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VENTILATION IN TRADITIONAL AND MODERN HOUSING

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1 SUMMARY

Historically, the Gas Industry has always maintained a close interest in the ventilation of buildings, mainly because of the need to supply combustion air for unflued and open flued appliances. A supply of fresh air is required for a multitude of other purposes and in the U.K. this is almost exclusively provided by natural ventilation. However, ventilation is also a source of heat loss from a building. In the past, ventilation by natural means has been taken for granted. The only complaint at times has been of draughts; the energy loss due to excessive ventilation had not attracted attention because the energy thus lost had only been a small fraction of the total loss.

Recent years have seen the introduction of much higher levels of insulation in new housing which has dramatically altered the ratio of fabric to ventilation loss. There is now a growing awareness that when designing space heating systems the ventilation heat loss has to be treated as rigorously as the fabric loss in order to prevent oversizing, resulting in less competitive costing, and yet maintaining high levels of customer

satisfaction. The formulation of a rigorous method of predicting ventilation rates is a difficult problem to tackle, because natural ventilation is not only strongly influenced by weather conditions but also depends on the adventitious openings of the building. To date, the major barrier to the estimation of natural ventilation rates has been the lack of knowledge of leakages of current housing. To overcome this problem, Watson House Research Station in collaboration with four British Gas Regions carried out an experimental survey of 200 dwellings which, at the time, was the largest survey in the U.K.

This paper describes the methodology and instrumentation required to carry out the survey. The results of the survey are presented and discussed. The main conclusion is that the most important determinant of leakage is the type of construction of the house. The practical importance of the survey to the Gas Industry is demonstrated. The leakage data collected has enabled the development of a practical, yet sufficiently accurate, method of estimating ventilation heat losses. Such a method is currently being refined by Watson House Research Station in collaboration with British Gas Regions. The survey has also provided evidence to support the continued application of the adventitious ventilation allowance for the supply of combustion air to open flued appliances.

2 BACKGROUND

NATURAL VENTILATION AND INFILTRATION

The natural ventilation of a house arises as a result of pressure differences generated across openings by the action of the external wind (wind effect) and by buoyancy (stack effect). The openings can take a wide variety of forms, and it is usual to divide them into three groups. In the first group are purpose-provided openings such as air vents, flues, chimneys and open windows. The second group consists of the cracks in and around room components such as doors and windows. These cracks are such that they are readily identifiable and their dimensions can in principle be measured. In the third group, are the open areas which remain when the two other types have been sealed. This group is referred to as "background leakage areas". Within this group are cracks around electrical fittings and around the joints between ceilings and walls and also the porosity of room surfaces, which for certain types of floor can be very large.

It is the component openings and the background leakage areas which are of prime concern here. Together they comprise what are known as <u>adventitious openings</u>. The air flow which occurs through them is known as <u>infiltration</u>. Strictly speaking the term 'ventilation' refers specifically to the air flow through purpose-provided openings, but it is common practice to use it to refer to the sum of infiltration and ventilation. This practice will be adopted here.

Although infiltration is the major source of ventilation in many UK dwellings, very little is known about adventitious openings. Previous work has concentrated on detailed examination in a small number of houses[1,2] and the need for an overall view of UK dwellings was a major stimulus to the survey described below. Another important factor was the possibility of a trend to "tighter" dwellings, brought about by the desire for energy conservation and the adoption of new construction techniques. Of particular interest were timber-framed dwellings which employ vapour barriers and factory pre-fabrication. Such a trend could only be identified by a large survey.

It is important to appreciate that there is no way of directly measuring the total area of adventitious openings in a dwelling. It can only be done indirectly by what is known as a pressurisation test, whereby air flow is forced through the openings. This flow of air is known as the adventitious leakage, and it is the leakage which is commonly used as a measure of the size of adventitious openings. A pressurisation test is a relatively simple procedure and is well suited for the basis of a survey. Techniques exist for measuring actual infiltration rates but they are more time-consuming. Furthermore, the infiltration rate is not a property which is solely dependent on the size of the adventitous openings; it depends on the weather conditions at the time of the test.

VENTILATION HEAT LOSS - ITS SIGNIFICANCE AND METHODS OF CALCULATION

When sizing heating systems, the ventilation heat loss is usually calculated on the basis of a recommended air change which varies with the use of a room. However, the recommended values can vary from source to source by a factor of two or more. For example, the National House-Building Council[3] recommended 2 air changes per hour in bedrooms whereas the Chartered Institution of Building Services Engineers[4] and BS 5449[5] recommend only 0.5 air change per hour. Furthermore, the assumption that there is a ventilation heat loss at all times in each and every room is obviously fallacious. Figure 1 shows typical flow patterns through a dwelling as generated by the wind, stack effect and a combination of both. The flow patterns indicate that at any given time only some rooms are subjected to a ventilation heat loss; the magnitude of which varies with many parameters, notably climatic conditions and house design, but scarcely with its designated use.

In the past, the uncertainty of the magnitude of the ventilation heat loss was of relatively little concern. The ventilation heat loss was but a small proportion of the total heat demand. Figure 2 shows the changing balance of the ventilation heat loss as a proportion of the total heat demand as successive revisions of the Building Regulations have imposed higher insulation standards. A number of highly insulated dwellings have already been built where the ventilation heat loss accounts for more than 50% of the total heat demand, and the indications are that the trend will continue.

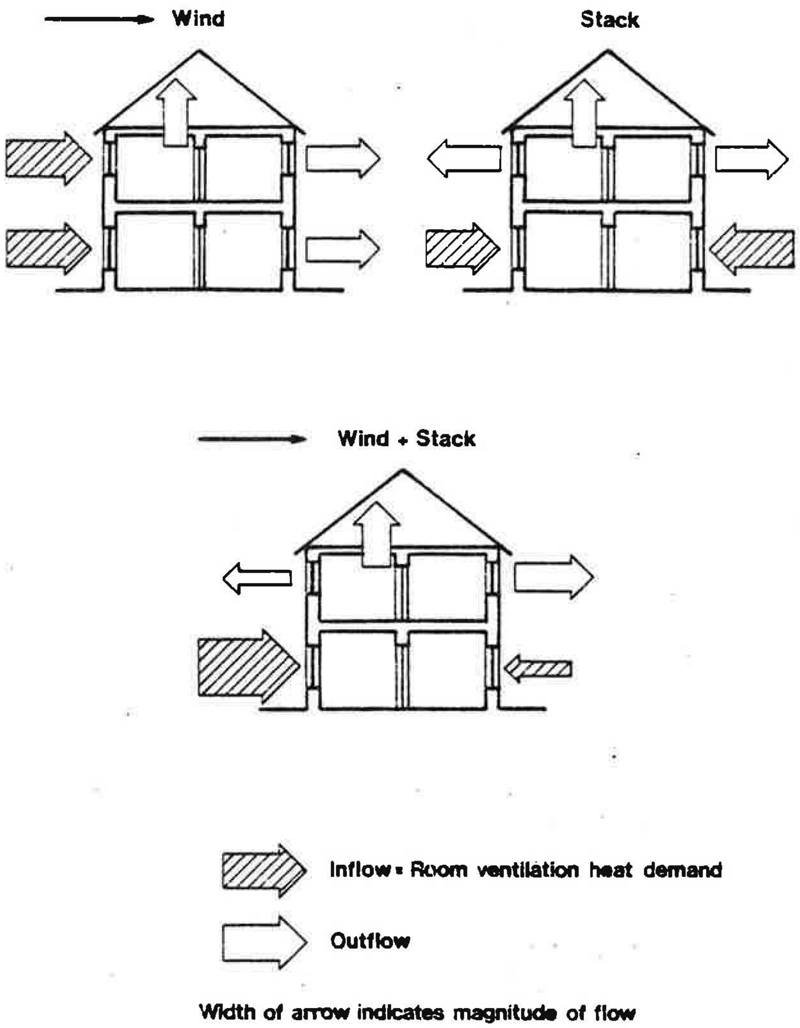

Figure 1: Distribution of Ventilation Within a House as Affected by the Wind and Stack Effects

In these changed circumstances, it is desirable to ascertain the magnitude of the ventilation heat loss correctly. An undersized heating system will inevitably result in customer complaints, whereas an oversized system will be needlessly costly and could be less efficient. Conventionally, the boiler size is arrived at by the summation of the individual room heat losses, both fabric and ventilation, and then adding further capacity expressed as a percentage of the total, to account for warm-up and other factors. Such a procedure can lead to boiler oversizing. Figure 1 shows that air that enters the dwelling through some rooms must leave by others. As a guide, only one half of the sum of the individual room ventilation heat losses occur at any one time. Significant oversizing can occur in tighter dwellings if the higher conventional design air change rates, for example, 2 air changes per hour, are applied.

A method of estimating ventilation heat losses that would take into account the true nature of air flow through buildings and which could predict the adventitious leakage would therefore be of benefit. However, before any progress can be made, a knowledge of leakage characteristics of the housing stock has to be obtained.

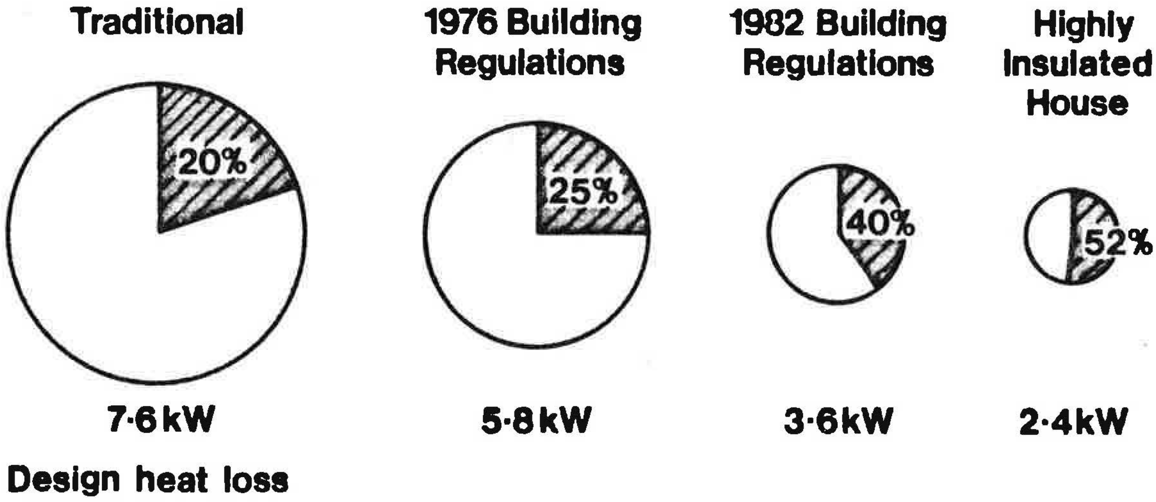

Figure 2: Ventilation Heat Loss as a Percentage of the Total Design Heat Loss of a Typical Semi-Detached House (External Temperature -1°C and a Mean Ventilation Rate of 1.0 Air Changes Per Hour)

SUPPLY OF COMBUSTION AIR FOR GAS APPLIANCES

BS 5440[6] recognises that adventitious ventilation openings are always present within rooms even after considerable effort has been made to restrict the air change rate by weatherstripping and double glazing. Based on previous work carried out by Watson House Research Station, BS 5440 assumes that adventitious openings in habitable rooms will not be less than 35cm^2. This is sufficient for an open flued appliance with an input not exceeding 7kW not to require an air vent in the room or internal space in which it is installed. In the intervening years since BS 5440 was published, changes have taken place in house construction and design. It would therefore be prudent if the assumptions in BS 5440 concerning the minimal adventitious openings were re-examined.

3 LEAKAGE SURVEY OF HOUSING

OBJECTIVES AND BASIC PHILOSOPHY

There were two major objectives of the survey. The first was to obtain data which would enable at least a rough estimate of the total adventitious leakage of a dwelling to be made simply from a knowledge of its basic physical characteristics. These characteristics are ones which are either obvious or easily obtained (e.g. the presence of weatherstripping and the volume of the dwelling). Characteristics which require extensive measurement for their determination (e.g. the measurement of gaps in windows) were excluded. Such characteristics allow a deterministic method of estimating leakage to be employed, whereby the leakage of an opening is calculated from a knowledge of its geometry[7]. However it is not often possible to measure the geometry of background openings, and even if it were, such a lengthy and tedious procedure could not be contemplated for general purposes. Hence the emphasis was placed on basic dwelling characteristics, and this means that the method for predicting leakage would be probabilistic in nature i.e. it would be derived from a statistical analysis of data and would predict the probability that the leakage of a dwelling lies within a certain range. At the outset it was appreciated that the statistical analysis would of necessity be limited, because some of the characteristics which were thought to influence leakage could not be expressed precisely in a quantitative way. Nevertheless it was felt that any information would be an improvement over the situation existing at the time.

The second objective was to use the data to assess whether the continued application of the adventitious allowance is justified in new dwellings. Clearly the main interest would lie in the tight dwellings and these would inevitably be a small proportion of the total sample. However it will be seen that the results from the total sample also provided useful information in this respect.

It was decided to measure only the total leakage of each dwelling, rather than individual room leakages. This is obviously in accord with the first objective, but it might be thought preferable to measure room leakages for the second objective. However it was argued that any trend for reduced leakage of new dwellings would probably be more apparent in the total leakage, because energy conservation measures are primarily concerned with the leakage of external surfaces. Furthermore, total leakage is much easier and quicker to measure than room leakages.

It was decided to aim for a sample size of about 200 dwellings (217 dwellings were eventually measured). At the time no survey of this magnitude had been carried out in the U.K., the largest being that of 17 dwellings reported in Reference [8]. To obtain a geographical spread and to reduce the time required for the survey, it was decided to carry out measurements simultaneously in four Regions with the cooperation of regional staff. British Gas Southern, North Eastern, Northern and West Midlands agreed to participate. Special equipment and procedures were developed for the survey, with each Region being provided with its own set of equipment and a one-day training session.

SELECTION OF SAMPLE

Each Region was asked to divide their chosen dwellings into an approximate split of two-thirds "new" and one-third "old", where "new" is defined as less than 5 years old. The "old" dwellings were to be divided roughly equally between pre-1940 and post-1940 types to reflect the known age distribution of such dwellings. Specific requests were made for dwellings with timber-frame construction and for new unoccupied dwellings (including showhouses), because it was felt that these might tend to be tighter than average. Any form of house was allowed (i.e. detached, semi-detached, terraced) with 1, 2 or 3 storeys. Flats and maisonettes were also requested. Within this framework, dwellings were selected primarily on the basis of their availability (e.g. many were staff homes).

The above sampling procedure is unlikely to lead to a sample which is completely representative of the distribution of leakage of U.K. dwellings. This is partly due to the fact that dwellings were not picked at random and partly to the fact that a bias towards tight dwellings was specifically requested. However this is not a disadvantage, because the primary aim was to discover which characteristics have an important influence on leakage. Until these are known, and their distribution within the U.K. population of dwellings is also known, the attainment of a completely representative sample is unlikely to be achieved.

TEST PROCEDURE

Having selected a dwelling the following three tasks were carried out. A questionnaire was completed which asked for extensive details of the physical characteristics of the dwelling and its location. The dwelling was then prepared for the test according to set instructions. This included the sealing or closing of purpose-provided openings, such as air vents, flues, chimneys and fans.

This was followed by the leakage measurement. Figure 3 illustrates the basic technique and shows the two essential items of equipment i.e. a leakage tester and a manometer. The leakage tester contains a large fan, which sucks air from the house, and a flow meter for measuring the flow rate Q. The pressure difference Δp generated by the flow is measured with the manometer. By varying the fan speed, a graph of Q against Δp can be plotted. The resulting curve is known as the leakage characteristic of the dwelling.

It should be noted that there is no simple relationship between the natural ventilation of a dwelling and its leakage characteristic. Indeed leakage measurements are usually made at relatively high pressure differences ($10 < \Delta p < 60$ Pa) in order that the results are not influenced by the wind and buoyancy pressures which are responsible for natural ventilation. In this way a leakage characteristic is obtained which is truly representative of the openings in the dwelling, and this can then be used as input data to a mathematical model.

Figure 4 shows a typical leakage characteristic. As a convenient basis for comparison of dwellings it has become common practice to make use of the leakage at a pressure difference of 50 Pa. This leakage is denoted by Q_{50} (m^3/s).

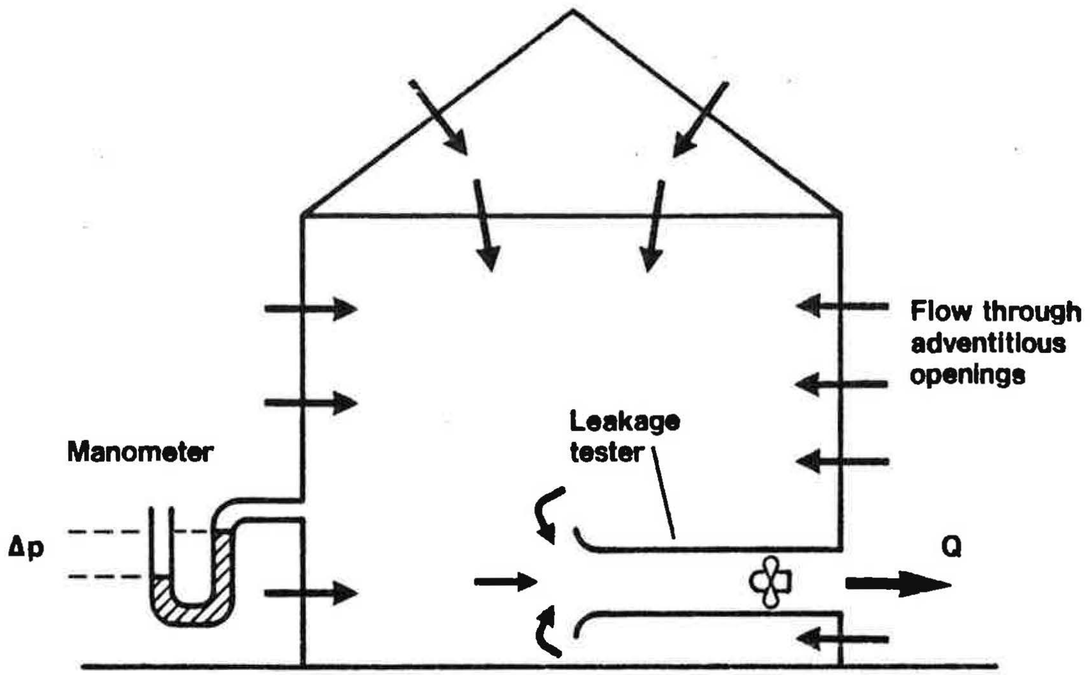

Figure 3: Basic technique for leakage measurement

TEST EQUIPMENT

Figure 5 shows the test equipment. The sloping gauge liquid manometer was chosen primarily for its ruggedness and convenience. A particular advantage of this instrument is that it comprises two manometers in a single case, one of which could be used for measuring Δp and the other for measuring the pressure drop across the flow measuring device in the leakage tester.

The leakage tester was specially developed for the survey by Watson House Research Station. Several design requirements were identified i.e. ease of transport, ease of use, ruggedness, stable calibration, insensitivity to installation effects. Previous equipment used by Watson House Research Station[9] was considered to be unsuitable on the basis of the first two of the above requirements. Equipment used by other organisations was also considered to be unsuitable for a variety of reasons. One common form of leakage tester is a "false door" containing a fan in a very short duct. It was felt that this type of device might be susceptible to installation effects, because the short duct does not allow for flow conditioning, upstream or downsteam of the flow meter.

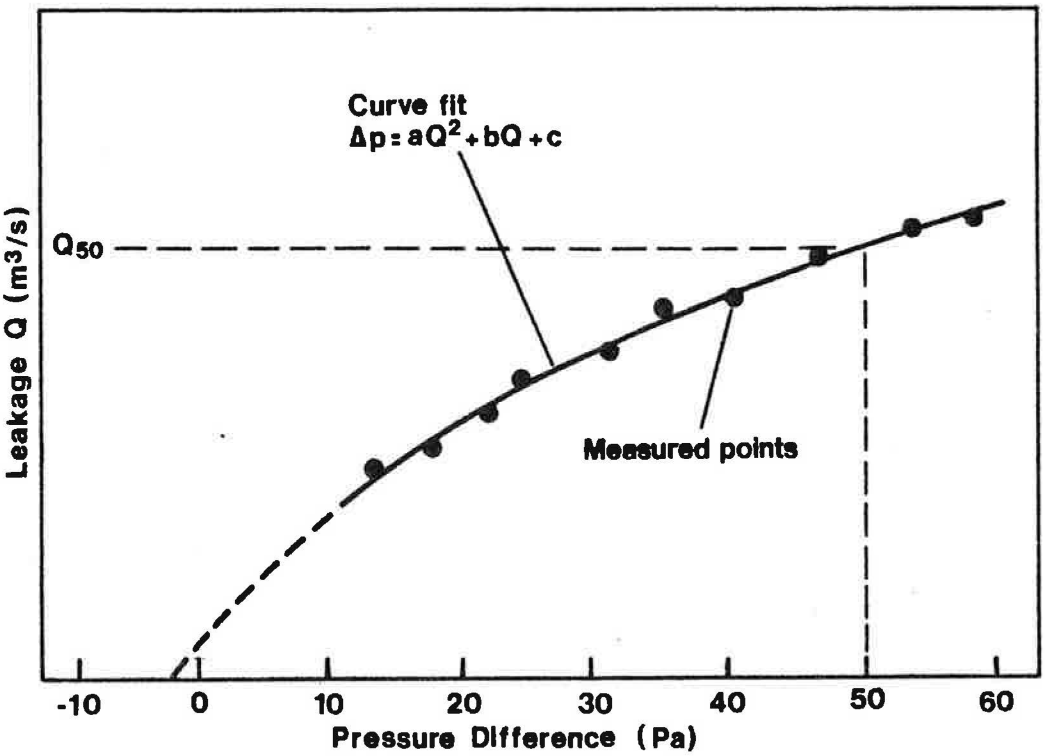

Figure 4: Typical leakage characteristic showing measured points and curve fit

Following consultations with Airflow Developments Ltd., it was decided to base the leakage tester on their "Wilson Flow Grid" meter which is basically a device for recording an average value of the dynamic pressure of a flow. Figure 6 shows the components of the complete unit. A bell-mouth inlet is followed by the flow grid, a flow straightener (to reduce the effects of swirl induced by the fan) and an axial fan. The fan has variable-speed control.

Four units were manufactured to special order by Airflow Developments Ltd., who also carried out the calibration on a rig conforming to BS 1042 and capable of giving accuracies of $\pm 2\%$. In view of the importance of this calibration, and the possibility of large systematic errors[10], an independent check was made using a tracer-gas technique, whereby the flow rate was determined from the dilution of a tracer gas in a test chamber. This confirmed that there were no large systematic errors in the calibration.

STORAGE AND PRELIMINARY ANALYSIS OF DATA

A large amount of data was produced by the survey and considerable emphasis was placed on the development of software which enabled the information to be handled and analysed in an efficient manner. A desktop computer was used to perform the following tasks:-

(i) storage of the completed questionnaire and leakage data in their original forms,
(ii) fitting a curve to the leakage data to define the leakage characteristic,
(iii) compilation of a summary database from which the data from any group of dwellings could be selected and plotted.

A quadratic equation, $\Delta p = aQ^2 + bQ + c$, was used for the curve-fit[11], with the coefficient c representing the pressure difference due to wind and buoyancy at the time of the test.

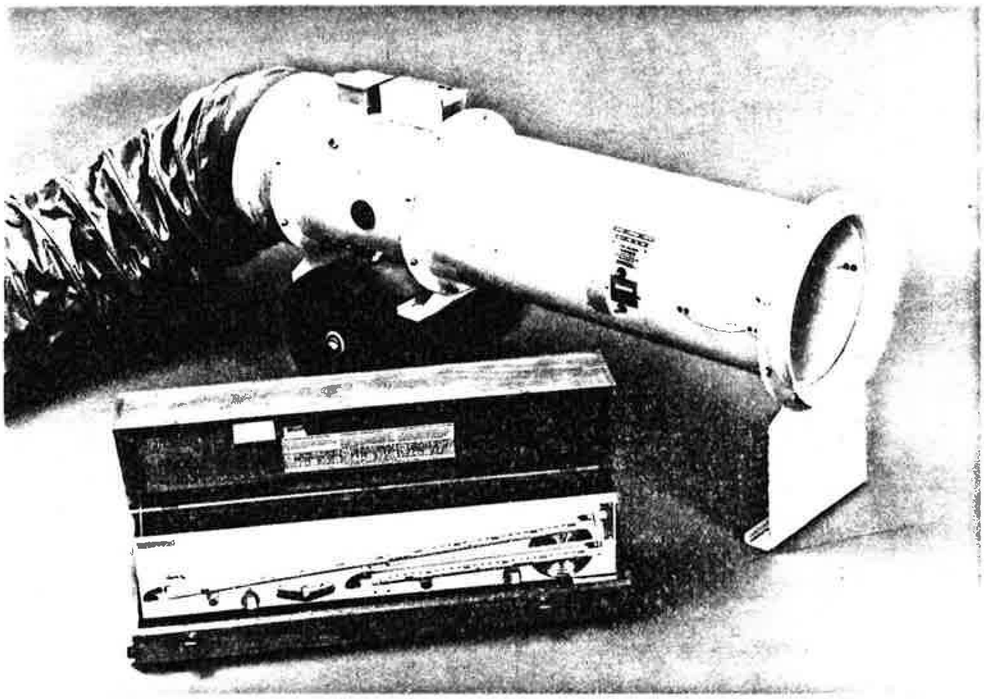

Figure 5: Test equipment comprising dual-gauge manometer and leakage tester

4 RESULTS OF THE SURVEY

DWELLING PROPERTIES AND LEAKAGE

The results were examined to see what light they shed on the relationship between the basic physical characteristics of dwellings and their leakages Q_{50}. It is these relationships which are needed for a method for estimating leakage.

An initial visual inspection of the data revealed that timber-frame dwellings should be treated as a separate group. The remaining two groups were then classed as "new traditional" and "old traditional", with the term "traditional" meaning that

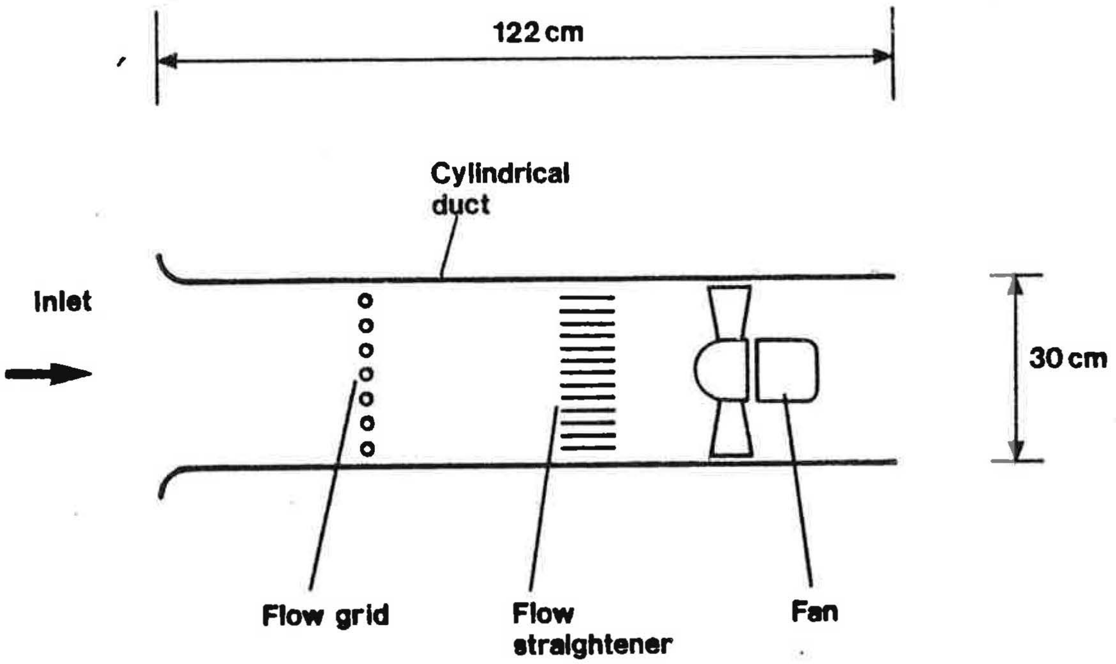

Figure 6: Cross-section of leakage tester showing its components.

the construction was not timber-frame. A statistical analysis of the frequency distributions of these two groups revealed that there were no significant differences between them. For much of the subsequent analysis these two groups were combined to form a single "traditional" group. Thus, Figure 7 compares the leakages plotted against volume of the dwelling, V, of the "traditional" and "timber-frame" groups.

The two lines in Figure 7 are the linear regressions for the two groups i.e. least-squares fits of the linear relationship $Q_{50} = A + B.V$. These lines show that on average the timber-frame dwellings are approximately half as leaky as the traditional dwellings with the same volume. In addition both lines display a trend for leakage to increase with volume, and this trend is what one would physically expect.

Another feature of Figure 7 is the wide range of leakages encountered. Some of this variation is associated with the wide range of volumes, but there is still a large variation about the regression lines. The success of a leakage prediction method will ultimately be judged by how much of this variation it can account for.

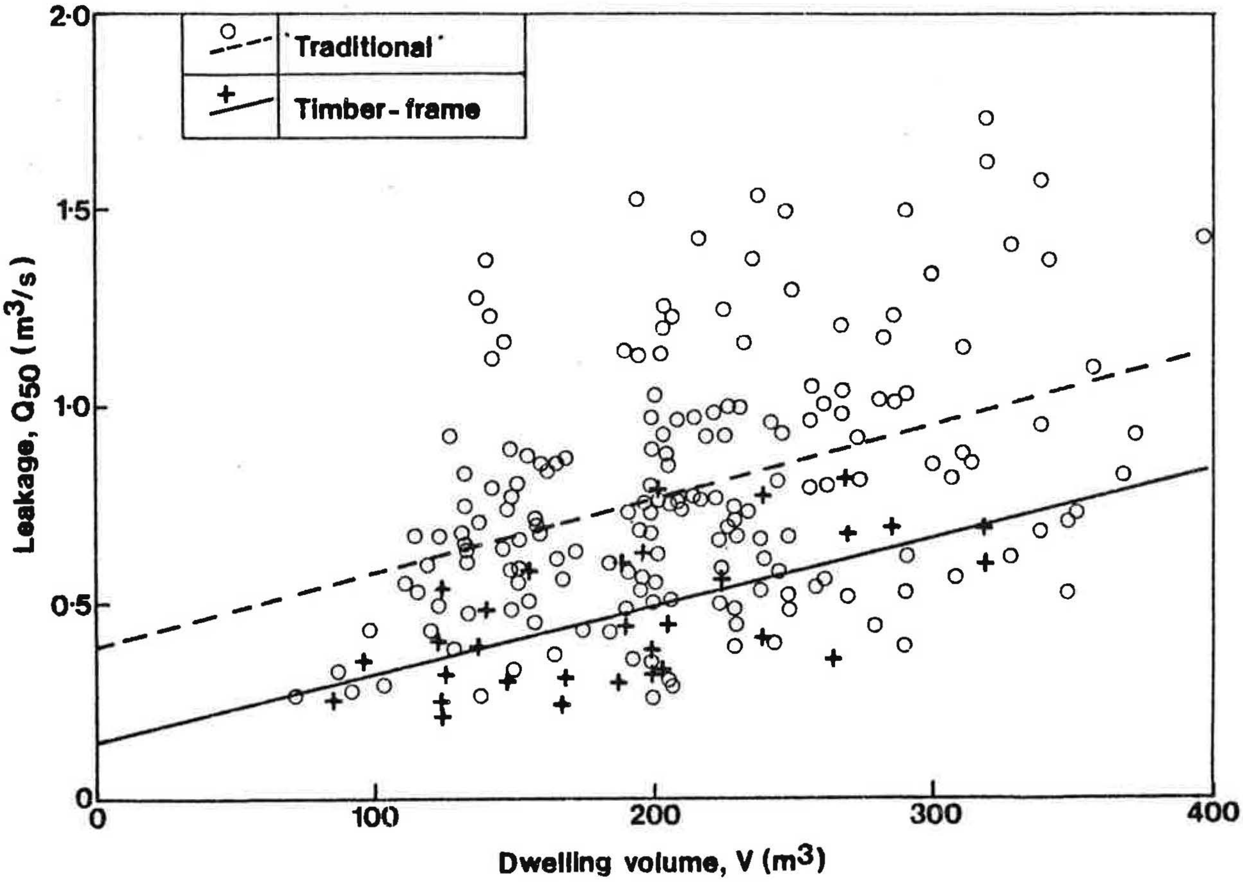

Figure 7: Leakages at 50Pa plotted against dwelling volume for the "traditional" and "timber-frame" groups

To examine the effects of other characteristics of the dwellings a simple comparative procedure was adopted. Only the largest group of dwellings, the "traditional" group, was used for this purpose. To have included the timber-frame dwellings could have given spurious indications, because of the large effect of construction type. The presumed influence of volume was accounted for by using plots of Q_{50} against V for the comparison. Thus the effect of a particular characteristic was examined by separating the data into two sets corresponding to whether or not the dwellings had that characteristic. This simple procedure can only be relied on to identify a characteristic which has a relatively large influence on leakage compared to other characteristics. Under the circumstances (i.e. a large number of possibly important characteristics distributed amongst a relatively small sample) it was considered to be the best procedure. The effects of weatherstripping, double glazing, floor type, wall type, occupancy and dwelling form were examined in this way.

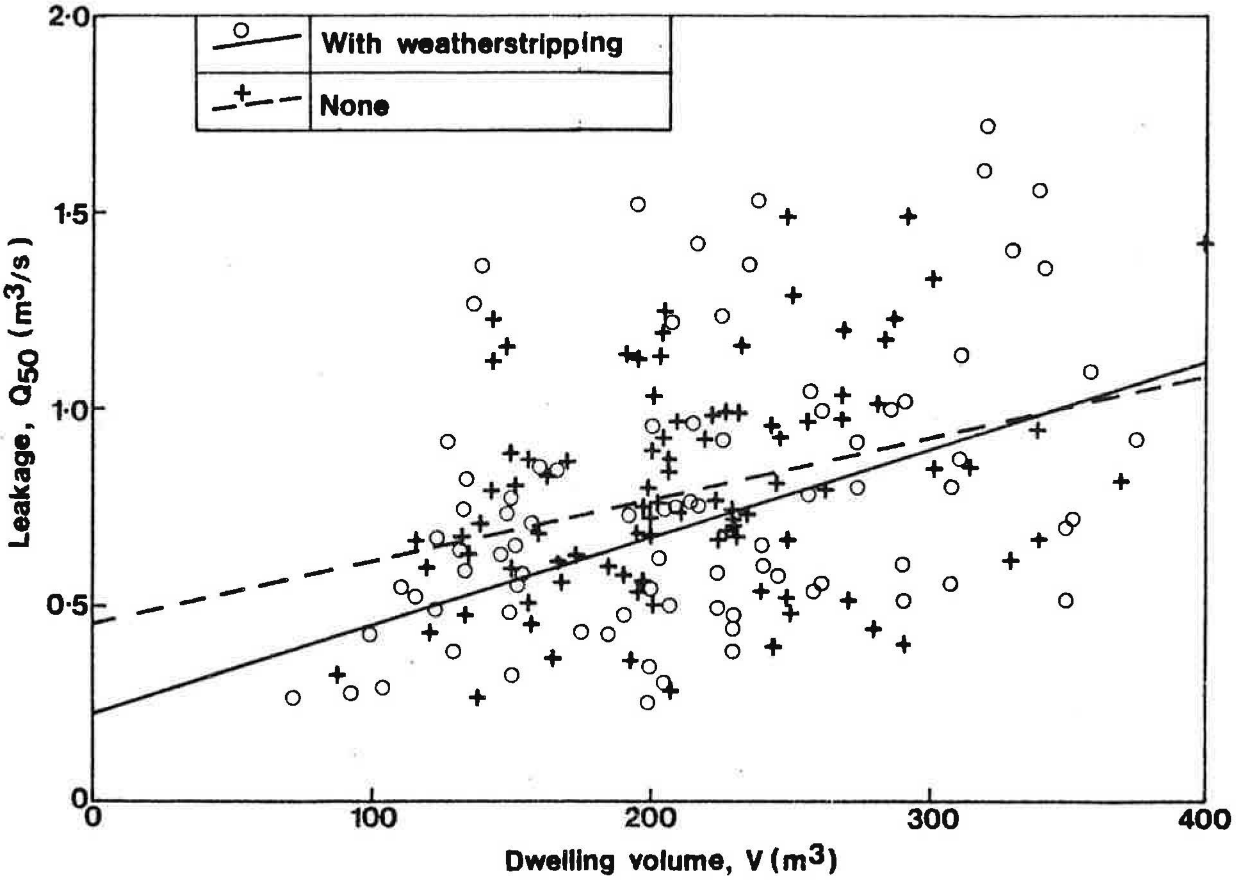

Figure 8: Leakages at 50Pa of "traditional" dwellings with or without weatherstripping

Figure 8 shows the graph obtained for the effect of weatherstripping. It should be noted that dwellings which were only partially weatherstripped were included in the weatherstripped category. The regression lines show that, on average, weatherstripped dwellings are less leaky than those without weatherstripping, but the effect is nowhere near as pronounced as the effect of construction type. This observation is not particularly surprising, because weatherstripping is usually only applied to components (windows and doors) and it is known the majority of the leakage can occur through background openings. Of course in some dwellings weatherstripping will have a larger effect than in others and Figure 8 is only indicative of the effect of weatherstripping on average, and not on the effect of weatherstripping on a particular dwelling.

Figure 9 shows the results of the comparison for wall type. Although little is known about the influence of empty cavities on leakage, one would intuitively expect a filled cavity or solid wall to be less leaky. On average this expectation appears to be realised, but again the effect is smaller than that of construction type.

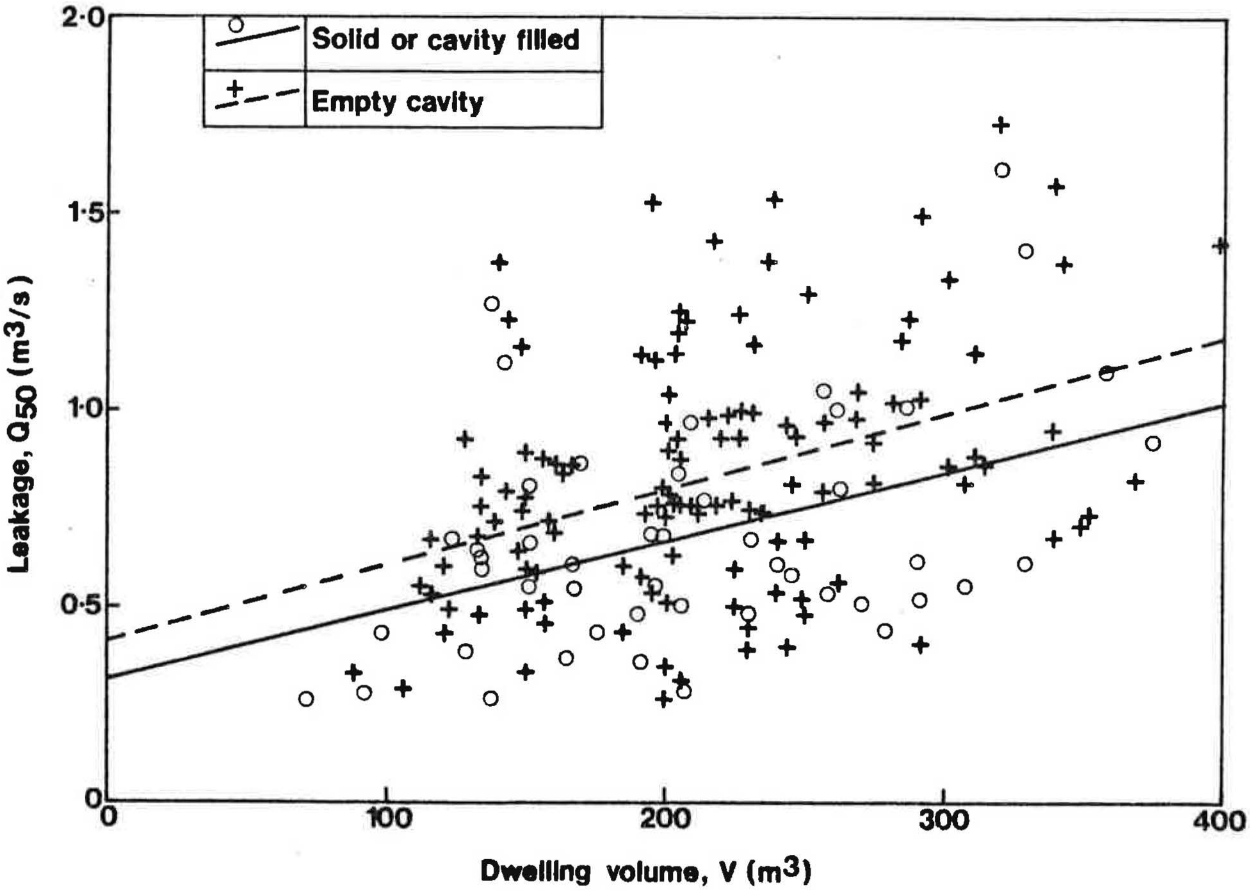

Figure 9: Leakages at 50Pa of "traditional" dwellings with or without empty cavities

Similar results to the above were found for double-glazing, floor type and occupancy, with the effect of dwelling form being less clear.

PREDICTING ADVENTITIOUS LEAKAGE

From the preceding analysis some important conclusions can be made about methods for predicting or estimating adventitious leakage. Any method should certainly differentiate between timber-frame dwellings and more traditional types of construction. The distinction should probably be made on the basis of whether or not the dwelling has a vapour barrier, since it is probably this feature which contributes most to the relatively low leakage of timber-frame dwellings. Factory pre-fabrication could also be a contributory factor.

The method should also include volume as one of the parameters, but there is no need to include age as a parameter.

The inclusion of construction type and volume as parameters still leaves a very large variation of leakage which is unexplained (see Figure 7). This is associated not only with identifiable characteristics (weatherstripping, floor type etc.), but also with more subjective factors such as quality of construction, quality of maintenance and modifications by the occupants.

Further work is needed to quantify the effects of the identifiable characteristics . The underlying difficulty here is to isolate the effect of one characteristic from results in a sample of dwellings having different combinations of characteristics. The effects of the subjective factors can never be completely resolved and they will always introduce an uncertainty in a prediction method. However for the purposes of sizing heating systems a moderate level of uncertainty in the leakage of a particular dwelling is acceptable. It is sufficient to predict a design leakage for the dwelling. The design leakage is defined here as the leakage for which there is a 90% probability that the actual leakage of the dwelling will be less.

It is convenient to work in terms of specific leakage i.e. the leakage per unit volume Q_{50}/V, as it takes into account the influence of house volume. From the frequency distributions of Q_{50}/V two specific design leakages, L, have been obtained and these constitute the basis of the prediction method:-

L = 20, for "traditional" dwellings
and L = 12, for timber-frame dwellings and dwellings with vapour barriers.

L is expressed in dwelling volumes per hour, so the design leakage of a dwelling is simply arrived at by multiplying L by the volume of the dwelling. L should not of course be confused with ventilation rate, which is also expressed in volume changes per hour. L is much larger, it is a direct measure of the tightness of a dwelling and does not depend on weather conditions.

Allowance can be made for other characteristics by multiplying the above value of L by the following factors, where appropriate,

(i)	solid ground floor	0.9
(ii)	majority of windows and external doors double-glazed or weatherstripped	0.9
(iii)	solid wall or cavity filled	0.9
(iv)	strip vents in most windows	1.05
(v)	purpose-provided air vents and/or flues (any number)	1.05
(vi)	solid-fuel chimneys (any number)	1.10

The above correction factors are based on experience from other work as well as on indications from the survey data. They are obviously very approximate and should not be used for any other purpose.

ADVENTITIOUS ALLOWANCE

One important finding which concerns the validity of the adventitious allowance has already been mentioned i.e. the absence of significant differences between "new" and "old" traditional dwellings. Bearing in mind that the allowance has been successfully applied for a number of years, there is a clear justification here for continuing its application to new traditional dwellings. This finding is based on an examination of complete frequency distributions, rather than the lower "tail" of the distributions which are more relevant to the allowance (i.e. the lower values of leakage). Also, the finding does not relate to timber-frame dwellings. In view of this, more detailed examinations of the "tails" of the frequency distributions, including the "timber-frame" group, were made.

The characteristics of the tightest dwellings were examined to assess whether the tightest timber-frame dwellings are likely to be appreciably tighter than the tightest traditional dwellings. This was done not only with Q_{50}, but also with leakages corresponding to 20 and 2.5Pa, and with the leakages per unit volume. No evidence was found for any large differences. Although the tightest dwelling measured was timber-frame, it had a smaller volume than the tightest "traditional" dwelling. Also it was a showhouse and is probably unrepresentative of occupied dwellings (e.g. sealing around pipe runs).

The above examinations are purely comparative in nature and make no reference to the adventitious allowance itself. The analysis was therefore extended by calculating the effective open areas of the dwellings so that they could be compared directly with the allowance. A major problem here is that the effective open areas (as distinct from the actual geometric areas) of adventitious openings depend on the pressure difference applied to them. More precisely, the discharge coefficient varies with Reynolds number. This means that the leakage characteristic has to be extrapolated down to a low value of Δp in order to give leakages appropriate to natural ventilation conditions. A value for Δp of 2.5 Pa was chosen because it was used for the original derivation of the allowance, it being considered to be the minimum likely to be encountered in practice. At this pressure difference the leakage of the tightest dwelling (a showhouse) was found to be equivalent to a gas input rate of 26 kW. The corresponding value for the tightest occupied dwelling was 33 kW. These values were considered to be sufficiently large to support the continued application of the allowance.

To summarise the above it can be said that in several ways the survey has given support to the adventitious allowance. By its very nature the validity of the allowance can never be conclusively demonstrated, but the technical judgement which was made when the allowance was included in BS 5440 has been substantiated by experience, and the present work gives some added justification. Further investigations should not however be ruled out. Future monitoring of the leakages of dwellings is desirable, to keep up to date with changing construction techniques. There might be justification for modifying the allowance to make it dependent on volume.

5 ESTIMATING VENTILATION RATES FOR SIZING HEATING SYSTEMS

Current procedures for sizing heating systems differ somewhat in their treatment of ventilation, but they all use fixed values of air change rates either for the complete dwelling R_D or for the rooms R_R. The main advantage of this is that little or no effort is required to calculate R_D and R_R. Also if the value of R_D is large, the chance of customer complaints arising from underheating is small.

The above procedure has worked well in the past, but in modern dwellings, where the ventilation heat loss can exceed the fabric heat loss, it becomes questionable. The underlying criticism of the procedure is that it takes no account of the ventilation characteristics of dwellings. With such dwellings it is somewhat illogical to carry out detailed calculations of fabric heat loss, and yet to rely on a value for R_D which is little more than a guess. The major practical disadvantage is that in some cases the fixed value of R_D might be too high, and thereby unnecessarily restrict the choice of heating system.

To improve the situation the new method which is described below in its basic form was derived. This was made possible by two separate areas of work. The first is the leakage survey, leading to a method for estimating the design leakage of a dwelling, which has already been described. The second is the derivation from a mathematical model, of a single graph linking the ventilation rate coefficient to a weather parameter. This graph forms the basis of the new method and its derivation is described below.

REQUIREMENTS OF THE NEW METHOD

The aim was to retain the advantages of the existing method whilst dispensing with the disadvantages. This led to four requirements, as follows.

- (i) The amount of time required to estimate R_D should be small compared to that required for the calculation of fabric heat loss.
- (ii) The method should be simple to use e.g. it should not require any prior knowledge of ventilation theory.
- (iii) It should give more realistic estimates of R_D.
- (iv) It should be biased so that there is little chance of ventilation heat loss being underestimated.

It is believed that all of these requirements have been satisfied. The first two follow from the various simplifications and assumptions which have been made, and there is clearly a compromise between these two requirements and the third one. It is important to appreciate therefore that the method is extremely approximate when compared to the mathematical model upon which it is based and should not be used for any purpose other than that for which it was developed.

DERIVATION OF THE METHOD

Natural ventilation occurs as a result of pressures generated by wind and buoyancy acting on openings in the external surfaces of the dwelling.

An accurate mathematical description of the phenomenon of natural ventilation is difficult and any computer based model has to incorporate some degree of simplification. Even the simplified models are not appropriate for day-to-day calculations of design ventilation heat losses as the input of relevant data and the interpretation of results remains complex. However, computer models are an essential tool for the development of general sizing methods.

Watson House Research Station has developed two models, VENT 1 and VENT 2[12]. The former model treats the dwelling as a multi-cell building, whereas the latter is much simpler and treats it as a single cell. VENT 2 has been used in the development of the proposed sizing method.

For a given distribution of openings and a given form of dwelling the ventilation rate, F, can be predicted from a knowledge of the following parameters

h	height of dwelling
ΔT	temperature difference between inside and outside
U_R	wind speed
ΔC_p	coefficients of the pressure differences generated by the wind across external surfaces
Q_{50}	the leakage of the dwelling at 50 Pa
a/b^2	the parameter which describes the shape of the leakage characteristic (a and b are the coefficients in the quadratic equation $\Delta p = aQ^2 + bQ$)

For a terraced house with a given opening distribution the predictions of VENT 2 can be plotted on a single graph which covers all conditions likely to be encountered in the U.K. This is made possible by plotting the results in nondimensional form. The relevant nondimensional parameters are:-[13]

the ventilation coefficient,

$$S = \frac{F}{\sqrt{\frac{\rho}{2a}}\, U_B}$$

the weather parameter, $W = \Delta C_p . U_R^2/U_B^2$

and the leakage Reynolds number parameter, P

$$P = \frac{1}{\sqrt{2\rho} \quad U_B \quad \sqrt{a/b^2}}$$

In the above definitions, ρ denotes the density of the ambient air and U_B an effective air speed associated with buoyancy, is defined by

$$U_B = \sqrt{\frac{\Delta Tgh}{T}}$$

where T is the ambient temperature and g the gravitational acceleration.

VENT 2 has been used to investigate a number of possible combinations of dwelling types and opening distributions. An analysis of the results showed that by accepting an appropriate level of accuracy it is possible to reduce the number of graphs to a manageable value. This process is described in reference 13 where an example is given which shows how four graphs can suffice for a simple graphical prediction method.

For the present design purposes, this process was taken a stage further and led to the selection of a single graph, as shown in Figure 10. As can be seen it takes the form of curves which show the relationship between S and W for a given value of P. For sizing heating systems further simplifications can be made.

For heating system design the temperature difference ΔT and the ambient temperature T are fixed (e.g. 21°C and -1°C respectively). By taking a representative value for a/b^2, it can be seen from the definition of the parameter P that it is determined solely by the height h. Thus each curve in Figure 10 corresponds to a certain building height, as indicated.

The determination of the weather parameter W can be simplified by using what is known as the gradient wind speed as the reference wind speed. The gradient speed is the speed at the top of the wind boundary layer and has the useful property that it does not vary greatly over the U.K. A fixed value of U_R can thus be chosen, which leaves only ΔCp to be specified. In general ΔCp is determined by the wind direction and the shape of the dwelling and its surroundings. For the present purpose, attention can be restricted to the maximum likely value of ΔCp, and this can be obtained from a knowledge of the surrounding environment.

Having determined P and W, the value of S can be immediately determined from the graph. It is then a simple matter to obtain the ventilation rate F by substituting the values of a and U_B into the definition of S. It is here that the design leakage value is used i.e. the predicted value of L gives Q_{50} which is used with the value of a/b^2 to determine a. Thus the ventilation rate is given by:-

$$F = S \sqrt{\frac{\rho}{2a}} \; U_B$$

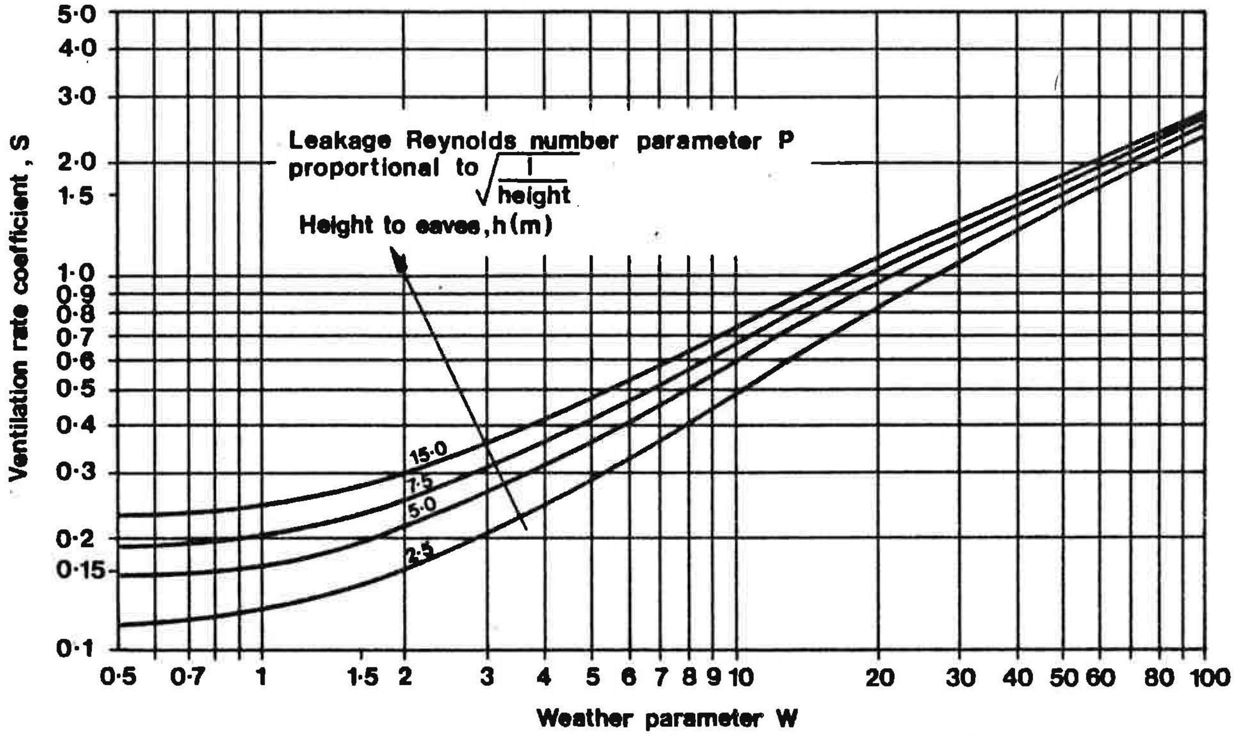

Figure 10: Non-dimensional graph derived from VENT 2 calculations

The above procedure can be used further to provide information about room ventilation rates. By calculating the ventilation rate of the dwelling at two wind speeds it is possible to determine whether or not the ventilation pattern is sensitive to wind speed. This can then be used to decide on the design air change rates for the rooms, by adopting the simple principles illustrated in Figure 1.

FINAL FORM OF THE METHOD

The method described above is a graphical one, but it is easy to develop an even simpler tabular method. This is done by fixing the values of h to those commonly encountered in practice. To obtain the design ventilation rate it is only necessary for the user to specify h and the surrounding environment of the dwelling, and read from a table the relevant value of R_D.

Both versions of the method were presented to representatives from all Regions of British Gas, so as to obtain views of potential users of the method. There was a very clear preference for the tabular method, and the feedback obtained is now being taken into account in a revised version of that method. It is planned to issue the revised method to the Regions in the near future. It is hoped that eventually the method will be incorporated into the standard procedures for sizing systems.

6 CONCLUSIONS

The leakage survey described was, and perhaps still is, the largest to have been carried out in the UK. It has revealed new information about adventitious leakages, in that it has shown that the type of construction has a major influence on leakage, whereas the age of the dwelling does not. In particular, timber-frame housing is, on average, much tighter than traditional housing. It supports the expectation that, on average, the influence of other factors such as weatherstripping and double glazing is not large.

As far as domestic gas utilisation is concerned, the importance of the survey lies in the support it has given to the adventitious allowance, and in the fact that it has enabled a simple method for predicting the design leakage of a house. By combining this method with the generalised results of a mathematical model of ventilation, it has been possible to derive a novel method for estimating ventilation heat loss when sizing heating systems. This latter method is a considerable advance over the estimation procedures currently employed and should lead to more appropriate sizing of space heating systems.

On a more practical level, the survey has demonstrated how valuable the participation of the British Gas Regions in a research project can be. Regional staff were not only involved in carrying out the survey, but they have also provided valuable feedback on the application of the results.

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