APPLICATION OF AIRTIGHTNESS TO HEALTHCARE BUILDINGS

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ABSTRACT

The thrust of airtightness specification and testing is derived from energy considerations. The application to healthcare buildings and specialist laboratory facilities embodies the same principles but derives the appropriateness of the criteria with reference to [a] producing controlled and controllable cascading pressure zones and [b] specifying or quantifying the potential exposure in the event of failure of mechanical ventilation.

The paper discusses the application of airtightness testing to two full scale physical models of isolation rooms. It will be shown that important information can be readily obtained to allow the commissioning of such facilities by determining component flows through closed doors, pressure stabilisers and the like. The modifications in approach necessary for application to Category 3 and above facilities are presented with discussion of the findings from field measurement data.

KEYWORDS

Airtightness, ventilation strategy, health care buildings, airborne pathogens.

INTRODUCTION

The development of airtightness standards now common in commercial and domestic building codes[1] has been driven by energy considerations – reducing the amount of unwanted and uncontrolled infiltration of external air. Low energy buildings require a high quality of design and construction. In the field of healthcare buildings and specialist laboratory facilities, conventional practice has been based on the priority of cascading pressure zones with the emphasis on the magnitude of the static pressure differences between adjacent zones – and by implication with doors closed. A secondary importance has often been assigned to the magnitude of the air volume flow rates – the priority being the cascading negative pressure. However, the dilution of airborne contaminants and pathogens is determined to a large extent by the provision of an appropriate quantity of air coupled to an effective ventilation strategy. The ventilation strategy is generally a well- mixed process in the context of isolation rooms but could involve displacement ventilation or a uni-directional (piston effect) regime.

Efficient design and effective construction of this type of facility can only be carried out by appropriate cognisance of the airtightness standards and subsequent representation and expression as inter-zonal flows.

A further consideration is that a component such as a (passive) pressure stabiliser regulates the static pressure differential between two spaces by changing the resistance to air flow. This can be done only over a limited dynamic range – once the damper is fully open or closed it will behave as a fixed opening. Typically, this dynamic range may only be 5 to 10 Pa with a near linear volume flow rate versus pressure differential characteristic. Under door flows (assuming intentional) can be estimated but in practice are difficult to adjust.

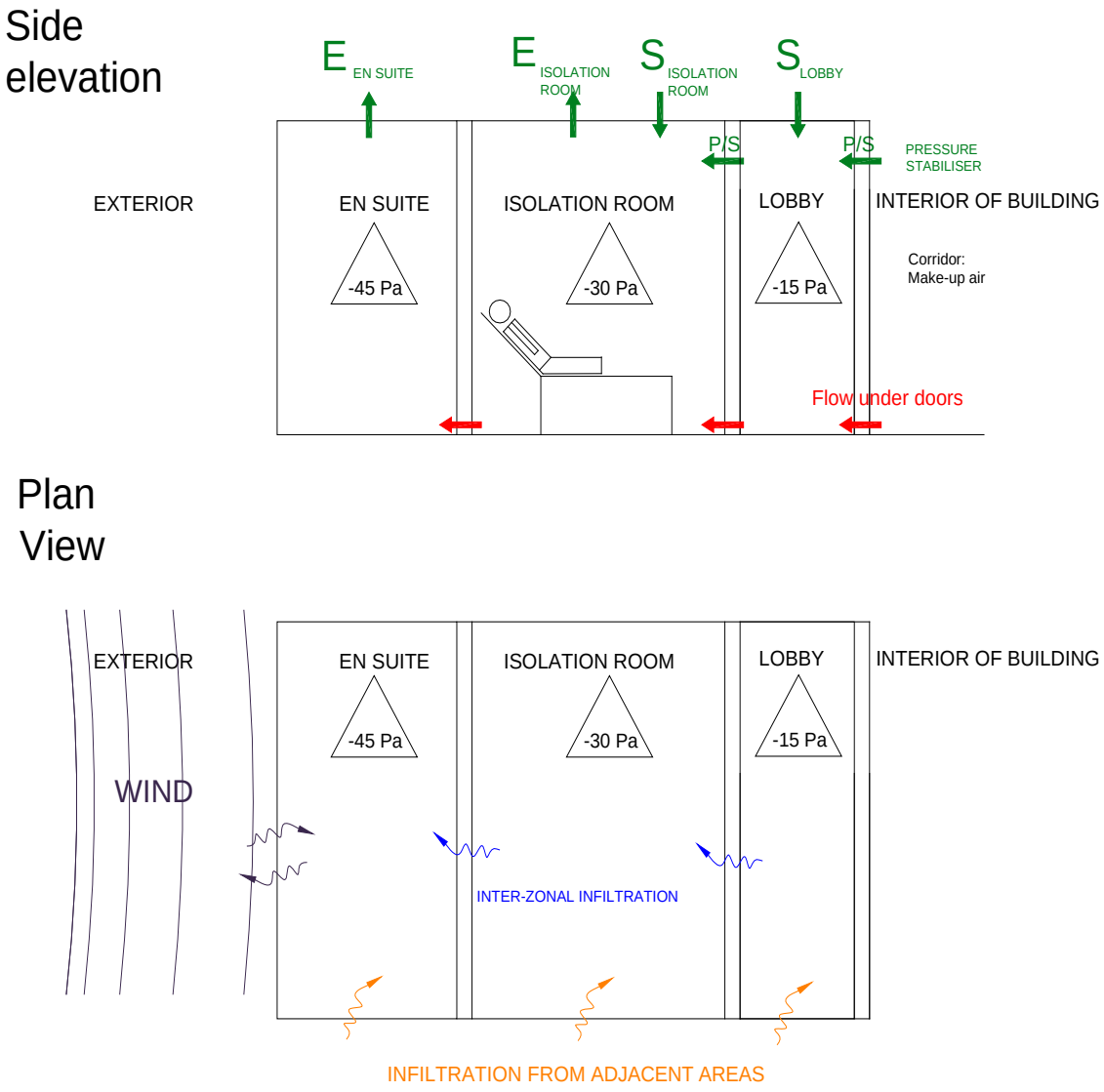

Figure 1. Schematic of component flows

Figure 1 illustrates in schematic form the key component flows for a (UK) typical negative pressure isolation room with en suite bathroom and entrance lobby. In the idealised situation with a perfect enclosure and no external wind effects, the relationship between the flows is readily defined. (NB There is an implicit assumption that sufficient air is available to be drawn into the lobby.) At commissioning and subsequent maintenance, the two mechanical extracts and two mechanical supplies can be adjusted to produce the desired regime although this assumes that the pressure stabilisers and under-door flows are appropriate. If either of these are not appropriate, the consequences of adjusting the mechanical volume flow rates to achieve the desired cascading pressure differentials can cause practical problems such as poor room air movement and mixing (supply much lower than design compromising diffuser

selection), draught and thermal discomfort risk (supply much higher than design). Lower than design dilution rates are also a probability. In the non-idealised situation (i.e. when constructed), leakage into (NB outward for positive pressure) the controlled spaces may reduce the mechanical supply requirement. It follows from the expression of the inter-zonal flows that practical bounds can be set on acceptable levels of infiltration (and hence minimum airtightness requirements) by realising that the undesirable flow rates must be less than the dynamic range of control offered by the pressure stabilisers and the maximum design variances in mechanical supply and extract volume flow rates. It is prudent to include the potential uncertainty in under door flows within the overall allowance.

In reality, the situation becomes more complicated with the effect of wind on external walls being one factor to be considered. The effect of the rest of the building or hospital on the corridor also has an influence.

PHYSICAL MODEL INVESTIGATIONS

BSRIA has conducted a programme of investigations[2] using full size physical models. The objectives were to validate two different isolation room designs in England and Northern Ireland. Understanding the component flows and the potentially significant impact of airtightness criteria became one of the major findings. The first study, commissioned by DH, is described in the Guidance HBN4[3] and it consisted of an entrance lobby, isolation room and en suite. The second study, a proposed Intensive Care Unit(ICU) isolation room for the Royal Victoria Hospital of Belfast, commissioned by DHSSPS, consisted of an entrance lobby and the patient isolation room but no en suite. The ICU had a much higher provision of medical equipment and therefore heat load than the HBN4 design.

Both rooms were tested under a cascading negative pressure configuration and as neutral isolation rooms with a Positively Pressurised Ventilated Lobby (PPVL). A PPVL room provides protection from infections originating in the room (equivalent to a negative pressure isolation room) and from infections originating in the corridor (equivalent to a positive pressure type).

In the HBN4 design, air was supplied into the lobby through a 4-way square ceiling diffuser and then entered the isolation room via a pressure stabiliser and gaps around and below the lobby- to- isolation room door. The pressure stabiliser was designed to open when the ΔP between the lobby and the room was 10 Pa.

The air mixed in the room, diluting the contaminants concentration and went through a door grille into the en suite, where it was extracted. The lobby was kept at a ΔP of +10 Pa with respect to the isolation room and the hospital corridor, the room was kept at Neutral pressure with respect to the corridor and the en suite at -10 Pa. The air change rate (ACR) in the room was 10 ACH (nominal).

To achieve a cascading negative pressure design, the room was modified and an extract was built in the isolation room and only the top blade of the pressure stabiliser was used. The air change rate was still 10 ACH and the pressures were -4 Pa in the lobby, -18 Pa in the isolation room and -18 Pa in the en suite.

The PPVL design of the Intensive care unit at the Royal Victoria Hospital, also consisted of a pressurised lobby at +10 Pa and a 10ACR in the neutral isolation room. In this case, the air passed into the Isolation room through two pressure stabilisers above the door and it was

extracted from the room into an adjacent plant room where the air was treated (filtered) before being released outside the hospital.

In order to achieve a cascading negative pressure configuration in the ICU, the supply and extract flows were modified, the doors were changed so that they opened into the corridor, and the pressure stabilisers were set so they opened at a differential pressure of 15 Pa. The ACR was now 18 ACH instead of 10ACH in the patient's room. The heat load in the room was not modified. The lobby was kept at –15 Pa and the room at -30 Pa with reference to the hospital corridor.

FINDINGS

The investigations carried out by BSRIA demonstrated that the effectiveness of an isolation room does not depend solely on pressure differentials, but also on achieving good mixing and dilution within the space. Protection levels of 10^3 were obtained inside the room (outside the 1 m patient breathing zone) and of 10^5 outside the room. [4]

Air tightness tests were carried out in these rooms for two reasons. Firstly, in order to commission the room, the airflows through the structure derived from the pressure differentials between the rooms, (in addition to the flows under and around doors and through the pressure stabilisers) needed to be quantified and minimised. (i.e in a fan failure mode resulting in altered pressure differentials in the room , or anomalous room operation-leaving doors open) the walls offer a degree of protection, this term is known as passive protection.

Unknown or unaccounted for air leakage though the structure of an Isolation room could translate into risk of contamination in adjacent areas where it would not be expected. Secondly, air tightness tests were used to determine the flow through key design components (pressure stabilisers, doors).

Table 2 shows the study of air leakage through the envelope. HBN4 suggests a test pressure of double the operating pressure for isolation rooms. For a given Air leakage index (ALI) the maximum test flow rate is calculated. Table 2 shows that the air leakage through the walls for a room at 20 Pa is considerably much higher than the same room at 10Pa (45% for Model 1 and 50% for Model 2).

Model	Working P	Test P	ALI	ALI (used)	Max Test Flow Rate	Max. Test Flow Rate / unit volume
	(Pa)	(Pa)	$m^3/(h.m^2)$	$m^3/(h.m^2)$	$(l.s^{-1})$	$(l.s^{-1}$ per $m^3)$
1	10	20	3.16	3	72.5	1.01
	15	30	3.87	3.9	94.3	1.31
	20	40	4.47	4.5	108.8	1.51
	25	50	5	5	120.8	1.68
2	10	20	3.16	3	99.2	0.75
	15	30	3.87	3.9	128.9	0.98
	20	40	4.47	4.5	148.8	1.13
	25	50	5	5	165.3	1.25

Table 1. Air leakage maximum values

The experimental work clearly demonstrated that determination of airtightness enables component flows to be readily determined thus providing a straightforward route for commissioning and in-service maintenance.

FACILITIES UP TO CAT3

The traditional view of facilities such as isolation rooms has been to focus on the relative de-pressurisation (negative) or pressurisation (positive). The quality and quantity of airflow within the space has generally not been accorded the same attention – the dilution of potential pathogens is the mechanism by which personnel within a space are afforded protection. The provision of all three parameters – pressure steps, air change rate and effective ventilation – has been shown to be necessary.

The integrity of the building fabric forming isolation and other specialist facilities subject to cascading pressure differentials is expressed in the form of appropriate airtightness specifications. The primary driver for specification is to ensure the pressure cascades can be achieved and controlled. The secondary driver is to ensure there are no adverse effects on delivered air change rate and effective ventilation.

For facilities up to CAT2, some consideration should be applied to the challenge arising from a first order failure. For example, for a negative pressure facility, loss of the mechanical extract could result in positive pressurisation of the all or part of the facility with the consequent potential hazard of leakage of airborne pathogens to surrounding spaces or the external environment. *(NB It is worth noting completely different considerations apply when a door is opened between adjacent spaces. Only in very specialist applications will there be a high enough inward volume flow rate for negative pressure cascades (outward for positive). Generally, this is regarded as a transient situation with some potential for interchange of air between the adjacent spaces, possibly compounded by entrainment of air in the wake of a walking person, for example.)* A risk analysis approach could involve identification of the maximum acceptable leakage of pathogens from the isolation room under normal operation (e.g. potential cross-transfer due to air interchange from isolation room to lobby and lobby to corridor resulting from personnel movement) and under a single mode failure (e.g. extract fan failure leading to positive pressurisation of the isolation room). Relative pressurisation of adjacent spaces such as flanking corridors, plant rooms and service voids must be taken into account. It is not realistic to prescribe a zero leakage. It may be helpful to view this target in more prosaic terms such as a permissible "*bugs per minute*" transmission.

This target can then be converted by designers into specifications that in turn can be validated at commissioning and throughout the operational life of the isolation facility.

EXTENSION TO CAT3 AND ABOVE FACILITIES

When dealing with extremely hazardous situations, the rationale for setting performance based targets is shifted to reflect the overriding concern to avoid escape of airborne pathogens under failure modes as the priority. This leads to much high airtightness standards and directly to lower actual flow rates and changes to the measurement techniques applied.

The method of measuring the air leakage of rooms using a pressurisation (or de-pressurisation) technique is well documented with various standards giving the basic test method (for example)[5] [6]. These involve supplying (or extracting) air to an enclosure and measuring the resulting pressure differential. This is repeated for a number of different flow rates, the air flow rate and resulting pressure differential being related by the following equation:-

$$Q = C_L . (\Delta P)^n \qquad 1$$

Where Q = air flow rate supplied to the building ($m^3.s^{-1}$)
ΔP = pressure differential across building (Pa)
C_L = the air leakage coefficient ($m^3.s^{-1}.Pa^{-n}$)
n = an exponent normally between 0.5 and 1.0

A regression analysis is carried out on the data and the results expressed as an air flow rate at a specific pressure differential, and normally normalised by either surface area ($m^3.(h.m^2)^{-1}$, or volume (ach^{-1})).

Where the air leakage through the door is small compared with the remaining air leakage the use of blower door fan sets can be used, as the air flow rate required to test an enclosure reduces, the air leakage through a normal door fan set-up could become a significant proportion of the air leakage, in these circumstances an alternative method of supplying (or extracting) will be required. This can be either a purpose made attachment or utilise existing apertures within the enclosure such as the balancing dampers. In addition the air flow rate range of this type of equipment may not be appropriate or provide the required pressure differential. In these circumstances it may be preferable to use an in-line flow meter rather than the 'inlet flow meter' which is regularly used to measure the air leakage of buildings. The in-line flow meter could be, for example, a laminar flow element or a venture nozzle. The air flow rate being determined by measuring the pressure differential across the flow meter. In addition, the information on the airflow rate through the access door will be required.

As the room air leakage decreases the time taken for the room pressure to stabilise after the air flow rate is adjusted can increase, and some circumstances can be in excess of 45 minutes. In these circumstances a different method has to be adopted. The method used has been to set the air flow rate at the required air leakage, and allow the room pressure differential to stabilise (some adjustment of the air flow rate may be required during this period). The room pressure attained should be greater than required by the air leakage criteria to indicate compliance. Once the room has attained its maximum pressure differential, the fan is left to

operate for a minimum of 15 minutes, with measurements recorded every 2 minutes to confirm that stability has been reached.

Table 2 lists some of the performance targets for some of the test work carried out by BSRIA over the last four years. To facilitate comparison, the criteria have been converted to an equivalent air tightness expressed as a conventionally reported air permeability at 50 Pa.

Room description	**Air tightness criteria**	**Equivalent air tightness expressed as an air permeability $m^3.h^{-1}.m^{-2}$ @ 50 Pa**
Clean room with close control of humidity required	0.2 $m^3.h^{-1}.m^{-2}$ @ 50 Pa	0.2
Clean rooms & labs within a hospital	2.5 $m^3.h^{-1}.m^{-2}$ @ 50 Pa	2.5
Cat 2 & 3 labs	0.6 air changes per hour at ±60Pa	0.45 – 0.5
Cat 3 labs within a hospital	1 $l.s^{-1}$ @ 100 Pa	0.012
Cat 3 labs within an animal research facility, (temporary building)	2 $l.s^{-1}$ @ 200 Pa	0.015
Cat 4 Rooms within an animal research establishment	0.009 $m^3.h^{-1}.m^{-2}$ @ 200 Pa	0.0025

Table 2. Recent air tightness criteria

CONCLUSIONS

The extension of energy based airtightness specifications to healthcare and specialist laboratory facilities has been illustrated. The rationale for performance criteria based has been explained via component flows identified from an idealised scenario. The need to characterise pressure stabilisers and under door flows has been shown to be essential for design selection and in use commissioning and maintenance.

Application of blower door techniques to two types of isolation room has been reported. These techniques can yield data on component flows (e.g. pressure stabilisers) as well as the actual standard of airtightness achieved at construction. These techniques can be utilised routinely.

The modification in measurement technique necessary when extending to high integrity structures (i.e. for CAT3 and above) has been described.

It has been shown how high risk applications can use the component flow approach to specify airtightness standards based on hazard assessment in failure modes. This may require buffer zones in extreme applications to decouple protected areas from the external environment and the effects of wind in particular.

In summary, the application of appropriate airtightness standards to healthcare buildings and specialist laboratory facilities goes beyond the energy-based origins of airtightness. Confidence in design and construction can be achieved by specification, effective construction and good commissioning practice. The underlying theme is the optimisation of desirable air flows and the minimisation of undesirable flows.

ACKNOWLEDGEMENTS

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