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A Study of Humidity Variations in Canadian Houses

The temperature and humidity of the air in houses affects the comfort of the occupants and the performance of the building and furnishings. Very low humidity may have adverse physiological effects and may cause damage due to shrinkage of moisture-sensitive materials. Excessive humidity may result in objectionable condensation on windows and within the structure in winter and deterioration of materials due to high moisture content.

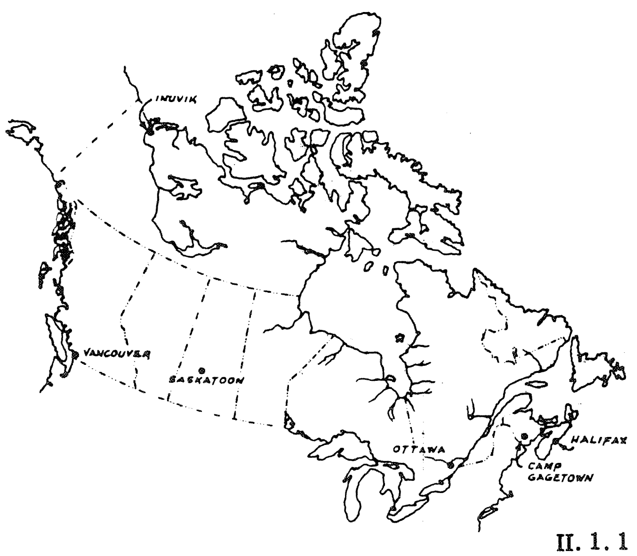
The humidity level in a house that has no automatic humidity control will depend on the natural balance between moisture gain and loss, due consideration being given to the effect of moisture storage. Moisture sources include the occupants and their household operations, humidifiers and, in some cases, soil moisture from basements or crawl spaces. The major loss of moisture will be by ventilation whenever the moisture content of the outside air is below that in the house. Some dehumidification may also occur through condensation on cold surfaces.

The rate of moisture production is primarily influenced by the number and habits of the occupants. The occupants may also influence the rate of moisture loss by ventilation through opening windows, but the air leakage characteristics of the house and the outside climate should be the main factors involved, especially during winter. The complexity and variability of these factors, however, make it extremely difficult to estimate the natural humidity levels in houses. Actual field measurements are therefore of value as a basis for evaluating factors that affect humidity and for predicting indoor climate.

Published information on the actual temperatures and humidities in residences in Canada is very limited. Surveys of some American homes have been made by the National Bureau of Standards[1] and by the Housing and Home Finance Agency,[2] but these results are not directly applicable to Canadian conditions. As a supplement to these data, this paper presents similar information on indoor conditions in Canadian houses which has been accumulated by members of the Div of Building Research, National Research Council, over a period from 1956 to 1961.

Records of temperature and humidity were first obtained by the Div in 1956, as part of a study of house heating systems in Camp Gagetown, New Brunswick. The following year a program was

Fig. 1 Location of survey sites



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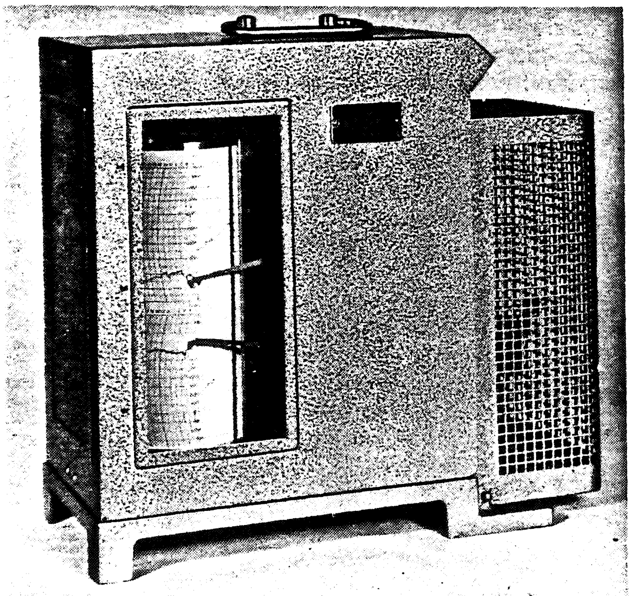


Fig. 2 Thermohygrograph

initiated to obtain more complete records of indoor climate in Ottawa, Ontario, and in Saskatoon, Saskatchewan, as well as some limited measurements in houses in Vancouver, British Columbia. This program subsequently included a study in Halifax, Nova Scotia, and some readings during the winter in buildings at Inuvik, Northwest Territories. The geographical location of these centers is shown in Fig. 1.

The only complete annual records obtained in this project were for houses in Ottawa, Saskatoon and Halifax. The extent of the measurements in other locations ranged from complete records for the heating season in Camp Gagetown to short-term records in Vancouver and Inuvik. These have been included as they provide some indication of the humidity levels in houses in other regions of Canada.

HOUSES AND INSTRUMENTATION

Pertinent details of the houses involved in Ottawa, Saskatoon and Halifax are listed in Table I. They were almost entirely single-family dwellings, with the majority having forced warm-air heating systems. The primary fuel used was oil in Ottawa and Halifax, and natural gas in Saskatoon. The Camp Gagetown units were single-family dwellings or doubles with separate heating systems, approximately half of which had oil-fired, gravity, warm-air systems, and half had coal-fired, hot-water systems. The Vancouver houses varied widely in type of construction and type of heating system, but one common feature was single-glazed windows. Two of the four homes at Inuvik were end units of a row housing development, one was a 1 1/2 story single-family home, and the fourth was a church hostel housing a varying number of persons. All were heated by forced hot water from a district heating system.

Continuous records of inside dbt and rh were obtained in the occupied space of each house using 7-day thermohygrographs, similar to the one shown in Fig. 2. This instrument uses strands of hair as the humidity sensing element and a bimetallic coil for a temperature sensor. Calibration of the thermohygrographs was carried out periodically using a battery-operated, aspirated psychrometer.

Efforts were made to place the instruments away from cold walls, windows, warm air registers and radiators, or radio and television sets. An attempt was also made to standardize the room location and height of the instrument above the floor, but this was not possible in all cases. It was believed, however, that the humidity ratio, as calculated from simultaneous temperature and rh records, could be assumed the same in all parts of the occupied space.

Values of outside temperature and rh were obtained from the Meteorological Div of the Dept of Transport for each of the centers involved. In the major cities, these measuring stations were located some distance from the houses under study, and microclimatic variations would be expected. For the purposes of this investigation, such differences were neglected.

RESULTS AND DISCUSSION

Daily average values of inside temperature and rh were estimated by visual examination of the chart records and were used to calculate weekly and monthly averages. Weather records of daily maximum and minimum air temperature and rh readings four times daily were used to obtain weekly and monthly averages of outside temperature and rh. Based on this information, the weekly average inside and outside humidity ratios were calculated and were plotted with the inside and outside temperature, Figs. 3 to 7, for the houses in Ottawa, Saskatoon, Halifax, Camp Gagetown and Vancouver.

In the case of the Vancouver houses, the records of interior conditions are based on a series of measurements made in different houses as the instruments were moved periodically from one group of houses to the next throughout the season. At any given time, the plotted values are the average for from 2 to 5 houses.

It is apparent from the figures for Ottawa, Saskatoon and Halifax that the average indoor humidity ratio follows an annual cycle from a minimum in winter to a maximum in summer, corresponding to a similar cycle in outdoor humidity ratio. A rough correlation also exists between the weekly variations in average indoor and outdoor humidity ratio. The general similarity between the two curves indicates the influence of air infiltration on the indoor humidity level, but the fact that the difference between indoor and outdoor humidity ratio changes throughout the year is of some interest.

With a constant rate of air exchange throughout the year, and with a constant average rate of moisture production in a house, the difference between inside and outside humidity ratio should remain the same. That this difference actually decreases from winter to summer suggests that the rate of air leakage increases or the rate of interior moisture

Table I. Details of Houses

House No.	Location	Stories	Age yr	Foundation	Walls: Structure	Walls: Exterior	Area sq ft	Heating: Fuel	Heating: System*	No. Occupants	Humidifier	Clothes drying
1	Ottawa	1-1/2	10	Basement	Frame	Wood	1040	Oil	FWA	2	Pan	Basement
2	Ottawa	1-1/2	5	Basement	Frame	Wood	1400	Oil	FWA	6	Pan-Plate	Basement
3	Ottawa	1-1/2	3	Basement	Frame	Brick	1260	Oil	FWA	4	Pan-Plate	Basement
4	Ottawa	1	2	Basement	Frame	Brick	1200	Oil	FWA	3	Pan	Vented
5	Ottawa	1	3	Basement	Frame	Brick	1200	Oil	FWA	4	Nozzle	Basement
6	Ottawa	1	5	Basement	Frame	Wood	1200	Oil	FWA	5	Pan-Plate	Basement
7	Ottawa	1	3	Basement	Frame	Brick	1000	Oil	FWA	3	Pan	Basement
8	Ottawa	1	3	Basement	Frame	Brick	1000	Oil	FWA	4	None	Basement
9	Ottawa	2	11	Basement	Frame	Brick	1790	Oil	FWA	2	Pan	Basement
10	Ottawa	2-1/2	33	Basement	Frame	Brick	1820	Oil	GWA	6	Pan	Basement
11	Ottawa	2-1/2	55	Basement	Brick	Brick	2860	Oil	GHW	5	Cabinet	Basement
12	Ottawa	1	6	Slab	Frame	Wood	1370	Oil	FHWP	5	None	Utility room
13	Ottawa	1	7	Slab	Frame	Wood	1870	Oil	FHWP	6	None	Furnace room
14	Saskatoon	1	4	Basement	Frame	Wood	1100	Gas	FWA	3	Pan-Plate	Vented
15	Saskatoon	Split	5	Basement	Frame	Stucco	1130	Gas	FWA	6	Pan-Plate	Vented
16	Saskatoon	1	2	Basement	Frame	Stucco	960	Gas	FWA	4	Pan-Plate	Basement
17	Saskatoon	1	4	Basement	Frame	Stucco	1000	Gas	FWA	5	Pan-Plate	Basement
18	Saskatoon	1-1/2	12	Basement	Frame	Asbestos Shingle	800	Gas	GWA	5	None	Vented
19	Saskatoon	1-1/2	12	Crawl Space	Frame	Wood	1050	Gas	SH	3	None	Porch
20	Saskatoon	1-1/2	12	Crawl Space	Frame	Wood	1050	Gas	FWA	3	Pan-Plate	Porch
21	Saskatoon	1	4	Basement	Frame	Wood	800	Gas	FWA	4	Pan-Plate	Vented
22	Saskatoon	1	1	Basement	Frame	Stucco	1000	Gas	FWA	4	Pan-Plate	Basement
23	Saskatoon	1-1/2	8	Basement	Frame	Asbestos shingle	1050	Gas	GWA	5	Pan	Basement
24	Saskatoon	2	30	Basement	Frame	Stucco	1340	Gas	GHW	3	Cabinet	Basement
25	Saskatoon	1	1	Basement	Frame	Stucco	1200	Gas	FWA	7	Pan-Plate	Vented
26	Saskatoon	1	1	Basement	Frame	Stucco	1230	Gas	FWA	2	Pan-Plate	Basement
27	Saskatoon	1	1	Basement	Frame	Wood	1100	Gas	FWA	5	Pan-Plate	Basement
28	Saskatoon	1	3	Basement	Frame	Wood	1200	Gas	FWA	5	Pan-Plate	Basement
29	Saskatoon	1	1	Basement	Frame	Stucco	1100	Gas	FWA	4	Pan-Plate	Basement
30	Saskatoon	Split	4	Basement	Frame	Stucco	975	Gas	FWA	7	Pan-Plate	Basement
31	Saskatoon	1	4	Basement	Frame	Wood	1060	Gas	FWA	3	Pan-Plate	Vented
32	Saskatoon	Split	1	Basement	Frame	Wood	1100	Gas	FWA	4	Pan-Plate	Basement
33	Halifax	1	2	Basement	Frame	Wood	1620	Oil	FWA	6	Pan-Plate	Basement
34	Halifax	1	1	Crawl space	Frame	Wood	865	Oil	FWA	4	None	Utility room
35	Halifax	1	2	Crawl space	Frame	Wood	810	Oil	FWA	2	None	Utility room
36	Halifax	1-1/2	11	Basement	Frame	Wood	1323	Oil	FHW	4	None	Basement
37	Halifax	1	1	Crawl space	Frame	Wood	730	Oil	FWA	3	None	Utility room
38	Halifax	1	1	Slab	Concrete block	Concrete block	2630	Oil	FWAP	9	None	Vented
39	Halifax	1	2	Crawl space	Frame	Wood	810	Oil	FWA	4	None	Hall
40	Halifax	1-1/2	10	Basement	Frame	Wood	2113	Oil	FWA	6	Pan-Plate	Basement
41	Halifax	1	1	Slab	Frame	Wood	865	Oil	FWA	4	None	Utility room
42	Halifax	2	1	Basement	Frame	Wood	2038	Oil	FWA	6	None	Basement
43	Halifax	1	3	Basement	Frame	Wood	2400	Oil	FWA	3	Pan-Plate	Basement

* FHW = Forced hot water; FHWP = Forced hot water; panel; FWA = Forced warm air; FWAP = Forced warm air; panel; GWA = Gravity warm air; GHW = Gravity hot water; SH = Space heater

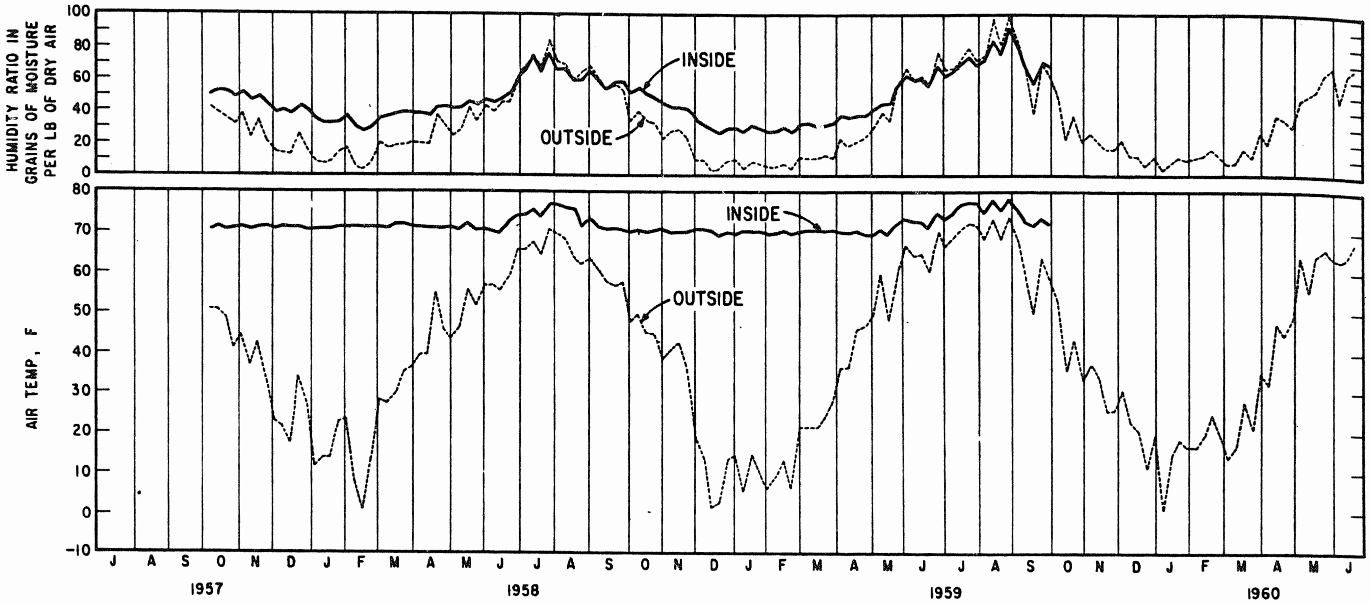


Fig. 3 Air temperatures and humidity ratios, Ottawa

production decreases. The Ottawa and Halifax records indicate, moreover, that at some time in summer the inside humidity ratio is actually less than that outside.

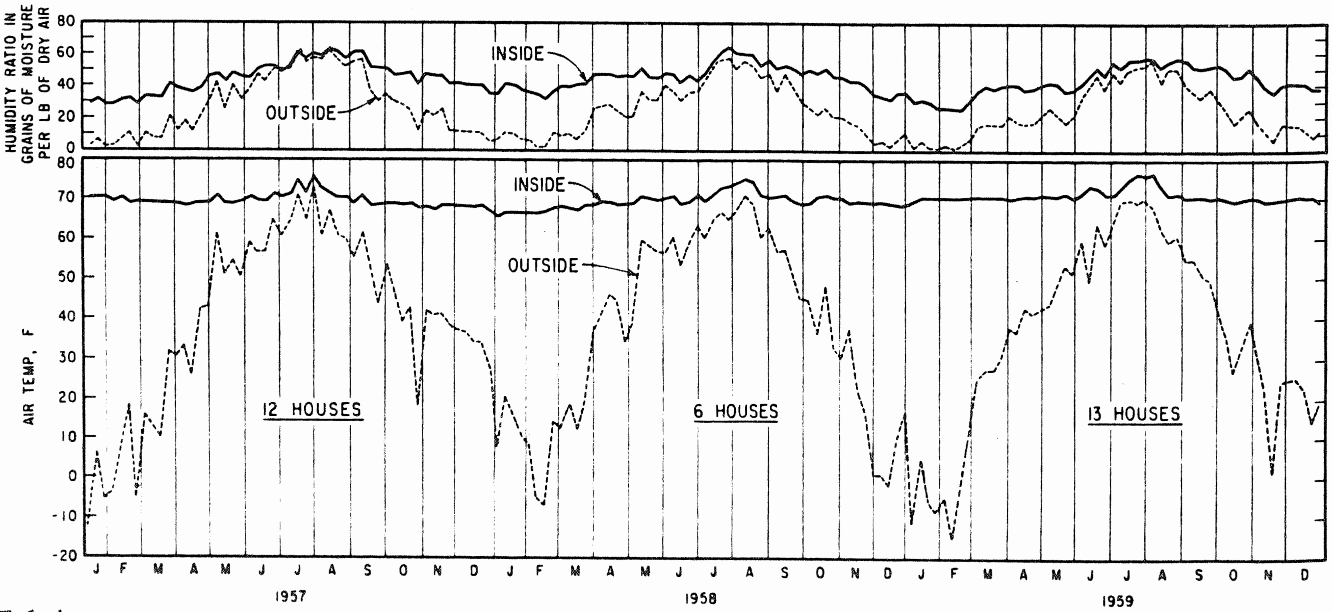
The pressure differences inducing air exchange are generally accepted as being due to wind and temperature difference, with the latter of decreasing significance in summer. It would appear, therefore, that any increase in ventilation rate during summer must be the result of increased intentional ventilation, unless much higher wind velocities prevailed. In the three locations in question, there is no significant difference in average wind speed between summer and winter.

The rate of moisture production in houses is largely a function of the living habits of the occupants. There seems to be no obvious reason why bathing, washing and housecleaning operations should change during the year. Humidifier operation will cease in summer, and a reduction in moisture-producing cooking operations and occupant load may occur in summer.

From the foregoing considerations, it seems probable that increased summer ventilation through opening of windows and doors is the primary reason why the humidity ratio curves approach each other during summer. The transposition of the humidity ratio curves in the Ottawa and Halifax measurements requires that some means of moisture removal other than ventilation must occur.

The maximum outside humidity ratio in Ottawa and Halifax reaches values above 55 grain/lb, corresponding to a dew point in excess of 62 F, while the peak in Saskatoon corresponds to a dew point

Fig. 4 Air temperatures and humidity ratios, Saskatoon



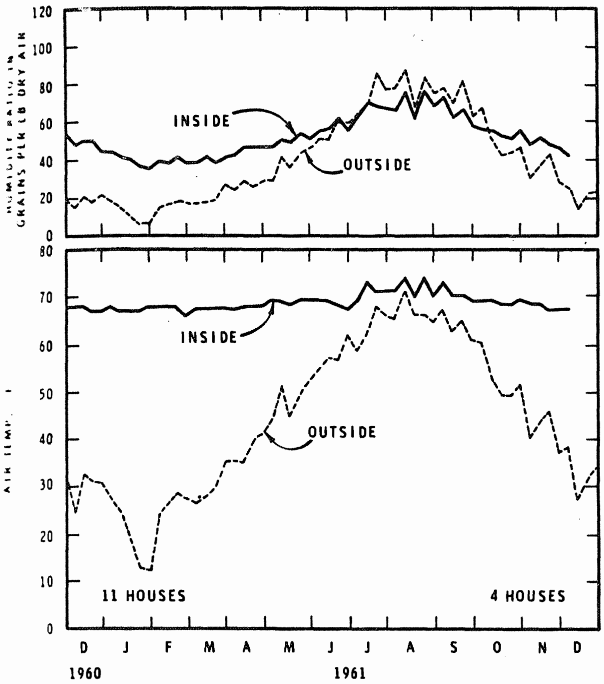


Fig. 5 Air temperatures and humidity ratios, Halifax

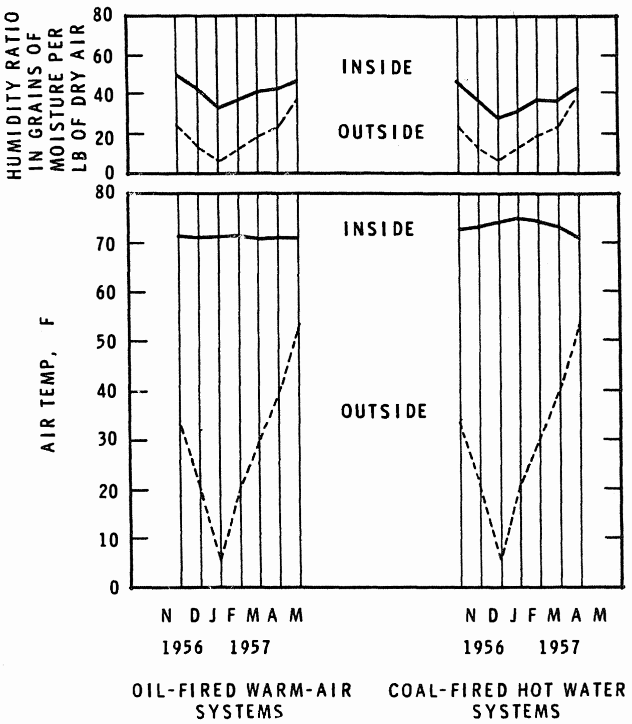


Fig. 6 Air temperatures and humidity ratios, Camp Gagetown

of less than 52 F. It is conceivable that summer dew points in Ottawa and Halifax are high enough to cause summertime condensation in basements, while those in Saskatoon are not. This situation is at least partly confirmed by the fact that basement dehumidifiers have little sale in Saskatoon, but are relatively common in Eastern Canada because of the more humid conditions. It is also possible that sorption of moisture by hygroscopic materials in the house produces a dehumidifying effect. Another possibility is that windows are closed in the daytime and open only at night in the hot humid weather, outside air dew points usually being lower at night than in the daytime.

In contrast to the disparity between summer conditions in Saskatoon and Ottawa or Halifax houses, minimum winter indoor humidities are almost the same. This may be due to the similarity in outside humidity ratios at the various locations in winter, or to the added precautions taken to decrease infiltration in houses in colder regions. Comparable monthly average values for these regions and for the other locations at which records were obtained are listed in Table II. It will be noted that the minimum monthly relative humidity in houses in relatively cold regions was maintained at between 25 and 30%. Even at Inuvik, in houses with no intentional humidification, interior relative humidities were much higher than would be predicted on the basis of outside conditions alone. The humidity level was, in fact, close to the maximum attainable with no window condensation.

Most of the houses involved in the Ottawa, Saskatoon and Halifax studies were equipped with simple pan-plate-type humidifiers in the furnace plenum. One house in Ottawa had a special spray-type humidifier; two hot-water-heated houses, one in Ottawa and one in Saskatoon, had cabinet-type humidifiers; the remainder had no other source of humidification except the occupants and their household operations. It is of interest to speculate on the relation between ventilation rate and the resultant humidity within the house when a pan-plate-type humidifier is used.

Studies undertaken at Purdue University,[3] published in part in the ASHRAE Guide And Data Book, indicate an average rate of moisture production of approximately 0.7 lb/hr for a family of four, rising to about 2.0 lb/hr on washdays when

Table II. Minimum Indoor Conditions in Winter

Year	Location	Monthly Minimum			Equivalent Inside rh at 70 F, Per Cent
		Outdoor Tempera-ture, F	Humidity Ratio		
			Outside	Inside	
1958	Ottawa	11	9	32	29
1959	Ottawa	10	8	29	26
1957	Saskatoon	0	5	31	28
1958	Saskatoon	4	7	36	33
1959	Saskatoon	- 7	3	30	27
1960	Halifax	22	14	38	35
1957	Camp Gagetown	6	6	33	30
1957	Camp Gagetown	6	6	27	25
1961	Inuvik	-24	1	24	22
1959	Vancouver	39	30	45	41

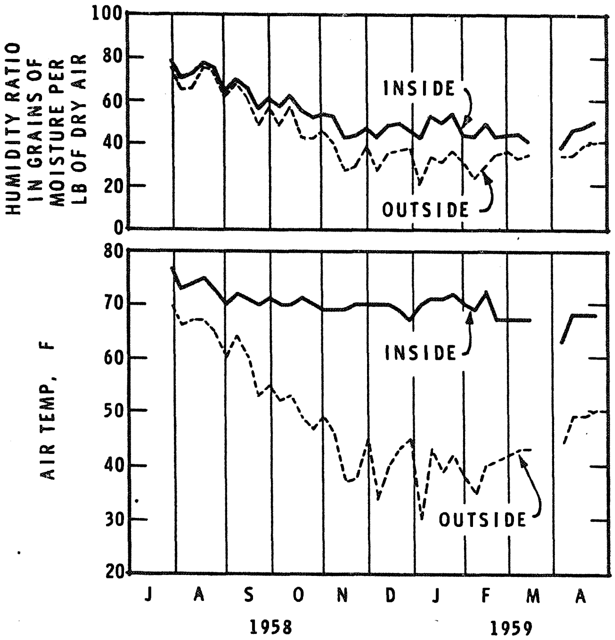


Fig. 7 Air temperatures and humidity ratios, Vancouver

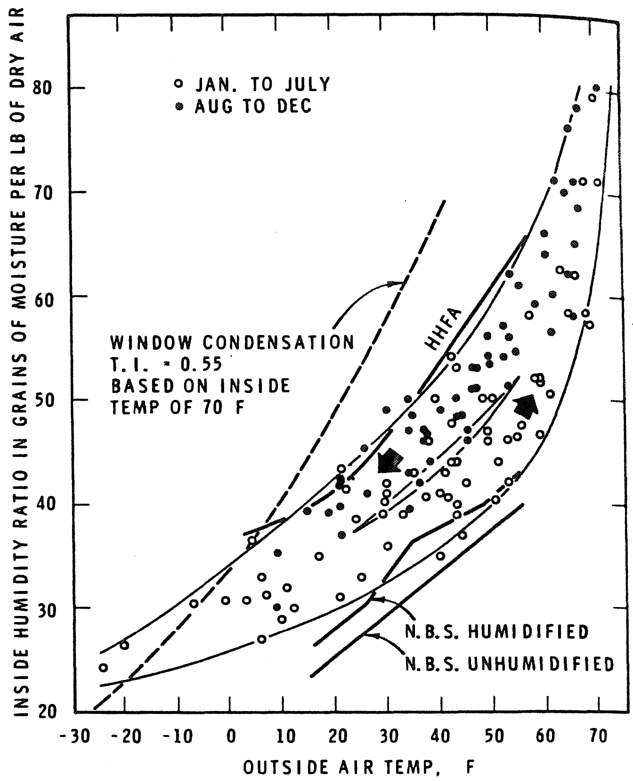


Fig. 8 Inside humidity ratio vs outside air temperature

clothes are dried indoors. Investigations at the University of Saskatchewan[4] have shown that the output of a simple pan humidifier under continuous furnace operation is about 1.5 lb/hr with 10 new plates, and about 0.75 lb/hr with plates that had been used for one heating season. Assuming an average output of 1.0 lb/hr, and allowing only 50% operating time, a rough estimate of the total output of a family of four in a house with a plate-pan humidifier is

$$0.5 + \frac{(0.7 \times 6) + (2.0)}{7} = 1.4 \text{ lb/hr}$$

The average difference between inside and outside humidity ratios for the three main groups of houses was about 23 grain/lb, as indicated in Table II. The average effective volume of the various houses, including basements, where applicable, was about 13,000 cu ft. Based on these figures, an average ventilation rate can be estimated as

$$\text{Ventilation rate, air changes/hr (ach)} = \frac{1.4 \times 7000}{13{,}000 \times 0.075 \times 23} = 0.44 \text{ach}$$

This value, however approximate, is of the same order as that normally assigned to a tight house in heat loss or humidification calculations, and agrees with the infiltration rates of Tamura and Wilson[5] for a bungalow with an oil burner in operation and subjected to winds of about 10 mph.

The monthly average inside humidity ratio for the group of houses in each location for each of the years of record is plotted as a function of outside temperature in Fig. 8. Values for the summer-to-winter period are purposely coded differently than those for the winter-to-summer period in order to indicate the effect of moisture storage. This hysteresis effect is suggested by the upper shaded band for the period approaching winter, when hygroscopic materials are giving up moisture and providing an additional source of moisture, and by the lower band for the winter-to-summer period, when these materials act as a moisture sink. Fig. 8 includes the curves established by Phillips[1] in a survey by the National Bureau of Standards for a group of 142 humidified houses, and 73 nonhumidified houses. Also included in Fig. 8 are the results of the Housing and Home Finance Agency survey[2] conducted on nine houses in Minneapolis, Minn. The units of measurement used in these two studies (rh at 70 F) have been converted to humidity ratio so that the curves could be replotted for direct comparison with the average values for the Canadian houses. The curves of Phillips were derived from spot readings of wbt and dbt, both inside and outside, taken with a sling psychrometer twice daily in the morning and afternoon, and therefore cannot be construed to represent the average values over a 24-hr period. On the whole, however, they may not differ widely from the true daily averages, since both the inside and outside temperatures could be expected to be lower using 24-hr average values rather than the spot readings of morning and afternoon. Unfortunately, the H. H. F. A. does not give a complete record of the rh at 70 F vs outside temperature for the nine houses in State College, Pa. which were also studied. From the single value given in Table 4 of the H. H. F. A. paper[2] it would appear that the State College values of rh might be somewhat lower than those of the Minneapolis houses for the same outside air temperature, which would bring them closely into line with the results of the Canadian house survey.

The dotted curve in Fig. 8 represents the maximum humidity ratio for no condensation on the inside surface of a double window. This curve is based on a surface temperature index of 0.55 which has been established for double-glazed windows.[6, 7] The measured interior humidity ratios at the lower outside temperatures fall close to or above this limiting line.

CONCLUSIONS

A survey of humidities in Canadian homes indicates that the indoor humidity ratio is a function of outside conditions but is influenced by the seasonal ventilation habits of the occupants and the moisture storage of hygroscopic materials in the house. Because of increased ventilation in summer, the indoor humidity ratio approaches that outside, and may actually fall below this value in humid areas because of basement condensation or dehumidification by sorption. The difference between indoor and outdoor humidity ratio reaches a maximum in winter, and suggests that the ventilation rate is reduced to a value equal to or even less than that normally assumed in design calculations. The resultant indoor relative humidity level is between 25 and 30% on the average, even in areas having low winter temperatures, and approaches the maximum humidity attainable without condensation on double-glazed windows.

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance given by L. P. Chabot of Ottawa and R. G. Nicholson of Saskatoon in servicing of the field instrumentation and reduction and compilation of the data. They wish to thank A. G. Wilson for assistance in the planning and coordination of the project.

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DISCUSSION

R. A. HEIMAN, Columbus, Ind. (Written): I believe the report to be well written and documented. However, I question the interpretation of the results. The conclusions lead one to believe that there is no need for additional humidification in Canadian homes Though naturally biased by being directly involved in the design of humidifiers, I can't help but question this, based upon knowledge of thousands of power type humidifiers being sold in Canada and hundreds of thousands being sold in the U. S. A.

If the results were interpreted on an individual home basis, rather than on an average basis, perhaps the conclusions would be different. It is possible that on an average the 25 to 30% rh inside Canadian homes would hold true in the winter. No doubt though, there is a certain percentage of homes with much lower rh where additional moisture is necessary. Bracketing the home results in ranges of indoor rh may be more meaningful to potential readers of this report than the averages as presented.

The only other major comment I have is that the calculated average ventilation rate seems abnormally low for homes with single-glazed windows. This may be due to inaccuracies of the Purdue report, certain assumptions made in this report or inaccurate measurements.

In any event, this report is an excellent start toward what I believe should be more extensive investigation of this subject in both Canada and the U. S. A. sponsored by ASHRAE.

AUTHOR HANDEGORD: Mr. Heiman is correct in suggesting that some individual houses had lower average humidities than the group averages listed in Table II. Group averages were used in the paper only to simplify the presentation of results.

The minimum monthly average indoor rh observed in individual houses ranged from 21 to 35% in Ottawa, from 19 to 42% in Saskatoon, and from 28 to 47% in Halifax during the periods listed in Table II. It may be suggested therefore that a market for auxilliary humidifiers exists for some of the homes, while in others, increased humidification could lead to increased window condensation.

The only group of houses with single glazing were those in Vancouver, although this is not clearly stated in the paper. All of the other homes were double glazed as is common in most areas of Canada. The infiltration rate of 0.44 ach is the result of a very approximate calculation, but the value is consistent with actual measured rates in some homes. It does suggest that on the average, the homes involved in this study should be classed as "tight houses", as defined in the ASHRAE Guide And Data Book.

B. T. CARROL, Union, N.J.: Didn't I understand however, that these houses had humidification instruments in a great many of them and that some had pan type and cabinet type humidifiers; therefore, that this is not a conclusion based on non-humidified houses, since humidity was added to some of them?

AUTHOR HANDEGORD: Most of the warm air heated houses had a standard pan type or plate pan type humidifier installed.

MR. CARROL: Yes, but have no figures of houses without any additional mechanical humidification.

AUTHOR HANDEGORD: Only those listed in Table I.

E. P. PALMATIER, Syracuse, N.Y.: I think one of the interesting things is the relationship between the NBS data, which is quite old, in Fig. 8 and the current data, which is covered in this paper.

I think the indication is that the houses in this study, were perhaps a good deal tighter and had lower ventilation rates (or infiltration rates) than may have been the case in the 1940 study that was made by the Bureau of Standards.

AUTHOR HANDEGORD: I can only agree with that.