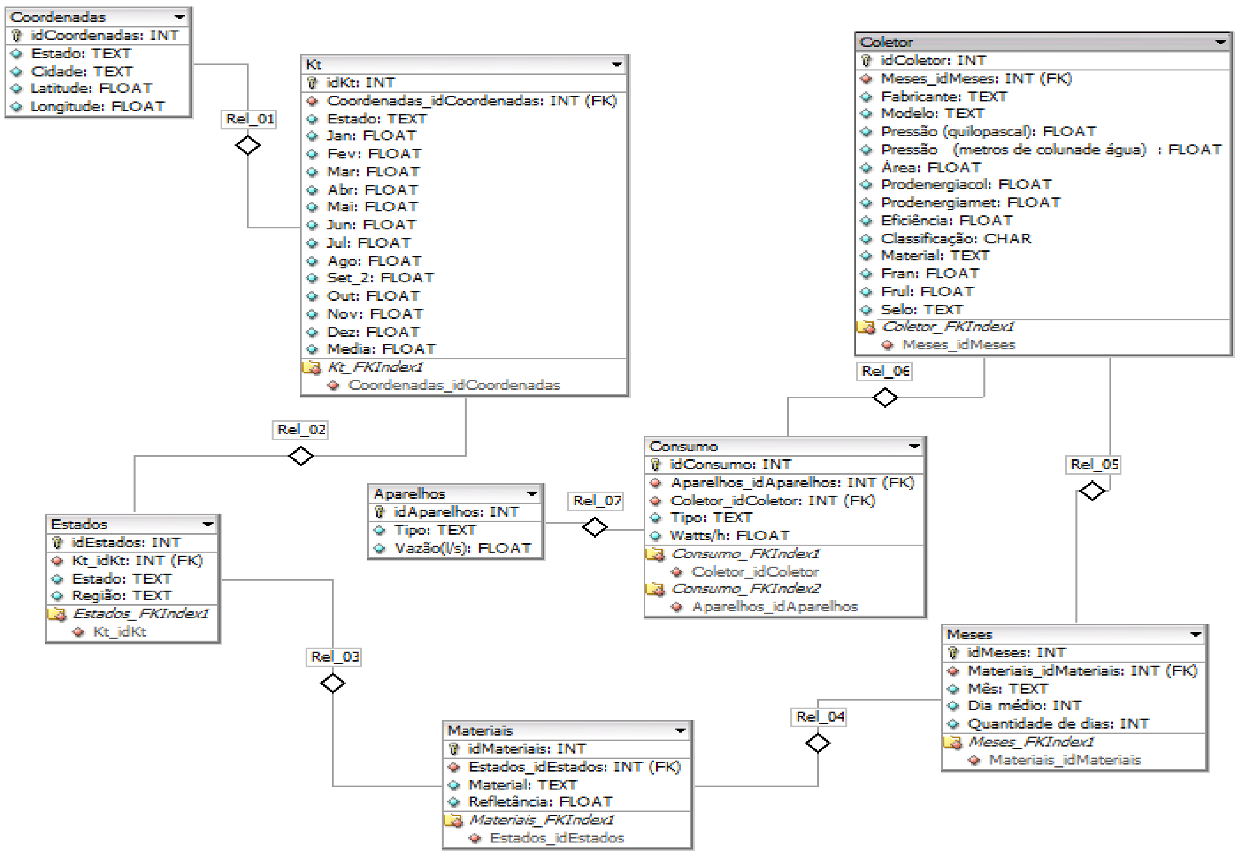

Figure 3. Data Model / Entity Relationship

8.3 Coding System

Table 2 contains the main Java classes developed. The Java programming language was chosen because it has some advantages such as:

1. Portability: Java can run on any platform or device that has a Java interpreter, and that has been especially compiled for the system to be used;
2. Object Orientation: Java is a fully object-oriented, which allows codes reuse (packages, classes, etc.).
3. High Performance: Java language supports multiple high-performance features such as multithreading, build just-in-time and the use of native code.

Table 2. Key Java System Classes

Function	*Classe Java*	*Description*
FunctionA	*public class Calculo_A*	Java class to calculate the radiation by location.
FunctionB	*public class Calculo_B*	Java class for calculating the number of reservoirs.
FunctionC	*public class C_Util1*	Java class energy calculation gives availability.
FunctionD	*public class Conv_D*	Java class to calculate the feasibility of the project.
Function E	*public class Reser_E*	Java class to compare the performance of collectors.

8.4 Graphical Interface

The graphical user interface of the software was developed in order to facilitate and turn practical the interaction with the user. Due to the complexity of some functions of the system, it was built an interface consisting of tabs that allows a more dynamic and interactive navigation during use. Each window function represents a software graph.

9. TESTS AND RESULTS

9.1 Validation of the solar fraction calculation

Firstly, the current software results have attained excellent agreement with results from examples presented by (Duffie and Beckman, 2006).

The software validation is based on a comparison between software results with those from the calculation of the solar fraction for the Student Accommodation Project from UFRGS, presented by (Kehl, 2004). Data about location, installation characteristics and hot water consumption are reproduced in Table 3.

Table 3. Data from (Kehl, 2004)

Location	Porto Alegre
Latitude (^{o})	- 30.04
Longitude (^{o})	51.2
Azimuthal (^{o})	180
Angle of inclination of the collectors (^{o})	40
Demand points	Shower
Number of users	18
Hot water temperature (^{o}C)	38
Number of baths per day	1
Average time of the bath (min)	10
Average consumption of hot water for bathing (l / min)	7

To calculate the energy demand, the public water mains temperature was approached as 3°C below the monthly average environmental temperature.

Table 4 and Fig. 4 show comparisons among results produced by the current software with those reproduced from (Kehl 2004), obtained with the F-Chart method and the Termodim software.

Table 4. Solar fractions from the current software and from (Kehl, 2004)

Month	F-Chart	Termodim	Current	Deviation C/FC (%)	Deviation C/T (%)
January	0.83	0.80	0.87	4.4	7.3
February	0.81	0.80	0.88	8.5	8.9
March	0.72	0.77	0.84	13.6	8.6
April	0.63	0.69	0.78	19.3	11.4
May	0.46	0.62	0.70	33.9	11.6
June	0.36	0.56	0.53	32.5	-6.0
July	0.46	0.56	0.58	21.1	2.8
August	0.50	0.59	0.60	15.8	1.4
September	0.58	0.62	0.62	6.7	0.0
October	0.72	0.68	0.78	7.1	12.9
November	0.80	0.73	0.81	1.4	10.3
December	0.84	0.77	0.86	1.3	10.5
Averege Deviations				13.8	6.7

ISSN 2176-5480

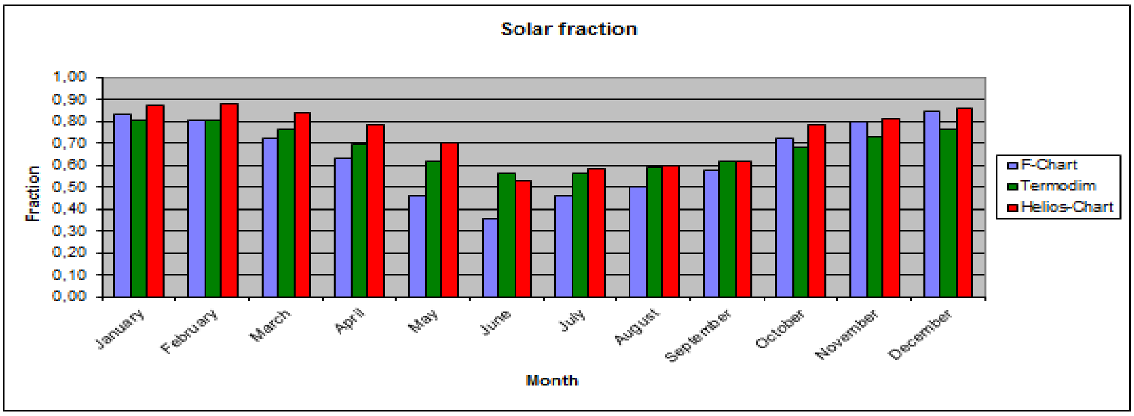

Figure 4. Solar fractions from the current software and from (Kehl, 2004)

From January to May the current software results were significantly above. From June to September the results were closer to those from the Termodim. For the remaining months, the results were closer to the F-Chart ones.

As the Termodim deals with solar radiation data generated by the Radiasol, new data were generated by the current software, now using solar radiation data produced by Radiasol. Table 5 and Fig. 5 show these new results.

Table 5. New comparison of solar fractions from the current software and from (Kehl, 2004)

Month	F-Chart	Termodim	Current	Deviation C/FC (%)	Deviation C/T (%)
January	0.83	0.80	0.86	3.2	6.2
February	0.81	0.80	0.84	3.8	4.3
March	0.72	0.77	0.78	6.6	1.3
April	0.63	0.69	0.69	9.0	11.4
May	0.46	0.62	0.55	16.7	-11.4
June	0.36	0.56	0.41	13.1	-36.5
July	0.46	0.56	0.54	15.0	-4.8
August	0.50	0.59	0.57	11.9	-3.2
September	0.58	0.62	0.64	9.9	3.4
October	0.72	0.68	0.78	6.5	12.3
November	0.80	0.73	0.84	4.6	13.1
December	0.84	0.77	0.88	3.6	12.6
Average Deviations				8.6	-0.2

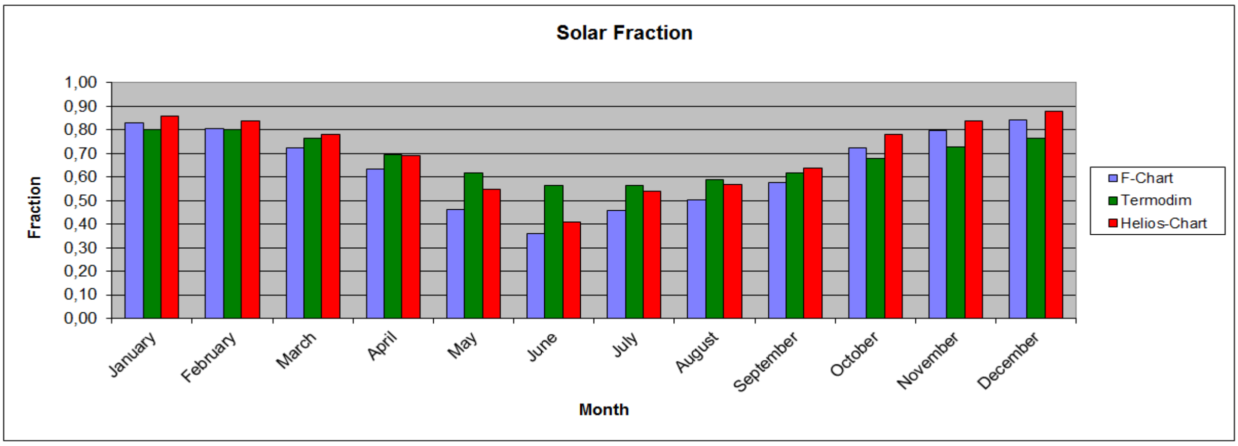

Figure 5. New comparison of solar fractions from the current software and from (Kehl, 2004)

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By using solar radiation data generated by the Radiasol, the yearly average solar fraction produced by the current software deviates 8.6 from that calculated by the f-chart method and only -0.2% from that of the Termodim, as shown in Tab.5.

The discrepancies found are partially justified by the lack of information about some data from (Kehl, 2004), p. ex., mains water temperature.

9.2 Validation of the solar radiation calculation

Table 6 presents a comparison of the results generated by the software developed here and the Radiasol. Figure 6 presents the same results in a graphical form.

From January to July, the values generated by the current software are above of those generated by the Radiasol, and from August to December the opposite occurs. In Fig. 6, it can be seen that the annual average solar radiation coincides for both programs. The highest deviation was 18% for May. These differences were expected, since the solar radiation databases used are different.

Table 6. Comparison of results generated by the current and Radiasol software

Porto Alegre City												
$B=40^0$							$\Upsilon=180^0$					
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Radiasol	19.0	18.4	17.1	16.0	13.2	11.1	13.7	14.3	15.6	18.3	19.5	20.2
Helios-Chart	18.5	19.1	18.1	17.4	15.5	12.8	13.8	14.0	14.2	17.4	17.7	18.6
Radiasol(annual average)	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4
Helios-Chart(annual average)	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4	16.4
Correction Factor	2.3%	-3.45%	-5.66%	-8.52%	-18.04%	-14.83%	-0.24%	1.85%	8.78%	4.84%	8.85%	7.72%

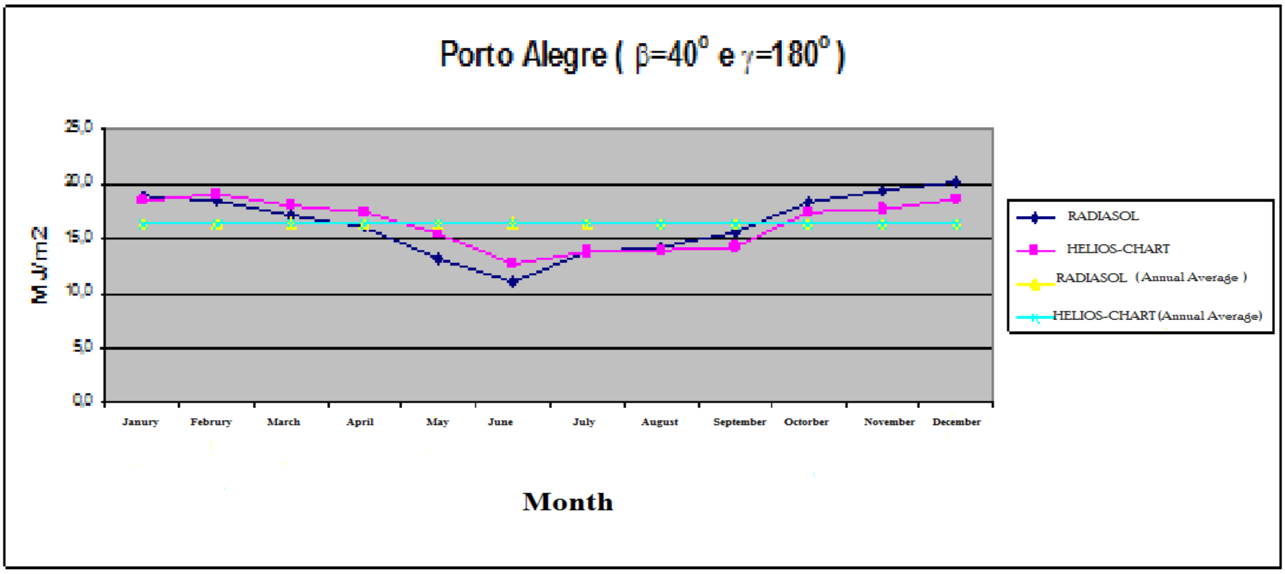

Figure 6. Graphical comparison of results generated by the current and Radiasol software.

7. CONCLUSION

The software presented here is suitable for Brazilian designers because it uses meteorological data from the Brazilian Solarimetric Atlas and performance data published by the Brazilian Labeling Program for solar collectors and thermal reservoirs. Additionally, the software takes into account typical Brazilian domestic hot water consumption data and includes design specifications from Brazilian standards.

It is expected that the current software contributes to increase the solar water heating penetration, since it carries out both thermal and economical analysis, and the major barrier to solar energy is the lack of performance information.

The increasing availability of economical performance data possibilitates the Government to make Public Policies to incentivate solar energy. It is essential to highlight here that the electrical showerheads receive economic incentives from the Brazilian Government.

The software can be enhanced to include environmental analysis, by calculating greenhouse gas emissions avoided along the total useful life of the solar water heating system.

In a long-term future research, it is interesting to carry out an experimental comprovation of the thermal performance predicted by this software.

8. ACKNOWLEDGEMENTS

This work was executed with financial support from the Brazilian Innovation Agency (FINEP), under contract number 01.07.0275.00.

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ISSN 2176-5480

Felix do Rêgo Barros, Adriano Gatto M.Sc., Sildenir Alves Ribeiro M.Sc., Manoel Antônio da Fonseca Filho D.Sc.
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