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A New Method for Potable Water Collection from Central Air Conditioning Systems

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ABSTRACT. Large central air conditioning systems, located in a hot and humid environment typical of the Gulf, can be a useful source of high quality water. Moisture condensing on the cooling coils could be collected and treated for use as drinking water.

The system considered is as follows: The return air to the cooling coils is divided into two streams. One, after mixing with fresh ventilating air, is passed over the cooling coil at a low dew point to condense the maximum amount of vapour. This cooled stream is then mixed with the second hot stream, to provide air for the conditioned space at the required comfort condition.

A method is outlined for estimating the amount of condensation. Daily outputs, per 1000 cfm of air, have been calculated for atmospheric conditions prevailing at Jeddah and Dhahran at different times of the year. The results have been applied to a typical school building to show that a useful amount of potable water is produced.

The Kingdom of Saudi Arabia may be considered as one of the most arid countries in the world. There are no rivers and the precipitation is generally small and highly irregular. In some regions, such as Rub Al-Khali for example, no rainfall may be observed for a number of years. The average annual precipitation is around 50 mm (Al-Gwaiz 1981).

At the same time, the need for potable water in the Kingdom is increasing. It follows that all known conventional and non-conventional water collection systems should be utilised. Multiflash evaporation, reverse osmosis, electrodialysis and freezing are all in practical use. At present, most of these techniques are used in plants powered by conventional fossil fuels directly or by electric energy from a grid system; only a few small systems are powered by solar energy.

Many other non-conventional water collection systems of limited capacity have been developed for use in rural areas, such as isolated camps and communities in hot dry or hot humid zones as given by Sofrata (1981).

Condensate Collection System (CCS) Process

Figure 1 is a schematic of the CCS system. The return air flow rate, V_{ra}, is divided into two streams. One stream of the return air will by-pass the cooling coil. The return air by-pass factor (RABF) will control this amount of air to meet the human comfort requirements. The second stream will be mixed with outdoor fresh air required for ventilation before entering the cooling coil. This mixture of outdoor air and return air will be subjected to a cooling coil with very low apparatus dew point temperature, in order to condense the maximum possible amount of vapour. The dehumidified cold air is mixed with the by-passed air and is supplied to the space to be cooled. The air supplied to the space picks up the room loads, heat and moisture, and the cycle is repeated.

Mathematical Model

The mathematical model to determine the amount of potable water collected is simple and straightforward. Almost all air conditioning references give procedures on how to determine the required unknown parameters. Here we will use the symbols and procedures described in Carrier (1965). However, we advise the reader to turn to Carrier (1965) for justification of the approximation and definitions used in this paper.

Cooling and dehumidification is the simultaneous removal of heat and moisture from the air, process line 3-4 in Fig. 2. Cooling and dehumidification occurs when the ERSHF and GSHF are less than unity. The ERSHF generally varies from 0.95 where the load is predominantly sensible, to 0.45 where the load is predominantly latent as in our model. Using any air conditioning load estimation procedure, we may determine the RSHF, ERSHF, GSHF, dehumidified air quantity, entering and leaving air conditions at the apparatus, points 3-4 (Fig. 2) (Carrier 1965).

Once the ventilation air requirement is determined, and noting that since the supply air quantity is not fixed, the best approach to determining the apparatus dewpoint temperature is to assume a maximum allowable temperature difference between the supply air and the room. Then, calculate the supply air conditions to the space. The supply air conditions to the space must fall on the RSHF line to properly offset the sensible and latent loads in the space. This may eliminate the need for reheat or at least reduce the required reheat.

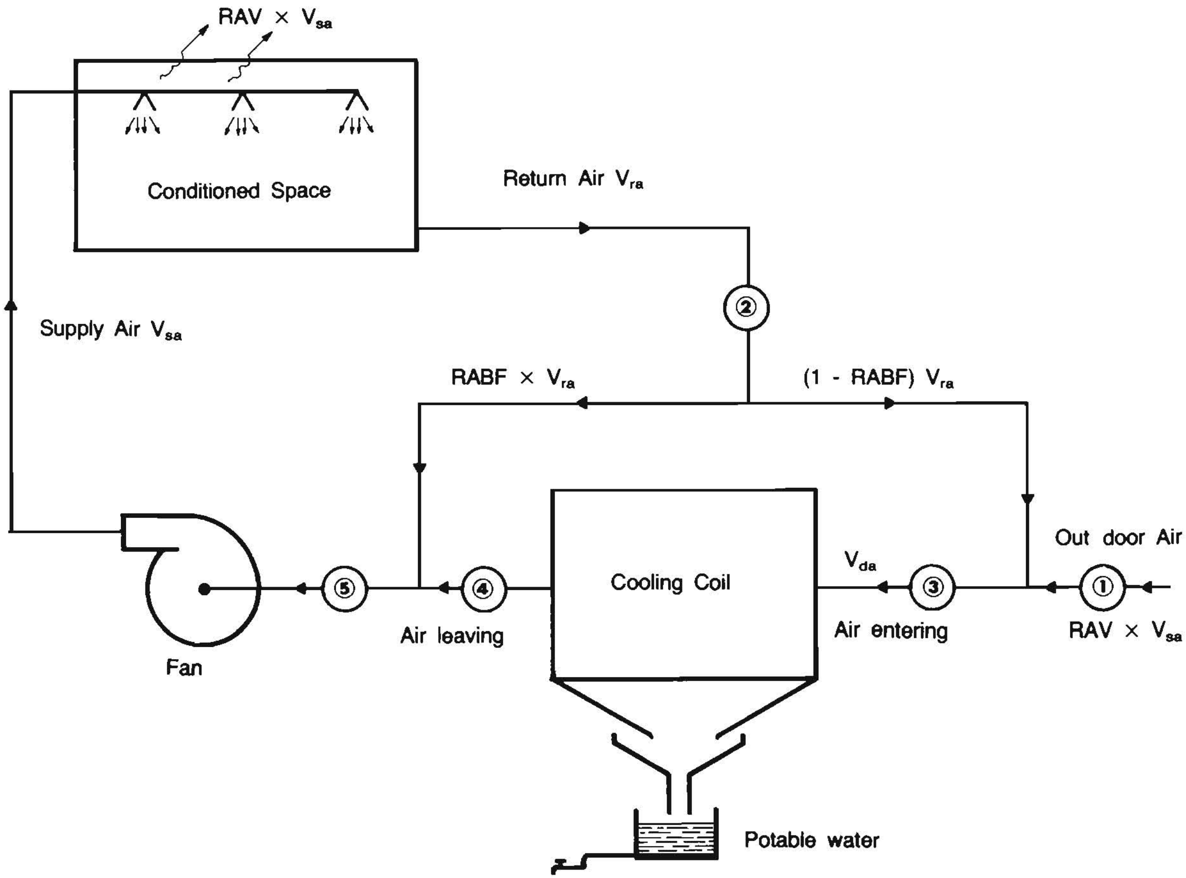


Fig. 1. Schematic sketch of air conditioning layout

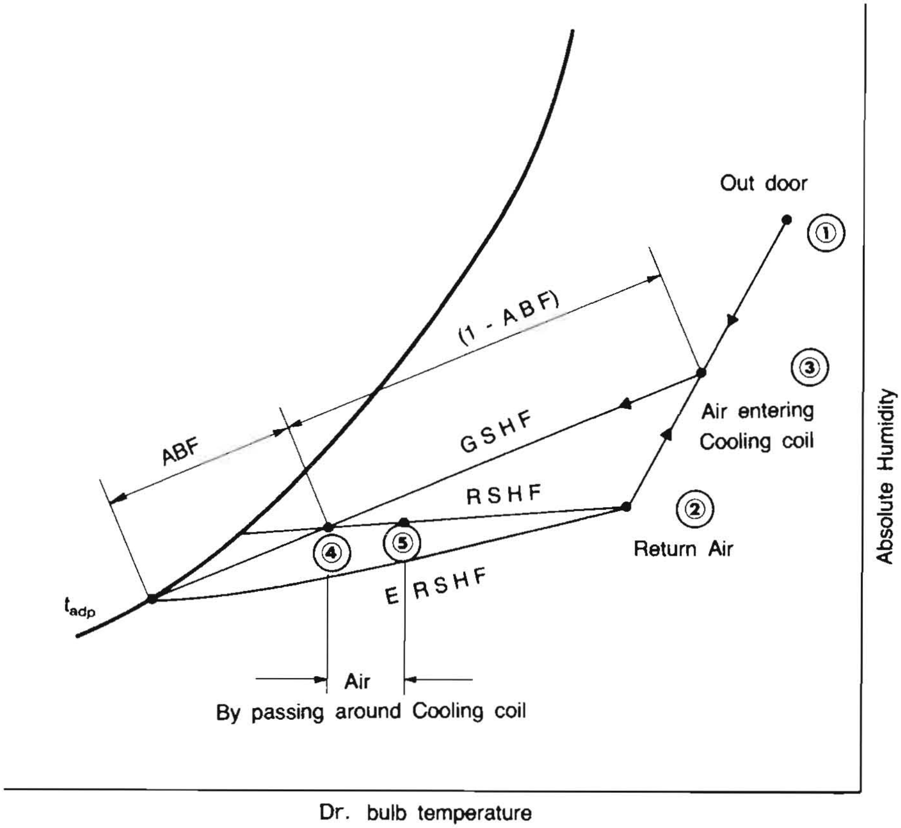


Fig. 2. Psychrometrics of cooling water collection process

The determination of the gained potable water may now be considered and the mathematical model may be described.

Knowing the outdoor conditions, the state point (1) is defined. The required air ventilation (RAV) ratio and the room design condition (state point (2)) may be selected according to data based on test observation of the clean outdoor air required to maintain satisfactory odor levels with people smoking and not smoking. Ventilation standards and room design conditions may be found in air conditioning references ASHRAE (1985) and Carrier (1965).

We use the simple well known mixing relations for two air stream to define the apparatus entering state 3 as follows (see Fig. 1):

$$t_3 = ((1\text{-RABF}).\ V_{ra}\ .\ t_2 + \text{RAV}.V_{sa}.t_1)/V_{da} \quad (1)$$

$$h_3 = ((1\text{-RABF}).\ V_{ra}\ .\ h_2 + \text{RAV}.V_{sa}.h_1)/V_{da} \quad (2)$$

$$W_3 = ((1\text{-RABF}).\ V_{ra}\ .\ W_2 + \text{RAV}.V_{sa}.W_1)/V_{da} \quad (3)$$

It is required to determine the air quantity to offset simultaneously the room sensible and latent loads. Also, the air quantity required thru the apparatus to handle the total sensible and latent loads should be calculated. These calculations may be achieved using the conditions on the RSHF, GSHF line, the apparatus dewpoint temperature (adp) and ABF. The room sensible heat factor (RSHF) may be defined as the ratio of room sensible heat (RSH) to the total room sensible and room latent heat (RLH):

$$\text{RSHF} = \text{RSH}/(\text{RSH} + \text{RLH}) \quad (4)$$

The grand sensible heat factor (GSHF) is the ratio of the total sensible heat to the grand total heat load that the conditioning apparatus must handle, including the outdoor air heat loads;

$$\text{GSHF} = \text{TSH} / (\text{TSH} + \text{TLH}) \quad (5)$$

where

$$\text{TSH} = \text{RSH} + \text{OASH} \quad (6)$$

$$\text{TLH} = \text{RLH} + \text{OALH} \quad (7)$$

Equations 6 and 7 neglect duct, fan, and leakage heat gains and losses. However, in practice, these loads should be taken into account.

Now, the air quantity required to satisfy the room load may be calculated from the following relations:

$$V_{sa} = \frac{RSH}{(Cp_a/v_5)(t_2 - t_5)} \tag{8}$$

and air quantity required thru the conditioning cooling coil to satisfy the total air conditioning load may be calculated as follows:

$$V_{da} = \frac{TSH}{(Cp_a/v_2)(t_3 - t_4)} \tag{9}$$

Assume the value of $(t_2 - t_5)$ and calculate V_{sa}. Use this value of V_{sa} in determining the mixing conditions, equations (1-3), together with following volume balances (see Fig. 1):

$$V_{ra} = (1 - RAV).V_{sa} \tag{10a}$$

$$V_{Oa} = RAV.V_{sa} \tag{10b}$$

$$V_{da} = RAV.V_{sa} + (1 - RABF)V_{ra} \tag{11}$$

and $$V_{sa} = V_{da} + RABF.V_{ra}. \tag{12}$$

The temperature rise $(t_3 - t_4)$ is determined and checked against equation 9. If this temperature difference is not equal, a trial-and-error procedure should be used.

The amount of collected water may be calculated from the following:

$$M = \frac{V_{da}}{v_a} \cdot (W_3 - W_4) \tag{13}$$

To carry out the previously mentioned calculation on an hourly basis of outdoor conditions, an interactive computer program has been developed.

Computer Program

An interactive program has been developed to calculate the maximum possible amount of collected water (Fig. 3). The program is able to handle the weather data from different cities. It also gives results for one specific day or for any period of time as desired. Sensible, latent and design room conditions may be changed for the same city and day conditions. The program may be used, also, with different set of values of RAV, RABF and ABF.

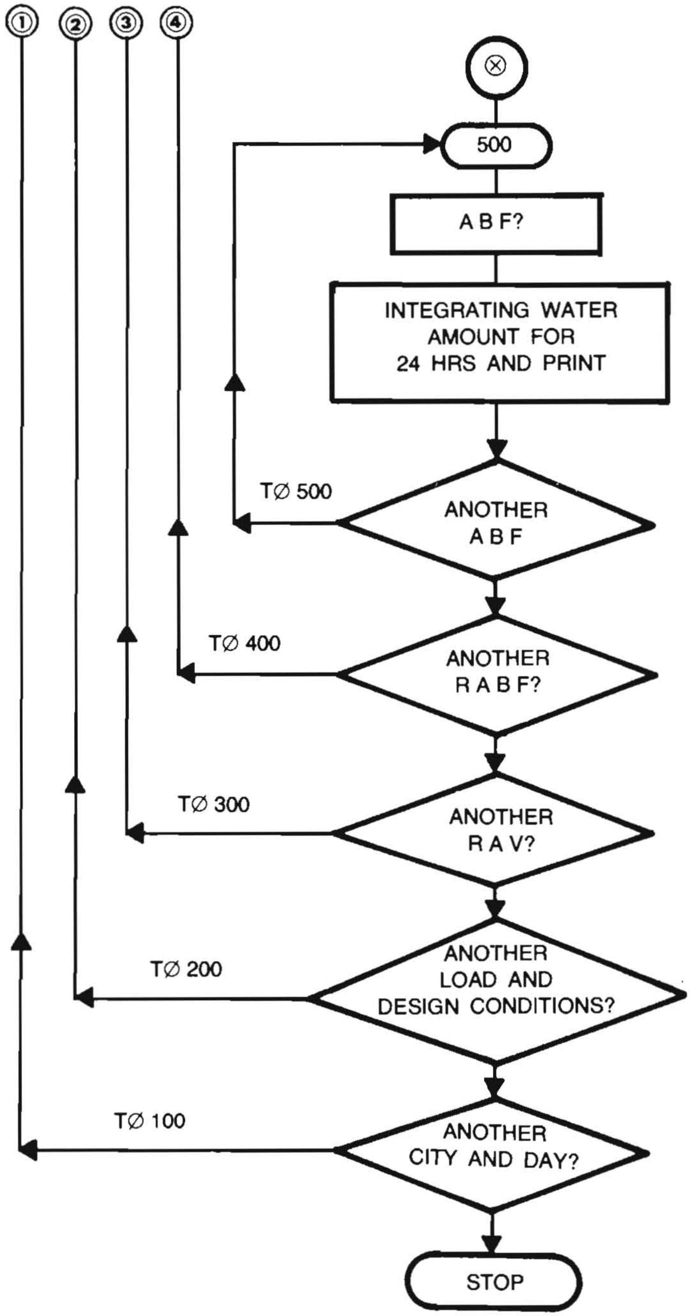


Fig. 3. Computer Program

Results and Conclusion

The water collected for 1000 cfm of air cooled thru the coil has been calculated. Weather data for Jeddah and Dhahran were taken from Stations No. 477 and Station No. 416 by UPM. The results are displayed in Figs. 4-13, in which a sample from a typical year around data for Jeddah and Dhahran have been used, namely, 15 of May,14, 15 of June, 18 of July and 12 of August 1977 (These dates are arbitrarily chosen). The dry bulb-, wet bulb-temperatures, relative humidity and weight of collected water are displayed hour by hour for a day, which reflects the influence of each parameter. The similarity between wet bulb temperature and the collected water curves is obvious in all curves. The total water collected per day per 1000 cfm of air going through the coil is given on each curve.

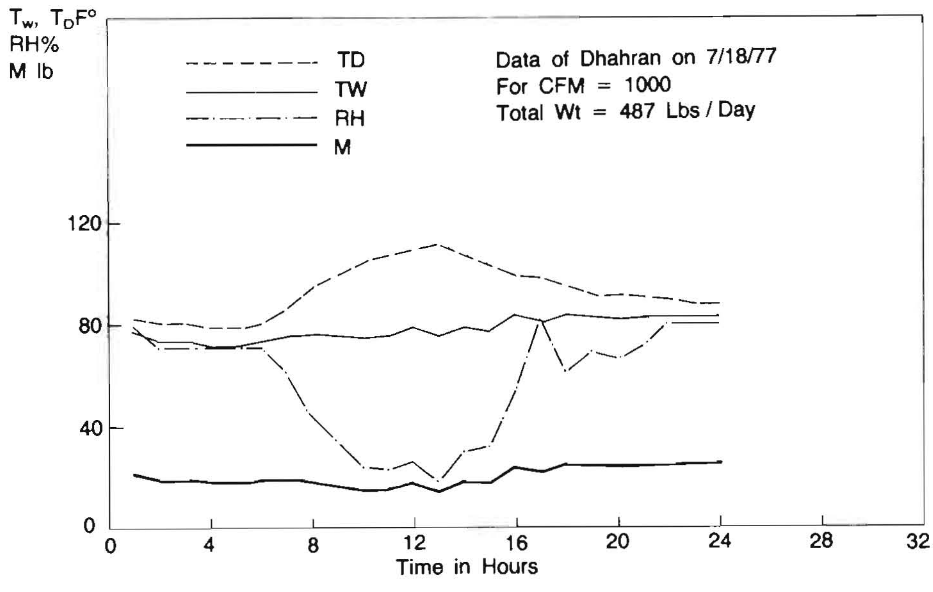


Fig. 4. → 13. Typical data (T_w, T_D in F° and RH%) with the calculated water collected in lbs.

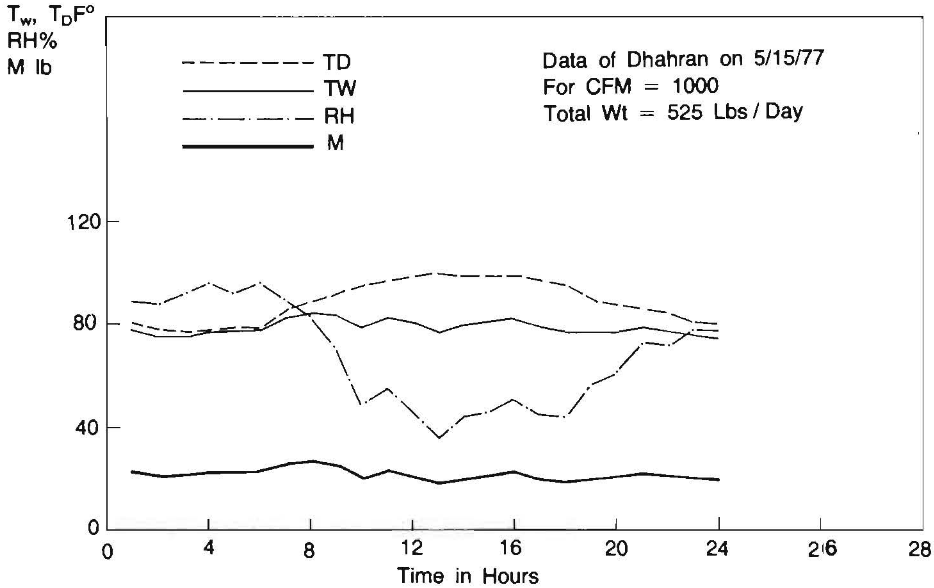

Tw, TDF°
RH%
M lb
TD
TW
RH
M
Data of Dhahran on 5/15/77
For CFM = 1000
Total Wt = 525 Lbs / Day
120
80
40
0
0
4
8
12
16
20
24
26
28
Time in Hours

Fig. 5.

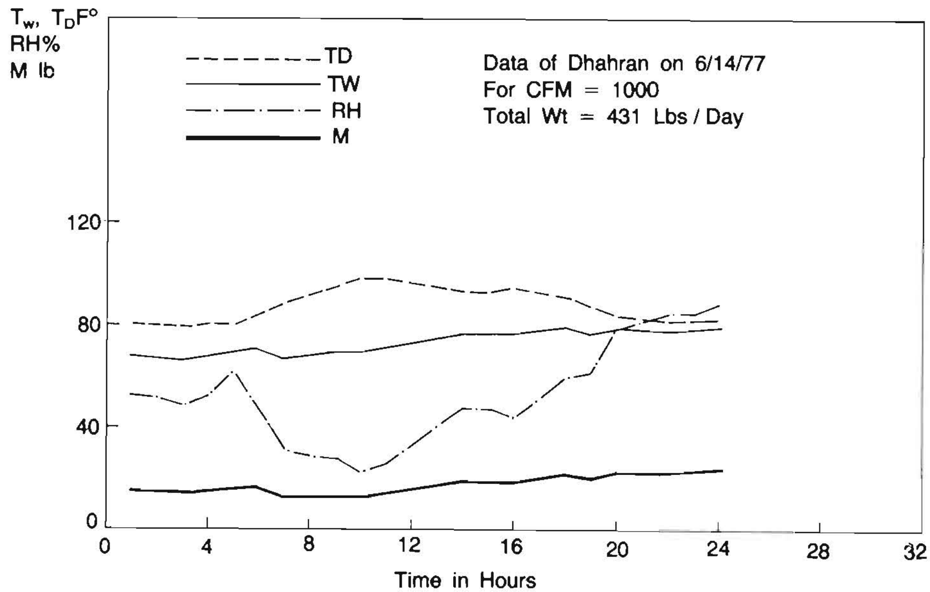

Tw, TDF°
RH%
M lb
TD
TW
RH
M
Data of Dhahran on 6/14/77
For CFM = 1000
Total Wt = 431 Lbs / Day
120
80
40
0
0
4
8
12
16
20
24
28
32
Time in Hours

Fig. 6.

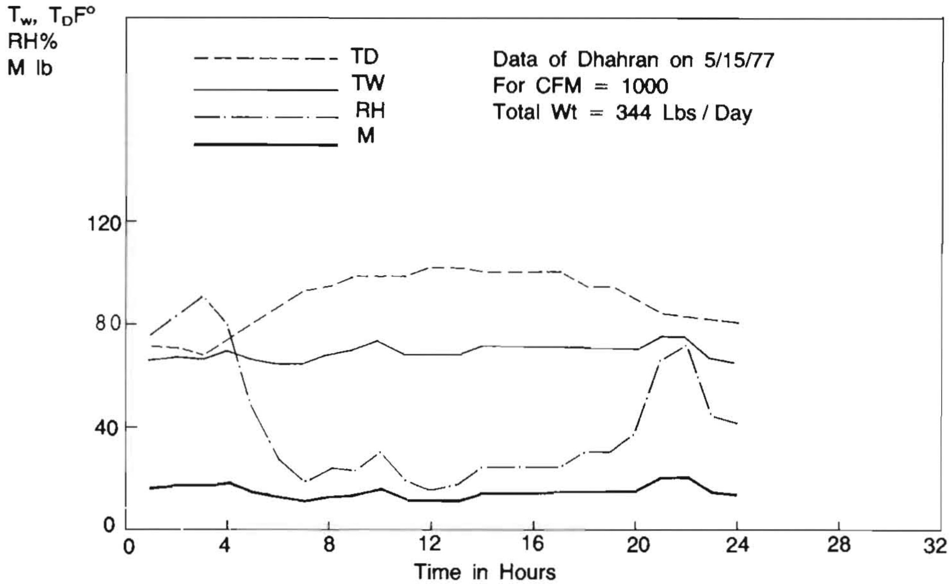

Tw, TDF°
RH%
M lb
TD
TW
RH
M
Data of Dhahran on 5/15/77
For CFM = 1000
Total Wt = 344 Lbs / Day
120
80
40
0
0 4 8 12 16 20 24 28 32
Time in Hours

Fig. 7.

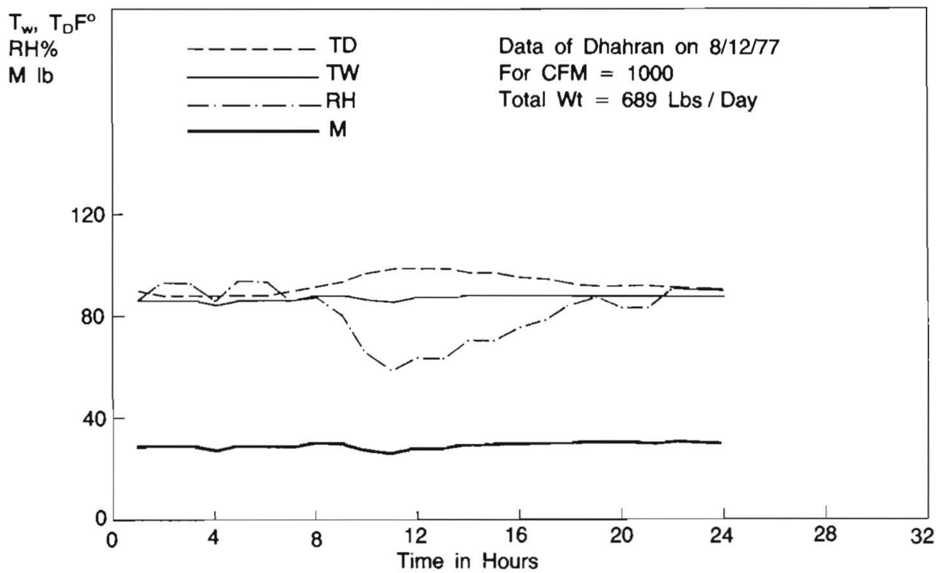
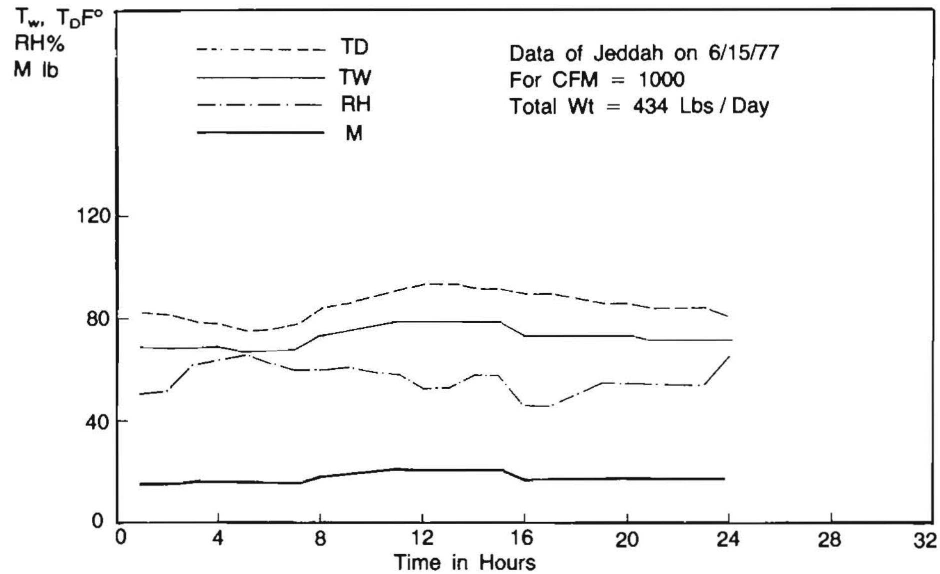
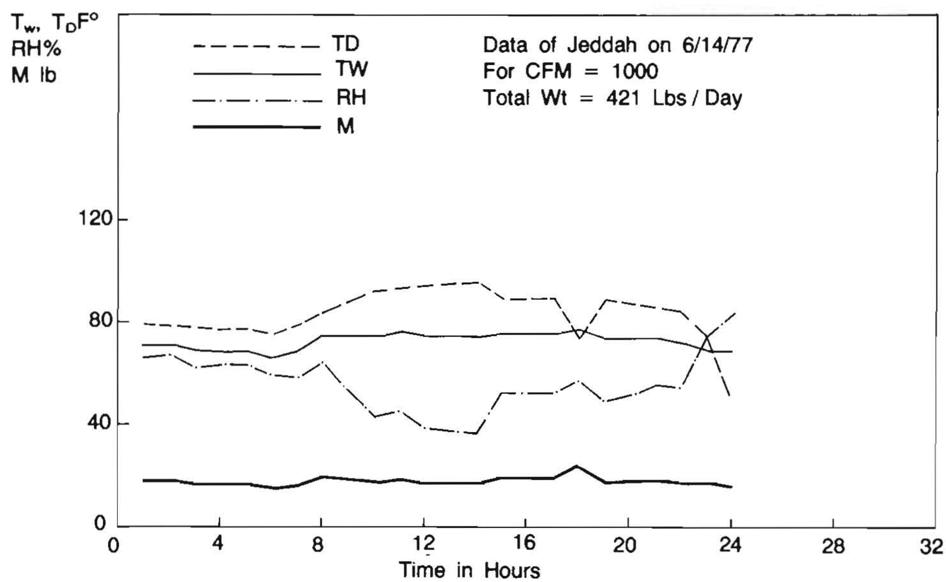

Tw, TDF°
RH%
M lb
TD
TW
RH
M
Data of Dhahran on 8/12/77
For CFM = 1000
Total Wt = 689 Lbs / Day
120
80
40
0
0 4 8 12 16 20 24 28 32
Time in Hours

Fig. 8.



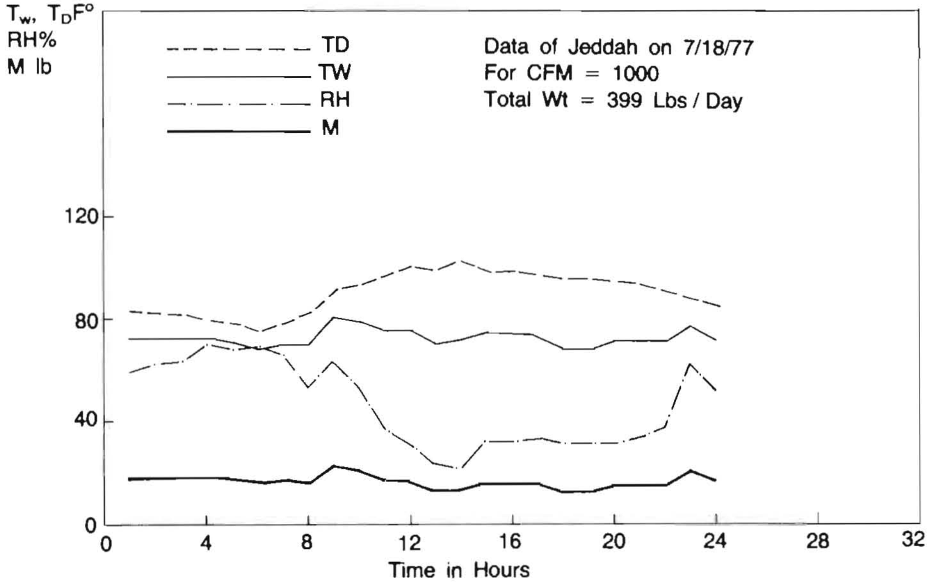
T_w, T_DF°
RH%
M lb
TD
TW
RH
M
Data of Jeddah on 6/15/77
For CFM = 1000
Total Wt = 434 Lbs / Day
120
80
40
0
0
4
8
12
16
20
24
28
32
Time in Hours

Fig. 9.



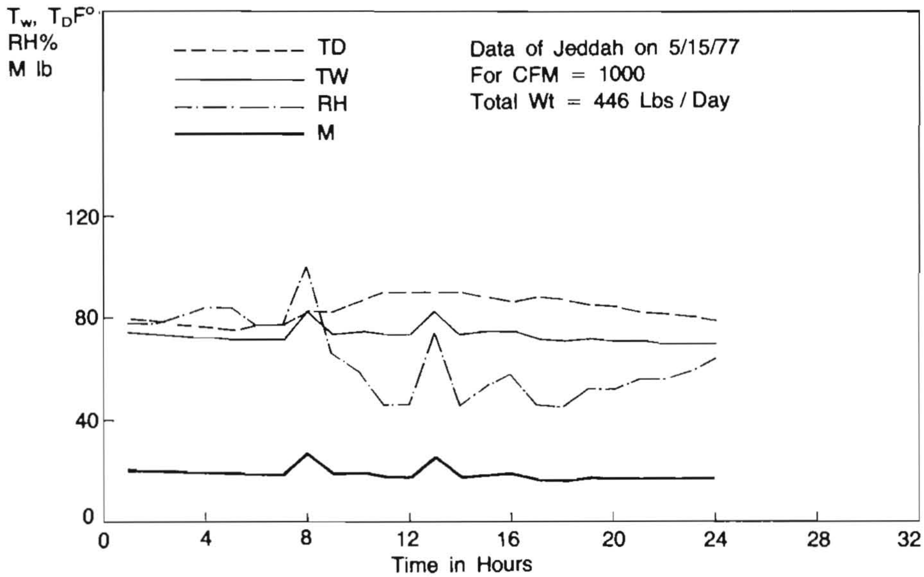
T_w, T_DF°
RH%
M lb
TD
TW
RH
M
Data of Jeddah on 6/14/77
For CFM = 1000
Total Wt = 421 Lbs / Day
120
80
40
0
0
4
8
12
16
20
24
28
32
Time in Hours

Fig. 10.



T_w, T_DF°
RH%
M lb
TD
TW
RH
M
Data of Jeddah on 7/18/77
For CFM = 1000
Total Wt = 399 Lbs / Day
120
80
40
0
0
4
8
12
16
20
24
28
32
Time in Hours

Fig. 11.



T_w, T_DF°
RH%
M lb
TD
TW
RH
M
Data of Jeddah on 5/15/77
For CFM = 1000
Total Wt = 446 Lbs / Day
120
80
40
0
0
4
8
12
16
20
24
28
32
Time in Hours

Fig. 12.

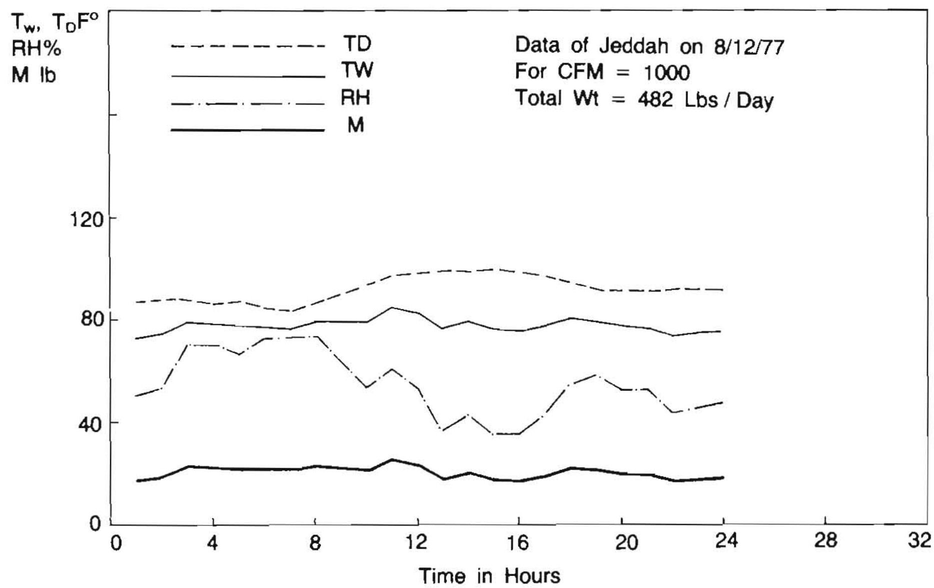


Fig. 13.

Now, for a three storey school building (360 students) the required supply air V_{sa} is 36000 cfm. Assuming return air ventilation ratio (RAV) of 10% and return air by-pass factor of 20% the air going through the cooling coil is 2880 cfm, which produces a daily water collection of 1300 lb in Jeddah on 12 August 1977. In Dhahran on the same day the water collected of amounts to 1990 lb. Moreover, this amount of water collected is cooled enough to be supplied as drinking water after adding some salts to it.

We may conclude that this method of water collection is very adequate and may be recommended for large central air conditioning systems located in hot and humid environments typical of the Gulf area conditions.

Abbreviations and Symbols

Abbreviations

ABF : Apparatus by-pass factor.
adp : Apparatus dewpoint temperature.
ERSHF : Effective room sensible heat factor.
GSHF : Grand sensible heat factor.

OALH	:	Outdoor air latent heat.
OASH	:	Outdoor air sensible heat.
RABF	:	Return air by-pass factor.
RAV	:	Return air ventilation ratio.
RLH	:	Room latent heat.
RSH	:	Room sensible heat.
RSHF	:	Room sensible heat factor.
TLH	:	Total latent heat.
TSH	:	Total sensible heat.

Symbols

Cp_a	:	Moist air specific heat.
h	:	Enthalpy of wet air.
M	:	Condensed water quantity.
t	:	Air dry bulb temperature.
v	:	Specific volume of moist air.
V_{da}	:	Dehumidified air quantity.
V_{Oa}	:	Outdoor air quantity.
V_{sa}	:	Supply air quantity.
V_{ra}	:	Return air quantity.
W	:	Air moisture content.
1,2..5	:	Air state point on the psychrometric chart Fig. 1.

References

Al-Gwaiz, A.A. (1981) The water resources of Saudi Arabia, *Proced. Solar Desalination Workshop,* Denver, Colorado, U.S.A., pp. 41-53.

ASHRAE (1985) *Handbook of Fundamentals,* New York, U.S.A.

Data Collected by UPM, Station No. 477 and 416.

Carrier Corp. (1965) *Handbook of Air Conditioning System Design,* by Carrier Corp. McGraw Hill, New York, U.S.A.

Sofrata, H. (1981) Non-Conventional System for Water Collection, *Proc. Solar Desalination Workshop, Denever, Colorado, U.S.A. pp. 71-87.*

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طريقة جديدة للاستفادة من المياه المتكثفة على ملفات التبريد في وحدات تكييف الهواء المركزي

حامد صفراطة

قسم الهندسة الميكانيكية ـ كلية الهندسة ـ جامعة الملك سعود

الرياض ـ المملكة العربية السعودية

ان محطات التكييف المركزي في الأجواء الحارة ذات الرطوبة العالية تمثل مصدراً من مصادر المياه ذات النقاوة العالية إذا أحسن الاستفادة منها. ان دول مجلس التعاون تعتبر مثالاً حيا لمثل هذه التطبيقات حيث تتوفر الشروط المطلوبة من الرطوبة المرتفعة والمباني العملاقة ذات التكييف المركزي.

ان بخار الماء المتكثف على ملفات التبريد يمكن جمعه بسهولة ومعالجته ليكون ماءاً عذبا بارداً وصالحاً للشرب.

ان النظام المقترح للقيام بالمهمة السابقة يمكن توصيفه كالتالي:

- يتم تقسيم الهواء الراجع إلى ملف التبريد إلى تيارين.
- التيار الأول يتم خلطه بالهواء النقي من خارج المبنى ثم يتم إدخال الخليط على ملف تبريد ذي درجة حرارة ندى منخفضة جدا وذلك لتكثيف أكبر قدر ممكن من الرطوبة.
- يتم اضافة هذا الخليط البارد والجاف للتيار الثاني من الهواء الراجع والذي تم فصله قبل ذلك بحيث يكون الخليط الناشيء في حالة درجة الحرارة والرطوبة المناسبة للمكان المراد تكييفه.

وقد تم استعراض طريقة في البحث باستخدام حزمة برامج على الحاسب الالكتروني الشخصي لتحديد كمية بخار الماء المتكثفة بالنسبة ١٠٠٠ قدم مكعب في الدقيقة وذلك على مدار الأربعة والعشرين ساعة وذلك لمدينتي جدة والظهران في المملكة العربية السعودية لأيام مختارة على طوال العام.

كما يعرض البحث لمبنى مدرسة ثانوية لحساب كمية الماء المتكثفة والتي ثبت أنها تكفي لامداد الطلاب بماء نقي بارد صالح للشرب.