Dependency of Air Heating and Cooling for Karbala Buildings on a Salinity Gradient Solar Pond Area

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Dependency of Air Heating and Cooling for Karbala Buildings on a Salinity Gradient Solar Pond Area

Dependencia del calentamiento y enfriamiento del aire para los edificios de Karbala en un área de estanque solar con gradiente de salinidad

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ABSTRACT/ The Salinity Gradient Solar Pond (SGSP) can be an effective way of capturing and storing thermal energy from incident solar radiation. The concept of using the SGSP to provide cooling or heating air for buildings models is studied. The idea seems appealing for a number of reasons, the design study shows it to be technically feasible and provide in the cost of electricity. The simulation program in FORTRAN is designed to investigate the possibility of the SGSP for cooling and heating of the models of the buildings in Karbala city, Iraq (32.62° N, 44.03° E). The obtained results have been shown the SGSP could be used for the cooling and heating loads during all hours of the simulation time and to meet 100% of the cooling and heating air the SGSP needed is 4-5 times the area of the building model. Keywords: Salinity gradient solar pond, cooling and heating air, solar thermal energy, and FORTRAN Program. RESUMEN/ El estanque solar con gradiente de salinidad (SGSP) puede ser una forma efectiva de capturar y almacenar energía térmica de la radiación solar incidente. Se estudia el concepto de utilizar el SGSP para proporcionar aire de refrigeración o calefacción para los modelos de edificios. La idea parece atractiva por varias razones, el estudio de diseño muestra que es técnicamente factible y proporciona el costo de la electricidad. El programa de simulación en FORTRAN está diseñado para investigar la posibilidad del SGSP para enfriar y calentar los modelos de los edificios en la ciudad de Karbala, Iraq (32.62 ° N, 44.03 ° E). Los resultados obtenidos han demostrado que el SGSP podría usarse para las cargas de refrigeración y calefacción durante todas las horas del tiempo de simulación y para cumplir con el 100% del aire de refrigeración y calefacción que el SGSP necesitaba es 4-5 veces el área del modelo de construcción. Palabras clave: estanque solar con gradiente de salinidad, aire de refrigeración y calefacción, energía solar térmica y programa FORTRAN.

Introduction

In recent years, global warming has begun to rise gradually as a result of the CO_2 emissions from the generation of electricity by using the fossil fuels, and buildings in Iraq are the bigger source of consumption of the electricity (it consumes 48 % of the total used electricity [1]). Therefore, by using solar ponds, saving electricity production from fossil fuels and preserving the earth's environment will be saved.

There are techniques for storing solar thermal energy such as the solar pond or the solar collector, but the latter technique is not very efficient, especially during the cloudy days and during night hours moreover the cooling and heating process of buildings requires high thermal storage by a large warehouse. A large number of experimental solar ponds have been constructed around the world. There have also been a considerable number of demonstration solar ponds constructed in Australia, India, USA and Israel which are supplying heat [2].

There are several types of solar ponds; the Salinity Gradient Solar Pond (SGSP) is one of the types of the Non-Convective Solar Ponds. The SGSP usually consist of three saline water zones: Upper Convective Zone (UCZ), Non-Convective Zone (NCZ) and Lower Convective Zone (LCZ), where the salt concentration is highest in the LCZ and lower in the UCZ as shown in Fig. 1.

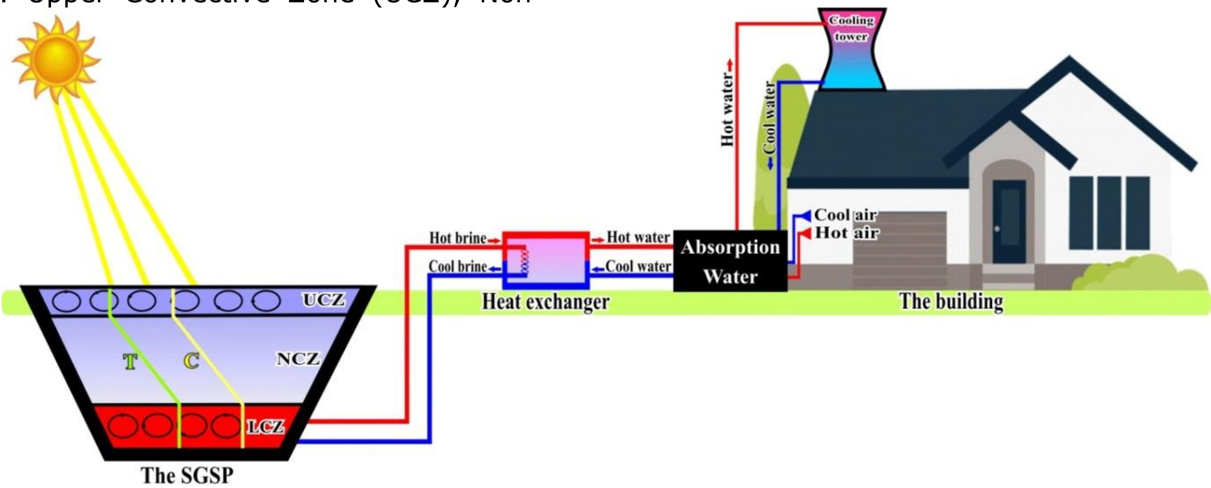

Figure 1: Schematic view of the SGSP, the absorption water and the building.

The NCZ is the key to the working of the SGSP because of it does not allow to the convective currents to transfer from the LCZ to the UCZ, so the heat is accumulated in the LCZ.

The area of the SGSP is the determining factor in the amount of heat extracted for cooling and heating of the selected building model. So several researchers have studied to this factor such as Wafik A. Kamal (1992) developed the concept of using a SGSP to provide **air conditioning** for a typical small family Qatari house and this study showed to meet 100% of the cooling load from March until December (1992), the SGSP needed is 4-5 times the floor area of the air-conditioned space [3]. Safwan and *et. al* (2015) found the SGSP could be used to drive the absorption chiller and produce **cool air** for a single-family house during the summer period and approximately 400 m^2 of the SGSP area was required to provide satisfactory cooling for a typical house with a floor area of approximately 125 m^2 [4].

The absorption water chillers and heaters are the most commonly used with solar cooling systems. These products are a water-fired absorption unit which provides chilled water for cooling or hot water for heating (WFC-SH units only) in central plant type air conditioning systems. Units of the chiller and heater with capacities of 10, 20, 30, and 100 TR/TH (Tons of refrigeration or Tons of heating) and it are energized by heat medium from the SGSP that can supply the heat medium fluid within the operating temperature range of 70-95°C [5]. For to get the absorption water system with big capacities more than 100 TR or TH a new data file was created based on the Yazaki manufacturer's data. The external heat exchanger pulls the hot brine from the top layer of the LCZ in the SGSP to the absorption water and it returns the cool brine to the lower layer of the LCZ in the SGSP as shown the Fig. 1.

Hence, in this paper a coupled mathematical simulation between a transient model of the SGSP and the cooling and heating loads of the selected building model in FORTRAN language is designed to investigate the dependence of the cooling and heating air for the buildings in Karbala city, Iraq (32.62° N, 44.03° E) upon the SGSP area.

Mathematical modelling

This part of the investigation covers the mathematical equations to calculate the total area of the SGSP which can be used for the purpose of this paper; therefore, some assumptions were used for simplifying the analysis as follows:

The distributions of temperature and salinity for the SGSP are in one-dimensional (1D), because of the variations along the y-direction are small [6].

The area of used SGSP in cooling and heating air usually is bagger, so heat losses through the walls of the pond's sides are small enough, and is to be considered negligible [7, 8].

The thermal conductivity (k), density (ρ) and specific heat (c_p)of NaCl brine are given by the following correlations (these correlations depend on the temperature and concentration of NaCl solution) [9]:

$k_s^t = 0.5553 - 0.0000813T_s^t + 0.0008(T_s^t - 20)$ (1)

$\rho_s^t = 998 - 0.4(T_s^t - 20) + 0.65c_s$ (2)

$c_{ps} = 4180 - 4.396c_s + 0.0048{c_s}^2$ (3)

Where *t* and *s* are represented time and space, respectively.

The energy balance equation for the LCZ with a thickness X_{LCZ} can be written as [6, 8]:

$H_{n-1} = Qcond_4^t + Qext^t + Qg_1^t + \rho_n^t c_{pn} \frac{\partial T}{\partial t} X_{LCZ}$ (4)

From this above equation and Fig. 2, the temperature in the heat storage zone (LCZ) can be calculated by using [6, 8]:

$T_n^{t+1} = T_n^t + \frac{\Delta t}{\rho_n^t c_{pn} X_{LCZ}}\left[(H_{n-1}) - k_n^t\left(\frac{T_n^t - T_{n-1}^t}{\frac{\Delta x}{2}}\right) - Qg_1^t - Qext^t\right]$ (5)

The absorbed solar radiation (H_{n-1}) of the LCZ in Equation (5) can be calculated by this formula [10]:

$H_{n-1} = H_0\left\{0.36 - 0.08ln\left(\frac{X_{UCZ}+X_{NCZ}}{cos(\theta_r)}\right)\right\}$ (6)

Where: *H₀* is the incident solar radiation on the pond's surface, X_{UCZ} the depth of the upper convective zone, X_{NCZ} is the depth of non-convective zone and θ_r is the refracted angle of the incident solar radiation at the pond's surface.

The ground heat loss (Qg_1^t) can be calculated by [8]:

$Qg_1^t = U_g(T_b^t - Tg_1^t)$ (7)

Where T_b^t is the bottom temperature of the SGSP, and the ground overall heat transfer coefficient (U_g) can be obtained from [7]:

$U_g = \frac{k_g}{\Delta x_g}$ (8)

Where Δx_g is the element depth of the pond ground layer and k_g is thermal conductivity of pond's ground as shown in Table 1.

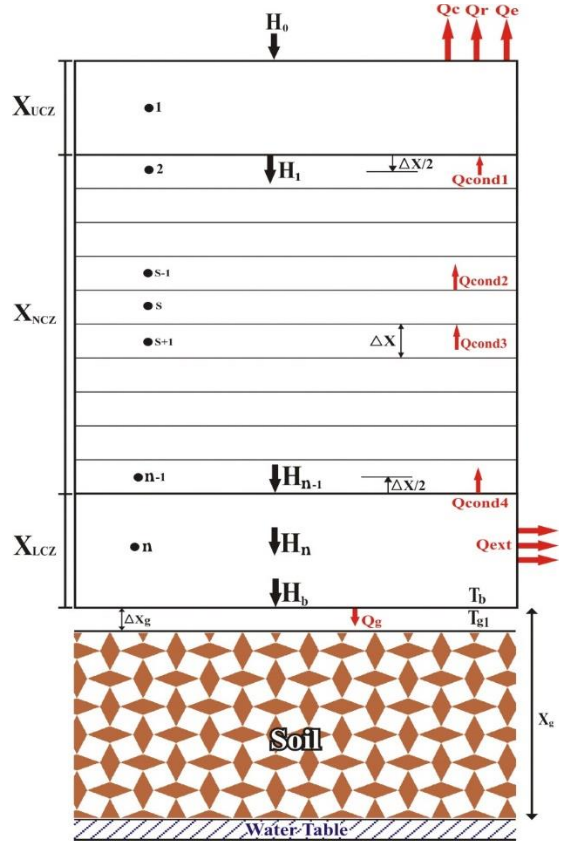

Figure 2: Solar pond and heat loss mathematical model.

Table 1: The thermal conductivity for the different types of the Karbala's ground.

Type of soil	k_g (W/m.°C)
Clay and Sandstone [11]	1.7
Clay and Silt [11]	2.15
Sand [11]	1.082
Coarse and soil [12]	2.5

To calculate the heating and cooling loads, the following information about a building design and weather data in Karbala city are stipulated:

1. The outdoor air design temperature obtained from the local meteorological station.
2. The indoor air temperature is maintained uniform in each room during the hottest and coldest days. Comfort design conditions are usually taken the temperature of 25°C.
3. The area of all surfaces through which heat is expected to be lost is determined.

The heat loss from all surfaces of the building (Qhl_m) results from summation of the heat loss from external surfaces (wall, glass, door, floor and roof) and the heat loss from the internal surfaces (occupancy, appliance and lights).

These heat loss are calculated by using the following equation [13]:

$$Qhl_m = U_m A_m (T_2 - T_1) \quad (9)$$

Where in the heating load T_2 is ambient temperature T_1 is set room temperature (25°C), whereas in the cooling air T_2 is set room temperature and T_1 is ambient temperature.

Table (2) shows the overall heat transmission coefficients for all internal surfaces.

Table 2: The overall heat transmission coefficients for all surfaces [14].

Type of surface	Material	Thickness (m)	U_m (W/m^2.°C)
Wall	Gypsum plaster, concrete block and cement mortar	0.22	2.295
Glass	Glass	0.004	5.68
Door	Wood	0.175	0.16
Floor	Tile and concrete	0.185	3.753
Roof	Gypsum plaster, concrete, and tile		3.655

The extracted heat (in Equation (5)) from the SGSP could be used to drive an absorption chiller and heater to produce cooling and heating air for the buildings and it is given per unit area of the SGSP as follows [14, 15]:

$$Qext^t = \dot{m} c_{ps} \frac{(T^t_{obrine} - T^t_{ibrine})}{A_p} \quad (9)$$

Where $\dot{m}$ is the brine mass flow rate, T^t_{obrine} is the outlet temperature from the LCZ which is assumed to be equal to T^t_n the LCZ temperature, and T^t_{ibrine} is the inlet returned temperature from heat exchanger to the LCZ layer.

Buildings Data

The selected buildings in this research are based on a real typical modern single-family houses situated and some big buildings in Karbala city, Iraq. The orientation of the buildings is towards the south and the height is 3 m. The FORTRAN simulation to calculate **the heating and the cooling loads** starting from 1st of January 2017 until 31st of December 2018.

The First Building Model has a total land area of 125 m^2 and a floor area of 100 m^2 (with dimensions 10m×10m), the Second Building Model has a total land area of 600 m^2, a floor area of 500 m^2 (with dimensions 25 m×20 m), the Third Building Model has a total land area of 1250 m^2 and a floor area of 1000 m^2 (with dimensions 40 m×25 m) and The Forth Building Model has a total land area of 6250 m^2 and a floor area of 5000 m^2 (with dimensions 200 m×25 m). Table 3 presents the input data (external and internal components data) of selected buildings.

Table 3: External and internal components data of these buildings.

	No. of the building model	1st Building	2nd Building	3rd Building	4th Building
External components	Area of wall (m^2)	116	190	295	1000
	Area of glass (m^2)	12	70	90	300
	Area of door (m^2)	2	10	15	50
	Area of floor (m^2)	100	500	1000	5000
	Area of roof (m^2)	100	500	1000	5000
Internal components	Infiltration (1/hr)	0.7	0.7	0.7	0.7
	Occupancy(person)	4	20	50	250
	Appliance power (Watt)	300	1500	3000	15000
	Lights power (Watt)	300	2000	4000	20000

Fig. 3 shows the simulated annual heating and cooling loads for these buildings when the room temperature was 25°C in the heating and cooling air. It is clear from this Fig.:

1. In the First Building Model: The peak of heating and cooling loads was 18.66 kW and 19.84 kW, respectively, therefore it needs of 6 TR/TH (21.10 kW) and the required heat input of 30.15 k.
2. In the Second Building Model: The peak of heating and cooling loads was 98.95 kW and 117.9 kW, respectively, therefore it needs of 35 TR (123.1 kW) and the required heat input of 175.9 kW and it needs of 30 TH (105.5 kW) and the required heat input of 150.7 kW.
3. In the Third Building Model: The peak of heating and cooling loads was 183.1 kW and 229 kW respectively, therefore it needs of 70 TR (246.2 kW) and the required heat input of 351.7 kW and it needs of 55 TH (193.4 kW) and the required heat input of 276.3 kW.
4. In the Forth Building Model: The peak of heating and cooling loads was 889.0 kW and 1091.6 kW, respectively, therefore it needs of 315 TR (1107.9 kW) and the required heat input of 1582.7 kW and it needs of 255 TH (896.9 kW) and the required heat input of 1281.3 kW.

All these rated capacities with the rated coefficient of performance (COP) of 0.7 for the absorption water chiller and heater.

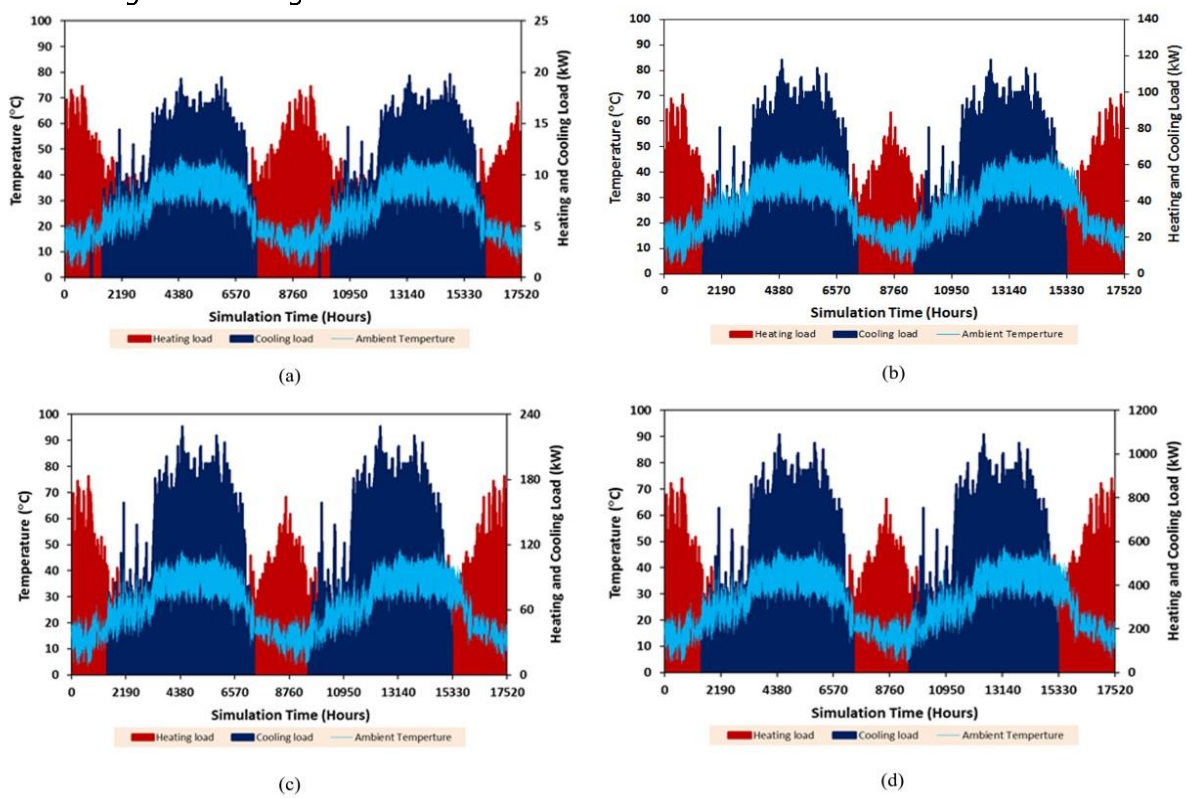

Figure 3: The simulated annual heating and cooling loads for: a) The First Building Model. b) The Second Building Model. c) The Third Building Model. d) The Forth Building Model.

Results and Discussions

Fig. 4 shows the variations of the lower and upper convective zone temperature with the ambient temperature of the SGSP **without extracted heat** during the simulation time.

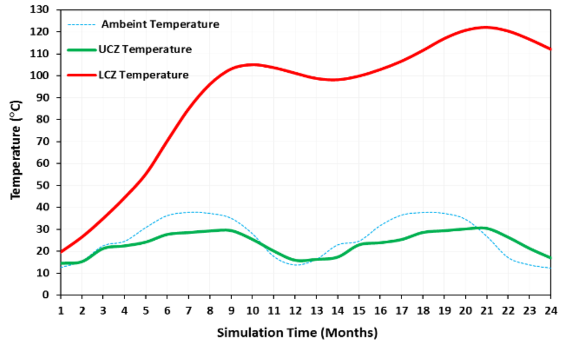

Figure 4: Variations of the lower and upper convective zone temperature with the ambient temperature of the SGSP without extracted heat during the simulation time.

It was clear from this Fig., the zones temperatures vary with the simulation time of the two year, depending on the ambient temperature, and incoming solar radiation. Practically the temperature of each of the zones increases with increase the incident solar energy per unit area. In the second year of the simulation time, the ambient temperature was observed to be at a maximum of 38.1°C in July while the temperature of the UCZ was observed to be of a maximum of 31.2°C during August and the temperature of the LCZ was observed to be at a maximum of 122.5°C in October (**No Heat Extraction**). Fig. 4 also shows the temperature of UCZ is close to the ambient in winter, but lower in summer. As expected, since the ambient relative humidity is high in winter and low in summer hence the evaporation is low in winter and high in summer.

Fig. 5 shows the temperature profile of the lower and upper convective zone of the SGSP with the ambient temperature of these buildings during the simulation time.

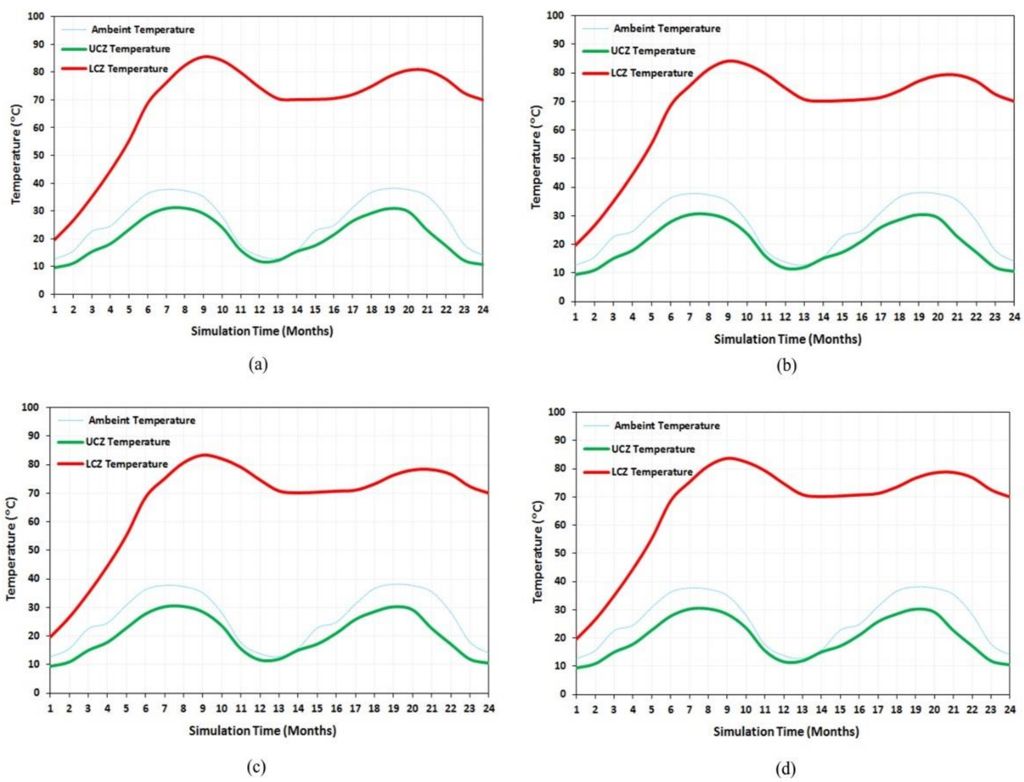

Figure 5: Temperature profile of the lower and upper convective zone of the SGSP with the ambient temperature of these buildings during the simulation time: a) The First Building Model. b) The Second Building Model. c) The Third Building Model. d) The Forth Building Model.

It is clear from this Fig., in the first simulation year starting from 1st of January 2017 the LCZ temperature of the SGSP without extracted heat reaches 70°C during June and this temperature is the minimum temperature required to drive Yazaki absorption chiller [5], so the cooling air is starting. After September the ambient temperature becomes less than 25°C (set point of room temperature) and the temperature of the LCZ was still above 70°C under 95°C and this temperature is the maximum temperature required to drive Yazaki absorption chiller [5], so the heating air for the building is starting until April in the second simulation year. Fig. 5 shows also in the first and second year of the simulation time the maximum temperatures of the LCZ and UCZ in the First Building Model (Fig. 5-a) were 85°C and 81°C, 31°C and 30.8°C, respectively, in the Second Building Model (Fig. 5-b) were 84°C and 79°C, 30.5°C and 30.3°C, respectively, in the Third Building Model (Fig. 5-c) were 83°C and 78°C, 30.3°C and 30.2°C, respectively, and in the Forth Building Model (Fig. 5-d) were 83.7°C and 78.7°C, 30.3°C and 30.2°C, respectively.

The useful heat extraction from the SGSP for the cooling and heating air of these buildings with the simulation time is shown in Fig. 6. In the First Building Model (Fig. 6-a), the maximum values of average heat extraction from the SGSP for the cooling and heating air were the equal and it's values of 65 W/m^2, due to the absorption chiller and heater has equal capacity for chiller or heater (6 TR/TH). Whereas, in other buildings the maximum values of average heat extraction from the SGSP for the cooling air and heating air were different e.g. in the Second Building Model (Fig. 6-b) were 70 W/m^2 and 60 W/m^2 for cooling and heating air, respectively, in the Third Building Model (Fig. 6-c) were 73 W/m^2 and 58 W/m^2 for cooling and heating air, respectively, and in the Forth Building Model (Fig. 6-d) were 71.8 W/m^2 and 58.1 W/m^2 for cooling and heating air, respectively.

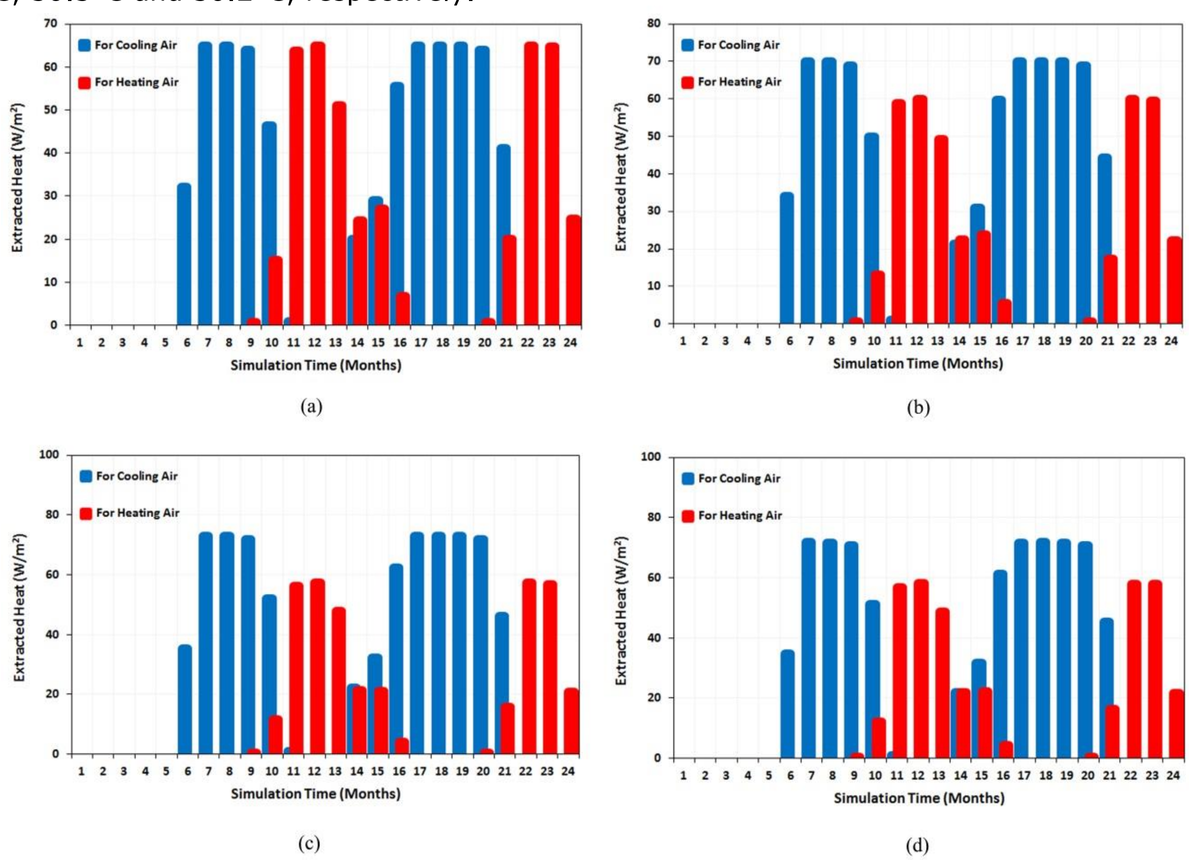

Figure 6: The useful heat extraction from the SGSP for the cooling and heating air of these buildings with the simulation time: a) The First Building Model. b) The Second Building Model. c) The Third Building Model. d) The Forth Building Model.

Thus the base case pond area to meet the cooling and heating loads of these buildings were given by:

$$A_p = \frac{30150\ W}{65\ W/m^2} \approx 470\ m^2$$

for the First Building Model.

$$A_p = \frac{175900W}{70\ W/m^2} \approx \frac{150700\ W}{60\ W/m^2} \approx 2520\ m^2$$

for the Second Building Model.

$A_p = \frac{351700\ W}{73\ W/m^2} \approx \frac{276300\ W}{58\ W/m^2} \approx 4850\ m^2$

for the Third Building Model.

$A_p = \frac{1582700\ W}{71.8\ W/m^2} \approx \frac{1281300\ W}{58.1\ W/m^2} \approx 22100\ m^2$

for the Forth Building Model.

Conclusions

1. According to the range of LCZ temperature achieved during the second simulation year, this SGSP could be used to drive an absorption chiller and heater system to cool and heat the air for the Karbala buildings during the summer and winter period.

The range of LCZ temperature shows that the SGSP takes several months to warm up. So heat storage is significant in the lower convective zone and therefore the first year was considered to be a warm-up time of the solar pond and the second year was considered as a representative year of the solar pond results.

To meet 100% of the cooling and heating loads during all hours of the year and the set room temperature is still constant (25°C) the SGSP area needed is 4-5 times of the floor area of the building and this is in a good agreement with the expectations of the published papers

Nomenclature

Symbol	Quantity	Units
A_p	Pond's area.	m^2
A_m	Area of the building surface.	m^2
c_p	Specific heat capacity of NaCl brine.	J/kg.°C
c	Concentration of NaCl brine	kg/m^3
H_0	Net incident radiation flux.	W/m^2
H_i	Incident radiation flux.	W/m^2
H_{n-1}	Absorption radiation flux at LCZ.	W/m^2
k	Thermal conductivity of NaCl brine.	W/m.°C
k_g	Thermal conductivity of pond's ground.	W/m.°C
$Qext$	Heat extracted from the pond.	W/m^2
Qg	Heat loss to the ground.	W/m^2
T	Temperature.	°C
T_b	Bottom pond temperature.	°C
T_g	Ground water temperature.	°C
t	Time.	s
s	Space.	
X	Depth.	m
U_g	The ground overall heat transfer coefficient.	W/m^2.°C
U_m	The overall heat transfer coefficient of the building surface.	W/m^2.°C
$\dot{m}$	The brine mass flow mass rate.	kg/s
θ_r	The refracted angle.	degree
ρ	The density.	kg/m^3

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