BUI

NO.79
(1988)

BUILDING RESEARCH ASSOCIATION OF NEW ZEALAND

# REPRINT



# Air, Earth, Water - the Sources of Moisture

H.A. Trethowen

Reprinted from the Proceedings of the New Zealand Workshop on Airborne Moisture Transfer, Wellington, 23-26 March, 1987.
Air Infiltration and Ventilation Centre, Technical Note AIVC 20



branz
BUILDING RESEARCH ASSOCIATION OF NEW ZEALAND

AIR INFILTRATION AND VENTILATION CENTRE
MOISTURE WORKSHOP 1987

Building Research Association of New Zealand (BRANZ)
23rd March 1987

PAPER 1

# AIR, EARTH, WATER ......
# THE SOURCES OF MOISTURE

H.A. TRETHOWEN

Building Research Association of New Zealand
Private Bag
Porirua
New Zealand

# AIR, EARTH, WATER .....
# THE SOURCES OF MOISTURE

H.A. Trethowen


## Synopsis

For 50 years moisture control technology in buildings has been presented as primarily a matter of vapour diffusion and vapour barriers. The evidence on which the technology is based is briefly reviewed, and shows that for 25 years there has been evidence that air movements are more important. In evaluating the amounts and behaviour of typical moisture flows in timber framed houses this paper draws particular distinction between "forced" and "floating" indoor vapour pressure regimes, and argues that in the normal "floating" case certain features of the traditional vapour diffusion model are inconsistent with observations.

The paper concludes that moisture control is predominantly related to air movements, often in miniscule amounts, and that deliberate effort to encourage application literature to reflect this is needed.

## 1. Introduction

The intention of this paper is to review three issues concerning moisture in buildings:

- the methods and basis for moisture design
- the sources and transfer of moisture
- attitudes to moisture control

There are two major classes of building moisture problem, excluding those related to leaks. The first is "surface condensation" or "mildew growth", on indoor surfaces visible to the occupants. The second is interstitial "structural" or "cavity" condensation, within the structure and usually not visible to the occupants. The two classes have little to do with each other.

An important but little-discussed classification point is whether the building indoor moisture state is "floating", or "forced". The floating condition is taken to mean that whilst the building may be heated and there may be miscellaneous moisture sources, these occur in a way equivalent to "natural ventilation", without any particular end result being forced. The forced condition is taken to mean that a particular level of indoor moisture is persistently imposed, eg., by humidification or dehumidification equipment. The point of interest is whether indoor moisture level is floating or fixed, rather than what that level is, and is discussed later.

The usual sources of building moisture, in typical order of importance in New Zealand, are:

- construction moisture
- subfloor ground moisture (by direct contact or by evaporation into subfloor air)
- indoor air-borne moisture (including improperly vented dryers)

- rain and pipe leaks
- indoor vapour diffusion

No discussion of building moisture is complete enough to be valid, without simultaneous consideration of the effects of sunshine, material hygroscopy, moisture storage capacity, thermal and moisture response times.

## 2. The foundations of building moisture science

The science of moisture control would be taken to originate with Fick (10) in his classic work showing that water vapour moved through materials under the influence of the local vapour pressure gradient. However it now seems that Dalton and others who established the science of psychrometry should be bracketed with Fick.

Although much work was done since those origins, the next developments having major influence on building technology were the studies in U.S.A. by Rowley (20, 21, 22) and Teesdale (24). These were notable for the experimental work they included on typical building structure elements. Sample structures or test huts were exposed to specific environmental conditions for a period, then opened and examined.

Although Rowley concentrated his attention on what was presumably the current difficulty of showing that occupant-generated moisture was capable of accumulating in the structure under the influence of vapour diffusion, he was also careful to consider the influence of material hygroscopy, and showed that moisture accumulation was more severe under constant conditions than under cyclic conditions of the same mean values. He did not consider air leakage or construction moisture in any depth, and dismissed the influence of sunshine on the grounds that it would not apply to polar-facing walls. Rowley described what was later called the "dew-point profile" method for moisture design, and laid principal stress on the use of vapour barriers.

The next well-known milestone came in the late 1950's when Glaser (11) popularised the method since named after him. This method differed from the dew-point profile method only in that the mathematics used were better defined, and that the local vapour pressure was forced to be not higher than the dew point at every point in the walls. The latter was taken at the time to be an important conceptual step by technologists, although it appears in all Canadian literature through the early 1950's and indeed was a specific part of Rowley's 1939 method.

A major change was signalled in 1962, when Platts (19) reported Canadian observations that "... vapour diffusion plays only a small part ..." and "... air flow, rather than vapour diffusion, is nearly always the cause of severe condensation ..." in structures. This observation has been repeated in many Canadian research papers since, e.g., Wilson and Garden (33), Latta (16), Handegord (13), to mention only a few. Dutt (9) reported the same conclusion from work at Princeton. Most contributions to the "Moisture Problems in residential construction" conference Seattle, 1985, (eg. Lstiburek (17)) demonstrated or implied that air-borne moisture, construction moisture and leaks, rather than vapour diffusion, was the cause of most significant moisture failures.

In the 1970's and 1980's several field surveys were reported - Tsongas (28), (29), Weidt (32) - which show in more detail the real influence of moisture in buildings, with the influence of vapour barriers being found to be not significant in the avoidance of moisture problems. Most problems were ascribed to leaks, and to airborne moisture.

## 3. Applied Technology

Consider now the information available to designers, builders, inspectors in regard to moisture control.

In 1952 Billington (4) in U.K. must have concluded that Rowley's 1938 work was the last word on the subject, as his chapter on structural moisture control was a verbatim copy from Rowley. Other British engineering handbooks did not mention moisture control until the (then) Institution of Heating and Ventilation Engineers, London, published the 1970 edition (15) of their Guide Books. The I.H.V.E/C.I.B.S. Guides are widely used, and in Britain and New Zealand at least are quite influential. The 1970 edition presents information on how to calculate "the dew point" and considers diffusion only. Around 1960 the London College of Heating and Ventilating was teaching its students the same thing, with barely even mention of the Glaser corrections. Other influential British documents include the M.P.B.W. 'Condensation in dwellings', (18) and B.R.E. Digest 110 (5). Books from the 1960's by Diamant (8), Van Straaten (31), Gratwick (12), and others, follow much the same tenor. Collectively these publications have spawned a wide variety of building recommendations, and institutional and commercial publications which endorse a collective attitude that vapour diffusion and vapour barriers are the only issue.

In U.S.A, the influential ASHRAE Guide to Fundamentals (2) was until 1969 also giving detailed information on how to calculate dew point profiles, and although giving a brief discussion on air-borne moisture, stated that this would commonly not be of interest. However by 1972 the emphasis on air-borne moisture movement was strengthened, and further strengthening has continued with each subsequent issue. By 1981, the "practice" section of the guide to Fundamentals carried the message "....It has become recognised that air movement which carries the water vapour with it, is a far more powerful mechanism for transporting water vapour to the point of condensation." and "..Rarely has vapour diffusion been identified as a major factor". These are strong words, they are in direct contradiction to the conventional wisdom of the time, and their sources are highly respected.

However in many circles these changes appear to have gone unnoticed, with the principal interest of designers, manufacturers, inspectors and publications still frequently being directed at vapour diffusion. Most leading designers at any time will have received their training many years previously, and the present group will have been taught to believe that vapour diffusion is the key. Only the leading designers see much of the research papers and conference proceedings and the bulk of routine designers only receive what their seniors or market contacts provide. Although the ASHRAE handbooks now offer a reasonably balanced review of moisture control, they still include - as the only <u>quantitative</u> item - the calculation of dew point profiles, and this item retains prominence. Under today's economic pressure the designer can be expected to take a quick glance at the new Handbook chapter, note that the familiar bits are still there, and ignore additional text.

Engineers are trained to calculate, and what they can't calculate they don't trust. There seems to be a tendency to regard things which can be calculated as more relevant than those which haven't been calculated. The expected result is apparent in N.Z. designers: few think of moisture: many of those who do ask only "where do I put the vapour barrier?"

4. Moisture Sources

Much of non-leak building moisture comes from occupant activity. It has been repeatedly noted that unoccupied buildings don't suffer from surface condensation. A notable exception occurs in the case of construction moisture, where unoccupied new houses are sometimes found to suffer rapid and extreme damage from surface condensation or mildew.

More needs to be known about indoor conditions in real buildings. Fig 1. shows the observed long-term trend of indoor humidity in a set of eight houses studied intensively in 1974 (Trethowen 25). This data is derived from pen records with monthly charts. When replotted onto a psychrometric chart, as in Fig 2, it is immediately evident that these records imply that the (smoothed) indoor vapour pressure was virtually independent of indoor temperature, but was dependent on outdoor conditions. In the short-term daily fluctuation, however, this pattern was not maintained, and the indoor conditions followed a trend intermediate between constant vapour pressure and constant humidity. Only one cycle is drawn, but it is very characteristic of this set of observations for 8 houses over 2 years.

Various estimates of occupant moisture release range from 3-4 kg/day to 10-12 kg/day, with peak days perhaps doubling these estimates. Hansen (14) gives a typical summary. Many of these estimates apply to worst-case rather than to normal cases. The "worst" buildings may have two to four times the moisture generation as in the normal case, and in addition the average day emission for any particular house is usually much lower than the peak-day emission. Whilst peak-day emission is important in respect of surface condensation, it is the average-day emission which matters for structural condensation.

It has been amply demonstrated that this indoor moisture is removed principally by ventilation, with only a small portion passing into the structure, even without vapour barriers (e.g., Trethowen (25), Hansen (14) 1985). The indoor moisture release of 5-10 kg/day, with a mean ventilation rate of 0.5 air change per hour, therefore indicates a mean indoor vapour pressure 2-4 mbar higher than outdoors. Trethowen (25) suggested a "design value" of 3 mbar and an extreme value of 5 mbar, based on separate considerations of moisture balance, energy balance, and field observation. If 10% of the 5-10 kg/day passed into some 250 $m^2$ of structure, this would represent a moisture flux of only 2-4 $g/m^2$ day. Peak vapour flow rates for low permeability linings ( 1 MNs/g) have been calculated in the range $\pm$ 5 to $\pm$ 20 $g/m^2$ day.

Other sources of moisture include subfloor ground surface evaporation under suspended floors. A BRANZ survey (yet to be published) showed that such evaporation typically averages 300-600 $g/m^2$ day in New Zealand, amounting to some 40 kg/day for a 100 $m^2$ house, over a wide range of conditions year-round. Short-term variations from - 200 $g/m^2$ day to + 3000 $g/m^2$ day were noted. Hansen (14) reported a very similar mean figure. Elementary calculation again shows that this moisture must be removed principally by subfloor ventilation, which must exceed 10 air changes/h to be successful. Structural details such as open cavity walls or vented linen cupboards which allow subfloor air to pass into exterior wall or roof spaces, lead to rapid and severe roof space condensation of air-borne subfloor moisture. The condensation rate has been estimated (by calculating likely airflow from buoyancy and flow path size, and comparing observed roofspace and subfloor conditions) as up to 200-400 $g/m^2$ nightly, with some daytime evaporation. This estimate is consistent with actual moisture accumulation. The process has been observed extensively by BRANZ, particularly with masonry veneer construction. Additional roof ventilation has been found to be of no assistance, and the reason for this becomes clear when it is noted that the condensation occurs predominantly on clear nights. The roof cladding is then perhaps 5°C below outdoor air temperature because of radiation cooling, and so introducing more nearsaturated outdoor air at 5°C above the cladding temperature will aggravate rather than help.

These various moisture flows are indicated in summary form in Fig.3, which shows that rather large moisture flows are common, and that long term flow rates are not well represented by short-term flow rates.

## 5. Movement of moisture in the structure.

What of the 2-20 $g/m^2d$ water vapour that enters the structure? Here several classical physics issues arise which might well turn the traditional arguments on vapour movements on their head.

The first issue is hygroscopy of materials. If a structure includes a substantial amount of timber, then that timber will always emit or absorb water in an attempt to maintain its surroundings at a humidity corresponding to the current moisture content of the timber. This humidity depends on the moisture content of the wood, and also on the current temperatures of wood and surroundings. The moisture transfer rates can be very large, and can be maintained for sizable periods because the moisture storage capacity is large. In short term, and usually medium term also, the moisture flow patterns in timber-based construction depend on the current moisture content and temperatures in the timber, not on the externally imposed vapour pressure gradient. For example, part of the initial drying of a new construction will be inwards to occupied space whence it is vented to outdoors, in spite of a persisting adverse vapour pressure gradient. In very ordinary structures examined by computer simulation by Trethowen (26), the drying was principally inwards.

The second issue is dynamics. Note firstly that the "dew-point profile" calculation method is a steady-state calculation. It is invalid where steady-state has not been reached. But in contrast to the corresponding thermal case where equilibrium is typically reached in hours or days, moisture equilibrium is approached only in weeks or months. Thus the calculation is invalid where applied to any form of peak conditions. Furthermore, computer simulations involving cyclic variations of boundary temperatures show that drying through the warm part of the cycle tends to outweigh wetting during the cold part (e.g. Trethowen (26)). Rowley (21) demonstrated this effect experimentally, by showing that moisture accumulation was much less in cyclic than in steady conditions of what he described as equal mean value.

Thirdly there is solar radiation. Moisture workers have traditionally dismissed solar radiation on the grounds that it can't be assured, especially on the polar faces of a building. This seems too severe, as it is now well known that appreciable diffuse radiation reaches all exterior surfaces, that the proportion of diffuse radiation approaches 100% of total radiation on cloudy days, and that days where less than 10% of maximum radiation is received are rare. The effects of sunshine were reported by Sherwood & Peters (23) who showed that winter moisture contents on equatorial facing walls in Wisconsin were some 5% lower than polar walls, with E/W walls intermediate. Since Wisconsin has a quite cloudy winter (mean radiation received is some 40-45% of extraterrestrial), it can be expected that even the polar walls in this case were benefiting from diffused sunshine.

Fourthly there is cavity ventilation. This subject has been discussed in general terms for decades but it has not apparently been made plain just how small are the rates of ventilation needed to achieve moisture control. Trethowen (27) showed by use of the Keiper method that cavity ventilation rates of 0.1-0.5 cavity air change/h (too small to have any thermal influence) would be sufficient in a case of moderate condensation to totally prevent all accumulation of moisture. Similar results were obtained from computer simulation. These represent trace quantities of ventilation of the cavities. Consider these rates in terms of building infiltration. Typical in-service infiltration rates for New Zeland houses are 0.3 - 0.5 room airchanges/h. Bassett (3) reports that in typical timber houses with "unvented" wall cavities, about 1 $l/s.m^2$ (or 0.15 room airchange/h) passes out through indeterminate widely distributed leakage paths in the structure. This equates to some 3 cavity air changes/h in the cavities, about one order of magnitude more than needed to totally control the cavity moisture condition. Bassett also reports that in typical houses with unvented wall cavities, the outward (cladding) air flow resistance was less than 10% of inward (lining) airflow resistance.

There seems to be grounds to expect that outdoor-cavity-outdoor air flows may be larger than the indoor-cavity-outdoor air flows.

Perhaps the above four points will answer much of the now well-reported discrepancy mentioned by Lieff and Treschel in their introduction to ASTM STP 779 (1) that:- "(a) laboratory work continues to forecast increasing moisture problems (b) field evidence persistently shows that it does not happen". Evidence for the latter comment is found in the Tsongas field studies in Western Oregan (28) (93 houses) and in Spokane (29) (103 houses), and the Weidt study (32) in Minnesota (39 houses), all of which show that structural condensation is not a general problem, whether winter is mild or severe, vapour barriers are present or not, insulation is present or not.

BRANZ experience on this point, based on routine advisory work, is that insulation per se has not been found to be a cause of building moisture problems, although it can influence the degree. The cause has always been traced to some specific building defect. Wall and ceiling vapour barriers are rarely used in N.Z.

As if this were not enough evidence for a change in traditional concepts concerning moisture movement, consider also the field observations reported by Trethowen (25) (8 houses). Here the distinction between "floating" and "forced" moisture conditions becomes crucial. In the event of a sudden spell of cold weather, the traditional concept is that cladding temperature will fall, moisture flow towards the cladding will increase, condensation there will probably commence, and moisture flow into the structure from indoors will increase under the now-greater vapour pressure difference. This sequence is followed in most of the experimental work reported, from Rowley onwards. But it applies to "forced" indoor moisture conditions, where indoor vapour pressure is forced to remain at some set value.

In reality in most of the houses of the world, certainly in N.Z. the indoor moisture condition is floating, not forced. When a cold snap occurs, the cladding temperatures will still fall. But very quickly the indoor moisture concentration also falls, by virtue of infiltration, and in fact is inhibited from falling as far as it might, by a corresponding flow of moisture from the structure to the now-drier building interior. Some evidence for this can be seen in the processed field records of Fig 4. On each occasion when there is a drop in outdoor dewpoint there is a corresponding (smaller) drop in indoor dewpoint. The condition now indicated is that a cold spell would result in a burst of inwards drying or at least reduced wetting of the structure along with some internal moisture redistribution, and not to a burst of increased wetting. Sherwood and Peters (23) found that in a set of three rooms in Madison which were set up to be as nearly comparable as possible, those with floating moisture conditions had drier framing and cladding than in a room forced to 35% relative humidity.

The above factors point to a total inappropriateness of the traditional view of moisture as an outward flow process, and that concept should be abandoned. A more appropriate concept would appear to be that used by Cunningham (6,7) of viewing the structure as a set of moisture sinks, each of which may pass moisture to or from its neighbours according to the conditions of the moment. The most important short and medium term conditions are the local temperatures, and the availability of any moving air streams to carry water vapour.

Finally, I want to advocate that the research community begins to put real pressure on technology, as purveyed in handbooks, design procedures, building codes, to accept and apply the messages which began emerging with Platts (19) and put behind the near-exclusive preoccupation with vapour diffusion and vapour barriers, except where moisture conditions really are forced (as in cold stores, swimming pool halls, cotton mills). There is a tendency even in publications which set out overtly to avoid the "vapour barrier syndrome" - as for instance the 1983 US Department of Energy publication "Moisture and house energy conservation" (30) - to include a rather traditional statement on vapour barriers with only token exceptions. This is not enough - it must be made clear to entrenched thinkers that the rules have been found to be different.

## Conclusions

- Key historical events have been noted which underpin the science and practice of moisture control.

- A concept of classifying the moisture risk of buildings according to whether indoor moisture conditions are "forced" or "floating" is introduced.

- The dominant role of airborne rather than diffusion driven moisture as the key issue has been highlighted.

- The powerful influences of material, hygroscopy, non-steady conditions, diffuse solar radiation, and air infiltration have been outlined.

- The concept of moisture movement as an outward flow process should be abandoned, and replaced by one of viewing a structure as a set of moisture sinks responding to surrounding conditions, especially temperatures and air movements.

## References

1. ASTM: Moisture Migration in Buildings. STP 779, Philadelphia, 1980.

2. ASHRAE Handbook of Fundamentals: American Society of Heating, Refigeration, Air Conditioning Engineers. 1969, 1972, 1977, 1981, 1985.

3. Bassett, M: Air flow resistances in timber frame walls. 8th AIVC Conference, Wellington, March 1987.

4. Billington, N.S: Thermal Properties of Buildings. Cleaver-Hume, London, 1952.

5. BRE Digest 110: Building Research Establishment, U.K. - Condensation, 1969 (reissued 1972).

6. Cunningham, M.J: A new analytical approach to the long term behaviour of moisture concentrations in building cavities, Parts 1 and 2. Building and Environment. Vol 18. No.3 1983 p109-116, 117-124.

7. Cunningham, M.J: Further analytical studies of building cavity moisture concentrations. Building and Environment. Vol. 19 No.1. 1984, p21-29.

8. Diamant, R.M.E: Insulation of Buildings. Ch 4,6. Iliffe, London. 1965.

9. Dutt. G.S: Condensation in attics: Are vapour barriers really the answer? Energy and Buildings, Vol.2 1979 p251-258.

10. Fick, A: Uber Diffusion (On diffusion.) J.G.Poggendorff's Annalen der Physik und Chemie, Leipzig, Band 94 (1855).

11. Glaser, H: Moisture condensation in porous walls from the diffusion of vapour. B.R.S. Lib. Comm. 1295 trans.from J. Gaz.Mat.Han., 25th June 1959, 103-116. 1965.

12. Gratwick, R.T: Dampness in buildings. Crosby Lockwood & Son, London. 1966.

13. Handegord, G: The need for improvement airtightness in buildings. Building Research Note 151, Division of Building Research, NRC. Ottawa. 1979.

14. Hansen, A.T: Moisture Problems in Houses. Proceedings of Moisture Problems in Residential Construction. Seattle. 1985.

15. IHVE Guide Book A: Institution of Heating and Ventilating Engineers, London (now Chartered Institution of Building Services) Ch. A10. 1970.

16. Latta, J.K: Vapour barriers: what are they? are they effective? Canadian Building Digest 175 NRC Division of Building Research, Ottawa. 1976.

17. Lstiburek, J: Moisture movement and its control. Proceedings of Moisture Problems in Residential Construction. Seattle. 1985.

18. M.P.B.W: Condensation in Dwellings, part 1: A Design Guide. (H.M.S.O., London.) 1970.

19. Platts, R.E: 1962: Condensation control in stressed skin and sandwich panels. Forest Products Journal Sept. 1962. 429-30.

20. Rowley, F.B: A theory covering the transfer of vapour through materials. ASHVE Transactions July 1939, Paper 1134, p545-560. (also published in Heating, Piping and Air Conditioning, p452-456, July 1939).

21. Rowley, F.B: Algren A.B, Lund, C.E: Condensation of moisture and its relation to building construction and operation. ASHVE Transactions; Jan 1939. Paper 1115, p231-252.

22. Rowley, F.B.. Algren A.B, Lund, C.E: Condensation within walls. ASHVE Transactions, Jan 1938. Paper 1077. p95-129 (also printed in Heating, Piping and Air Conditioning p49-60, Jan 1938).

23. Sherwood G.E: Peters C.C. Moisture conditions in walls and ceilings of a simulated older home during winter. USDA Forest Products Laboratory research paper FPL 290. 1977.

24. Teesdale, L.C: Condensation in walls and attics. Forest Products Laboratory, Madison, Wis. Oct 1937.

25. Trethowen, H.A: Condensation in cavities of building structures. N.Z. Journal of Science Vol 19. 1976. p311-318.

26. Trethowen, H.A: Drying and condensation in walls, a computer simulation. Building Research Association of N.Z. Report R.14. 1975.

27. Trethowen, H.A: The Keiper method for moisture design in buildings. Building Research Association of N.Z. Reprint No 12. 1979.

28. Tsongas G.A: A field study of moisture damage in walls insulated without a vapour barrier ASHRAE/DOE/ORNL. 1979.

29. Tsongas, G: The Spokane wall insulation project: A field study of moisture damage in walls insulated without a vapour barrier. Portland State University report to Bonneville Power Administration. Oregan, 1984.

30. U S Department of Energy: "Moisture and house energy conservation" reproduced in Proceedings of Moisture Problems in Residential Construction, Seattle, 1985.

31. Van Straaten G.F: The thermal performance of buildings. Ch.11. Elselvier, Amsterdam, 1967.

32. Weidt, J., Saxler. R and Rossiter, W: Field investigation of the performance of Residential retrofit insulation. NBS Technical Journal 1131. 1980. (also referred to as the "Minnesota insulation retrofit program")

33. Wilson, A.G., G.K. Garden: Moisture accumulation in walls due to air leakage. Canada, NRC, Div. Bldg. Res., NRC 9131. Technical Paper 227, 1966.

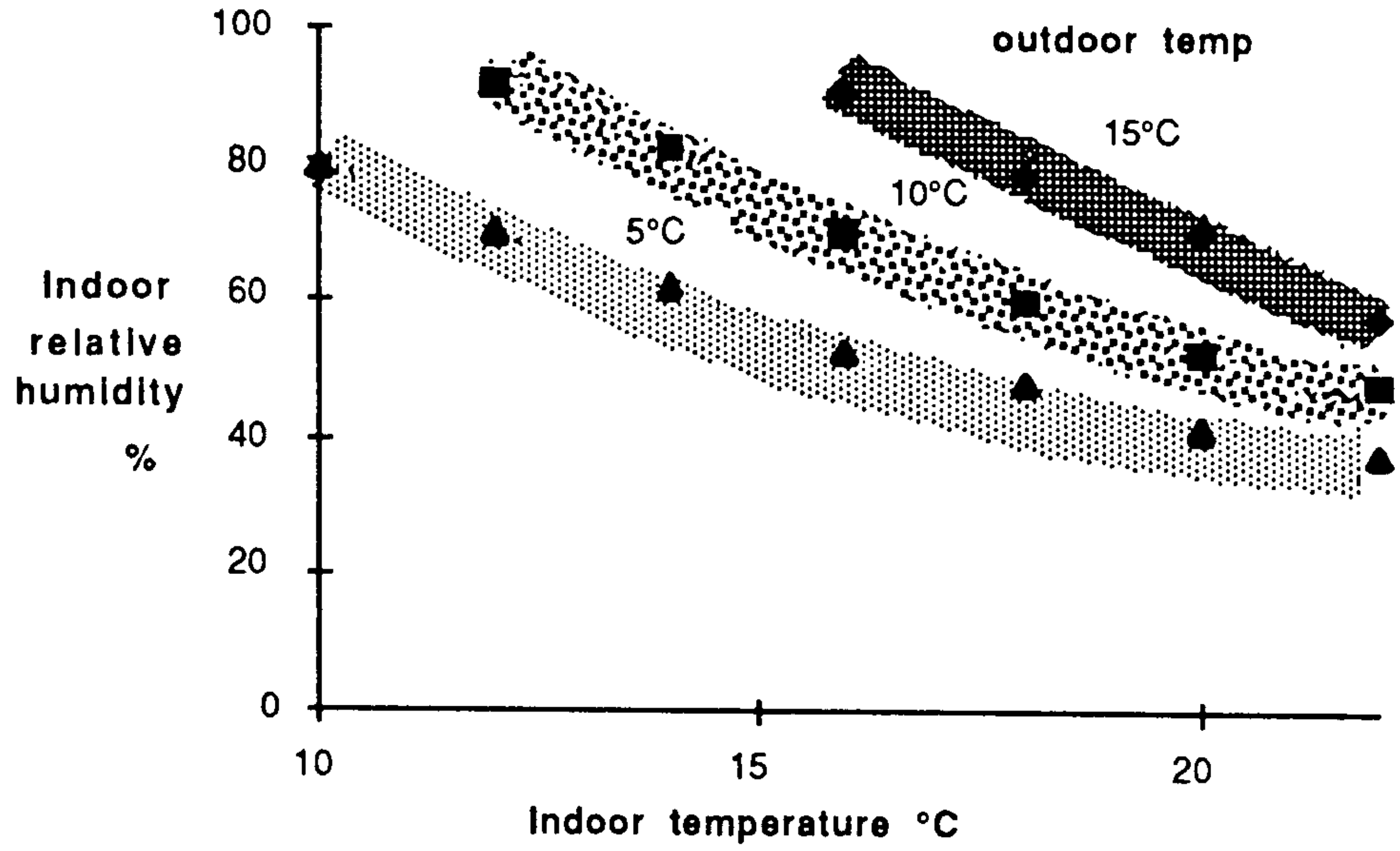



Fig. 1: Observed indoor humidity v temperature
(visual mean of 8 houses, Wainuiomata)

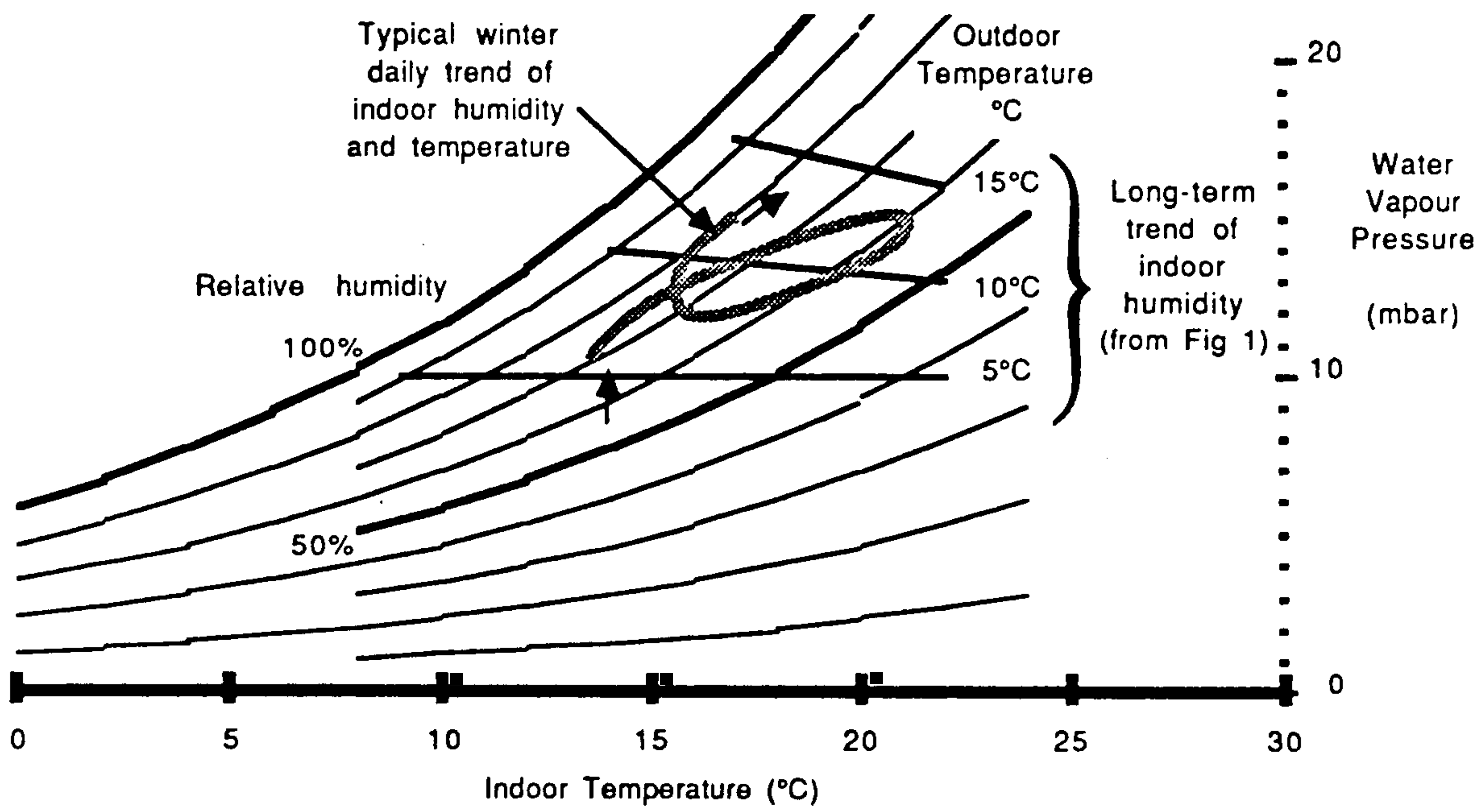
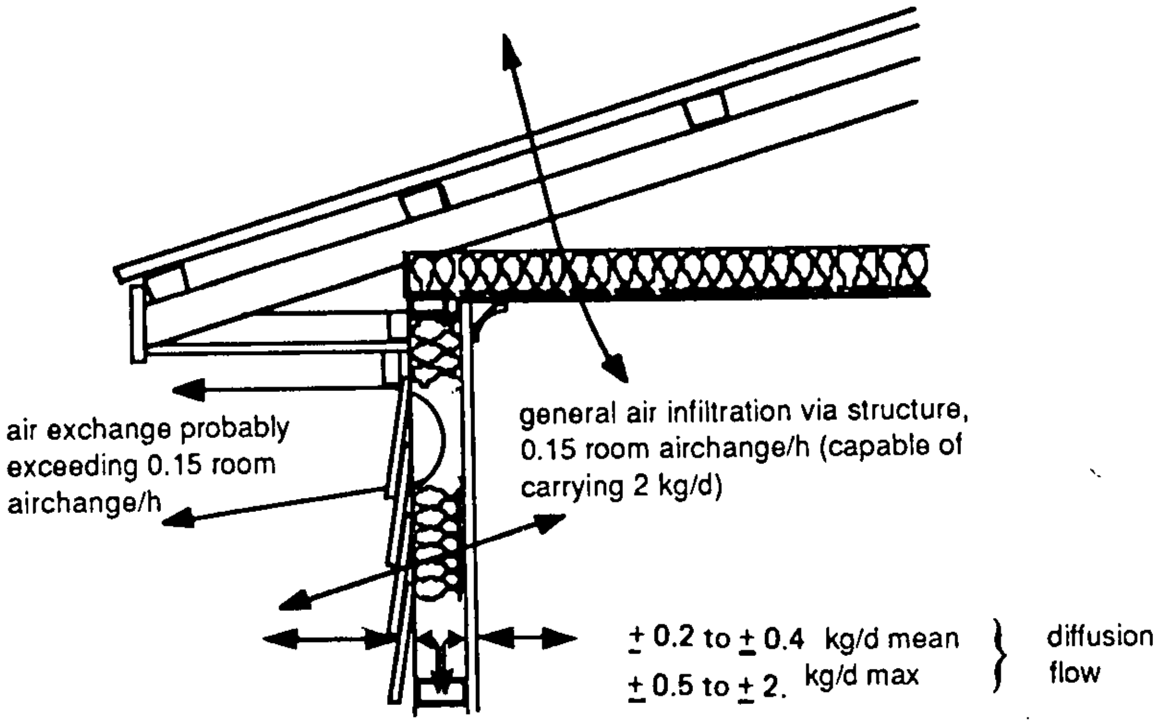
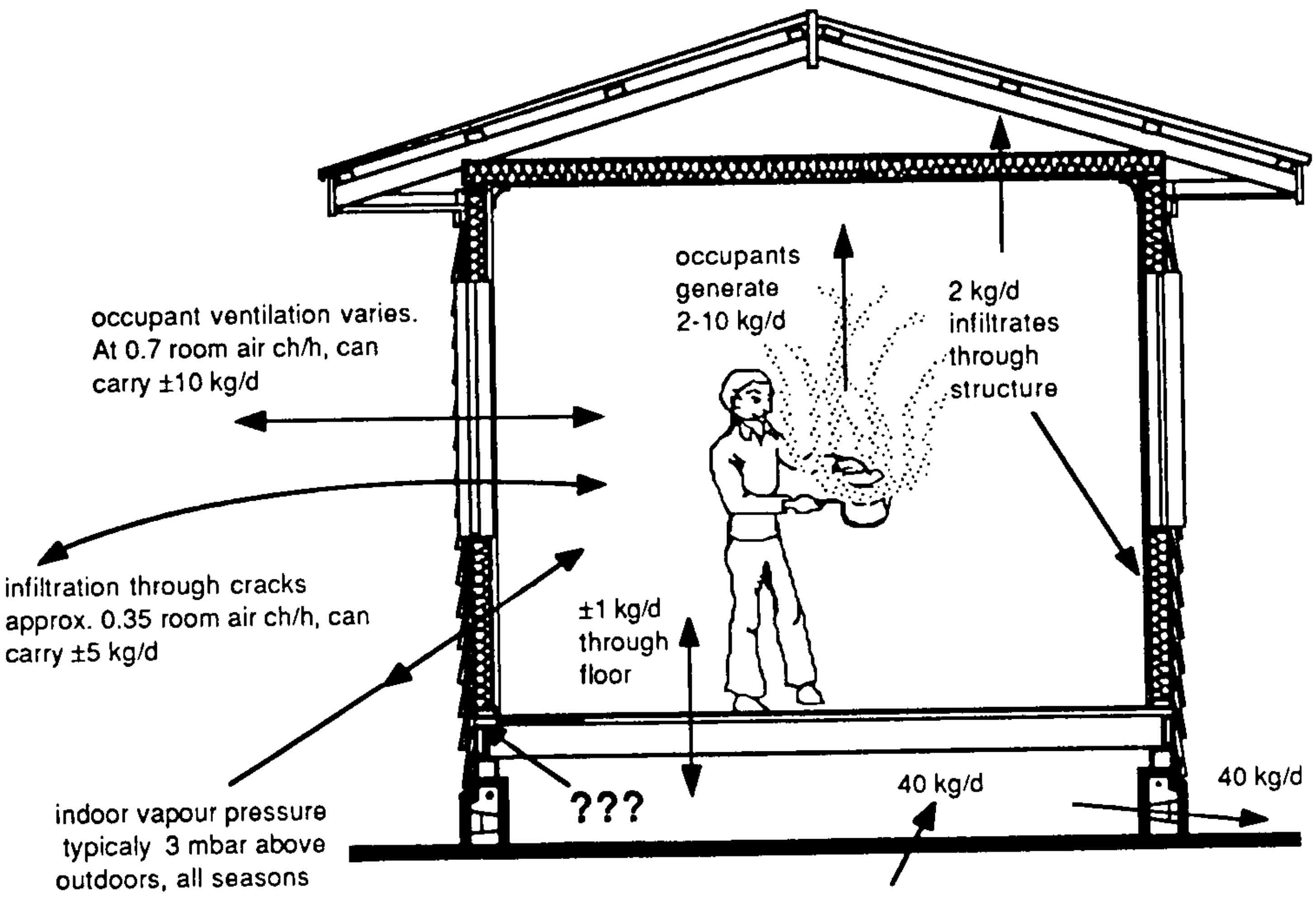



Fig.2: Typical daily and long-term indoor conditions
(visual mean of 8 houses, Wainuiomata)




(b) Within structure




(a) whole house

**Figure 3: Size of moisture flows, typical NZ timber house.**

**Figure 4: Recorded dew points in 7 houses (from ref 25)**

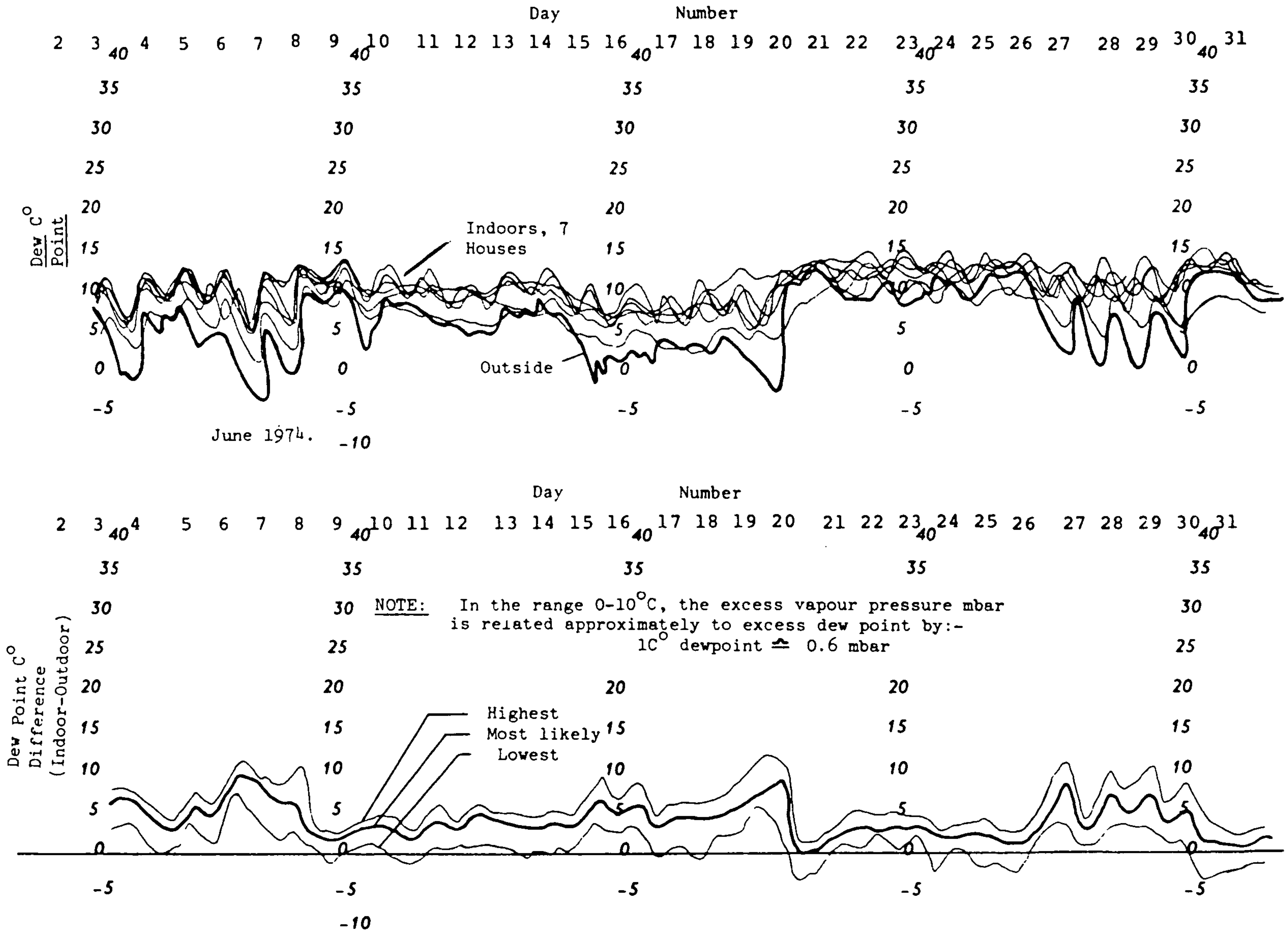



Fig. 4 Recorded dew points in 7 houses, Wainuiomata, June 1974.

BUILDING RESEARCH ASSOCIATION OF NEW ZEALAND INC.
HEAD OFFICE AND LIBRARY, MOONSHINE ROAD, JUDGEFORD.

The Building Research Association of New Zealand is an industry-backed, independent research and testing organisation set up to acquire, apply and distribute knowledge about building which will benefit the industry and through it the community at large.

Postal Address BRANZ, Private Bag, Porirua

ISSN 0111–7459