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THERMAL AND HYDRAULIC DESIGN FIELD SOLAR HEATERS OF A PRIMARY SCHOOL POOL

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Abstract. The methodology and results of the thermal and hydraulic design for a solar heating field of an elementary school's semi-olympic is presented. Improved flat solar collectors with copper tube and aluminum fins, were used.
From own experiences, many Mexican solar fields does not operate correctly because of their poor irrigation, may be due to lack of attention given to this aspect. That's why the research of this work focuses on studying the behavior of the pressure drop in a hydraulic arrangement, particularly of this facility, in which all collector batteries are connected in parallel.
Previously two solar heaters were sent to a specialized laboratory for certification tests, obtaining the optimum water flow value for maximum thermal efficiency. The results show an optimum range between 4 and 11 L/min.
On the other hand, the develop of a thermal model based on a temporal energy balance, allowed us to determine that the optimum solar heating area is about 338 m^2, using 195 flat-coated solar heaters, copper tube and aluminum fin.
For this heating system a volume water/solar collection, called REVA, of 1.45 m^3/m^2 was obtained. Referred to the hydraulic design and using the program EPANET 2.0 was found that in the proposed arrangement, 192 solar heaters were irrigated with the optimal range and only 2 solar collectors were below the lower range at 3 L/min.

Keywords: Solar collectors flow, thermal and hydraulic design, heating pool, Epanet 2.0

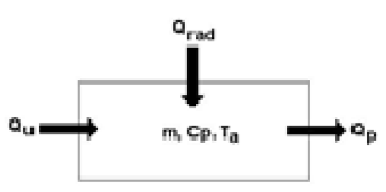
Introduction. In México, many solar heating fields do not work properly due to its deficient irrigation, that because many companies that market and install such systems lack or do not use computational tools for the thermal and hydraulic design and are based on imprecise rules of thumb. A solar field based on tens of collectors is a complex pipe network of small diameters which require specialized software for it analysis. The fact that some designs of collectors are more likely to develop non homogeneous flow distributions in their tubes, and its decreasing thermal efficiency effect has been widely reported. Duffie and Beckman [1] mentioned that if the distribution of flow in the raiser is not uniform, smaller heat removal factor would be obtained on the lower flow rate areas and that this phenomenon is particularly important in systems with forced circulation.
Martín Dominguez [4], who develops a methodology for the hydraulic analysis of several solar heaters arrangements interconnected, and established that the behavior of a solar heater must be modeled as a network flow. The behavior of two or more interconnected solar heaters arrangement corresponds to a new pipeline network, that is, each arrangement will have a different behavior according to others, not deductible from the behavior of an individual heater and the other arrangements. The interconnection of two or most heaters, across its headers, induces non-uniform flow distributions on the raisers. This effect is incremented by the number of interconnected heaters. Referred to the pool's thermal design Ruiz et al. [5] analyses the case of the thermal behavior of a swimming pool of 100m^2 using TRNSYS 16 validated by experimental results. There is shown that exists high dependency of the wind speed over the temporal development of the water temperature, originated by the evaporation heat losses.


Panoramic view of the "Ejercito Mexicano" elementary school's swimming pool in Azcapotzalco, Mexico City. Took from Google Earth, 2010.

Due to the importance of consider both thermal and hydraulic design aspects, this work presents an own methodology that considers temporally heat losses and gains including the flow distribution through a pipe network. So, it begins with the hypothesis that all the solar heater are irrigated in the range of flow rate where the efficiency is the best, to determinate the optimum number of s lly using meteorology data. After the hydraulic design is developed, which has the objective of irrigate the most as possible solar heaters with the optimum flow rate.
This work presents a methodology that uses both parts, first, the develop of an own thermal model that considers an energy balance on the solar heated swimming pool. On the other hand EPANET 2.0 software has been used for the hydraulic design to find the best network arrangement that permits to irrigate the solar heaters optimally.

Methodology. By mean of energy balance in the swimming pool [6] it could be determined the temporally thermal behavior [6]. Figure 2 shows the used control volume where the swimming pool is modeled as a thermal storage.

$$\sum Q_U + \sum Q_{RAD} - \sum Q_P = m\, c_p\, dT_a/dt \quad (1)$$



Energy balance in the swimming pool

Solving this differential equation by means of the finite differences methodology for T_a, it gets:

$$T_a^+ = T_a + (\Delta t / m\, c_P)\,(\sum Q_U + \sum Q_{RAD} - \sum Q_P) \quad (2)$$

where $T_a^+=T_a\,(t+\Delta t)$ is the swimming pool water temperature, but an instant Δt after considering constant during this time lapse $\sum Q_U$, $\sum Q_{RAD}$ y $\sum Q_P$ defined below:

$$\sum Q_U = \eta * I * A_c \quad (3)$$

where A_c is the total solar heaters field area (variable), I is the solar irradiation in W/m^2 and η is the thermal efficiency of the solar heater provided by a Certification Laboratory defined as:

$$\eta = 15.856[(T_a - T_0/I) + 0.6571 \quad (4)$$

where T_a is the inlet water to the solar heater, which is considered as the swimming pool temperature and T_0 the surrounding temperature. Mean while Q_{rad} is defined as:

$$\sum Q_{rad} = \alpha * I * A_s \quad (5)$$

where A_s is the surface area of the swimming pool, I the solar irradiation in W/m^2 and α the water absorptivity coefficient.

<u>Heat flux losses to the surroundings:</u>

$$\sum Q_P = Q_{evap} + Q_{conv} + Q_{emi} \quad (6)$$

According to Ruiz et al. [5] the most trustable equation for evaporating mass flow calculation for time unit m_{evap} (kg/s) y Q_{evap} (W) is the Richter equation, where:

$$Q_{evap} = A_S * h_{evap}(P_{v,sat} - P_{v,amb}) \quad (7)$$

where: $h_{evap} = 0.0638 + 0.0669 \cdot w \quad (8)$

<u>Convection losses:</u>
The convection losses are defined as:

$$Q_{conv} = A_s * h_{ca} * (T_a - T_0) \quad (9)$$

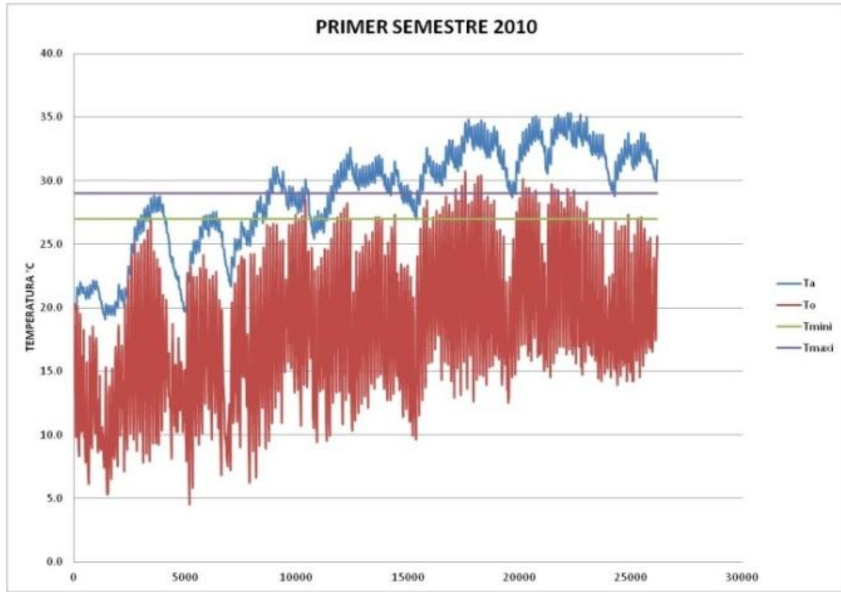
<u>Radiation heat losses from the pool to the surroundings:</u>

$$Q_{emi} = A_s\,[\varepsilon\, \sigma\, (T_a^4 - T_0^4)] \quad (10)$$

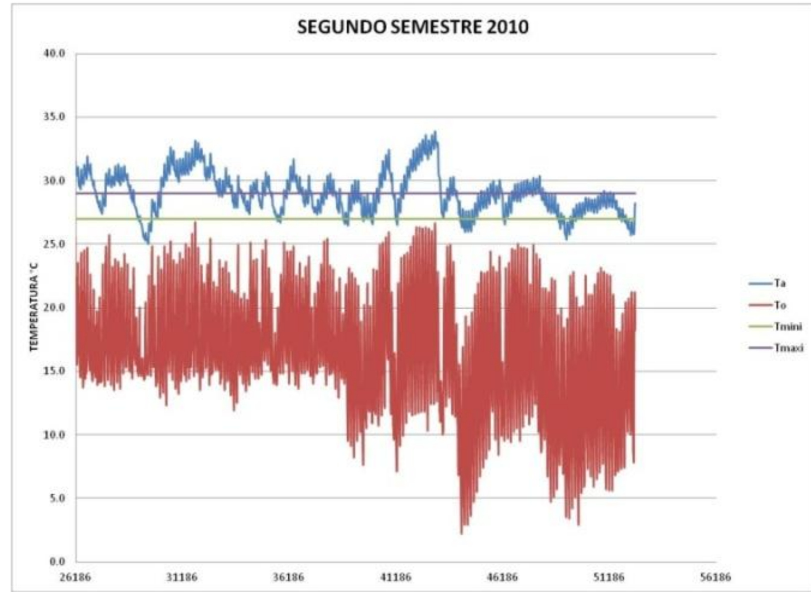
Varying A_C and evaluating the dynamic behavior of the temperature T_a according with equation 2 and evaluating equations 3, 4, 5, 6, 7, 8, 9 and 10 the more convinient area was determinated,. The following data was considered.

A_c = Solar heaters area (variable to determinate), A_s = surface area for the pool = 251 m^2, m = 491,771 kg, c_P = 4.186 kJ/kg°C, ε = water emitance coefficient = 0.8 a 0.95 without heat cover, ε = water emitance coefficient = 0.2 with heat cover y α = water absorption coefficient = 0.6 a 0.8.

Results and discussion



Behavior of the water temperature for the first semester of 2010 with a collector area of 338m^2 and 195 collectors

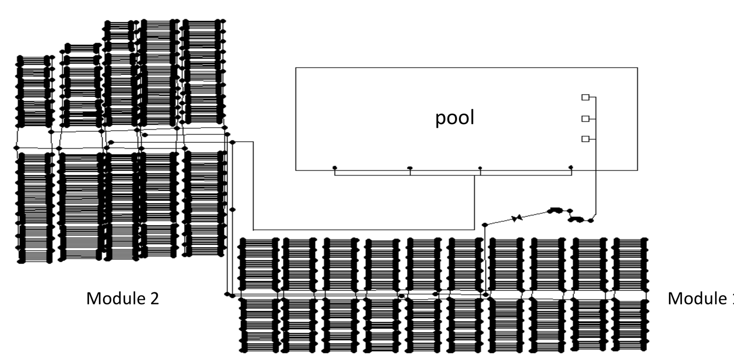


Behavior of the water temperature for the second semester of 2010 with a collector area of 338m^2 and 195 collectors.

Therefore for this heating system it was obtained a water volume/collector area rate, called REVA of 1,45 m^3/m^2. This means as a ruler of thumb that for this operating condition you need 1,45 m^2 of collectors area for every 1 m^3 of water.

Hydraulic design methodology. By means of the software EPANET 2.0 the nodes and lines that represents the pipes of the solar collectors were drawn, considering that for the thermal analysis was determined to use 195 flat solar collectors to mantain the temperature of the pool near the range of the comfort zone.
Also it was required to visit the zone to determine the install area for the design. So from this actions the hydraulic design was developed.
For this project several simulations were made of which two of the best designs are presented. Above referred to obtaining the optimum flow rates of 4 to 11 L/min according to the Certification Laboratory on the University of Guanajuato.

Results for the hydraulic design. Due to the available surface, the solar field of 195 collectors was divided in two modules one with 100 collectors and the other with the remaining 95. The figure 7 shows the proposed distribution.



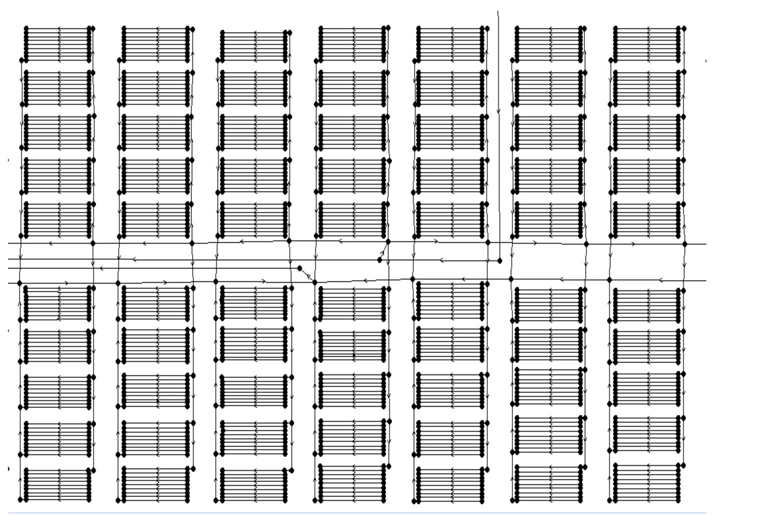
Solar field distribution proposal. Module 1 shown in the bottom and module 2 on the top. Also is shown the principal pipe network from the collectors to the pools.

Pipe diameter selection of the module 1

MODULO 1			MODULO 1		
Row	Main headers diameters (inches)	Distribution headers diameters (inches)	Row	Main headers diameters (inches)	Distribution headers diameters (inches)
1	3"	2" ½	6	4"	2" ½ y 2"
2	3"	2" ½	7	4"	3"
3	3"	3" y 2" ½	8	4"	3"
4	4"	2" ½ y 2"	9	4"	3"
5	4"	2" ½ y 2"	10	4"	3" y 2" ½

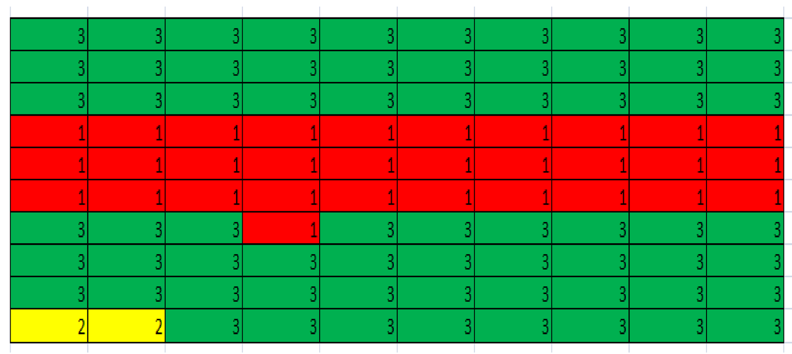
Pipe diameter selection of the module 2.

MÓDULO 2		
Row	Main headers diameters (inches)	Distribution headers diameters (inches)
1	4	3" – 2" ½
2	4	3" – 2" ½
3	4	2" ½ y 2"
4	4	3" – 2" ½
5	4	3" – 2" ½


Behaviour of the irrigation in module 1.

Flow in Liters per minute for the module 1 by each collector from a total of 100 flat solar collectors.

Fila					MODULO 1					
1	4.34	4.37	4.52	4.81	5.35	5.35	4.82	4.51	4.36	4.33
2	5.2	5.24	5.42	5.8	6.44	6.47	5.82	5.44	5.26	5.22
3	8.91	8.96	9.19	9.69	10.54	10.6	9.74	9.24	9.02	8.96
4	11.56	11.71	13.72	13.6	15.78	15.91	13.79	12.54	11.96	11.81
5	16.73	16.94	17.77	19.57	22.62	22.7	19.64	17.84	17	16.79
6	11.79	11.94	12.52	13.78	15.9	15.97	13.84	12.58	12	11.78
7	9.67	9.71	9.87	11.42	10.87	10.91	10.29	9.85	9.63	9.65
8	6.42	6.44	6.55	6.78	7.18	7.22	6.82	6.59	6.48	6.46
9	4.92	4.45	4.52	5.33	5.58	5.54	5.23	5.09	5.02	5.01
10	2.94	2.42	3.43	3.51	3.81	4.21	4.41	4.19	4.05	4.03


Flow distribution in module 1. The red ones corresponds to an irrigation >11 L/min. Green ones are into the optimum irrigation. The yellow ones are below 3 L/min.

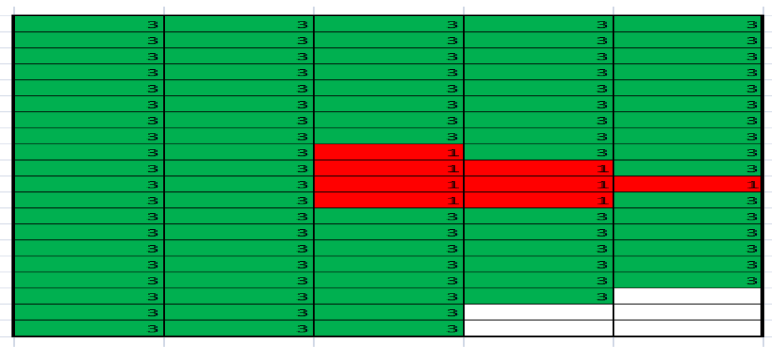

Flow distribution on module 2 for the optimum ranges. The red ones corresponds to an irrigation >11 L/min and green ones to an irrigation below 3 and 1 L/min.

Figure 10 and table 4 refers to the obtained flows in each collector of the module 2, meanwhile figure 11 shows graphically the volumetric flow distribution were only 8 collectors are irrigated slightly above 11 L/min. The remaining 87 collectors are optimally irrigated eliminating the possibility collectors with flow below 3 L/min. Therefore this arrangement shows the best flow distribution and was selected for the final design of the solar field and proceed to the construction.

Conclusions. **Thermal Design.** A transient model to calculate the optimum solar heating surface for a semi-olympic swimming pool has been developed. Also the model allows to understand the thermal behavior of the pool.
The thermal model allows to determine that 338m^2 of heating surface area is necessary to maintain the pool into the temperature of comfort. This may be carried out using 195 solar flat collectors with glass cover, cupper pipes and aluminum fins.
For this solar heating system a water volume/collector area rate named REVA of 1.45 m^3/m^2 was obtained.
The simulations determined the benefic effect of heat cover using
Hydraulic Design. A dependable hydraulic model has been obtained which guarantees a total irrigation of 195 collectors of the solar heating field.
According to the achieved results using EPANET 2.0 its was found that in the irrigation proposal, both the module 1 and 2 have only 2 solar collectors with a flow below 3 L/min also achieving reduce the collectors with flows above 11 L/min.
We can indicate that the software EPANET 2.0 represents a valuable tool to establish an hydraulic design of the solar field, where all solar heaters have to be irrigated in an optimum flow range to ensure the best thermal efficiency.

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