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Summary The avoidance of condensation problems in the future depends on designers having available accurate and reliable vapour permeability values. The emergence of free trade within the European Community requires the transferability of measurement data between countries, as well as between individual laboratories. This paper describes a recent European intercomparison carried out to assess the comparability of existing permeability measurement techniques, and to provide the information required to enable future international standards to be properly formulated. Identical samples of two materials were tested by eleven laboratories covering thirteen European countries. At the beginning of the project detailed instructions were issued on all aspects of the test procedure. Even with such an approach, many of the participants failed to comply with all of the test requirements, and the data produced exhibited unacceptably large variations between laboratories. The major contributory factors for this are discussed, and recommendations on a possible approach to the development and implementation of a future international test standard presented.

Vapour permeability: Suitability and consistency of current test procedures

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1 Introduction

Condensation, both on surfaces and within the fabric of buildings, is recognised as a major problem throughout the European Community. In the UK alone, it is estimated that 1.5 million dwellings are affected by severe condensation. The health, social and economic ramifications of such a widespread situation cannot be overstated. In order to obviate the problem, it is essential that in the design of new buildings, and in the evaluation of retrofit measures for existing buildings, detailed assessments of the hygric and thermal performance of the building envelope be carried out. Conventional techniques for carrying out such assessments require the availability of accurate vapour permeability and thermal data.

The procedures for the accurate determination of thermal properties are well established, and internationally recognised test standards exist. This is not the case, however, for vapour permeability measurements, as evidenced by the large variation of values quoted in literature for nominally identical materials[1, 2]. Without reliable vapour permeability data, the validity of any prediction technique is questionable, and the possibility of the recurrence of condensation problems remains.

Measurements of the water vapour permeability of building materials are carried out in all member states of the EC using standards recommended by each individual country, e.g. *DIN 52615* in Germany; *T56-131* in France. These standards utilise a gravimetric technique which involves the sealing of test samples, normally using a wax-like substance, into the mouth of an impermeable cup containing a vapour pressure regulator[1, 3]. The vapour pressure regulator generates a constant vapour pressure at the inside of the sample. The cup is then positioned in an environmental chamber with the outside of the sample exposed to a controlled atmosphere (Figure 1). This produces a constant vapour pressure difference across the material and, after the attainment of equilibrium conditions, the vapour flow rate can be calculated from the steady decrease (or increase) in cup weight.

Although this basic measurement principle is the same in all the EC member countries, significant differences do exist in the vapour pressure regulators used, the apparatus design, the sealant methods, and the recommended test conditions of relative humidity and temperature. It is commonly recognised that the environmental test conditions and vapour pressure regulator used significantly affect the permeability values obtained. It could therefore be expected that permeability tests will produce different data in different laboratories. In addition, various other factors related to the details of the test procedure and equipment used may well affect the results.

In a European context, it is important that data measured in one member state be consistent with similar measurements made elsewhere. In order to unify the results

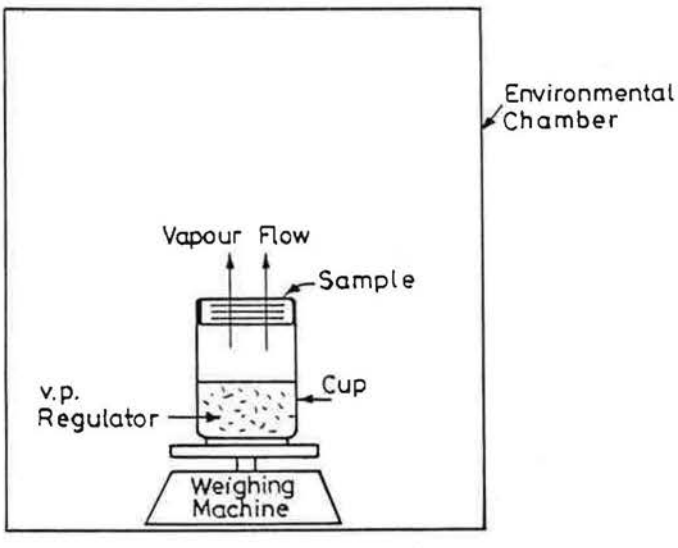

Figure 1 Standard vapour permeability test method

Table 1 Summary of test procedure

Stage	Activity
1	Precondition samples 23°C and 50% RH (A check on sample densities at this stage showed that no changes had occurred during transit.)
2	Seal polystyrene in 'dry' cup, particle board in 'salt solution' cup and place test cups in environmental chamber (23 ± 1°C, 50 ± 3% RH).
3	Allow equilibrium conditions to be attained (steady weight gain/loss).
4	Measure daily weight change of each cup and calculate permeability of each sample (six data points, correlation coefficient >0.98).
5	Report mean permeability and standard deviation for both materials.

obtained by laboratories throughout the Community, it will be necessary to bring together the individual test standards into a common framework. A draft CEN standard (*TC88/WG1/N52*) is currently being prepared to detail a suitable test method. However, up till now, little information has been available on the comparability of results from different laboratories or on the possible causes of result dispersion. Such knowledge is obviously essential if future standards are to be correctly formulated and successfully implemented.

This paper reports briefly on the results of a recent intercomparison programme in which essentially identical samples were tested by thirteen European laboratories (covering eleven countries)[4]. It also considers the consequences for a future test strategy. In the project Strathclyde University acted as the coordinator and issued strict guidelines on the various elements of the test procedure. In particular, specific vapour pressure regulators were designated and the environmental test conditions rigidly defined, with the intention of removing a major source of possible result discrepancy. It was then hoped that the significance of the other aspects of the test procedure would be manifest.

2 Test procedure

The project began in March 1990 with the issue of *Guidance Notes for Participants*[4]. These contained details of the test conditions to be adopted, the measurements to be made and their required accuracy, as well as information on the test procedure to be adopted.

Six samples of two materials were to be tested—extruded polystyrene (non hygroscopic) and particle board (hygroscopic). The polystyrene samples were prepared at Strathclyde University, the particle board sample at CSTB (Centre Scientifique et Technique de Batiment) France. In order to obtain consistency in the materials sent to the laboratories, a careful preconditioning and selection procedure ensured that the density of all the samples dispatched fell well within ±5% of the overall mean density. For the purposes of the project, the samples tested in each laboratory could therefore be considered essentially identical in nature.

Each laboratory was requested to use the design of gravimetric apparatus which corresponded to their own country's recommendations. They were expected to provide information on the test cup design and method of sample sealing, together with details of the balance used for weighing. In particular, it was specified that the balance should have an accuracy no less than ±1 mg.

The vapour pressure regulator specified for the polystyrene was calcium chloride (~0% RH in test cup). A saturated solution of ammonium dihydrogen orthophosphate ($NH_4H_2PO_4$) was used with the particle board (~93% RH in test cup). The temperature for the tests was specified as 23°C with a control accuracy within ±1°C, the relative humidity was specified as 50 ± 3%. Confirmation of the actual conditions maintained during testing was required and, in order to minimise boundary layer effects, the participants were asked to ensure that the air velocity across the samples was 1.0 m s^{-1} or greater. The steps in the test procedure are summarised in Table 1.

3 Test results

The results reported by the participants are summarised in Table 2. Full details are to be found in Reference 4. The mean permeability and standard deviation obtained by each laboratory are indicated, together with overall mean permeability and standard deviation. For the polystyrene, the overall mean permeability is evaluated as 2.17×10^{-12} kg m N^{-1} s^{-1} (or s) while for the particle

Table 2 Summary of test results for vapour permeability (kg m N^{-1} s^{-1})

Laboratory	Polystyrene		Particle board	
	Mean ($\times 10^{-12}$)	SD ($\times 10^{-12}$)	Mean ($\times 10^{-11}$)	SD ($\times 10^{-11}$)
1	2.48	0.24	2.03	0.05
2	1.84	0.46	1.77	0.06
3	2.58	0.54	2.41	0.07
4	1.99	0.17	1.82	0.06
5	2.23	0.38	2.26	0.05
6	1.55	0.10	0.828	0.08
7	2.19	0.44	2.37	0.08
8	2.02	0.44	2.05	0.04
9	3.30	0.13	1.62	0.06
10	1.95	0.30	2.22	0.13
11	1.36	0.05	1.89	0.06
12	2.46	0.51	2.90	0.31
13	2.20	0.42	2.17	0.11
Overall	2.17	0.57	2.03	0.40

board it is 2.03×10^{-11} kg m N^{-1} s^{-1}. Comparing the individual mean permeabilities with these overall values, a quite significant dispersion of results is indicated. The following comments clearly illustrate this.

3.1 Polystyrene

The mean permeabilities reported by Laboratories 9 and 11 represent deviations from the overall mean of +51% and −38% respectively. Even if these excessively deviant figures are ignored, a banding for the remaining results of some ±20% about the overall mean is indicated. The difference between the largest and smallest mean test permeability quoted is 1.94×10^{-12} kg m N^{-1} s^{-1}.

3.2 Particle board

The mean permeabilities reported by Laboratories 6 and 2 represent deviations from the overall mean of −59% and +41% respectively. Again, even ignoring these results, a banding in excess of ±20% is indicated. The difference between the largest and smallest quoted mean test permeability is 2.07×10^{-11} kg m N^{-1} s^{-1}, which is greater than the overall mean value!

4 Discussion

At the initiation of the project, it had been anticipated by the coordinator that the mean test permeabilities would fall within a banding of about ±5–10%. The actual results, as shown in Table 2, do not come close to this figure.

With this in mind, a detailed scrutiny of the reports submitted by the participants was carried out on the basis of the requirements laid down in the *Guidance Notes*. It was soon obvious that many of the laboratories had deviated in one or more respects from a strict implementation of the specified test procedure. The inherent potential for a large dispersion of results was clearly apparent. Some of the most important factors in this respect are outlined in Table 3 and summarised below.

(*a*) Only five laboratories provided confirmation that the specified environmental conditions had been maintained in the test chamber over both test periods. In three cases, no information on the actual conditions was given and 'assumed' values (obviously the chamber control system set-points) of 23°C, 50% RH were used in the subsequent calculation of permeability. In the remaining cases, for at least one of the tests, the temperature and humidity fluctuated outside the specified control range, sometimes to a quite alarming extent. For example, during the polystyrene tests in Lab. 9, the temperature varied between 21°C and 24.5°C. Apart from obvious effects on the vapour pressure external to the test cups, it is important to note here that the relative humidity maintained by a saturated salt solution within a test cup is temperature-dependent.

(*b*) Only four laboratories confirmed that a velocity of 1 m s^{-1} (or greater) had been maintained above the samples. Five laboratories gave no information. The remaining laboratories quoted values less than 1 m s^{-1}.

(*c*) In three cases, the balance used for cup weighing did not meet the specified accuracy of ±1 mg.

In addition to the above observations, various other interesting points emerged from the reports.

(i) In four cases it appeared that the test chambers used were too small to allow weighing to be performed within them. The test cup assemblies would most probably have to be removed from the controlled environment for weighing. Any resulting sorption effects are difficult to assess, but they could be important, especially where the test vapour flow rates are small.

(ii) The test periods employed by some laboratories were surprisingly varied when compared with the reference tests carried out by the coordinator which lasted about 2 weeks. One test period for particle board (Lab. 2) lasted 40 days while Lab. 9's test period for polystyrene exceeded eleven weeks! With such extended test periods, there is the distinct possibility that the vapour pressure regulators may cease to maintain the required relative humidity within the cups, e.g. saturated salt solutions may crystallise or become unsaturated; the moisture content of desiccant may become excessive. Degradation of the wax seal is also more likely, especially if significant temperature variations occur throughout the test period.

Table 3 Summary of test details

Laboratory no.	Balance accuracy ±1 mg?	Air velocity >1 m s^{-1}?	Temp. within 23 ± 1°C?	RH within 50 ± 3%?	Total test period (days)		Internal weighing?
					Polystyrene	Particle board	
1	Yes	No	Yes	No	15	16	No
2	Yes	No	No	No	41	35	No
3	Yes	Not stated	Yes	Yes	15	12	Yes
4	No	Not stated	No	No	11	29	Yes
5	Yes	No	Not stated	Not stated	12	11	Yes
6	Yes	No	No	No	16	20	Yes
7	No	Not stated	Not stated	Not stated	11	12	Yes
8	Yes	Yes	Yes	Yes	32	33	Yes
9	Yes	Yes	No	No	78	36	Yes
10	Yes	Not stated	Not stated	Not stated	28	30	No
11	Yes	Not stated	Yes	Yes	28	28	No
12	No	Yes	Yes	Yes	44	20	Yes
13	Yes	Yes	Yes	Yes	15	12	Yes

5 Conclusions and recommendations

On the basis of the intercomparison described it appears that, at the present time, a large variation in results is likely when permeability tests are carried out on identical materials in laboratories throughout Europe. The levels of dispersion found are clearly unacceptable. It would be expected that agreement within about $\pm 5\%$ should be possible for such measurements.

Some of the contributory factors identified from the intercomparison project have been highlighted in section 4. However, even allowing for these, it is felt that the spread of results is possibly greater than might be expected. In this respect, it is interesting to note that, for most laboratories, the permeabilities determined for both materials fell on the same side of the overall mean value. The possibility of a systematic error in the test procedure is indicated, and attention naturally focuses on those aspects of the procedure associated with the mounting of the samples and the weighing of the test cups. Experience has shown that any sealing procedure using a wax-like substance is highly dependent upon the expertise and care taken by the individual concerned.

On the basis of the observations made above, the following recommendations are offered as regards the content of any international standard for permeability measurement and possible future developments in this field.

(*a*) The test conditions should be strictly defined, and continuous monitoring of the controlled environment made mandatory to ensure compliance.

(*b*) Restrictions on the length of test period should be incorporated, and limits should be imposed on the initial and final states of the vapour pressure regulators.

(*c*) Test chambers should be such that the test cup assemblies need not be removed for weighing.

(*d*) Compliance with strict instrumentation accuracies should be enforced.

(*e*) A new test cup assembly which does not involve the uncertainties associated with wax sealing should be developed and its use incorporated into any new standard.

(*f*) A standard reference test material should be developed to allow apparatus calibration and the validation and certification of any given laboratory's test procedure.

Items (*e*) and (*f*) are currently under investigation at the University of Strathclyde. The results from this project have been made available to, and discussed with, the UK representative and coordinator of the relevant CEN Standards Task Group. It is envisaged that the issues raised will play an important role in formulating future European permeability test standards.

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