SIMPLE EXCEL SHEET
doe vertaling vi van AIVC
publicatie over air tightness

VENTILATION AND COOLING

18TH ANNUAL AIVC CONFERENCE
ATHENS, GREECE, 23-26 SEPTEMBER, 1997

Blykbaar sterk gelykaardige
studie aan TNO, Willem de Gid
+ Co

Predicting Envelope Air Leakage in Large Commercial Buildings Before Construction

M D A E S Perera[1], J Henderson[2] and B C Webb[1]

1. Building Research Establishment Ltd, BRE
Garston, Watford,
Herts., WD2 7JR
United Kingdom

2. Department of Physics
The University of Reading
Whiteknights
P O Box 220
Reading, RG6 6AF
United Kingdom

This paper will also be presented at the CIBSE National Conference 1997

Predicting Envelope Air Leakage in Large, Commercial Building Before Construction

by

M D A E S Perera, J Henderson and B C Webb

SYNOPSIS

The concept of 'build tight - ventilate right' requires minimising air infiltration through the envelope of a building and then providing adequate ventilation in a controlled manner to satisfy the fresh air requirements of occupants. This paper describes a simple-to-use design tool (PC based and in spreadsheet format) for predicting the airtightness of office building envelopes either at the design stage or before a major refurbishment. The predicted value can be used as an indicator for post-completion air leakage testing to confirm the design assumptions and check on build quality.

Input of data is kept to a minimum. The simple design tool provides an overall leakage rate by considering the building size, glazed area, construction type and whether or not various tightness measures have been incorporated. The paper concludes with good comparisons between measured and predicted leakage rates in 10 office buildings. The paper also provides an example of how the tool can be used to assess the individual effectiveness of various key airtightness measures.

1. INTRODUCTION

This paper describes a prototype version of a 'simple to use' design tool (PC based and in spreadsheet format) to predict the airtightness of office building envelopes; either at the design stage or before a major refurbishment. This is a significant development since hitherto the only means available to quantify this leakage was through a fan pressurisation test [1] once the building was constructed.

1.1. Air infiltration in office buildings

Adequate ventilation is essential for the health, safety and comfort of building occupants, but excessive ventilation leads to energy waste and sometimes to discomfort. A building needs to be ventilated by design through controlled openings (e.g. openable windows) rather than by adventitious infiltration of air through the building envelope.

Air infiltration is the uncontrolled flow of air through cracks and gaps in the building envelope. It is driven by pressure and air temperature differences between the inside and outside of the building and is highly variable in response to changes in the weather. It cannot be designed for, and may therefore be considered as an overhead or penalty. Infiltration is not a reliable substitute for properly designed ventilation.

Good office design should therefore separate the mechanisms, which provide a good supply of fresh air to occupants, from the adverse and unpredictable effects of air infiltration. This demands good ventilation design and coupled to a clear and workable specification for an effective and maintainable airtightness layer. That is, the concept of 'build tight - ventilate right'. It has to be emphasised that a building cannot be too tight - but it can be underventilated.

A building with an airtight envelope provides identifiable benefits to those who own, maintain and occupy it through the following:

- Energy savings since energy costs for space heating may be up to 20% less than for an equivalent but leaky building. Additionally, sophisticated energy-saving heating control systems and heat recovery systems can be economically viable options in tight buildings.
- Enhanced comfort since draughts and localised cold spots are minimised in a tight building. Providing controlled ventilation, e.g. at high levels, ensures adequate fresh air for occupants with a minimum of draughts around people.
- Reduced risk of deterioration in a properly ventilated but tightly constructed building; since otherwise air leaking out of the building will tend to pull warm and moist internal air through the fabric of the walls and roof.

1.2. Current requirements and guidance

Requirement L1 of the England and Wales Building Regulations requires that 'reasonable provision shall be made for the conservation of fuel and power in buildings by: limiting the heat loss through the fabric of the building ...'. Supporting this is Approved Document (AD) Part L [2] which provides guidance on some sealing measures for the more common building situations. For methods of reducing infiltration in larger and more complex buildings, the AD refers to the Building Research Establishment (BRE) Report on 'Minimising air infiltration in office buildings' [3].

This BRE Report is an outline guide setting out the principles of providing an effective airtightness layer through the design of a tight envelope and the sealing of air leakage paths. In addition to air leakage through the fabric of the walls and ceilings, infiltration can occur through the junctions between building elements such as:

- doors and windows and their frames,
- window and door frames and the walls,
- wall to ceiling joints, and
- wall to floor joints.

1.3. Ensuring compliance and performance specification

Using 'fan pressurisation' [1], the airtightness (or the leakiness) of the building envelope can be quantified. At present, however, this can only be done once the whole building has been constructed or, as an interim measure, when various stand-alone phases (of a multiphase project) are completed. This testing involves sealing a portable fan, such as the BREFAN system [1], into an outside doorway and measuring the air flow rates from the fans required to maintain a series of pressure differentials across the building envelope.

A suitable measure used to quantify the overall air leakiness of a building envelope is the 'leakage index', Q_{25}/S, where Q_{25} is the air flow rate at the imposed pressure differential of 25 Pa and S is the total permeable external envelope area. Airtightness target for a 'tight' UK building is set at [4] a value less than 5 m^3/h per m^2, while an 'average' building should be less than 10 m^3/h per m^2 and with a 'leaky' buildings in the region of 20 m^3/h per m^2 or more [1].

2. 'AIRTIGHTNESS PREDICTOR' DESIGN TOOL

The objective was to produce a simple design tool which could be used at the design stage to predict the airtightness of office buildings. It was considered that this 'predictor' should have the following characteristics:

- Easy to use and requiring the minimum amount of data input.
- This input data should be readily available to the designer and should be at the gross building level rather than at any detailed component level.
- The output should be the predicted whole building leakage index.
- The tool should provide a clear indication of the contribution of each individual tightness measure to the overall building airtightness.
- In so doing, the tool should be flexible for the designer to consider 'what-if' scenarios of which tightness measures, when put together, will provide better return on investment while satisfying required tightness criteria.

2.1. Key parameters affecting airtightness

Extensive development work was carried out to determine the key parameters which affected the overall air leakage of office-type UK buildings. Key emphasis was placed on identifying the required gross characteristics of these parameters (rather than at any detailed component level) to ensure compliance with the design tool's requirements as set out above. The following is the final list of key parameters:

<u>Building form</u>

Users' input of actual or design values:

- Volume
- Surface permeable envelope area; i.e. the envelope area (usually walls and roof) separating the 'conditioned' space (i.e. heated and cooled) of the building from the unconditioned space or the outside
- Number of storeys
- Percentage of glazed wall area
- Number of single and double external doors

With these overall building characteristics and using an (unpublished) internal BRE database of UK office building characteristics, the total lengths of joints of the following possible leakage paths were derived:

- Between window glazing and frames
- Between window frames and walls
- Between walls and ceiling and between walls and floors

<u>General component information</u>

User input is through yes/no 'check' boxes for the following:

- Composition of walls, i.e. whether brick (bare, plastered or with wall board panelling), concrete block (bare or plastered), concrete panels (with or without gaskets), metal panels or curtain walling
- Whether windows and doors were weather-stripped or not
- Whether joints between walls and windows/doors, and between walls and floors/ceilings were caulked or not.
- Joints between walls and floor/ceiling (whether caulked or not)

2.2. Air leakage through components

Within the design tool, the air leakage Q induced through any porous surface areas or a leaky joint (at a pressure differential Δp across them) was determined using empirical equations of the form,

$$Q = k.\ \Delta p^n$$

where k is a flow coefficient expressed in terms of leakage per m^2 of porous surface area or for each metre length of crack. The flow exponent n characterises the type of flow and varies in value between 0.5 (fully turbulent) to 1.0 (completely laminar).

The values for k and n were obtained from compiled [5] measured data. In all instances, median values were used (to represent 'average' components) rather than the extremes (representing either high-performance or poor quality components). For example, for a caulked wall to wall timber joint, a k-value of $1.6 \times 10^{-3}\ dm^3.s^{-1}.m^{-1}.Pa^{-n}$ was used (rather than the quartiles 67×10^{-3} or 3.4×10^{-3}) with a common exponent 'n' of 0.6.

2.3. The prototype design tool

The prototype design tool is in spreadsheet form. The front worksheet receives input from the user and provides the leakage index and the percentage contribution made by each component and sealing measure. All calculations together with the database necessary to provide these results are contained in separate worksheets not obvious or accessible to the user.

The design tool works on the principle that leakage only occurs through the fabric or between building components. No specific calculations can be made if the building envelope is not designed from the outset for airtightness or this concept is not appreciated and significant large gaps are left in the building envelope. To ensure that the user is aware of the penalty for having large gaps, there is an additional check box which asks the users whether they are aware of these gaps in their building. If the answer is 'yes', then an empirical leakage (using previous in-house BRE measurements) of 10 m^3/hr per m^2 (at 25 Pa) is added to the overall calculated value.

The results are presented as both leakage indices (utilising permeable areas) and whole building leakage rates (using total building volume) at the standard pressure differential of 25 Pa for large buildings. However, corresponding values for a 50 Pa differential are also given even though it is difficult to establish this pressure in large UK office buildings with current pressurisation hardware [1].

3. RESULTS

3.1. Comparison of predictions with measurements

The design tool was evaluated using measured leakage rates in the following 10 UK office buildings held in an internal BRE database

Building		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Year built		*1980*	*1963*	*1991*	*1965*	*1987*	*1990*	*1990*	*1971*	*1986*	*1985*
Volume (m^3)		5,315	13,749	32,479	6,254	2,516	8,651	2,045	8,168	14,904	14,126
Surface area (m^2)		1,750	3,769	8,189	2,195	1,105	2,508	829	3,056	4,726	4,394
% glazed		33	13	35	25	39	36	39	25	21	25
Large gaps		no	no	no	no	no	no	yes	yes	yes	yes
Wall[1]		br/p	bl/p	bl/p	br/p	bl/p	bl/p	bl/p	c_p	br/p	c_p
Window[2]		w	w	w	nw	w	w	w	nw	w	w
Doors[2]		w	w	w	w	w	w	w	w	w	w
Wall to window/ door[3]		c	uc	c	uc	un	uc	c	uc	c	uc
Wall to floor/ceiling[3]		c	uc	c	uc	uc	uc	uc	uc	c	uc
Leak index (at 25 Pa)[4]	M	**5.5**	**5.3**	**5.5**	**11.8**	**6.7**	**9.0**	**15.3**	**16.8**	**17.9**	**20.4**
	P	**3.5**	**4.3**	**3.2**	**9.1**	**6.3**	**5.3**	**15.8**	**20.6**	**13.2**	**16.0**

Notes: 1 - bl(ock), br(ick), p(lastered), c_p (concrete panel); 2 - w(eatherproofed), nw (non- weatherproofed); 3 - c(aulked), uc (uncaulked); 4 - M(easured), P(redicted)

The comparison between measured and predicted is encouraging given the generalised characteristics of UK buildings used in this prototype simplified tool. However, there are sizeable variations on some of the cases. Our view is that this could be improved by the following measures:

- Take account of the quality of the components used, i.e. whether good, average or poor, and use the appropriate component characteristic from the built-in database.
- Similarly, take account of infiltration through paths which are not obvious (and not component based) but is elsewhere on the building envelope and dependant on the care taken to minimise infiltration at both the design and construction stages.
- Extend the comparison study to encompass other buildings contained within the more extensive BRE database and determine whether other aspects (e.g. roof form) contribute to building tightness.

3.2. Identifying key tightness measures

The design tool can be used to identify cost-effective key tightness measures by determining the impact they have on the overall airtightness and their percentage contribution to this overall value. The following example in Building #1 (the BRE Low-energy office of 1980) shows the effectiveness of weather-stripped windows in contributing to the overall airtightness of the building.

	Weather-stripped windows	**Windows without weather-stripping**
Leakage index (m^3/h per m^2 at 25 Pa)	***3.5***	***8.9***
Percentage contribution:		
through walls	15	6
through ceiling	36	15
through window glazing and frame	**34**	**73**
through door and frame	6	2
joints between wall and windows/doors	1	1
joints between walls and floor/ceiling	8	3

4. CONCLUSIONS

A prototype design tool to estimate the airtightness of large UK office buildings at the design stage is described here. This tool takes as input gross characteristics of the building such as volume and envelope area and converts these into possible leakage paths. A simple checklist then requests information about the methods used to seal these paths. The tool then uses this information and combines it with published leakage characteristics of individual components to provide an estimate of the leakiness of the building.

Comparison with full-scale results shows good agreement between measured and predicted. While the prototype design tool does require further refinement, it can be used to not only supply an airtightness estimate at the design stage but also a means by which the effectiveness of various airtightness measures can be considered.

However, it must be emphasised that the design tool is not a substitute for post-completion leakage measurement testing. Such testing is necessary to confirm design assumptions and provide a check on build quality. Data obtained through such testing could also be added to the growing database at BRE to refine this design tool as well as enhancing the derived practical guidance that could be provided to the UK construction industry.

ACKNOWLEDGEMENTS

This research was supported by the Department of the Environment (DoE) and carried out under the DoE Building Regulations programme. The authors would like to express their thanks to Malcolm Orme of the Air Infiltration and Ventilation Centre for useful discussions and help.

REFERENCES

1. Perera, M D A E S, and Webb, B C, Minimising air leakage in commercial premises, Building Services Journal, pp. 45-46, (February 1997).
2. Department of the Environment and The Welsh Office, Approved Document L (Conservation of Fuel and Power) 1995 Edition, HMSO, (1994).
3. Perera, M D A E S, Turner, C H C and Scivyer, C R, Minimising air infiltration in office buildings, BRE Report BR265, Building Research Establishment, Watford, (1994).
4. CIBSE, Natural ventilation in non-domestic buildings, CIBSE Applications Manual AM10, (1997).
5. Orme, M S, Liddament, M W and Wilson, A, An analysis and data summary of the AIVC's numerical database, Technical Note 44, Air Infiltration and Ventilation Centre, (1994).

2 interess. gebouwen.

IONICA HeadQuarter - Cambridge !!
BRE Environm. Office Watford
(Portsmouth University)

details of building.

Vol/h
mass = ?

~~2 à 8~~

→ Opm DUITSER

① Dehumidification wordt nt beschouwd !!

pro aircooling !!

② energy saving << komfort

[Kolokdr]
OK, maar ervaring wijst uit dat comfort in natural ventil. building >