Saving Energy by Reducing Cooling Load of Rural Houses with using Passive Solar System and Well Water

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Abstract. Saving energy helps in reducing the effect of the environmental contamination. This could be obtained by decreasing the cooling load of rural houses and small buildings by using passive and active solar systems. The big temperature differences between the well water and the ambient temperatures is also utilizing for the purpose of air conditioning. This is done by adding heat exchanger (Fan-Coil) inside the house, which is operated by external photoelectric cells to reduce the cooling load of the house. The passive systems have also been studied like the directions and areas of the windows. Its significance comes from the importance of passive system applications to reduce the cooling load of houses in summer. Energy balance is done to get the governing equation that is necessary to calculate the variation in cooling load along the day for different parameters design, then to find out the optimum values of these parameters in order to reduce the houses’ cooling load through the day hours. The results have shown that the use of well water to cool the house would help to reduce the cooling load by 30%. Also the best orientation of windows in the south direction with suitable length of overhang, which prevent the direct solar radiation through the windows is investigated. This results in a reduction by 6% in cooling load during the summer season. The use of the passive system and well water in house cooling decreases the cooling load of the house by 36%.

1. Introduction

Air conditioning of houses consumes approximately (60%) of the total electricity that is consumed during the summer season [1]. Therefore, it is wise to look for solutions to reduce the cooling load and to save energy by reducing the environmental influence on the houses. Since thirties of the last century, scientists had introduced the uses of solar energy to meet the houses’ requirements from hot water, which helped to save energy and overcome the economic crisis, that hits many countries at that time [2]. Therefore, attention has been focused on conditioning houses by solar power. Many researchers [3] have studied the effect of using the overhang in the buildings on cooling load, were their walls constructed using materials. Z-transformation method had been used to guess the cooling load of the building for different lengths and trends of overhang in order to show and count its effect on the cooling load. The researcher concluded that the use of a specific width of overhang on the southern wall leads to 9% reduction in the cooling load.

The importance of utilizing the subterranean water is studied [4] for the purposes of decreasing cooling load and air conditioning. They have concluded that the proposed system has less consumption of energy, in addition to, it is considered a clean source of power, but it needs more time their conventional electric air-conditioning systems to obtain the wanted temperature. Consequently it can be seen that the capacity of the subterranean water is clean power. In reality, energy consumption,
in Iraqi buildings, mostly for cooling purposes, because of Iraq weather, which is dominated by the driest and long days of high temperature over the summer season [5].

In this work the possibility of using both the passive and active systems in air conditioning of houses are studied. This study is done by designing and building a test room using local materials to investigate the effect of the passive system of the factors that affect the air conditioning load. Also studying the factors that are effecting the construction of windows which have different directions and areas as well as different types of windows’ shaded glasses facilities such as a horizontal external overhang. Also using the heat exchanger system (Fan and coil) which exploit the cold well water temperature to use it for the purpose of the air conditioning of houses is studied. In addition, it is significant to know what efficiency extent and capacity of the system that works in rural houses [6].

The air conditioning system that is used to air condition the house consists of a tubular heat exchanger using the circulating well water inside the tube, while the room air flows around the external fined surface. This study is carried out to know the maximum loads in order to guess the achievable proportion of power savings [7]. This application is integrated with all other passive system applications that are effecting on the air conditioning process in order to reduce the cooling load to the minimum range as is shown in Figure 1.

![Figure 1. Well water and passive system to cool rural houses.](image)

2. Experimental study

The experiment was conducted in summer months: June, July, and August with different passive and active parameters. The temperature of ambient air and internal air temperature before and after the heat exchanger was recorded by thermocouples. The temperature of well water when enters and exits from heat exchanger was also recorded. Circulated flow rate of air was measured by using normal anemometer and well water flow rates were measured by using Hot wire anemometer. To make sure of the accuracy of measurement, reading the experiments were repeated and many sufficient observations had been taken.

2.1 Experimental set up of test room

The test room (rural house) was built in Tikrit (34° 35 N, 43° 73E), Iraq, its a double sheet of wood with a glass wool used as a packing material and insulator. The test room dimensions are rectangular cabinets 3.2 m length, 2.914 m width, and 2.57 m height. The main components of the experimental set up are the passive system applications such as variable area of the window, its direction, and the overhang on the window. The (fan - coil) unit consists of a pump to circulate well water and a fan to
circulate room air, each one of them is operated by an electric power gain from photovoltaic cell. All technical specifications of the coil are presented in Table 1.

| Specification          | Heat Exchanger (HE) | Fan Coil |
|------------------------|---------------------|----------|
| Width, cm              | 82                  |          |
| Height, cm             | 36                  |          |
| Thickness, cm          | 4                   |          |
| Diameter of tubes mm   | 5.6                 |          |
| Number of tubes        | 128                 |          |
| Number of fins         | 250                 |          |
| Thickness of fins, mm  | 0.12                |          |
| Distance between fins, mm | 1                 |          |
| Distance between Tubes, cm | 2              |          |
| Tube thickness, mm     | 0.8                 |          |
| Height of fins, mm     | 8                   |          |
| Shape of fins          | plate               |          |

3. **Theoretical and physical analysis**

There are many applications of direct and indirect systems, which are used to reduce cooling load especially in the rural area. The use of cold well water to cool the houses is the most important source in summer season.

3.1 **Use of well water for cooling**

The process is executed by passing the water directly from the well or the pumping station underneath the earth to supply the tubular heat exchanger inside the house by well water for cooling purpose. This is done by pumping the well water through the tubular heat exchanger (fan - coil) before using it to irrigate the fields for agricultural purposes. A fan is used as a blower to circulate the internal room air (circulating the air) through the room via external surface of the heat exchanger to reduce the air temperature by thermal exchange. The values of thermal capacity of the water \( (C_{pw}) \), as well as thermal capacity of the air \( (C_{pa}) \) are used to calculate the rate of the water thermal capacity (heat capacity rate) by using the following formula [8]:

\[
C_w = m_w \cdot C_{pw} \tag{1}
\]

\[
C_a = m_a \cdot C_{pa} \tag{2}
\]

Afterwards the comparison between \( (C_w) \) and \( (C_a) \) is done. Then the smaller value is called \( (C_{min}) \) and the larger one is called \( (C_{max}) \).

\[
Q_{max} = C_{min} (T_{a,in} - T_{w,in}) \tag{3}
\]

Where: \( (T_{w,in}) \) is water temperature and \( (T_{a,in}) \) is the temperature of the air that is passing across the external surface of the heat exchanger.
The amount of the actual heat transfer rate \( (Q_{ac}) \) is calculated by the following relationship.

\[
Q_{ac} = \varepsilon Q_{\text{max}}
\]

(4)

Where: \((\varepsilon)\) represents heat transfer effectiveness.

\[
\varepsilon = 1 - \exp\left\{\frac{NTU^{0.22}}{c} \left[\exp(-c NTU^{0.78}) - 1\right]\right\}
\]

(5)

Where: \((NTU)\) Number of transfer unit.

\[
NTU = \frac{UA_s}{U_{\text{min}}}
\]

(6)

Where: \((U)\) is the overall heat transfer coefficient, \((A_s)\) is the surface area and \((c)\) heat capacity rate which is calculated from the following relationship.

\[
c = \frac{c_{\text{min}}}{c_{\text{max}}}
\]

(7)

3.2 Calculation of the factors that influence the passive system design

Normally, shading is used to avoid the direct solar thermal multiple modalities [9]; where the glass allows the direct solar radiation (widespread and direct falling), within the space. This would cause an increase in the cooling load, so screening the solar radiation that reaches the windows in the hot period using the shaded solar radiation is one of the most important factors in achieving climate control of the house or small building [10]. In the following, a detailed explanation of the factors influencing the design of the sun shaded:

The solar deviation angle \((\delta)\) declination angle), which is the angle made by the solar radiation incident on the surface of the earth with the equator. This angle value is in the range \((-23.45 and +23.45)\), this angle value varies from day to another along the year and is calculated using the following relationship [2].

\[
\delta = 23.45 \sin(360 \frac{284 + n}{365})
\]

(8)

Finding any hour angle \((\omega)\) which is a unit of measure in terms of many steps which is a measure of the sun instant position on its daily track across the sky. Seeking the zero reading at midday, then each hour time is corresponding to \((15^o)\) angle. The hour angle is negative at the morning and positive at afternoon and this is calculated of following relationship.

\[
\omega = 15 \times (\text{given time} - 12)
\]

(9)

Calculate the azimuth angle \((\theta_z)\) between the vertical line on the surface at any point and solar radiation direction that incident on it, and this is calculated by using the following relationship [7].

\[
\cos \theta_z = \cos \delta \cos l \cos \omega + \sin l \sin \delta
\]

(10)

(1) The longitude angle of the studied reign \((23^o, 35^o)\)
Then finding it at the sunset hour ($\omega_s$) angle using the following relationship.

$$\omega_s = \cos^{-1}(-\tan \delta \tan l)$$

Then calculating the angle ($\theta$) of solar direct radiation from the following relationship.

$$\cos \theta = \sin \delta \sin l \cos \beta - \sin \delta \cos l \sin \beta \cos \gamma + \cos \delta \cos l \cos \beta \cos \omega + \cos \delta \sin \beta \sin \gamma \sin \omega$$

The total radiation ($G$) which represents (direct, diffuse and reflected) that is received by the window at the angle of the studied reign [11].

$$G = G_s + G_e + G_r + G_d$$

Where ($G_s$) Beam radiation through shading plane, ($G_e$) the received direct solar radiation through unshading glass plane, ($G_r$) the reflected solar radiation about earth and overhang then received by window [12] and ($G_d$) the diffuse sky radiation that reach to window.

4. Results and Discussion

To examine the thermal performance of a house by the effect of passive and active systems, a test room was built as shown in Figure 1. The test room (rural house) was fully instrumented to measure the air temperatures at different locations. The readings were recorded over 24 hours based on one day a month at an hourly reading rate for three consecutive months (June, July, and August).

4.1 Effect of area and direction of the window

Figure 2 shows the variation of load gain from the window hourly along the day on August for different areas of the window. It is found that increasing the area of the window leads to an increase in thermal load, because of the increase in the thermal load gain from the diffuse and direct incident radiation which transmuted through the glass of the window to the internal space of the house. Also the solar energy warming the external surface of the glass then passing through the surface by conduction and convection to the internal space of the house along the day [13]. Increasing of temperature difference between ambient air and room temperature causes an additional load through the glass of the window during summer season.

![Figure 2](image_url)

**Figure 2.** Variation of the load gain from different windows area along the day.
4.2 Effect of using well water to reduce the house cooling load

Figure 3 shows the hourly variation of cooling load, heat exchanger (HE) load (amount of heat rejected), and the cooling load using HE along the day. It is noted that after the sun rise, the load increasing as well as the rejected heat in the heat exchanger due to increasing of incident radiation which results in the ambient temperature rising. The increase of ambient temperature leads to increase in temperature difference with well water, which increases the amount of heat rejected from the heat exchanger. Using fan-coil (HE) system, which is operated by well water to cool the houses, reduced the cooling load by (30%). The effectiveness of the system is increased respectively with the increasing of temperature difference between the ambient air and well water temperature which causes a cooling load reduction.

![Figure 3](image)

**Figure 3.** The variation of cooling load with and without using heat exchanger HE along the day.

Figure 4 shows the hourly variation of cooling load with and without passive and (HE) systems, along the day. It is clear that the difference had been appeared in cooling load between the case of using passive and active (HE) systems, and without them. The figure shows that the use of passive system and well water used in heat exchanger (HE) to cool the house, would help to reduce the cooling load of the house by 36%. The internal conditions (room conditions) in this case will be close to the comfortable conditions.

![Figure 4](image)

**Figure 4.** The variation of cooling load with and without using heat exchanger and passive system along the day.
4.3 Effect of using well water to reduce the room temperature

Figures 5 shows the variation of ambient, room, and well water temperatures hourly along the day for a selected day on 15 June. It is noted that after the sun rise, the ambient temperature during this period is increased every hour, till it reached the highest values at 2 PM, then it's began to decrease [14]. The figure shows that there is a significant difference between ambient temperatures and well water temperatures. This difference is increased during the period from 7 AM to 2 PM then began to decrease. The figure shows that the use of well water to cool the house would help to reduce the room temperature by 28% compared with ambient temperature.

![Figure 5](image)

**Figure 5.** The ambient, room and well water temperature variation along the day on June.

Figures 6 shows the variation of ambient, room, and well water temperatures hourly along the day for a selected day on 15 July. Also the figure shows that the difference between ambient temperatures and well water temperatures is increased during the period from 7 AM to 2 PM then began to decrease and the use of well water to cool the house reduced the room temperature by 27% compared with ambient temperature.

![Figure 6](image)

**Figure 6.** The ambient, room and well water temperature variation along the day on July.
Figure 7 shows the same manner as figures (6 and 7) along the day on August. The figure shows that there is an increasing difference between ambient temperatures and well water temperatures more than June and July. It is also noticed that the ambient temperatures during August are always higher than June and July temperatures. Generally, these figures show that the use of well water to cool the house would help to reduce the room temperature by more than 27% compared with ambient temperature.

![Temperature Variation Chart](image)

**Figure 7.** The ambient, room and well water temperature variation along the day on August.

| Table 2. Sample of test data recorded at 2 AM for selected days in June, July, and August 2017 |
| Days/Month | June | July | August |
| --- | --- | --- | --- |
| | $T_{Ambient}$ | $T_{Room}$ | $T_{Well}$ | $T_{Ambient}$ | $T_{Room}$ | $T_{Well}$ | $T_{Ambient}$ | $T_{Room}$ | $T_{Well}$ |
| 7 | 35.5 | 25.9 | 19.8 | 41.4 | 30.1 | 20.4 | 46.9 | 35.2 | 21.8 |
| 15 | 37.3 | 31.5 | 20.0 | 43.5 | 31.9 | 20.6 | 45.2 | 34.1 | 21.3 |
| 23 | 38.4 | 27.3 | 20.2 | 44.8 | 33.8 | 20.9 | 44.1 | 33.5 | 21.2 |

Table 2 represents the ambient, room, and well water temperatures during three selected days in the summer months (June, July, and August) at 2 PM. It's easy to observe that the room temperature always close to the required temperature in the case of comfortable conditions [15].

### 5. Conclusions
Choosing the window orientation in the south wall is the best among other sides, due to a largest amount of solar radiation in winter because of the long period of exposure to the sunlight during the day, and minimum amount of solar radiation during summer. The use of shadow and overhang on the windows in the south direction reduces the cooling load to (6%). The possibility of using well water to operate the heat exchanger reduced the cooling load to 30%. The use of the passive system and well water to cool the house would help to reduce the cooling load to 36%.

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