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Refrigerator Coupling to a Water-Heater and Heating Floor to Save Energy and to Reduce Carbon Emissions

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ABSTRACT

With an aim of rationing use of energy, energy safety, and to reduce carbon emission, our interest was geared towards the refrigerators and all the refrigerating machines. Indeed the heat yielded by the exchanger condenser can be developed for the water heating, floors heating etc. After an encouraging theoretical study, two prototypes were produced in order to validate the theoretical results. A first refrigerator was coupled with a water-heater and another with a heating floor. The water temperature reached, in one day, is of 60˚C; which makes it possible to predict better results with a continuously used refrigerator. In the same way for the heating floor coupled with the second refrigerator, the temperature reached high values because the surface is reduced; however for the heating floors the standard fixes the temperature between 28˚C and 30˚C.

Keywords: Refrigerator; Recuperator; Heating Water; Heating Floor; Heat Pump

1. Introduction

Energy consumption in the world is significant and in continuous growth. It is fundamentally linked to the life level. It promotes the thermal comfort of the citizen, through the heating and cooling systems (air-conditioners, water-heaters, refrigerators…). With the aim of saving energy and to reduce carbon emission, it is necessary to find some innovating solutions in this field and to create negawatts.

For this reason, we propose to recover the waste heat on the refrigerator condenser level, and this by two methods:

- The first method is to enhance the heat lost during condensation of Freon, and this, recovering it in a water cumulus to heat it and to use in the domestics or other needs.
- the second method consists in heating a floor to replace the traditional heating radiators.

Finally, the heat recovery system does not have any modification on the basic refrigeration cycle. The tests and experiments show the effectiveness of this heat recovery project [1-6].

2. Bibliographical Study

The publications evoking the use of heat pumps for water heating are relatively very few. Let us quote Grazini, Skrivan, Huang, Jie [7-10] which extracts heat from the ambient air like cold source of the heat pump. **Figure 1** is given as an example.

Others authors use solar energy like evaporator such as Hawlader, Li, Chyng, Borges, Huang [11-16].

Among the few publication jointly using the condenser and the evaporator of a heat pump (or refrigerator), we even quote our work concerning a solar sea water still developed by our self, at the National School Engineers of Gabes, Tunisia [17-23].

Figure 2 shows our system of solar desalination provided with the heat pump.

The condenser (6) heats water to be evaporated and the evaporator (2) makes it possible to condense instantaneously the vapour and thus to form the condensate collected in the gutter (3).

For the principle of refrigerator operation (**Figure 3**), this system can be considered as an insulated cupboard whose interior temperature is lower than the ambient temperature. To obtain cold inside the refrigerator, heat is extracted with the air and food and then is rejected by the condenser in the kitchen.

3. Theoretical Considerations of the Coupling of Refrigerator to a Water-Heater and a Heating Floor

We will begin by determining the intervals of real operating time of the refrigerator and the heat transfer between the condenser and water or floor to be heated.

3.1. Preliminary Study of Dimensioning

The tracing of the histogram of **Figure 4** allows to know

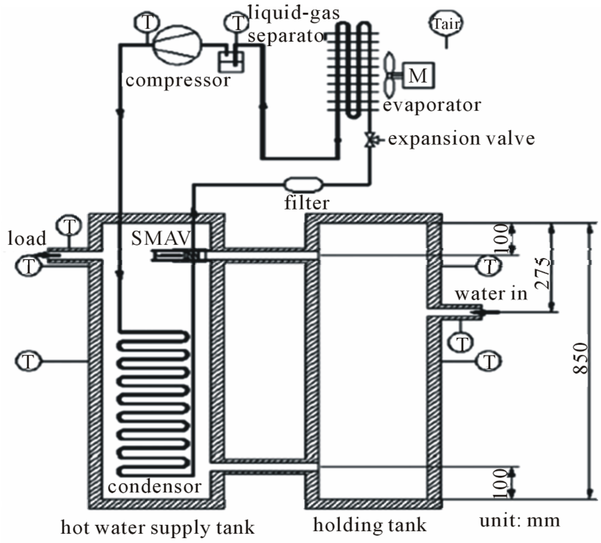


Figure 1. Water heating by heat pump.

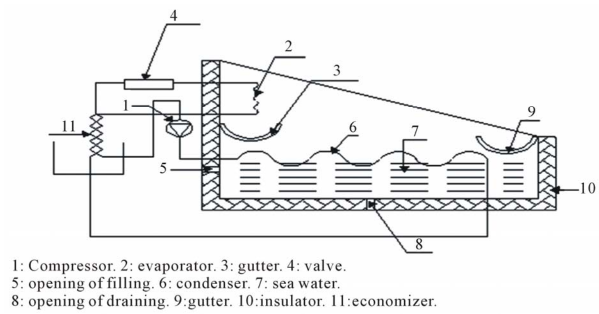


Figure 2. Solar distiller provided with heat pump.

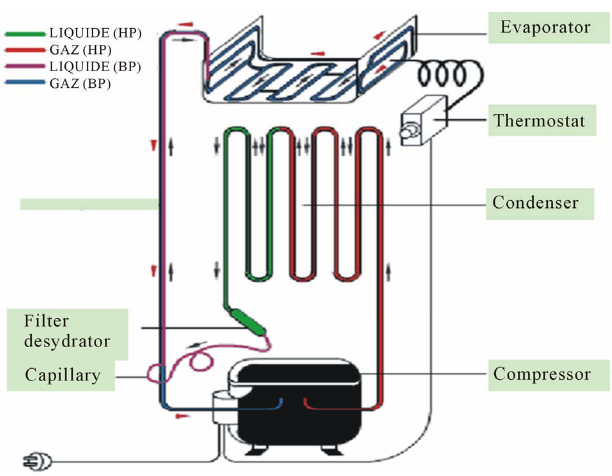


Figure 3. Refrigerator operation cycle [2].

the operating time of refrigerator' compressor during 24 hours. The operating time varies from one moment to another as required by the refrigerator.

Operation of a refrigerator during 24 hours.

$$\sum t_{compressor} = 9\text{ h }43\text{ min/day}$$

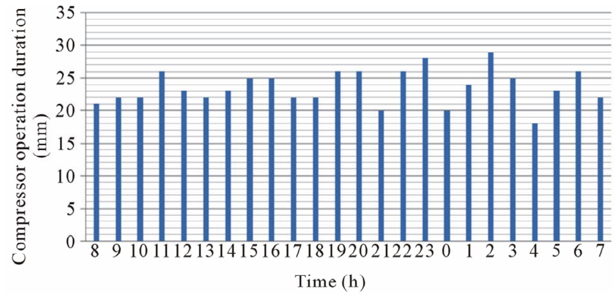


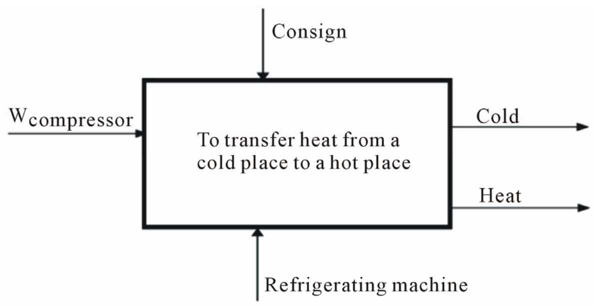
Figure 4. Time operation life of a refrigerator lasting 24 h. Compressor power of 140 W and using R13a freon. Room temperature = 19˚C (Tozeur, Tunisia, on March 20, 2009).

3.2. Theoretical Study of a Refrigerator to a Water-Heater Coupling

The energy yielded by the condenser is transferred to water to be heated. However, when water heats in the storage tank, thermals loss will appear (coefficient U = 4.92 W/˚C).

3.2.1. Modeling

The refrigerating machine can be modeled by considering energies on the level of the compressor, the condenser and the evaporator, as follows:



$$P_{comp} - Q_{condenser} + Q_{evaporator} = 0$$

$$P_{comp} - P_{comp} \cdot COP_{th} + P_{comp} \cdot COP_{fr} = 0$$

$$1 - COP_{th} + COP_{fr} = 0$$

$$COP_{total} = COP_{th} + COP_{fr}$$

The total COP can thus reach raised values, which confers on our system a great energetic effectiveness, because, usually the refrigerating machine is used either like refrigerator to produce the cold, or like heat pump to heat.

3.2.2. Thermal Transfer

For the coupling of a refrigerator to a water cumulus study, we make the calculation of the water mass which can be heated with different temperatures. The efficiency is then evaluated.

It is supposed that the heat yielded by the condenser is recovered by water to heat.

$$Q_{condenser} = Q_{water}$$

$$COP \cdot P_{comp} \cdot t \cdot \eta = M_{water} \cdot Cp \cdot \Delta T \qquad (1)$$

ΔT is the water temperature increase from initial to final state.

It is possible to determine the variation of ΔT according to time, in the same way for the efficiency.

Determination of heat water storage efficiency

$$\eta = Q_{useful} / Q_{absorbed} \qquad (2)$$

With:

$$Q_{absorbed} = P_{comp} \cdot COP \cdot t$$
$$Q_{useful} = Q_{abs} - Q_{loss}$$
$$Q_{loss} = U \cdot \Delta T \cdot t$$

P_{comp}: Compressor power.

t: summon operating time of compressor.

U: thermal loss ratio.

$$U = \frac{\rho \cdot Cp \cdot V}{\Delta t} \cdot \ln\left(\frac{T_i - T_{am}}{T_f - T_{am}}\right) \qquad (3)$$

Therefore we have:

$$\eta = \frac{P_{comp} \cdot COP \cdot t - U \cdot \Delta T \cdot t}{P_{comp} \cdot COP \cdot t} \qquad (4)$$

Temperature variation

We replace (4) in (1), then:

$$\Delta T = \frac{P_{comp} \cdot COP \cdot t}{U \cdot t + M_{water} \cdot Cp} \qquad (5)$$

Mass of water to heat

Replacing (5) in (4), so:

$$M_{water} = \frac{P_{comp} \cdot COP \cdot t}{\Delta T \cdot \left(\frac{Cp}{\Delta t} \cdot \ln\left(\frac{T_i - T_{amb}}{T_f - T_{amb}}\right) \cdot t + Cp\right)} \qquad (6)$$

The calculation of the water mass to heat, during 24 hours, can be carried out for different water temperature rise.

According to expression (6) we give **Table 1**.

1) ΔT variation and efficiency according to time for water capacity of 50 liters which is the experimentally capacity used.

Thermal loss coefficient

With:

$$Cp_{water} = 4185\ J/(kg^{\circ}C)$$

$$\rho_{water} = 1000\ kg/m^3$$

$$\Delta t = 11\ hours;\ 18:00 \rightarrow 5:00$$

$$V = 0.05\ m^3$$

$$T_i = 59^{\circ}C;\ T_{ami} = 26^{\circ}C$$

$$T_f = 35^{\circ}C;\ T_{amf} = 22^{\circ}C$$

$$U = 4.92\ W/^{\circ}C$$

According to the expressions (2) and (3) we calculated the temperature rise, the efficiency, the useful and absorptive energies, gathered in the following **Table 2** and **Figure 5**.

With:

$$P_{comp} = 140\ W;\ COP = 3;\ M_{water} = 50\ Kg$$

With time, water warms up by the heat yielded by the condenser; then, the quantity of heat contained in water increases. However, the energetic efficiency decreases following the increase in the losses by convection with the ambient air (**Figure 5**).

2) Checking length of the condenser immersed in the hot water cumulus

In our case, the flow of the refrigerant (R134a freon) in the condenser immersed in the cumulus is done from top to bottom, *i.e.* in against current with the circulation of the water to be heated which is done upwards.

Table 1. Value of water mass for different rise in temperature.

ΔT (˚C)	20	25	30	35	40
M (kg)	90	72	60	51	45

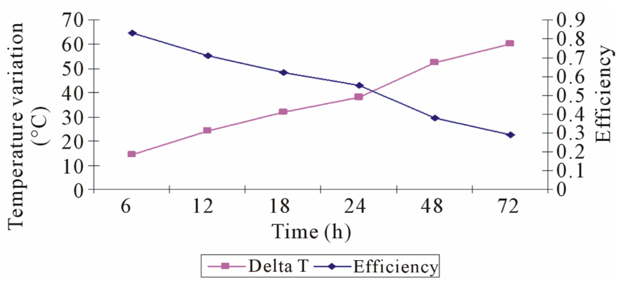


Figure 5. Rise variation in water temperature according to time.

Table 2. Variation of ΔT and efficiency according to time.

Time (hours)	ΔT (˚C)	efficiency	Q_{useful} (J)	Q_{abs} (J)
6	14.20	0.83	2972654	3565800
12	24.35	0.71	509736	7131600
18	32	0.62	6691162	10697400
24	38	0.55	7930746	14263200
48	52.50	0.38	10986005	28526400
72	60.22	0.29	12604349	42789600

Therefore the difference in logarithmic average temperature curve will be carried out in an against current cycle (**Figure 6**).

According to **Table 2** of comparison during 12 hours and according to measurements:

- Hot source: (condenser)
  $T_e = 62˚C$ and $T_s = 43˚C$
- Cold source: (water to be heated); with (ΔT = 24.35˚C)
  $t_e = 20˚C$ and $t_s = 44.35˚C$
- Determination of logarithmic average temperature difference ΔTmL
  The expression of ΔTmL is:

$$\Delta TmL = \frac{\Delta T0 - \Delta TL}{\ln\left(\frac{\Delta T0}{\Delta TL}\right)} \quad (7)$$

$$\Delta T0 = Te - ts = 62 - 44.35 = 17.65^{\circ}C$$

$$\Delta TL = Ts - te = 43 - 20 = 23^{\circ}C$$

$$\Delta TmL = 20.16^{\circ}C$$

- Heat exchange coefficient:
  The condenser exchanger contains freon which passes from vapor state to liquid state by yielding its heat to water to be heated (**Figure 7**).

$$Ui = \frac{1}{\frac{1}{h\ freon} + di \cdot \frac{\ln \ln\left(\frac{de}{di}\right)}{2 \cdot \lambda_{copper}} + \frac{1}{h_{water}}} \quad (8)$$

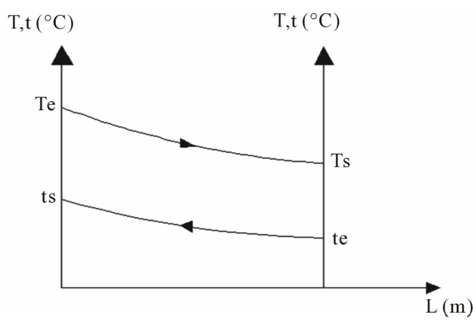


Figure 6. Cycle of against current.

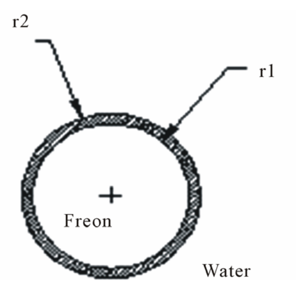


Figure 7. Heat exchanger (water condenser).

With:

$h\ water = 50\ W/\left(m^{2°}C\right)$; $h\ freon = 4200\ W/\left(m^{2°}C\right)$;

$\lambda\ copper = 390W/\left(m^{°}C\right)$

$$di = 0.004\ m;\ de = 0.006\ m$$

Then:

$$Ui = 50\ W/\left(m^{°}C\right)$$

3.3. Theoretical Study of the Coupling of a Refrigerator to a Heating Floor

In this section we will make the study of a refrigerator to a heating floor coupling, and the determination of the temperature variation for each surface for different periods and for different surfaces to be heated.

Calculation is carried out on concrete surfaces height h = 0.1 m.

There is a thermal contact between two bodies thus there is a heat transfer between the two bodies in contact (condenser/concrete).

$$\begin{aligned} Q_{condenser} &= Q_{concrete} \\ COP \cdot P_{comp} \cdot t \cdot \eta &= M_{concrete} \cdot Cp \cdot \Delta T \end{aligned} \quad (9)$$

ΔT: variation between the final and the initial tem- perature of the floor.

- Determination of the temperature variation ΔT
  We have:

$$\eta = Q_{useful}/Q_{absorbed} = Q_{absorbed} - P_{loss}/Q_{absorbed}$$

With:

- $Q_{absorbed} = P_{comp} \cdot COP \cdot t$
- $P_{loss} = U \cdot S \cdot \Delta T \cdot t$
- $Q_{useful} = Q_{absorbed} - P_{loss}$

The initial temperature is equal to the ambient temperature.

Thus:

$$\eta = \frac{P_{comp} \cdot COP \cdot t - U \cdot S \cdot \Delta T \cdot t}{P_{comp} \cdot COP \cdot t} \quad (10)$$

We replace (10) in (11):

$$\Delta T = \frac{P_{comp} \cdot COP \cdot t}{U \cdot S \cdot t + M_{concrete} \cdot Cp} \quad (11)$$

With:

$$M_{concrete} = \rho \cdot S \cdot H$$

Finally:

$$\Delta T = \frac{P_{comp} \cdot COP \cdot t}{S \cdot \left(\rho \cdot H \cdot Cp + U \cdot t\right)} \quad (12)$$

Table 3 and **Figure 8** indicate the variations of ΔT according to time and the floor surface.

The reached temperature on the floor level is a function of the exchange surface with the condenser; in fact also with the compressor power.

In practice, a prototype of heating sand floor of surface S = 0.43 m^2 was produced and in which a condenser of 6 m length is immersed there.

4. Experimental Study

First, we make the water cumulus then its coupling with the refrigerator and the heating floor.

4.1. Water Cumulus Realization

We have a cylindrical tank in plastic, diameter 0.38 m and height 0.48 m, which is isolated by five cm glass woo. The unit is then covered by a thin stainless steel jacket (**Figure 9**).

4.2. Coupling between the Refrigerator and the Water Cumulus

We replaced the refrigerator condenser by a copper spiral serpentine placed in the water cumulus, thus the freon condensation will allow to yield the latent heat to water and thus to constitute a hot water storage (**Figures 10, 11**).

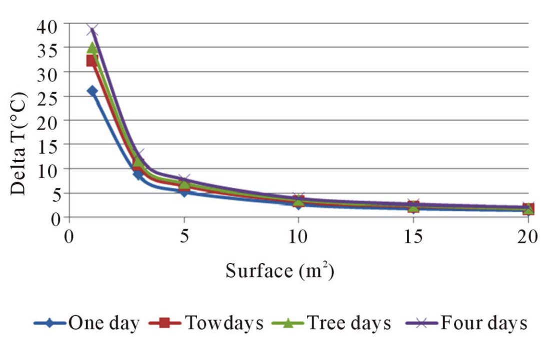


Figure 8. Floor temperature rise according to surface and a number of day.

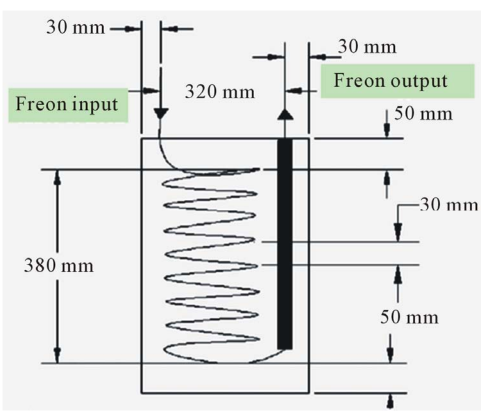


Figure 9. Dimensions of the copper condenser immersed in the water cumulus.

Table 3. Variation of ΔT according to time and of surface.

Surface (m²)	ΔT (°C)			
	1 day	2 days	3 days	7 days
1	26	32	35	38
3	8.77	10	11	13
5	5.26	6	7	7
10	2.63	3.2	3.5	3.8
15	1.75	2.15	2.33	2.6
20	1.31	1.61	1.75	2

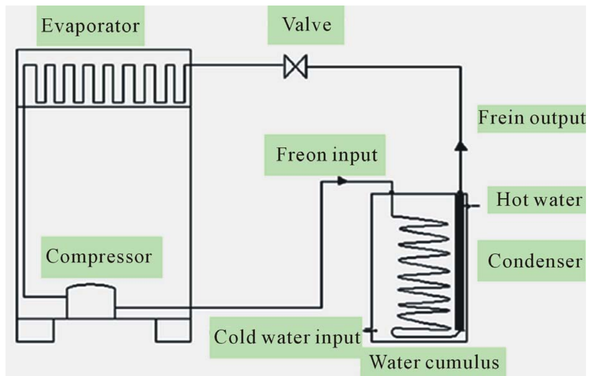


Figure 10. Refrigerating circuit binding the refrigerator and the water-heater.

Figure 11. Coupling of the refrigerator to a water-heater photograph.

4.3. Heating Floor Realization

The goal for the moment is to construct a transportable prototype. Thus the floor is carried out by some sand filling of a wood box of dimensions 0.66 m × 0.66 m, that is to say a surface of 0.43 m². As the selected height is 0.1 m, then the sand mass is:

$$M = \rho \cdot S \cdot H = 66.6 \text{ Kg}$$

The condenser of refrigerator is then placed in the wood box before filling this latter by dry sand (**Figure 12**).

4.4. Refrigerator and Heating Floor Coupling

For this system, the refrigerator' condenser is placed in the box filled with sand, thus, the foran condensation does not directly heat the air but the sand, and stores its heat in the heating floor (**Figures 13-15**).

Notice:

It is also possible to couple the water cumulus and the floor heating with only one refrigerator using an electromagnetic sluice gate which makes it possible to ensure the commutation of the refrigerating circuit of the refrigerator either towards the hot water cumulus, or towards the heating floor.

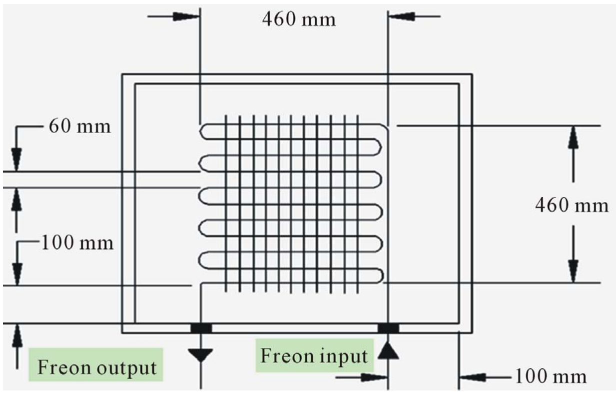


Figure 12. Dimensions of the refrigerator condenser immersed in the sand floor.

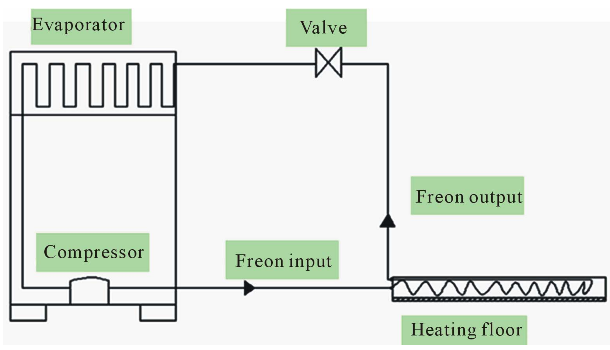


Figure 13. Installation circuit of refrigerator/heating floor coupling.

Figure 14. Small-scale model of the heating sand floor photographs.

Figure 15. Photographs of the two refrigerators: One coupled with the water-heater, the other with the heating floor.

It is also to be noted that the floor can be heated in a "conventional" way by the water from big tank storage, heated by the condenser of fridges which has restaurants and hotels or refrigeration rooms of foods conservation, or other.

4.5. Experimental Results

The experiments make it possible to bind the refrigerator to the system to be heated (water and heating floor) and to record the heating, refrigeration and ambient temperatures.

4.5.1. Evolution of Water-Heater Temperature

We study here the coupling of the refrigerator to a water heating cumulus.

1) First test

Figure 16 shows that in the morning, with the refrigerator starting, the rise in the storage water temperature is slower than that of the interior of refrigerator (approximately 8 h 30 against 2 h), this is because of the difference in heat mass capacity between water and air (4185 against 1000 J/kg˚C).

With an ambient temperature of 26˚C, water temperature reached is 59˚C, that is to say a rise in water temperature of 33˚C.

2) Second test

At the end of the one day operation, the refrigerator is voluntarily stopped for reasons of night safety. The following day at 5 am, the tests began again by the refrigerator restarting. The water temperature was 35˚C, that is to say 15˚C higher than for the previous day; what shows that the cumulus stores well heat thanks to its heat insulation with glass wool.

According to **Figure 17**, the temperature increases in the same manner than the first test, it reaches the permanent mode (59˚C) at the end of eight hours. A racking of ten liters hot water was carried out from the cumulus, followed by a filling of the same cold water capacity. Quickly the water temperature decreased up to 45˚C then it increased gradually to reach again the permanent mode at the end of four hours, against five hours and half for the preceding heating and the same variation in temperature. This is to show that hot water can be used several times per day.

4.5.2. Heating Floor Temperature Evolution

Is studied here the coupling of the refrigerator to a heated floor consisting of a layer of sand.

For the input/output curves of temperatures in the floor (**Figure 18**), we distinguish three zones: Zones 1 and 2 without insulation and zone 3 with insulation.

- Zone 1 [5 h – 10 h]: Fast rise in floor temperatures according to time.

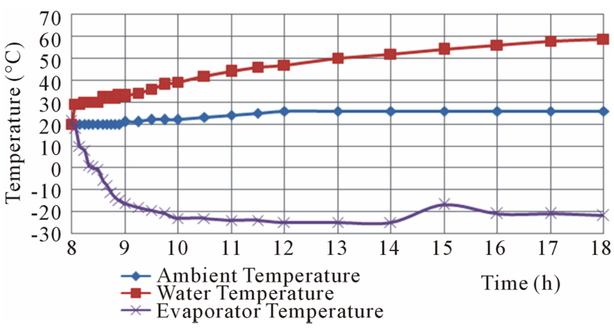


Figure 16. Variation of the temperatures according to time. Water heating case.

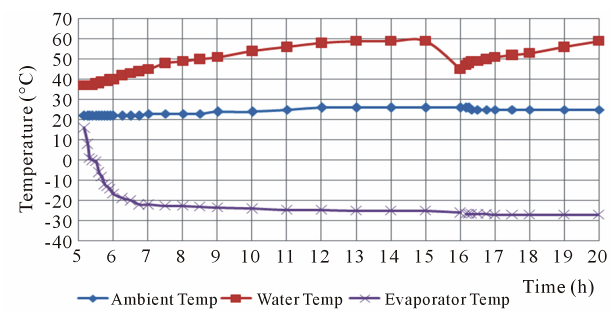


Figure 17. Variation of water, evaporator and ambient temperatures before and after draining of 10 liters water.

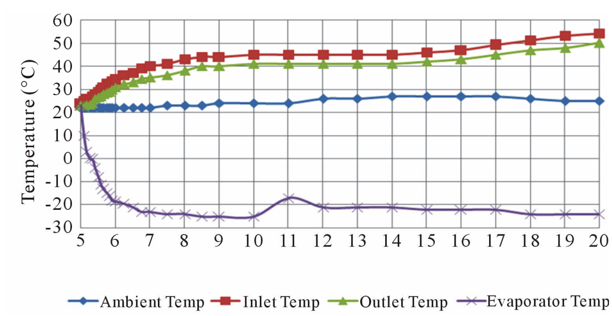


Figure 18. Temperature variation according to time. Heating floor case.

- Zone 2 [10 h - 14 h]: The temperatures reach their maximum values (permanent mode with 45˚C to 43˚C).
- Zone 3 [14 h - 20 h]: Floor temperatures rise compared to Zone 2 up to 54˚C/52˚C thanks to the heat insulation.

If the heating floor is insulated, then the heat quantity stored in sand increases in a significant way.

5. Conclusions

By this project, we tried to widen the use of a refrigerating system for the water heating, spaces or buildings, and this by the exploitation of the energy previously rejected by the condenser. With this manner the refrigerator can contribute to heat water and/or floor-heating; while keeping its principal function to cool.

The temperatures reached respectively, by water and floor, are approximately 60˚C and 50˚C, without modifying the temperature of the evaporator, which is at approximately −20˚C.

The elimination of the grid of the usual condenser located at the back of the refrigerator creates an advantage: to avoid its heating and consequently up time of the compressor and thus its electric consumption.

Finally, the results obtained as well theoretically as in experiments show clearly that the heat withdraws coming from the condenser immersed in water or sand, is a reliable source of heat, being able to be useful at least for pre-heating of water or room. The recovered heat enters in the négawatts production concept.

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Nomenclature

COP	coefficient of performance
Cp	heat mass ($J \cdot kg^{-1} {}^\circ C^{-1}$)
h	heat exchange cefficient ($Wm^{-2} \cdot K^{-1}$)
M	Mass (kg)
P_{comp}	power of the compressor (W)
Q	Heat quantity (J)
S	surface (m^2)
t	time (h)
U	convection losses coefficient ($Wm^{-2} \cdot K^{-1}$)
S	surface (m^2)
T	Temperature (˚C)
ΔT	Temperature variation (˚C)
Δt	time variation (s)
η	efficiency
ρ	density (kg/m^3)
λ	conductivity transfer coefficient ($Wm^{-1} \cdot K^{-1}$)
Signes	
amb	ambient
i	initial
f	final
th	thermal
fr	refrigerator