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ENERGY SAVING ENHANCEMENT USING WATER-COOLED ROOF WITH SOLAR ASSISTED SYSTEM FOR SPACE COOLING APPLICATION

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Abstract.

*Due to significant demand on electrical energy on residence sector, especially those spend on space cooling for extreme hot summer countries in the middle east; moreover, the national electrical shortage supply issue in Iraq, it is a kind of interested and challenge at the same time to research for solution and utilize the redundancy of solar energy in such region. A test room was constructed 4.7*2.5*2.85m subjected to solar radiation all day time situated in Baghdad, a bunch of experimental testes were conducted for parametric study over summer season from April till October, the experiment testes were recurrent on monthly basis. The roof of test room was cooled by circulated water in pipes, the water is pre-cooled by evaporative cooler in separate system whilst the relatively cooled air is blew towards the A/C outdoor unit and other stream directed on back side of solar panels to minimize its average temperature for promoting performance aspects. Results indicated the energy save 33.53% over entire season when cooling the roof by water circulation and 9.01% energy saved due to A/C COP enhanced from cooling the condenser by cold air. Therefore COP was enhanced due to cold air effect from 2.90 to 3.39The solar panel temperature was minimized about 11°C that results to enhance the efficiency of PV panels from 12.1% to 12.8 %, solar system can handle the operation for 3hrs peak time when A/C is off as more energy was saved.*

Keywords: Space Cooling, Energy Saving, COP Enhancement, Solar Assistance, Water-Cooled Roof, PV panel Enhancement.

I. Introduction.

Worldwide power consumption on residence sector is 27% with associated CO_2 emission is 17% as per [VII], as long as energy saving terminology attracts scientist interest mainly for cost saving, environment protection and utilize natural sustainable resources to participate of finding solution of worldwide energy crisis.

Current research focal point on enhance the energy saving for space cooling of a test room constructed in very hot and dry climate in Iraq-Baghdad. The study was curried out on experimental actual full-size prototype over summer season starting from April till October. The research is strived to minimize the heat gain mainly and introduce solar energy as an auxiliary system, the research originality concept is collected from different past studies ides, ideas were collected and merged in one integrated system.

It is common sense when use high thermal insulation material in building construction the heat gain will reduce as energy spend on space cooling will be saved, this proven by [III] and [VIII], another factor of minimizing heat gain is coating the roof surface with high reflectance material [XI], a major fraction of heat transfer from ambient towards the room space through the roof due to long term exposure to solar beam, [IV] has introduced an economic way to extract the heat from roof by circulating cold water supplied from evaporative cooling inside concrete slab core by set of piping connection. But [II] and [VI] has developed the A/C unit Coefficient of Performance (COP) by minimizing its outdoor condenser temperature, another endless pursue was made by [IX] to introduce solar energy as a secondary power generation system, [I] proposes the efficiency enhancement of PV solar panels by lowering its average surface temperature.

According to previously mentioned ideas imposed from past studies, an integrated hybrid system was designed and executed then intensively tested for results verification, as it was supported by theories and simulation, the obtained results showed acceptable margin compared with others.

The fulcrum objectives of current research as following:

1- Achieve energy saving, by using good thermal insulation material and introduce evaporative cooling method by water-cooled roof, which leads to save the cost end maintain the environment by minimizing the emissions.
2- Utilize a sustainable and available solar energy.
3- Develop the performance of A/C COP and PV panel efficiency.
4- Use purely domestic row materials in the research.

II. Problem Definition and Solution.

The main challenges are tremendous energy consumption on space cooling in very warm and dry summer countries, as well as the long term issue of national electricity energy shortage and supply in Iraq due to post war sequences, on the other hand the emission that directly damaging the environment resulted from fossil fuel burning to produce the electricity.

Entirely those reasons are encouraged factors to figure out a solution by adopting high quality thermal insulation in construction, introducing evaporative cooling which is an economic method of cooling and efficient in dry climate to extract heat from test room components as well as use the waste air with relatively low temperature was utilized to improve the performance of A/C and PV panel, as electrical solar system was took on to withstand the electric demand when national power shut down.

III. Description of Experimental Prototype.

The test room full-size prototype with dimension 4.7*2.5*2.85m wasbuilt in way exposed to solar radiation all day, and walls built from Autoclaved Aerated Concrete blocks AAC with very low thermal conductivity0.13 $W/m.K$, A 0.2m wall thickness.1.8m^2 door and 0.9m^{2}window were made from PVC and very good sealed, the roof is made of reinforced concrete slab with iron bar mesh, see figure (1) and (2).

Figure (1) Test room full-size prototype.

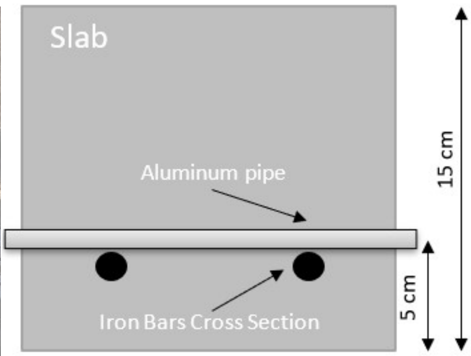

Figure (2) Aluminum piping installation inside roof slab core.

Aluminum piping with diameter 1cm systematically laid on the roof prior mixing concrete see figure (2), the design of piping is referred to basic estimation of ultimate day heat transfer may occur in the season which is 21-Jul at 12:00 pm [X], and the sizing of A/C was selected by running Hourly Analysis Program (HAP) as per table (1), the recommended A/C unit capacity is 1 ton.

Table (1)

Day - Month	21st - July
Time	12:00
Solar Radiation	853 W/m^2
Summer Design DB	45 °C
Summer Coincident WB	22.8 °C
Loadout on HVAC	1.7 KW
The Selected SPLT AHU	1 TR

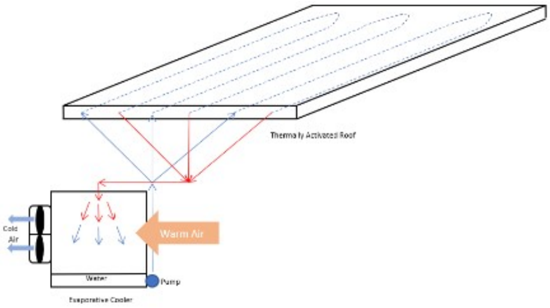

Figure (3) Water-Cooled Roof Schematic.

Solar system was designed by evaluating the overall required loads 225Wand expected duration operation 3hrs plus margin, a couple of solar panels 120W for each was used with DC battery and invertor.

IV. Working Operation.

The test room space is cooled by A/C unit, the evaporative cooler produce water its temperature close to wet bulb and it is pumped inside roof to extract heat, the roof is panted from top surface white to reflect as much possible of solar radiation, the waste of air with relatively lower temperature than ambient produced from evaporative cooler is blown towards A/C outdoor condenser and other part to back side of solar panels for performance enhancement, in one of the testes during certain period of time the electricity shut down and maintain the operation by electric solar system excluding the A/C. the experiment was carried out from 08:00 am till 05:00 pm (continuous operation), the below testes were repeated monthly for comparison reason.

Test 1: Continuous operation, roof is cooled by water, A/C is cooled by cold air.

Test 2: Continues operation, roof is cooled by water A/C is not cooled.

Test 3: continuous operation, roof and A/C are not cooled.

Test 4: Power shut down at peak time 11:00 am till 02:00 pm, solar system activated,roof is cooled by water, A/C is cooled by cold air, PV panel is cooled by air.

V. Calculation.

The electric energy consumption was directly measured by counter W.hr, the amount of heat gain is estimated by Cooling Load Temperature Difference (CLTD) [V]the effect of ambient temperature and solar temperature. By applying energy balance on test room.

$$\sum Q_{in} + \sum Q_{gen} = \sum Q_{out} + \sum Q_{store} \quad (1)$$

$\sum Q_{in}$: is Total thermal energy entering the room space KW.

$$\sum Q_{in} = Q_{wall} + Q_{roof} + Q_{window} + Q_{door} + Q_{infilitration} + Q_{ground} \quad (2)$$

The general equation of components facing solar radiation is:

$$Q = U.A.CLTD \quad (3)$$

$$Q_g = U.A.\left(T_{uncond.space} - T_{roon}\right) \quad (4)$$

$$Q_{infilitration} = 1.22\,.\,\dot{v}\,.\,1.005\,(T_{amb} - T_{roon}) \quad (5)$$

$\sum Q_{gen}$: Is thermal energy generated inside the control volume. Dissipated heat from lights and fan KW [XII].

$\sum Q_{out}$: Energy been extracted from control volume.

$$\sum Q_{out} = Q_{water-coole\ \ roof} + Q_{AC\ evaporator} \quad (6)$$

$$Q_{water-coole\ \ roof} = \dot{m}_{water}.Cp_{Water}\,.\,(\Delta T_{water}) \quad (7)$$

$$Q_{AC\ evaporator} = \dot{m}_{referegerent}.RE \quad (8)$$

RE: Refrigerant effect is evaluated by acquiring pressure and temperature at outlet condenser and outlet evaporator, fromp-h chart of R-22 find the values of enthalpies.

$W_{comp.}$: Compressor work directly measured by electric counter KW.hr.

The A/C COP was evaluated experimentally by measure low and high pressures in vapor compression cycle and placing thermocouples in inlet evaporator, outlet compressor and outlet condenser.

$$COP = \frac{\dot{m}_{referegerent}\cdot RE}{W_{comp}} \quad (9)$$

$$\dot{m}_{referegerent} = \frac{W_{comp}}{\Delta h_{compressor}} \quad (10)$$

Where:

$W_{comp}, \Delta h_{compressor}$ and RE; are measured experimentally.

Figure (4) Solar panels setup and air ducts passages.

VI. Results and Discussion.

- A seasonal power consumption was counted for three tests of comparison reason, figure (5) illustrates the variation of energy conserved. Test 1 saves energy 33.53% compared with Test 3, and can save 9.01% compared with Test 2, it is showing the effect of water-cooled roof is saving energy more than COP enhancement method.

As shown in figure (6) is thermographic imaging of water-cooled roof for piping loops parallel connection, which is more efficient than the series as proven by experiments and past studies [V], this because of parallel led to less pressure drop premising more flow rate to pass as more thermal extraction will occur.

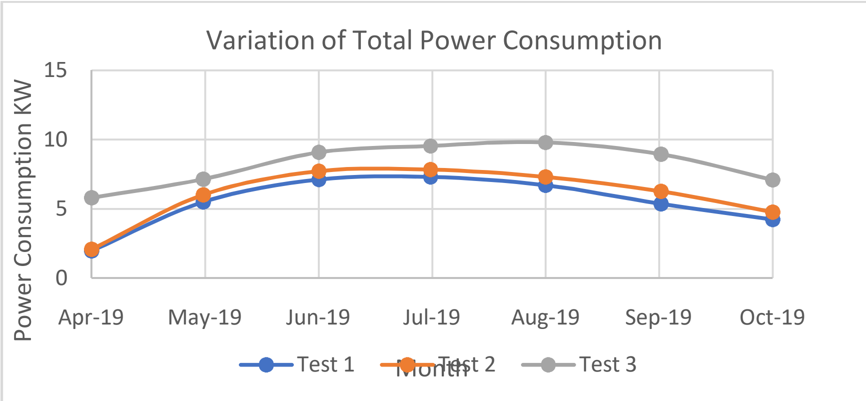

Figure (5) Trends of average monthly power consumption of three tests.

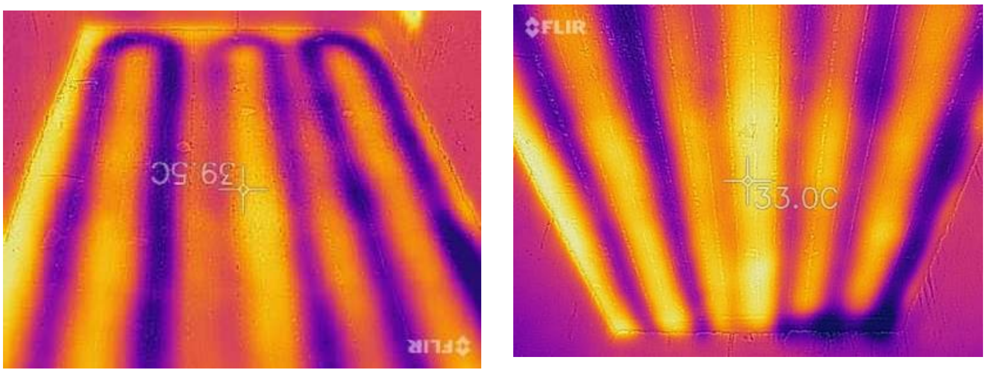

Figure (6)Thermograph of water-cooled roof with parallel connection.

- The effect of cold-water circulation resulted from evaporative cooling is minimized the average roof temperature is 5.2°C, as shown in figure (7) the monthly comparison between Test 1 and Test 3, as for figure (8) is the average roof temperature variation on hourly basis, as it is increasing to ultimate values at 03:00 pm. Due to effect of lagging resulted from thermal charging.

The amount of heat gain is directly affected by water circulation as shown in figure (9), because the results of equation (7) will be subtracted from total heat gain that is representing a thermal load on HVAC indoor unit, logically any minimization in heat gain via any method will lead into less power consumption.

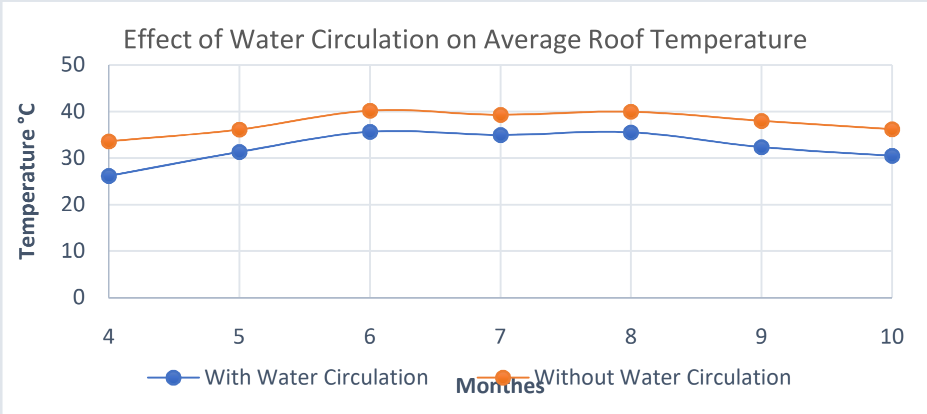

Figure (7) Average roof temperature vs. Test 1 and Test 3.

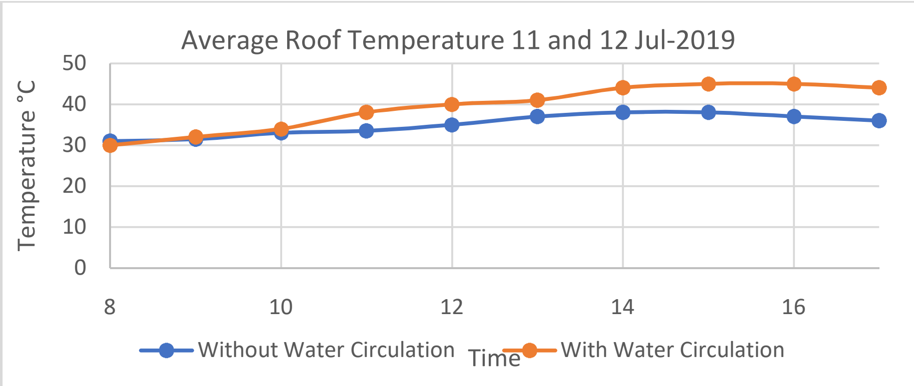

Figure (8) Effect of average roof temperature with time.

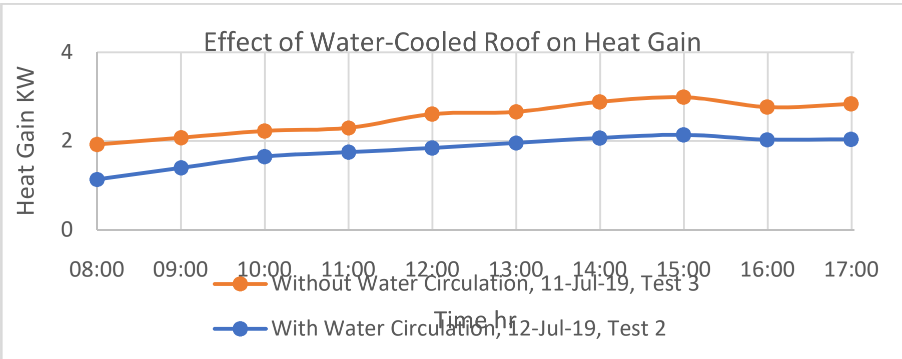

Figure (9) Effect of water-cooled roof on total heat gain.

- HVAC COP was enhanced in manner of blowing the cold air wasted from evaporative cooler, because the temperature and pressure in condenser will decrease accordingly as in figure (11), however figure (10) is general looking on effect of cold air on average value of COP, it is showing that the COP is very sensitive with temperature condition, it is decreasing with warmest month reaching to minimum values 2.32 and 2.37 for July and August respectively, overall the COP has enhanced 16.9% by increasing the effect of refrigerant and reduce compressor work from its definition in equation (9). Figure (12) showing a variation in vapor compression cycle during October month using RefrigerationUtilities software, because the COP showed more development in October because relatively low ambient temperature and highly efficient evaporation process.

- PV panels efficiency was enhanced due to lowering its average surface temperature about 11°C, that is lead to increase efficiency from 12.1% to 12.7% figure (13).

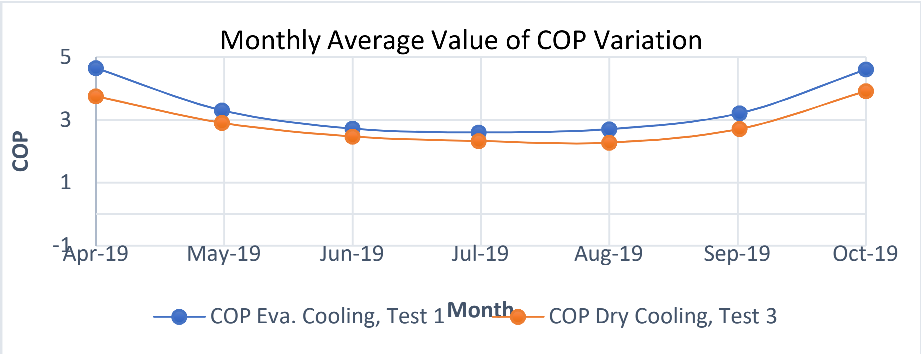

Figure (10) Effect of cold air on average value of HVAC COP.

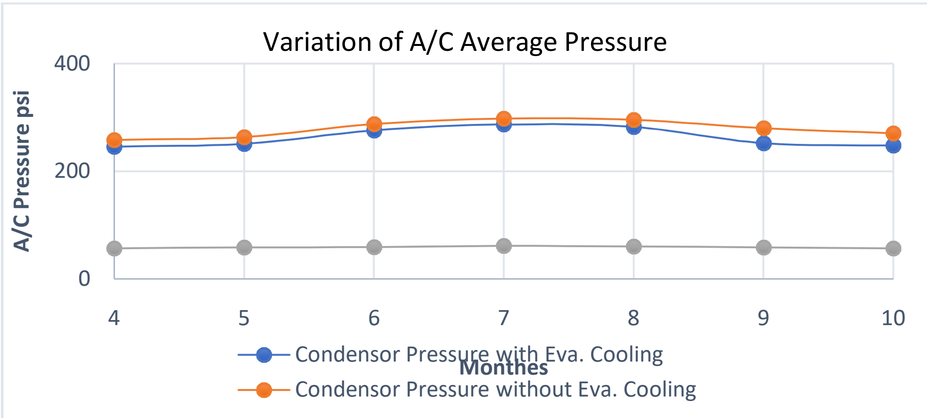

Figure (11) Effect of cold air on average condenser pressure.

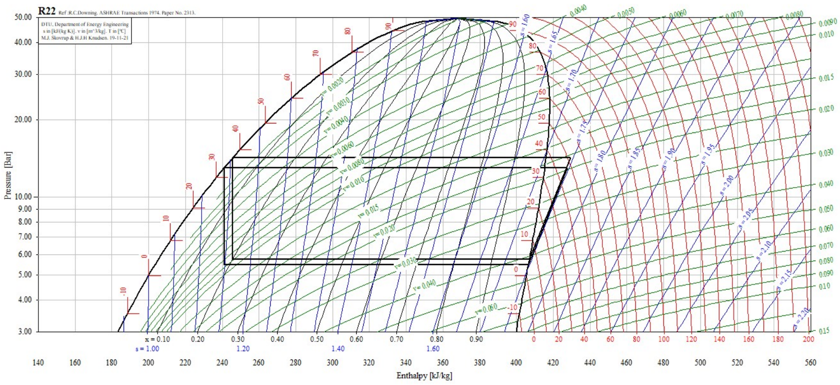

Figure (12) Effect of cold air on HVAC vapor compression cycle p-h diagram.

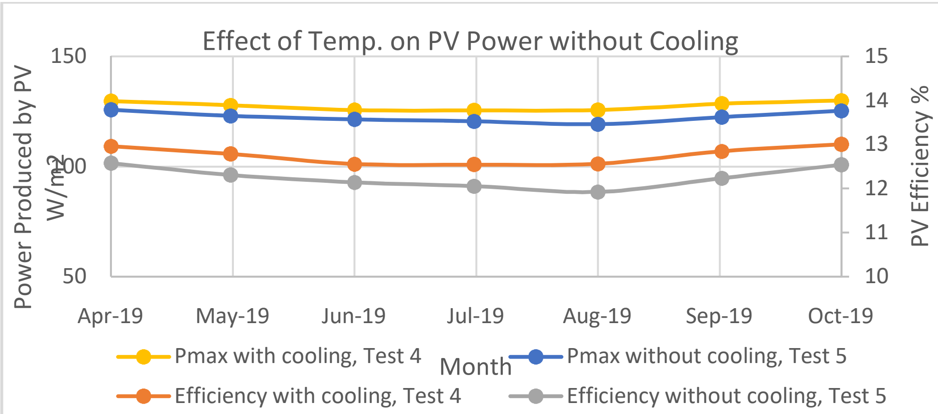

Figure (13), PV Panel efficiency vs. cooling process.

- Electrical solar system was introduced to simulate the case of shutting off the national electric power A/C off during peak time from 11:00 am till 02:00 pm, the room was pre cooled by A/C (discharged) previously, the shutting off power period will activate the solar system to handle the operation of water circulation inside roof and operating the fan of evaporative cooler as well as small indoor fan to circulate the stationary air inside the test room. As explained in test 4. Figure (14) is showing the average power consumed of Test 4, A/C is off during peak time for three hours, the power was minimized 56% compared test 4 with Test 1, but the indoor temperature seemed to be increased at last hour of A/C offline.

Figure (15) is a selective day in August Test 4 showing off the behaviors of power consumed, post peak time power curve is jumped to more than past peak, because the thermal effect was accumulated as the HVAC has towork more for overcome to retrieve the comfort condition.

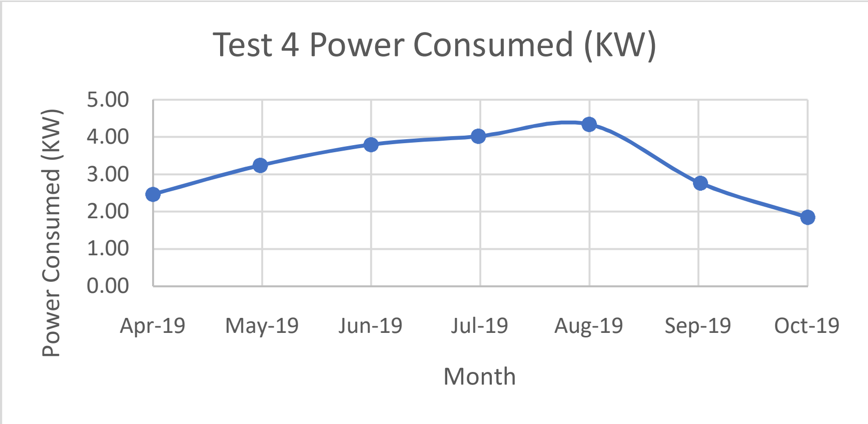

Figure (14) Average Power consumed of Test 4.

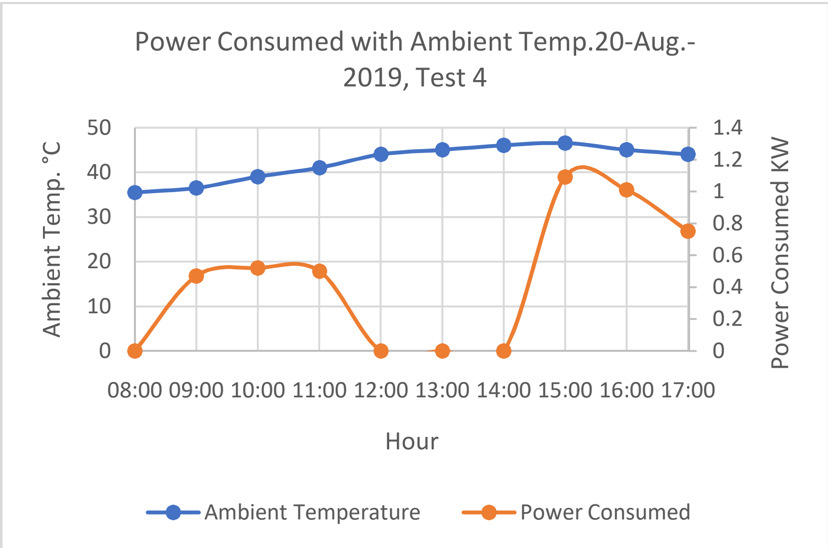

Figure (15) Hourly basis power consumption and ambient temp.

VII. Conclusion.

Extensive repeated experiment testes on test room, it is deduced the following facts:

1- Good thermal insulation building decrease power consumption on space cooling.
2- Water-cooled circulation saves energy more than COP enhanced by cold air.
3- Water circulation flowrate is directly proportional to heat extraction.
4- Parallel connection of water piping inside roof is more efficient than series.
5- The ultimate ambient temperature at 02:30 pm is shifted from ultimate solar radiation 12:00 pm because the thermal energy storage effect, response timing (lagging effect).

6- Lagging effect is influenced by overall thermal capacitance and thermal conductance of building construction and indoor furniture's.
7- HVAC COP is sensitive to ambient temperature.
8- COP enhance with decreasing the condenser pressure and temperature.
9- PV solar panels efficiency is affected by its body temperature. Reverse proportional relation.
10- Implementing electric solar system will strongly assist to save energy but the amount of heat gain will overcome the energy discharged and causing rise indoor temperature.
11- Majority of heat gain is pass through the roof due to facing solar radiation all day time.

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