FEASIBILITY OF DEHUMIDIFIERS FOR AIR-COMFORT AND STORAGE APPLICATIONS IN NIGERIA

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ABSTRACT

The use of a dehumidifier as a home appliance was advertised in one of the dailies. To investigate the feasibility of using dehumidifiers in Nigeria, fifteen-year dry - bulb temperature and relative humidity data for Ikeja and Ilorin were analysed to get the two-dimensional dry-bulb temperature/relative humidity data for the two locations. From the results, the average number of hours per year in the comfort zone defined by American Society of Heating, Refrigerating and Air- Conditioning Engineers (ASHRAE) were found to be 182 and 1177 for Ikeja and Ilorin, respectively. It was also found that using a dehumidifier that takes the room air through only a dehumidification process (dry-bulb temperature remaining constant) to bring the relative humidity below 70% can bring additional 76% and 58% of the 8766 hours in a year into the comfort zone at Ikeja and Ilorin, respectively. Taking the results of Ikeja as representative of coastal areas and Ilorin to be representative of locations further from the coast in the rest of southern states and parts of the middle -belt, it can be concluded that the use of dehumidifiers is feasible for air - comfort in the southern states and southern part of the middle-belt in Nigeria. Dehumidifiers can also be used to bring relative humidity below 65% required for grain storage even in the coastal areas. Therefore, a dehumidifier is a useful household appliance in the southern and middle-belt states.

1. INTRODUCTION

Dehumidification is a process used in air conditioning and the process industry in which air or other gases containing water vapour are subjected:-

i. to cooling below their dew point so that part of the water vapour is condensed and separated from the gas; or

ii. to the action of chemical desiccants which absorb moisture from the gas.

Processes (i) and (ii) above are illustrated as 1-2-3-4 and 1-5 figure 1 respectively. In Figure 1, the air reaches the dew point at 2, moisture is condensed from the air during 2-3 and the air is reheated to its original dry-bulb temperature during 3-4. The chemical dehumidification process 1-5 can be regarded as an adiabatic process and so it proceeds along a line of constant enthalpy. The dry-bulb temperature of the gas therefore rises.

In many applications, the removal of moisture from air is an essential part of air conditioning. For instance, Woods [1] has noted that control of moisture content for ambient air may be more important than temperature control from warehouse storage of materials subject to rust or mildrew damage, manufacturing processes and laboratory testing involving hygroscopic materials.

Different types of dehumidifiers have been developed for air comfort and industrial applications. A refrigeration dehumidifier which operates with process (i) above is a small hermetic refrigerating system that has both condenser and evaporator in a cabinet. Air is drawn over the cold surface of the evaporator coils to condense water vapour out of it and the air is then moved over the condenser coil to reheat it to a reasonable relative humidity. The condensate is collected in a container or a drain tube carries it off. This type of dehumidifier is commonly used in the home in damp places such as basements [2]. This type of dehumidifier is also often incorporated in air compressors as dryers so that the problem of condensed water in the lines supplying air to machine tools can be prevented.

An absorption dehumidifier operates on process (ii) above. This type of dehumidifier which is rarely found in residence is commonly used in commercial and industrial installations [3].

A spray dehumidifier operates by means of an air washer. The air bought in contact with the water spray from the nozzles is dehumidified if the temperature of the spray water is lower than the drew point of the air. Refrigerated water is mixed from the air washer sump before it is pumped to the spray nozzles [3].

Three factors which most directly effects human comfort are dry-bulb temperature, relative humidity and air motion. From studies carried out in U. S. A. on subjects who were asked to assess the warmth in a climate chamber, comfort chart and the concept of effective temperature were developed. Effective temperature lines on wet-bulb temperature versus dry-bulb axes of comfort chart are lines joining different combinations of dry-bulb temperature and relative humidity which give the same the feeling of comfort to a high percentage of people equally clothed and equally active, for a given air velocity (0.0762 - 0.1270m/s for the comfort chart for still air).

The comfort zone in the chart as defined by the American Society of Heating, Refrigerating and Air-Conditioning Engineering (ASHRAE) is between effective temperatures of 17.2°C and 23.9°C. The dry-bulb temperature and the relative humidity of the four corners of the comfort zone are:- 18.3°C/70%, 25.7°C/70%, 19.8°C/30%, and 29.2°C/30%[4, 5].

It has been recognised for several decades that fungi are responsible for heavy post-harvest losses in stored grains. The degree of damage caused by fungi depends on the conditions maintained during storage. It has been found that grain that is sound and in good condition when harvested can be kept in good condition by keeping it at a moisture content in equilibrium with air having relative humidity of 65% or below, which is too low for fungi to grow [6].

In places having tropical climate where ambient dry-bulb temperature and relative humidity are high, storage of cereal grains is very difficult because prevailing conditions, which favour the development of insect pest and moulds, are likely to lead to the deterioration of the grains.

Being a hygroscopic medium, grains absorbs and desorbs moisture with the liberation and absorption of heat respectively, depending on the moisture content of the grain and the relative humidity of surrounding air.

Thorpe [7] found that it is often possible to use ambient air for drying paddy without supplementary heating in Sri Lanka since the main requirement is that the relative humidity of the air used for drying should be less than 70%. For a grain bed of 1.5m depth, the energy required to drive fan blowing ambient air at 27.8°C and relative humidity of 70%, for drying paddy having a moisture content of 22% (wet basis) to a moisture content of 12.6% (wet basis) in 48 hours was calculated to be 59kWh per tonne of grain.

Using dehumidifier can move room conditions that are outside the thermal comfort zone to within the comfort zone. It can also reduce the relative humidity in very damp environment and thereby prevent some materials there from getting mouldy. One of the household appliances recently introduced into the Nigerian Market is dehumidifiers (see page 24 of THE GUARDIAN of June 2, 1997). In this paper, the possibility of using dehumidifiers to make room air comfortable or to make it conducive for storage of grain is investigated for Ikeja and Ilorin.

2. ANALYSIS OF WEATHER DATA

Hourly dry-bulb temperature and relative humidity data for Ikeja and Ilorin for fifteen years (1978 - 1992) were obtained from the Nigerian Meteorological Services, Oshodi, Lagos. The dry-bulb temperature data for each month of the year, for each city were stored on file for all the 15 years. The relative humidity records were stored in a similar manner. Thus, there were twelve files for dry-bulb temperature data and twelve files for relative humidity data for each of the two cities, for the twelve months of the year.

For each month of the year, two-dimensional bin data were compiled for each city using bin width of 1°C for dry-bulb temperature and 5% for relative humidity. The results for the twelve months were added to get the results shown in Figures 2 and 3 for Ikeja and Ilorin. The number in each cell shows the average number of hours per year that the dry - bulb temperature bin coincides with the relative humidity bin over the fifteen - year period. Thus, the two - dimensional dry-bulb temperature/relative humidity bin data shows the coincidence and distribution of temperature and relative humidity. This information is sometimes required for accurate estimation of building cooling load.

The average number of hours in the year in which the weather lies in the comfort zone for each location is the summation of the hours enclosed by the quadrilaterals which can be formed by joining the points marked with x in Figures 2 and 3. For ease of computation however, it is the summation of the hours enclosed by the rectangles shown with broken lines in Figures 2 and 3 that were found.

From the monthly relative humidity bin data compiled for Ikeja and Ilorin were obtained the data in Table 1 showing the average number of hours that relative humidity is less than 70% for the months of the year. It is during these hours that ambient air without supplementary heating, can be blown through a bed of grain to dry it.

3. DISCUSSION OF RESULTS

Each of the two-dimensional bin data shown in Figures 2 and 3 is actually a combination of dry-bulb temperature bin data and relative humidity bin data in one table. Adding hours in a row gives the average number of hours in a year that the relative humidity falls in that bin. If the total number of hours in each row is divided by the number of hours in a year (8766) and the result is further divided by the bin width (5% in this case) then we obtain the value of probability density for that bin. Similarly, adding the hours in a column gives the average number of hours the dry-bulb temperature in a similar manner to that of relative humidity.

For Ikeja, the modal bin for dry-bulb temperature is 25-26°C and temperature falls into this bin 14.9% of the hours in a year, on the average. The modal bin for relative humidity is 90 - 95% and relative humidity falls into that bin 27.5% of the hours in a year on the average. The intersection of the mode of the two - dimensional bin data.

For Ilorin, the modal bin for dry-bulb temperature is 23-24°C and its fractional frequency of occurrence is 11.8% on the average; whereas the modal bin for relative humidity is 90-95% but with a fractional frequency of occurrence of 15.2% on the average.

The number of hours in the comfort zone for Ikeja and Ilorin are 182 and 1177 hours in a year, respectively. These represent 2.1% and 13.4% of the 8766 hours in a year, respectively. From this result, it can be seen that the number of hours in the comfort zone for a coastal location is fewer than that for a town far from the coast despite the smaller temperature range and lower mean temperature for the coastal location. The higher atmospheric humidity in a coastal location is what causes the lower number of hours in the comfort zone.

The hours in the cells above the comfort zone rectangles, i.e. relative humidity range 70 - 100% and dry - bulb temperature range 18-29°C, are the hours that can be brought into the comfort zone if a dehumidifier just brings the relative humidity to below 70% while leaving the dry-bulb temperature unaffected. The hours in these cells for various relative humidity bins for Ikeja and Ilorin are shown in Table II.

For Ikeja and Ilorin, the total number of hours per year that can be brought into the comfort zone are 6678 and 5096, which are 76% and 58% of the total number of hours in a year, respectively. Adding the percentages of the hours in the comfort zone to these give 78% and 71% respectively.

For the case of grain storage for which it is desirable to keep the relative humidity below 65%, the average number of hours per year for which relative humidity is above 65% are 7964 and 5803 for Ikeja and Ilorin respectively.

These results show that the operating cost of dehumidifiers for air-comfort and grain storage applications would be much higher at Lagos than at Ilorin. However, these results also show that all that is needed to condition room air and ensure that more than 70% of the hours in the year are in the comfort zone for Ikeja and Ilorin is using dehumidifiers. Since the refrigerating unit in the dehumidifier is much smaller than that of a room unit air conditioner of appropriate capacity, the running cost of the dehumidifier is much smaller than that of the room unit air conditioner. Thus, air-comfort can be achieved with lower initial and running costs by using dehumidifiers.

Apart from the advantages of lower initial and operating costs, there are some other advantages in using dehumidifiers over the conventional room unit air conditioners. Dehumidifiers are much easier to install. If the wall is broken at all, it is to allow the drain pipe for the condensate to pass through. In some cases, a container is used to collect the condensate. Dehumidifiers that use a container to collect the condensate are equipped with an integral switch to turn off the unit when the container is full to avoid overflow of the condensate(3). Since dehumidifiers do not cool room air, there will be no problem of "thermal shock" which is experienced on entering or going out of space which is very much warmer or cooler than ambient temperature.

The disadvantage of using dehumidifiers is that it cannot lower room temperature even if sources of considerable sensible heat are present such as machines and several people in the room.

As can be seen in Table 1, the number of hours in the month during which relative humidity is less than 70% [when ambient air can be used for drying grains without supplementary heating (7)] are high during the dry season from November to April, particularly at Ilorin. These hours add up to 1322.9 and 3586.9 which constitute 15.1% and 40.9% of the hours in the year at Ikeja and Ilorin, respectively. During these hours, a dehumidifier can be used in grain dryers to achieve faster rates of drying. A plenum chamber can be supplied air using a dehumidifier. If the grain dryer takes all the air flowing through it from the plenum chamber , a faster rate of drying can be achieved than if the dryer takes in ambient air directly. If drying is to be during the hours when relative humidity is greater than 70% without heating the air, the use of dehumidifiers as described above would be inevitable if a reasonable fast rate of drying is to be accomplished. Chemical dehumidifiers are particularly suitable for dryers since the air undergoes an isenthalpic process in them, causing it to warm up appreciably.

In the discussions on air- comfort application of dehumidifiers, it has been assumed that the temperature of the air coming into the dehumidifier is the same as the temperature of the air going out. This assumption is supported by the claim of a manufacturer of a brand of dehumidifier. The PHILCO dehumidifier is said to return dried air to the room at its original temperature (8).

The discussions presented in this paper have been based on results obtained for two weather data location, for economic reasons. Many pages of weather data had to be photocopied and it took several hundreds of hours to manually input the fifteen-year weather data for the two locations on the computer. Efforts are being made to extend this study to other weather data locations scattered all over the country. However, conclusions drawn from results obtained for Ikeja can be assumed to apply to towns in the coastal area of the country while results for Ilorin give us an idea of what obtains in towns in southern states further away from the coast and towns in the southern part of middle belt. Since the weather is generally drier and hotter in the northern part of the country, one should think of using evaporative cooling/ humidifiers in such places rather than dehumidifiers.

The operation of a dehumidifier is controlled by a humidistat which switches the compressor and the unit fan on and off in response to changes in moisture content of the air. For maximum effectiveness, Brumbaugh(3) has suggested a dehumidifier should be placed as close to the centre of the room as possible so that good air circulation can take place.

The comfort zone used in this work is that defined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) for people living in the temperate zone. If a similar study is done in the tropics, it may lead to the definition of a warmer comfort zone in the comfort chart for people who have acclimatized to the tropical climate. Woods [1] mentioned clothing and previous conditioning among the factors that establish psychrometric limits for comfort for an individual.

4. CONCLUSIONS

It is feasible to use dehumidifiers in Nigeria since the use of dehumidifiers can help to bring the condition of room air to the comfort zone for as much as extra 76% of the hours in a year in the coastal areas and by as much as extra 58% in locations as far away from the coast as Ilorin.

Dehumidifier can also be used to keep storage space for grains below the required 65% relative humidity even in coastal areas. However, the operating cost is expected to be highest at the coast and reduce as one goes farther away from the coast.

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REFERENCES

1. **Woods, B. D.**, Applications of Thermodynamics, Addison-Wesley Publishing Co., Inc., Reading, 1982.
2. **Althouse, A. D., Turnquist, C. H. and Bracciano, A. F.** Modern Refrigeration and Air conditioning, The Goodheart Wilcox company, Inc., South Holland, Illinois, 1982.
3. **Brumbaugh, J. E.** Heating, Ventilating and Air conditioning Library, Volume III, The Bobbs - Merril Co. Inc., New York, 1983.
4. **Harris, N. C.** Modern Air Conditioning Practice, McGraw-Hill Book company, New York, 1983.
5. **Billington, N. S. and Robert, B. M.** Building Services Engineering: A Review of its Development, Pergamon Press, Oxford, 1982.
6. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. "Physiological Factors in Drying and Storing Farm Crops", chapter 10 in ASHRAE Hand book 1977, Fundamentals, New York, 1978.
7. **Thorpe, G. R.** "Energy Requirements for the cooling and In - store Drying of Cereal Grains in Sri Lanka", Int. Journal for Development Tech. Vol.4,pp.283 - 292, 1986.
8. **PHILCO International Company, "PHILCO Dehumidifiers", Pittsburgh, Pennsylvania, U. S. A.** (obtained from NEVERFAIL INDUSTRIES LTD., Ikoyi, Lagos on July 15 1997).

TABLE 1

NUMBER OF HOURS IN THE MONTH HAVING RELATIVE HUMIDITY LESS THAN 70% AT IKEJA AND ILORIN

MONTH OF THE YEAR	IKEJA	ILORIN
JANUARY	238.1	580.2
FEBRUARY	204.5	487.3
MARCH	189.3	429.4
APRIL	162.0	308.0
MAY	91.7	223.8
JUNE	31.9	158.1
JULY	17.5	106.9
AUGUST	37.3	87.2
SEPTEMBER	29.7	112.2
OCTOBER	49.2	199.0
NOVEMBER	96.1	374.2
DECEMBER	175.6	520.6
TOTAL	**1322.9**	**3586.9**

TABLE II

NUMBER OF HOURS IN THE YEAR THAT CAN BE BROUGHT INTO THE COMFORT ZONE BY DEHUMIDIFICATION PROCESS ONLY, FROM DIFFERENT RELATIVE HUMIDITY BINS FOR IKEJA AND ILORIN

RELATIVE HUMIDITY BIN, %	IKEJA	ILORIN
70-75	242.9	587.2
75-80	469.0	657.7
80-85	776.0	821.1
85-90	1187.8	988.3
90-95	2412.7	1328.0
95-100	1589.1	713.5
TOTAL	**6677.5**	**5095.8**

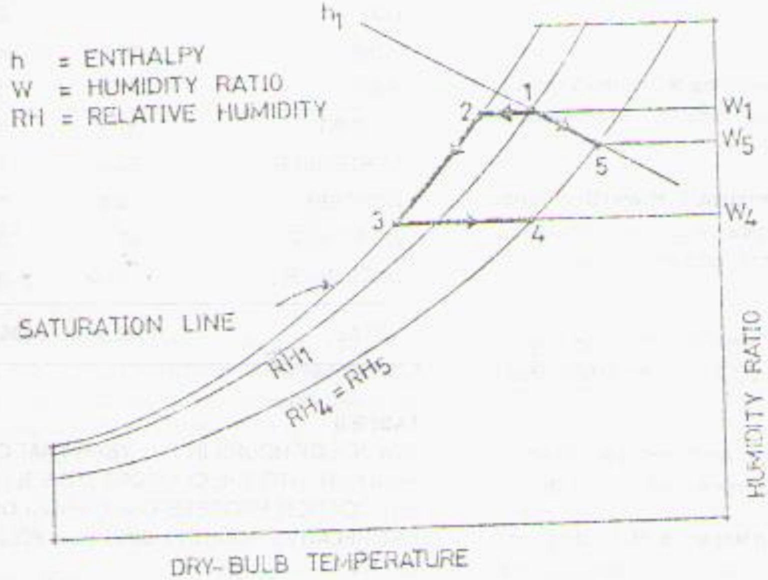

FIGURE 1 DEHUMIDIFICATION PROCESSES ILLUSTRATED ON A PSYCHROMETRIC CHART

FIGURE 2 ANNUAL DRY-BULB TEMPERATURE/RELATIVE HUMIDITY TWO-DIMENSIONAL BIN DATA FOR IKEJA

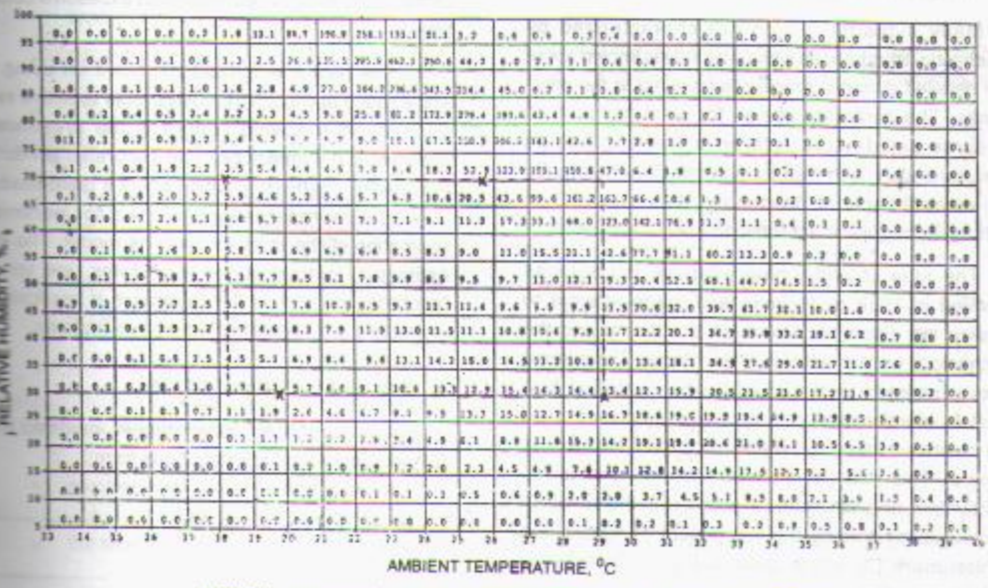

FIGURE 3 ANNUAL DRY-BULB TEMPERATURE/RELATIVE HUMIDITY TWO-DIMENSIONAL BIN DATA FOR ILORIN