PRESSURE TESTING A VERY LARGE BUILDING: THEORY AND PRACTICE

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ABSTRACT
The airtightness of a building envelope impacts upon the magnitude of uncontrolled air leakage and associated ventilation energy losses. A building's airtightness can be assessed using a steady state fan pressurisation technique. This paper describes a study on the largest building in the UK ever to have had its airtightness tested. Power law regression analysis revealed a good correlation between flow rate into the building and observed pressure differentials. Building internal - external pressure differentials were measured during the testing and compared with predicted values from a CFD model. The CFD analysis showed that using resistance areas derived from Effective Leakage Area calculations gave reasonable agreement between the predicted and measured differential pressures. However, further work on boundary conditions is required to improve the agreement.

KEYWORDS

airtightness, fans, loss coefficient, pressure distribution, CFD

INTRODUCTION

The gradual improvement in thermal insulation levels in buildings over the last thirty years has increased the relative proportion of energy losses associated with air infiltration. Consequently, it becomes more important to be able to design, test and seal buildings to have less leaky external envelopes. A recent study by Orme (2001) estimated, for 13 industrial countries, that unnecessary ventilation accounted for over 60% of the energy wastage, mainly through the loss of conditioned air. In cool climates exfiltrating air carries with it water vapour and lost energy. Water vapour condenses and causes wetting, bacterial growth and deterioration of the building envelope (Anis, 2001). Building envelopes with relatively airtight constructions help create more controllable internal environments, and the infiltration of pollutants and uncontrolled exfiltration of air can be minimised. Consequently, mechanical ventilation plant can be specified with confidence at a level that is both effective and efficient. However, despite these benefits, interest in air leakiness has, to date, been limited in the UK. The publication of the Approved Document L2 in the new UK Building Regulations (2002) introduced the requirement for building envelopes to attain a reasonable standard of airtightness for buildings with floor areas exceeding 1000 m^2. ‘Reasonable’ is defined as a leakage of no more than 10 m^3/hr/ per m^2 of building envelope surface at a pressure differential of 50 Pascal. It is estimated that approximately 3000 new, large buildings per year in the UK would need testing. Very large buildings (floor areas exceeding 5000 m^2 floor area) have represented a particular problem for pressure testing using conventional steady state (DC) techniques. Unsteady techniques (AC and pulse techniques) have been suggested by Carey and Etheridge (2001) as alternatives to the conventional steady state technique. However, uncertainties introduced by the inertia of the flow through imperfections in the building envelope add increased complexity and uncertainty to the calculations and results. Therefore, the DC technique is preferable *if* an acceptable steady state differential pressure can be achieved across the building envelope. The main focus of this paper is to report on a pressurisation test carried out on a very large building (floor area of 57,440 m^2). CFD simulations were carried out to model the pressure differentials obtained within the building. Measured data and CFD predictions are compared in this paper.

METHODOLOGY

The study of building envelope airtightness performance involves establishing a pressure difference Δp across the envelope. Measurements taken of the airflow rate Q in to a building produced by fans and the pressure difference Δp created across the envelope allow a relationship to be established between the two. In accordance with the current UK building regulations, adhering to CIBSE Technical Memorandum TM23 (2000), this Q-Δp relationship is defined in terms of the power law equation of the form:

$$Q = C\,(\Delta p)^{n} \qquad (1)$$

where C and n are constants that are assumed to relate to the geometry of a single opening in the building envelope. During testing the building envelope is typically subjected to differential pressures ranging from 20 to 70 Pascal. The actual testing work was carried out on a very large retail distribution warehouse (359 x 160 x 15.5m high). This is the largest building ever pressure tested in the UK, and possible Europe. Three variable speed fans were used to generate the pressure differential Δp across the building envelope; one large fan, 2000 mm in diameter and two medium sized fans, 1250 mm in diameter. The 2000mm fan was mounted on the back of a 7.5 tonne truck and the 90kW power required by the fan was provided by a diesel engine. The 1250mm fans were driven using the power take off from other trucks with a similar design to the 2000 mm fan rig. The largest fan was connected with a flexible duct to a wooden screen situated within one of the loading bay openings. Figure 1 shows the large fan and part of the building being tested. The two medium sized fans were positioned within other loading bay entrances and sealed in with temporary wooden frames. All three fans had previously been calibrated to give actual volumetric flow rates within ±2% accuracy. Temperature measurements were made before, during and after the test using digital thermometers. These were calibrated to an accuracy of ±0.5 ^{o}C. The three fans were positioned at intervals along one long side of the building envelope. For the purpose of the tests all external doors and windows were closed, with internal doors to the offices left open. Mechanical ventilation openings on the building roof were sealed with impermeable sheet and adhesive tape. Large openings containing open louvers, which were going to be sealed, constituting an area of around 40m^2, had been noted on previous site visits and these were also sealed during testing. Three 1m^2 openings in the building envelope remained unsealed to fulfil the requirement of ventilation to gas boilers. Three groups of two personnel were required to operate the fans and record the observed pressure differentials. Other observers were positioned around the building and on the roof to ensure that vents remained sealed and doors remained closed. Communication was maintained by two-way radio contact. The pressure differential across the building envelope was measured using a 60m length of 5mm internal diameter plastic tube that was connected to a differential digital manometer located inside the building at a 45^{o} angle to the fan at ground level. A 20m length of tube was connected to the same manometer and placed outside the building at a 45^{o} angle to the fan at ground level.

Figure 1: 2000mm diameter fan positioned in the loading bay door

The pressure differential across the building envelope was raised to 81 Pascal and then lowered in ten stages to 23 Pascal. Measurements were also made of the internal pressure distributions at a regular 7 x 7 grid of points inside the building when the differential pressure across the envelope was set at 50 Pascal. The first grid point was 20 m from the fan wall and 45 m from the side wall. These measurements were taken using 5mm internal diameter plastic tube, up to 140m in length. The tubing was arranged in straight lengths and did not come into contact with sources of heat. Using tubes of this length resulted in a damping of the fluctuations in pressure. These values were used as the basis of a comparison with pressure differentials predicted from the CFD software FLOVENT. This is an established commercial package that is typically used for building services application on a much smaller scale.

RESULTS AND DISCUSSION

The initial measurements established the relationship between the airflow through the fans, Q, and the differential pressure, Δp, observed across the building envelope. Figure 2 shows a log-log analysis of the Q-Δp data points for the retail distribution warehouse. Fitting a power law curve to these results gave a correlation coefficient of 1.00. The effect of pressure distributions within the building was investigated and Table 1 illustrates the pressure differentials observed at 20m intervals, with the building envelope Δp set at 50 Pascal. One of the objectives of this study was to test if CFD could be used to predict pressure distributions in very large spaces. Simplified methods have been suggested as a means of modelling mixing and displacement flows to give an indication of air distribution (Waters and Simons,2002). However, prediction of localised pressure distributions on such a large scale would require an established CFD package, coupled with currently available desktop computing power and considerable solving times. Investigations have been carried out into the airflow patterns in large buildings using CFD (for example, Simons et al, 2001; Yau and Whittle, 1991 and Kato et al, 1995). However, air leakage through building fabric was not incorporated into these studies.

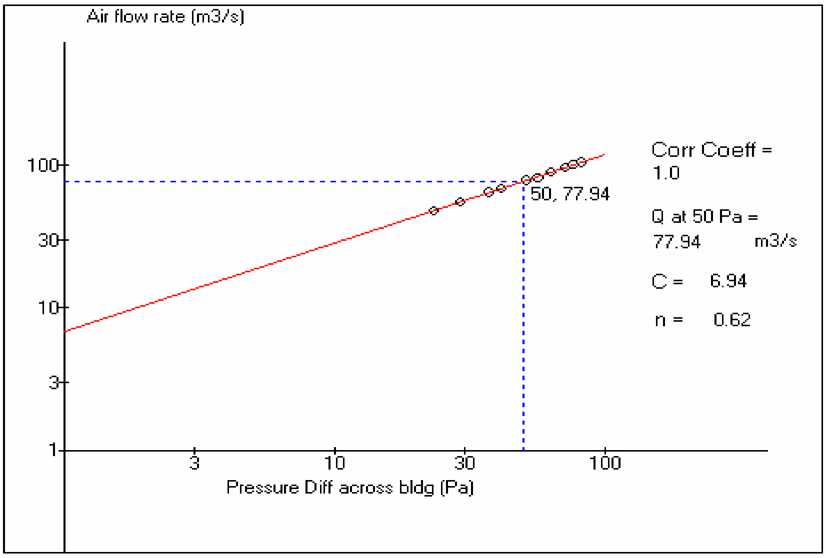

Figure 2: Q(m^3/s) v. Δp(Pa) data points for the building pressurisation test with a power law regression fit

Table 1 Pressure differentials observed at monitor points within the building

	Distance from wall with mounted fans						
Column	*20m*	*40m*	*60m*	*80m*	*100m*	*120m*	*140m*
1	49 Pa	49 Pa	51 Pa	51 Pa	51 Pa	51 Pa	51 Pa
2	50 Pa	51 Pa	51 Pa	51 Pa	52 Pa	53 Pa	53 Pa
3	49 Pa	49 Pa	49 Pa	51 Pa	50 Pa	51 Pa	51 Pa
4	50 Pa	51 Pa	52 Pa	56 Pa	58 Pa	59 Pa	56 Pa
5	51 Pa	51 Pa	52 Pa	52 Pa	51 Pa	51 Pa	49 Pa
6	49 Pa	51 Pa	51 Pa	52 Pa	53 Pa	55 Pa	55 Pa
7	54 Pa	55 Pa	52 Pa	52 Pa	52 Pa	52 Pa	52 Pa

The simulation model was created in FLOVENT version 3.2 and comprised of a room measuring 359 x 160 x 15.5 m high. The three fans used in the test were represented as fixed flow fans and located to reflect the actual set up. Current limitations in FLOVENT meant that expected fabric leakage rates could not be applied to whole surfaces of the building. Instead, resistances to flow were applied to sections of the building fabric. Leakage paths in the building fabric initially had to be estimated in terms of size and location. A uniform width was assigned to the leakage paths represented as resistances, which were positioned along the perimeters of the building. An approximate size of the total leakage path was obtained from the effective leakage area, ELA, calculated from Eqn. 2 below.

$$ELA = Q(\rho/2\Delta p)^{0.5} \qquad (2)$$

where ρ is the density of air. ELA was calculated to be 8.19m^2. A resistance width of 0.1m was applied evenly over the length of the building, resulting in a total leakage path area of 213.72m^2. To adjust this to the required effective leakage area a free area ratio of approximately 0.038 was applied to the resistances. The ELA was then used to estimate the loss coefficient k, given in Eqn. 3 below, representing the resistance (leakage path).

$$\Delta p = 0.5(k\rho v^2) \qquad (3)$$

Uniform lighting of 15W/m^2 was also included at a high level in the warehouse. Following the actual test, known values for internal and external temperature were added to the model. A uniform grid totalling 230,000 cells was used. Convergence was achieved within 3000 iterations and changes to the false time step were not required. Once the model parameters were assigned as above and the simulation solved, a first approximation to the solution was obtained. Initial results showed lower pressure differentials than experienced for the actual test. Altering the free area ratio to the resistances representing the leakage paths then refined these. Further adjustment of the free area ratio eventually resulted in a figure that lead to a pressure distribution similar to that obtained from the actual test. A free area ratio of 0.0561 was the final figure applied to the resistances, giving an actual total leakage area of 11.2 m^2 (similar to the calculated value ELA of 8.19m^2, taking into account assumptions made and time limitations. The pressure difference distribution within the building at a height of 1.0 m above floor level obtained from CFD is shown in Figure 3. Table 2 shows a comparison of the measured pressure differentials at a height of 1 metre and those values predicted from the CFD analysis. Differences are generally less than ±10%, which is encouraging given the size of the building and the complexity of the modelling. However, differential pressures observed near the wall adjacent to the fans were generally higher than predicted from the CFD model, particularly with readings taken in line with the 2000mm fan. This may possibly be due to discrepancies between the positioning of the resistances in the model and the actual leakage paths present within the building.

Table 2 Comparison of measured and predicted pressure differentials

Distance from wall with mounted fans		Pressure differential (Pa) at Column number						
		1	**2**	**3**	**4**	**5**	**6**	**7**
20m	Measured	49	50	49	50	51	49	54
	Predicted	51.6	52.1	51.6	51.7	51.7	51.9	51.6
	% difference	*-5.3%*	*-4.2%*	*-5.3%*	*-3.4%*	*-1.4%*	*-5.9%*	*4.4%*
40m	Measured	49	51	49	51	51	51	55
	Predicted	51.6	51.8	51.6	51.6	51.7	51.9	51.7
	% difference	*-5.3%*	*-1.6%*	*-5.3%*	*-1.2%*	*-1.4%*	*-1.8%*	*6.0%*
60m	Measured	51	51	49	52	52	51	52
	Predicted	51.6	51.8	51.7	51.7	51.8	51.9	51.7
	% difference	*-1.2%*	*-1.6%*	*-5.5%*	*0.6%*	*0.4%*	*-1.8%*	*0.6%*
80m	Measured	51	51	51	56	52	52	52
	Predicted	51.7	51.8	51.7	51.8	51.8	51.8	51.7
	% difference	*-1.4%*	*-1.6%*	*-1.4%*	*7.5%*	*0.4%*	*0.4%*	*0.6%*
100m	Measured	51	52	50	58	51	53	52
	Predicted	51.7	51.9	51.8	51.8	51.8	51.8	51.7
	% difference	*-1.4%*	*0.2%*	*-3.6%*	*10.7%*	*-1.6%*	*2.3%*	*0.6%*
120m	Measured	51	53	51	59	51	55	52
	Predicted	51.8	51.9	51.8	51.9	51.8	51.8	51.7
	% difference	*-1.6%*	*2.1%*	*-1.6%*	*12.0%*	*-1.6%*	*5.8%*	*0.6%*
140m	Measured	51	53	51	56	49	55	52
	Predicted	51.8	51.9	51.9	51.9	51.8	51.8	51.7
	% difference	*-1.6%*	*2.1%*	*-1.8%*	*7.3%*	*-5.7%*	*5.8%*	*0.6%*

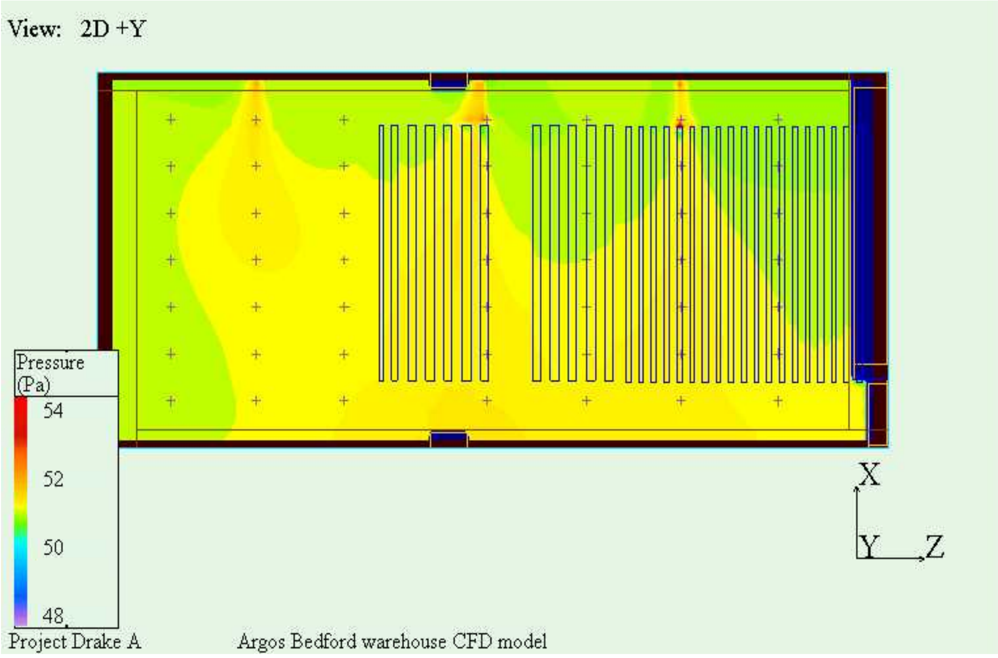

Figure 3: Predicted differential pressure distribution within the building at 1.0 m above ground level

CONCLUSION

This study has investigated some practical aspects of pressure testing a very large building and the possibility of using CFD modelling as a tool to predict the pressure distribution within the building. A relatively simple method was used to incorporate the impact of leakage paths into the CFD model, and this was quite successful in predicting pressure differentials. However, more work is needed to refine the application of CFD to building pressurisation testing. Software developers will need to produce better methods of representing the leakage of building fabric, and such developments are being made in the industry (Rose, 2003). Findings from this study will hopefully lead to more accurate methods of applying fabric leakage to models and so provide more precise ways of determining pressure distributions within buildings.

The authors would like to thank the UK Government's Teaching Company Scheme (Programme No. 3790) for their financial support of this work and Gazeley Properties for allowing access to the retail distribution warehouse.

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