An Investigation into Thermal Performance of Mist Water System and The Related Consumption Energy

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ABSTRACT

Experimental tests were conducted to investigate the thermal performance (cooling effect) of water mist system consisting of 5μm volume median diameter droplets in reducing the heat gain entering a room through the roof and the west wall by reducing the outside surface temperature due to the evaporative cooling effect during the hot dry summer of Baghdad/Iraq. The test period was Fifty one days during the months May, June, and July 2012. The single test day consists of 16 test hours starting from 8:00 am to 12:00 pm. The results showed a reduction range of 1.71 to 15.5℃ of the roof outside surface temperature and 21.3 to 76.6% reduction in the daily heat flux entering the room through the roof compared with the case of not using water mist system. Also the results show a reduction range of 1.3 to 18.8℃ in the wall outside surface temperature. Finally numerical simulation with ANSYS-FLUENT.14 was conducted to compare its results with the experimental results of the roof and wall tests.

Keywords: energy saving, water spraying, water mist, evaporative cooling techniques, air conditioning

دراسة الاداء الحراري لمنظومة رذاذ الماء و تاثيرها في استهلاك الطاقة

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الخلاصة

تم اجراء اختبارات عملية من اجل دراسة الاداء الحراري لمنظومة رذاذ الماء بقطيرات بمعدل قطر 5 مايكرون , في تقليل الحمل الحراري الداخل الى غرفة من خلال السقف و الجدار الغربي لها بخفض درجة حرارة السطح الخارجي نتيجة التاثير التبريدي التبخيري خلال فترة الصيف الحار و الجاف في بغداد/العراق. فترة الاختبارات كانت لمدة واحد و خمسون يوما خلال اشهر ايار و حزيران و تموز من العام 2012 , و تضمن يوم الاختبار 16 ساعة من الاختبارات ابتداءا من الساعة الثامنة صباحا و حتى الساعة الثانية عشرة ليلا. اظهرت النتائج العملية هبوط بمقدار 1.71 الى 15.5 درجة مئوية في حرارة السطح العلوي للسقف, و هبوطا بمقدار 21.3 الى 76.6 % من الحمل الحراري اليومي الداخل للغرفة من السقف. كذلك و بالنسبة للجدار الغربي فقد اظهرت النتائج هبوطا بمقدار 1.3 الى 18.8 درجة مئوية في حرارة السطح الخارجي للجدار. اخيرا تم استعمال برنامج المحاكاة الهندسي ANSYS-FLUENT.14 من اجل مقارنة النتائج العملية للسقف و الجدار مع النتائج النظرية المتولدة من هذا البرنامج.

الكلمات الرئيسية : توفير الطاقة, تذرية الماء, رذاذ الماء, تقنيات التبريد التبخيري, تكييف هواء.

1- INTRODUCTION

One of the most important problems that face the HVAC engineers is how to overcome the cooling load that is penetrated through the roof and the outside walls specially the ones that are exposed to the sun for a number of hours during summer days. In a country like Iraq where the weather is so hot and the temperature can exceed 50 ℃ in many days during summer, it is so important to find any new solutions to reduce the effect of these loads, and because the weather is dry beside it is hot in summer, it is very axiomatically to think that the evaporating cooling can be the most effected solution for this problem. Furthermore, by attacking at the roof surface, evaporative cooling is utilized where temperatures are highest (due to greater exposure to radiation) and relative humidity is lowest (air will hold more water vapor at higher temperatures). As a result, solar impacts on the roof surface can be negated before any of the other building's defense mechanisms come in to play, **Bachman1985.** By evaporating just enough water on the roof to drive the air to saturation (100% RH)**,** the roof surface and the air film against it approach the wet bulb temperature. The radiant energy which raised the roof temperature (sensible heat) has been relieved by causing a phase change (latent heat) from liquid to vapor. The only issue then, is control of spray sufficient to maximize evaporative cooling of the building skin yet not so much as to allow standing water. And this control is largely what distinguished the successfully designed systems. Evaporative roof systems are not without drawbacks, however, unlike insulation, roof spray contributes to comfort and energy conservation only during the cooling season. Final evaluation of the alternatives should take a lifecycle look at all of the assumptions of cost and benefit, energy savings and roof life. Perhaps the most important objection to roof spray systems is the attendant consumption of water, an increasingly depleted natural resource.

In 1940 interest in (roof spray cooling) had grown sufficiently to merit an ASHRE, study at the Pittsburgh Experiment Station. "Summer Cooling Load as Affected by Heat Gain through Dry, Sprinkled and Water Covered Roofs" by **Houghton et al 1940**, they compared time and heat flow relationships through nine different roof constructions for dry, sprinkled and ponded surfaces. Their conclusions indicated that the sprinkler system was, in all constructions, the most effective measure of reducing heat flow into the building. The results for concrete asphalt roof were as in **Table 1**.

Carrasco et al. 1986, performs an experimental study of the use of a roof spray system. The study was done on a building belong to A&M university in the hot and humid weather of central Texas USA in July 1986. The roof was of wood with thin layer of tar and gravel on top. The experimental results showed that there was a 60 % reduction in the heat transfer through the roof and 20 % (13.8℃) reduction in the roof top surface also a 2.3 to 3.4℃ reduction in the inside air temperature.

Narumi et al. 2007, conducted experimental tests and numerical simulations in order to investigate the effect of misting technologies on reducing urban heat flux and saving energy. An apartment house in Osaka Japan was used as the test building in an investigation of three types of evaporative cooling techniques: "Rooftop spraying", "Veranda spraying" and "Spraying to the outdoor unit of room air conditioner". The test period was from 10 August to 27 September 2007. For Rooftop spraying, the experiments show that a lowering effect was obtained even after cessation of spraying, with the whole-day average falling by 16.4°C. The indoor environment showed a fall of 1.2°C at 120 cm above floor level, while a larger temperature lowering effect was obtained closer to the ceiling.

2- EXPERIMENT PROCEDURE

1) **Test Building**, The experimental tests were carried out in the room located in the second story of a house in alkarkh Baghdad/Iraq. The house was built at the beginnings of the seventeenth of the 20th century. The room inside dimensions were (5.5m length ,4m width, 2.85 height) it has two (1.18m height, 0.96m width) Iron frame windows one at the east wall and the other is at the west wall, and one wooden door with dimension of (1.97m height by 0.98m width) at the north partition **Fig.1**.

2) **Test Period,** The roof and wall experiments days were conducted during the months of May, June & July 2012 which represent the starting of summer in May, till reaching the peak temperatures of summer in Baghdad / Iraq in July. The days of experiments types were divided as in **Table 2**; Fifty one days of experiments were done to study these effects. The single experiment day consisted of

generally pump operation from 8:00 am to 9:00 pm with some exceptions when the stopping time was earlier (7:00 pm - 8:00 pm) especially in May when the water flooded over the upper roof surface at evening because of low temperature which caused reducing of evaporating. Taking the readings of the thermocouples and other measuring instruments was from 8:00 am to 12:00 pm generally**.**

3) **Test Apparatus,** An experimental test Apparatus has been built, in a way that give a flexibility in changing the parameters to be suitable for different types of the tests that is expected to be done. The components of this apparatus can be seen in **Fig.2** to **Fig.4**. The main parts are High pressure reciprocating pump 10 to 100 bar, specialized mist nozzles (size 0.006", which can give droplets of median diameter of 5 μm), piping network.
The parameters to be tested, consisted of Different pump operation methods (continuous or by intervals), different pump pressures, Different mist direction (upward or downward) and different levels from the surface.

4) **Test Procedure** The main idea of this research is using a high pressure water pump (reciprocating pump) to force the water liquid through a very small orifice nozzle (special mist nozzle), with pressure that can reach 100 bar, to get the water in a very small droplets (can be less than 5μm in Volume median Diameter VMD) that can be effectively evaporate without wetting the surface or body that it is expose to it (flash evaporating). This process of evaporation requires energy to be completed. The energy is taken from the air in the form of heat. The result is a temperature reduction, depending on the ambient temperature and the relative humidity of the air. Concerning the roof and the wall tests, Experiments were done to investigate the effects of changing controlling parameters on the important variables which are:
a) Room Roof outside surface temperature.
b) Room Roof inside surface temperature.
c) Room wall outside surface temperature.
d) Room wall inside surface temperature.
e) The room temperature **Fig.5**.
The tests were conducted by using a network of twelve (size 0.006") mist nozzles as shown in **Fig.4**. The inside and outside temperatures of the roof and the west wall were used to calculate the heat flux through the roof and the west wall during the day hours were calculated by the Eq.(1) and Eq.(2)

$$q_r = \frac{(T_{ro} - T_{ri})}{\sum_1^n \frac{t_n}{k_n}} \qquad (1)$$

$$q_w = \frac{(T_{wo} - T_{wi})}{\sum_1^n \frac{t_n}{k_n}} \qquad (2)$$

3- RESULTS AND DISCUSSION

a) From the roof tests of different months a comparisons have been made between wet and dry test days which are of close dry temperatures during the day long (specially the peak temperature), and close relative humidity. The **Fig.6** to **Fig.8** shows comparison between two days 12-May (dry test) and 20-June (wet test) for the roof top temperatures and heat flux cross the roof in each case. We can see the reduction in the roof heat flux curve in **Fig.8**, and how it came to the negative values (cooling effect) earlier than the case of dry ones **Fig.7**. Another comparison where made between the dry and wet part of the same roof at the same day. **Fig.9** shows a sample of this comparison for the roof top temperatures of the test day 2-July. **Fig.10** shows a comparison for the roof test day's heat flux during June and July. The final conclusions for the roof tests were as listed in **Table 3**.

b) From the wall tests of different months, a comparisons have been made between wet and dry test days which are of close dry temperatures during the day long (specially the peak temperature), and close relative humidity. **Fig.11** shows comparison of two wet days' 29-May, and 9-June with dry test 13-May for the west wall outside surface temperatures. **Fig.12** shows a comparison for the west wall test day's heat flux in July. The low insulated wall behaved as a cooling surface during most of the test days. The final conclusions for the west wall tests were as listed in **Table 4**.

c) The downward misting operation for the roof (from 90 cm height) is more effective in cooling the roof than that of upward misting (mist network on roof surface) by 7.37%. The result of down misting caused the roof to be a cooling surface for more Time (hours) than upward misting.

d) The interval operating methods of the pumps (2-min on and 2- min off) reduce the water consuming. Although that the continuous operating method or semi continuous operating method (continuous operating for an hour time and then interval operating for a half an hour) can increase the cooling effect but it can cause bad effect on the building construction because of water specially at the evening and at the high level of relative humidity, and more water consuming. The best method of operating is the continuous or semi continuous operating method at the peak temperature time (from 11:00 am to 4:00 pm) and interval operating during the other hours. This caused in a thin film of water (only fog during peak temperature) over the roof surface to produce the cooling effect without the harmful effect of water spilling.

e) The using of mist water reduces the outdoor air temperature, the experimental tests shows a reduction of 12.4 to 21.2℃ during the day hours. The number of temperatures reduced depends on the relative humidity and the pump pressure, which will increase the water being misted.

f) This method can be used safely in buildings because most of the water mist will evaporates directly (flash evaporating) and don't spilled on the surface, therefore do not cause any damage of any type to the building. Although a surface humidification can happen during the high relative humidity days or at the morning and the evening, but this effect can be reduced by using the interval operating and the changing the intervals time.

g) Concerning the use of ANSYS-FLUENT.14 software, Two days for each test type (roof or wall) were selected to compare the results of the experimental work with the fluent software results, and to compare the wet and dry results generated by FLUENT. The simulation was conducted by using the software to solve three dimensions transient heat transfer problem. The results were in the form of static temperature contours of two surfaces at the middle of the room. The deviation between experimental and fluent results is 0.2 to 5.8%. **Fig.13** shows a comparison between the experimental and fluent results for the days 20-July (dry) and 15- July (wet) wall tests .**Fig.15** shows the contours of these cases generated by Fluent for the hour 11:00 pm.

4- COMPARISON OF THE PRESENT WORK RESULTS WITH A PREVIUOS WORK RESULTS

Comparison can be made with **Carrasco et. al. 1986** experimental results in July 1986 in Bryan city, Texas they reported that the roof evaporating cooling can reduce the roof-top temperature by up to 25˚F (13.89℃) or about 20%. To make a comparison with the present work, we can compare Carrasco results of 19 July 1986 which was one of the biggest reduction values that was conducted during the experiments as it shown in the result curves of Carrasco paper (5 to 10℃ reduction of the roof top temperature for the period from 1:00 pm to 4:30 pm), with a chosen roof test day in July of the present work which is 4 July 2012 (clear sky with moderate temperature of July in Baghdad).**Fig.14** shows that The present test results show a reduction of the top surface temperature for the same time period of range 5.1 to 11℃, and this is a close result to Carrasco one, although that the weather of Texas is less in temperature levels from that of Baghdad according to (National Oceanic and Atmospheric Administration in the United tate of America) which shows a maximum temperature of 29 July 1986 in Bryan city was 38℃, compared with the temperature of 4 July 2012 of Baghdad which was 44℃. But the high relative humidity of Bryan city that day (average 50%, max 96% and compared with Baghdad in 4

July which was about max. of 27%) may have been the reason of the close results (increasing the humidity will decrease the evaporating process). Knowing that, the wind speed was almost the same for the two cases of the present and Carrasco (about 3m/s).

5- CONCLUSIONS

1) From the experimental work we can confirm that the water mist system can reduce the outside surface temperature of the roof and the west wall of the room by 1.71 to 15.5℃ for the roof and 1.3 to 18.8 ℃ for the wall.
2) The tests confirm that this system can reduce the heat gain entering the building throughout the roof and the west wall by 21 to 76%.
3) The tests showed that, the using of mist water can reduce the outdoor air temperature by 12.4 to 21.2℃ during the day hours.

REFERENCES

- ANSYS, Inc, April 2009, *ANSYS FLUENT 12.0 Theory Guide*.

- Carrasco, A., Pittard, R., Kondepudi, S. N., and Somasundaram, S. Mechanical Engineering Department, Texas A&M University, College Station,1987, *Evaluation of a Direct Evaporation Roof-Spray Cooling System*, Proceedings of the Fourth Symposium on Improving Building Systems in Hot and Humid Climates, Houston, TX, September 15-16, 1987.

- Daisuke Narumi, Kentaro Shigemitsu and Yoshiyuki Shimoda, Osaka University Suita City, Osaka Pref., Japan , 2007 , *Effect of the Evaporative Cooling Techniques by Spraying Mist Water on Reducing Urban Heat Flux and Saving Energy in Apartment House*, PLEA 2009 - 26th Conference on Passive and Low Energy Architecture, Quebec City, Canada, 22-24 June 2009.

- Houghten, F.C., Olsen, H.T. & Gutberlet, C., 1940, *Summer Cooling Load as Affected by Heat Gain Through Dry Sprinkled and Water Covered Roofs,* American Society of Heating and Ventilation, (ASHVE Transactions) Engineers Transcripts,June,1940, Vol. 46, pp. 231.

- Leonard R. Bachman AIA President Building Climate Interface , Inc. Houston, Texas, 1985 , *Rain on the Roof-Evaporative Spray Roof Cooling*, Proceedings of the Second Symposium on Improving Building Systems in Hot and Humid Climates, College Station, TX, September 24-26, 1985.

- National Oceanic and Atmospheric Administration in the United State of America, http://www.ncdc.noaa.gov

6-NOMENCLATURES

k : thermal conductivity of the roof or the wall materials *W/m℃*
n: the number of the roof or wall layers
q_r :heat flux through the roof at the wet part (sprayed part) W/m^2
q_{rd} :heat flux through the roof at the dry part (not sprayed part) W/m^2
q_w :heat flux through the west wall at the wet part (sprayed part) W/m^2
q_{wd} : heat flux through the west wall at the dry part (not sprayed part) W/m^2
t : roof or Wall Layer Thickness *m*
T_{ri} : roof inside surface temperature ℃
T_{rm} : room average temperature ℃
T_{ro} : roof outside surface temperature at the wet part (sprayed part) ℃
T_{rod} :roof outside surface temperature at the dry part (not sprayed part) ℃
T_{wi} : wall inside surface temperature ℃
T_{wo} : wall outside surface temperature at the wet part (sprayed part) ℃

7-TABLES AND FIGURES

Table 1. The Results of Houghton et al. for Concrete Asphalt Roof.

	With spray	Without spray
Max. heat flow, w/m^2	6.6	56.7
Min. heat flow, w/m^2	-12.9	-7.24
Avg. heat flow, w/m^2 over 24 hour	-3.84	18.3
Length of time with zero or negative heat flow hour	16	8

Table 2. The roof and wall experimental days.

No.	Test name	No. of days
1	Dry test	9
2	Wet roof test (nozzle misting up)	18
3	Wet roof test (nozzle misting down)	7
4	Wet wall test	17
Total test days		51

Table 3. Final conclusions of roof tests.

	Range	Average
Tro peak reduction at 2:00Pm, ℃	4 – 11.14	7.57
Tro day hours range reduction ℃	1.71 – 15.5	8.6
Tri peak reduction at 8:00Pm, ℃	0.5 – 1.91	1.2
Tri day hours range reduction ℃	0.2 - 2	1.1
Roof heat flux day hours range reduction w/m^2	1.1 - 22	11.55
Daily total roof heat flux range reduction %	21.3 – 76.6	48.95*

* This result is for upward spraying, the daily total roof heat flux becomes negative (cooling) in many case with downward spraying

Table 4. Final conclusions of wall tests.

	Range	Average
Two peak reduction at 3:00-4:00Pm, ℃	2.2 – 18.75	10.5
Two day hours range reduction ℃	1.3 – 18.8	10
Twi peak reduction at 7:00Pm, ℃	2.54 – 5.83	4.2
Twi day hours range reduction ℃	0.8 – 6.83	3.8
Daily total wall heat flux range reduction %	**	**

** The daily total wall heat flux became negative (cooling)

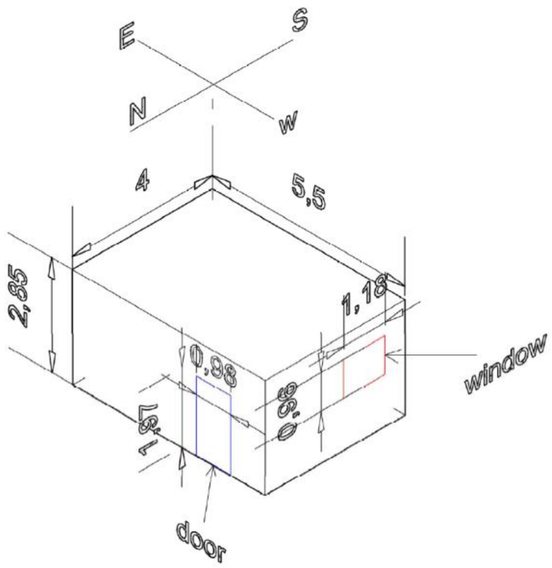


Figure 1. Test room dimension.

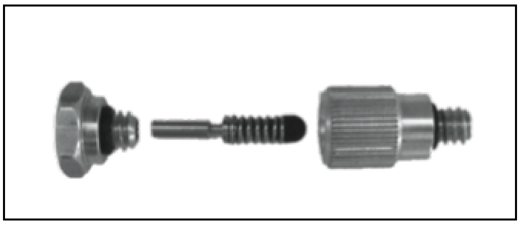
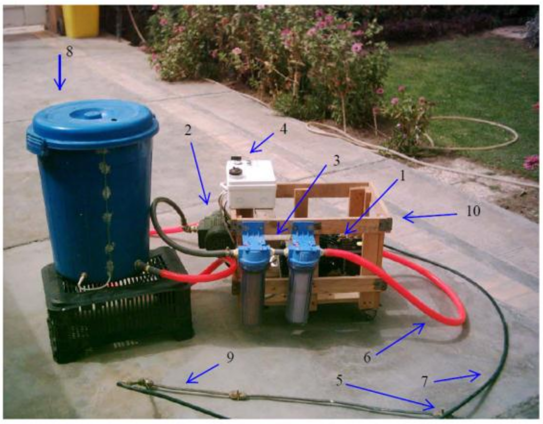


Figure 2. Mist nozzle.



1	High pressure pump	6	Low pressure elastic pipe
2	Low pressure pump	7	High pressure hose
3	5 microns water filter	8	Water tank
4	Operating electrical board	9	Copper Mist network
5	Mist nozzle	10	Wood frame

Figure 3. The test apparatus.

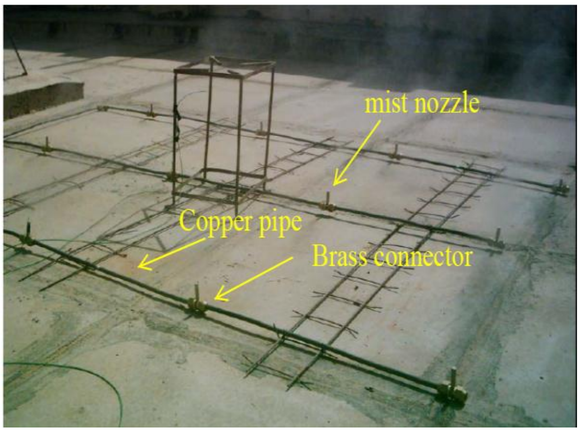


Figure 4. Piping network.

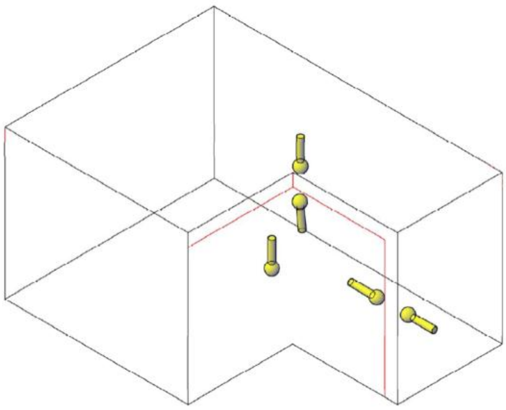


Figure 5.Main thermocouples places.

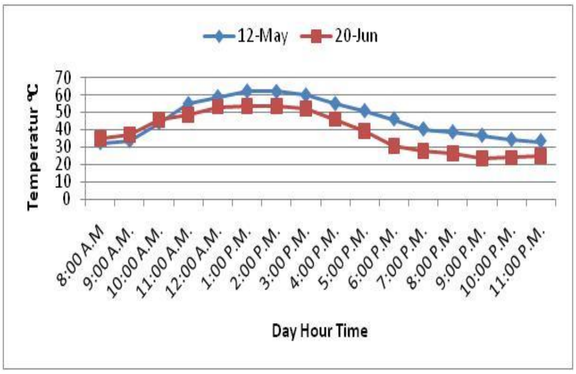


Figure 6. The outside roof surface temperature for the days 12-May (dry),20-June (wet).

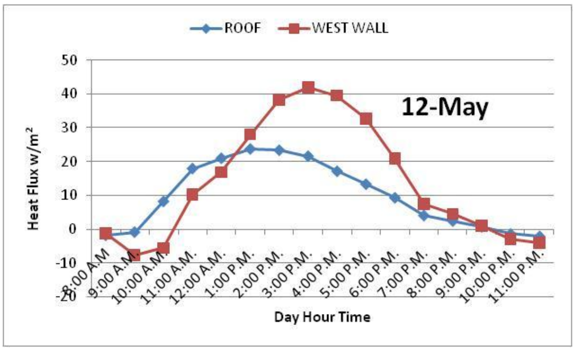


Figure 7. Heat flux throughout the roof and the west wall of the test room for the day 12-May (dry test).

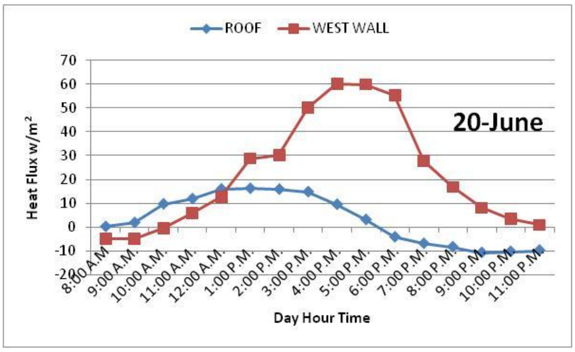


Figure 8. Heat flux throughout the roof and the west wall of the test room for the day 20-June (wet test).

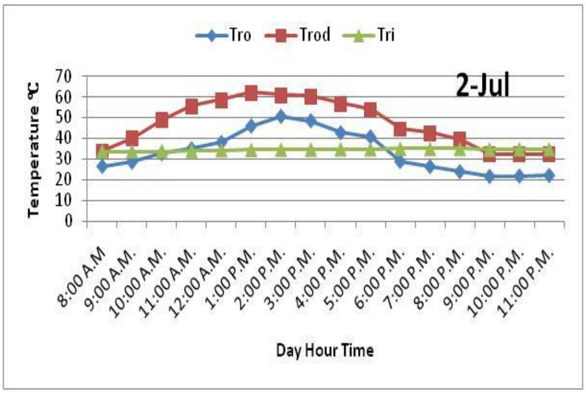


Figure9. The inside roof surface temperatures (tri), outside roof surface temperatures at misted part (tro) and the roof outside surface temperature at the dry part (trod) curves for the day 2-July.

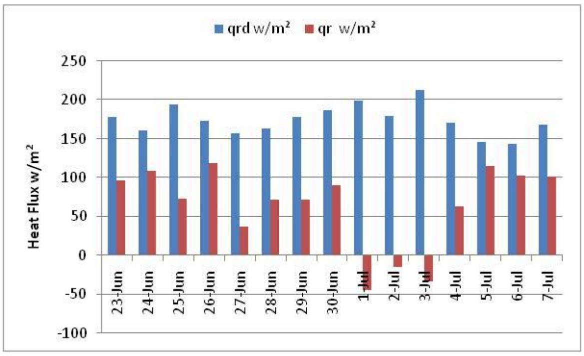


Figure 10. Daily total heat flux throughout the roof at the misted part (qr), the dry part (qrd) at June and July tests.

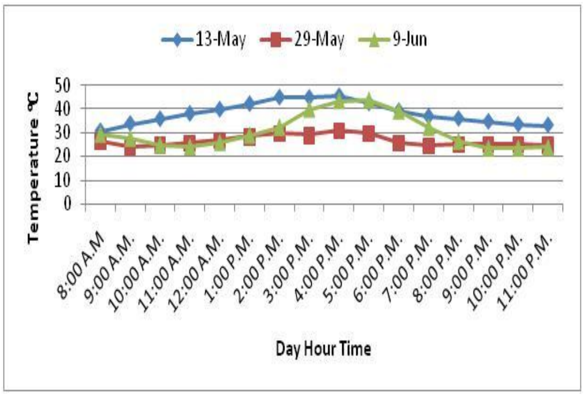


Figure 11. Wall outside surface temperatures of the day's 13- May (dry), 29-May (wet), 9- June (wet).

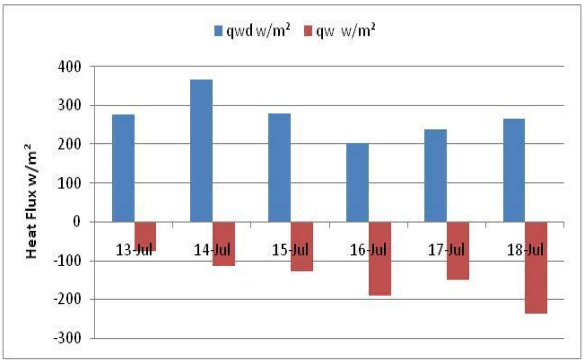


Figure 12. The heat flux throughout wet west wall part (qw), dry west wall part (qwd) of July tests.

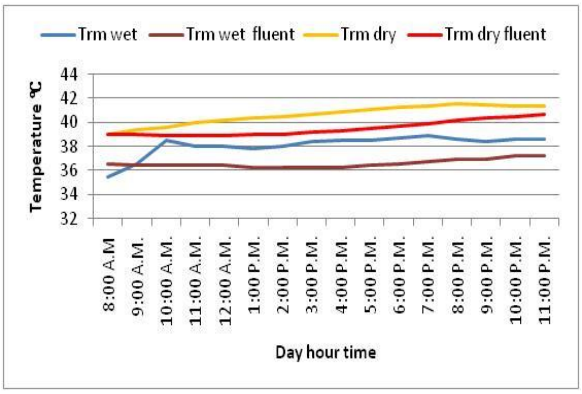


Figure 13. Comparison curves of the daily room temperatures measured experimentally and generated by ansys-fluent.14 software for dry (20/7/2012) and wet (15/7/2012) cases of wall tests.

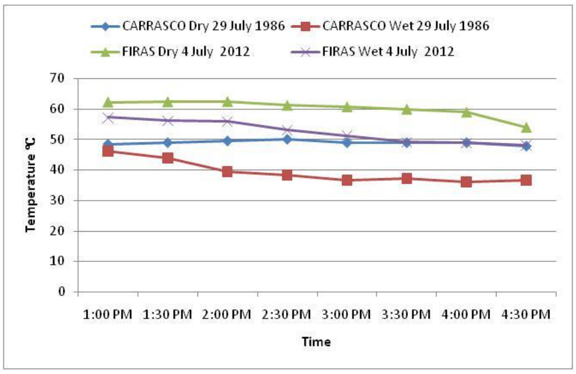


Figure 14. The temperature curves of 29 July 1986 by Carrasco and 4 July 2012 by Firas.

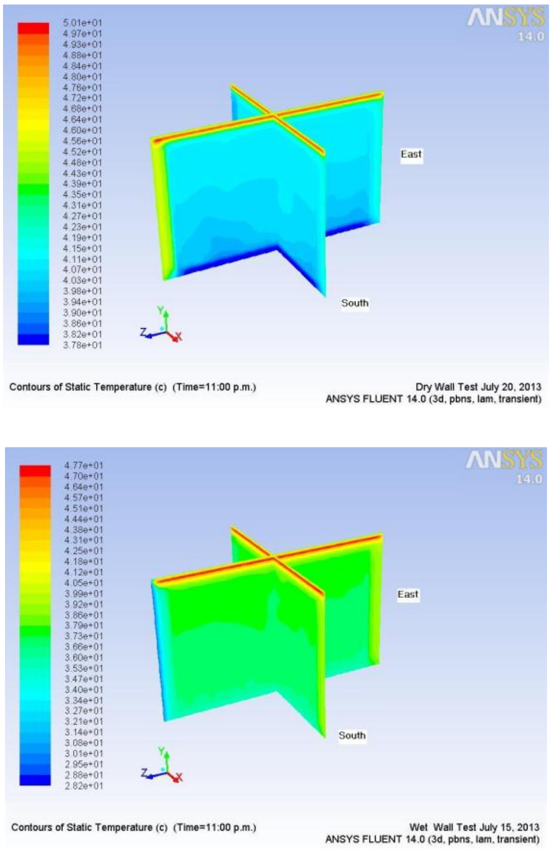


Figure 15. Temperature contours for the dry (20/7/2012) and wet (15/7/2012) wall cases at 11:00 pm.