OVERALL BUILDING ENCLOSURE PERFORMANCE: FIELD MEASUREMENT DATA COLLECTION FOR INPUT INTO DOE-2.1B ENERGY-ANALYSIS PROGRAM

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ABSTRACT

This paper deals with building enclosure tests carried out as part of a "total building performance" analysis of a large office building. Results include: field measurement of inside to outside pressure difference induced by different modes of operation of the air supply/exhaust systems; overall building air leakage by fan depressurization method; air infiltration by tracer gas method at two levels of depressurization; wall and roof thermal resistance by time weighted averaging formulae using heat flow meters and temperature differences; monitoring of micro-climate around the building using a remote weather station; and thermographic inspections for thermal anamolies during high pressure differences. While the tests were carried out to provide verification of specific inputs to DOE 2.1B, the results are of interest in themselves to those concerned with field evaluation of building performance.

INTRODUCTION

Total Building Performance

In 1980, thermographic studies (Phase 1) of 33 government buildings were carried out for the Western Region of Public Works Canada by its Architectural and Building Sciences (ABS) Directorate. Subsequent to these reports, a Phase 2 "building science" study was proposed and accepted for three of these buildings, including the Harry Hays Building in Calgary, the Taxation Data Center, and the Grain Commission Building in Winnipeg. These building studies were renamed stages 1, 2, and 3, respectively, in the development of a total building performance analysis (TBP) (Mill 1982). TBP is also known as "whole performance" and "overall building performance" in research communities; CIB (International Building Congress), ASTM (American Society for Testing and Material) and, ISO (International Systems Organization). ABS has completed Stage 2 in the development of this analysis.

The objective of a TBP analysis was to examine and improve the quality of the working environment while at the same time having a positive impact on energy consumption, durability, and overall operational costs (Mill 1983). Test procedures in the following areas were utilized to obtain performance data: functional planning and use, acoustics, thermal comfort, air circulation, mechanical systems, electrical systems, air quality, architectural components (enclosure), and energy simulation and analysis.

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The five levels of diagnostic measurement within the TBP framework are listed in Table 1. Each level has different resources for time, funding, instrumentation, and expertise that will result in varying degrees of problem identification and solution. The collection of data from all the levels is done on a unidisciplinary or multidisciplinary basis, but evaluation and solution generation are accomplished in a transdisciplinary fashion (Hartkopf et al. 1983).

PROCEDURES

The intent of the second stage in the development of TBP was to carry out a Level 5 evaluation. During this process, all levels of evaluation were employed to obtain as much data as possible in order to develop all aspects of total building performance analysis. The testing discussed in this paper, although primarily for complex instrumentation, includes work that is also part of lower level evaluation.

Energy Analysis Using DOE-2.1B

As part of the overall analysis, the energy study acted in a supporting role to the rest of the disciplines, providing information on the current energy use and its distribution and the impact that recommendations have on energy consumption. Because energy can be regarded as an indicator of the condition, usage, and quality of a building, an accurate and detailed energy model can be used to predict environmental performance indicators (i.e., zone temperatures, humidities). The secondary objective of the energy analysis was to assess this capability and, if successful, to provide input to the team on the environmental impact of the individual recommendations (McIntosh and Seifried 1985).

The energy analysis was carried out using a design model of the Winnipeg Taxation Data Center input into the DOE 2.1B program using Building Description Language (BDL). Many of the algorithms used in this program may be traced back to those in ASHRAE. This program provides hourly performance and response reports for a building described through input of variables specific to the program. Allowances have been made for extensive use of default values for many variables. In this way the user may provide small or large amounts of information, depending on the accuracy needed and appropriateness of the default values.

Building Enclosure Analysis

Generally, design data and estimated values for components of the enclosure are used as input into the LOADS program. ABS felt it necessary to utilize a number of post occupancy test procedures to determine accurately the performance characteristics of specific enclosure assemblies. Estimated design values were felt to be susceptible to unknown error and therefore unacceptable.

Analysis of the building enclosure, by means of field testing and review of as-built documents, was carried out by architects and building scientists from the project group. The majority of the performance tests were conducted to obtain data for DOE 2.1B. Some testing, namely thermographic inspections and visual inspection of potential problem areas (Mill and Kaplan 1982), produced qualitative findings that could not be directly used by the energy analysis. The building enclosure test data obtained to improve the accuracy of DOE 2.1B input included: (1) thermal resistances of major wall and roof components, (2) pressure differentials across the envelope for specific thermostat and mechanical system settings, (3) accurate interior and exterior ambient air temperatures and relative humidity readings, direct and diffuse solar data, wind directions and speeds, (4) infiltration rates for specific pressure differentials, and (5) air-leakage characteristics of the enclosure with mechanical louvres.

The test procedures that were used to obtain this information included: (1) tracer-gas decay-rate testing to measure infiltration rates, (2) depressurization testing to obtain leakage characteristics of the enclosure with and without sealed mechanical louvres, (3) pressure monitoring to determine the average pressure differentials during specific thermostat and mechanical system settings, (4) pressure monitoring to determine specific pressure profiles through the enclosure due to wind pressure, (5) constant monitoring of the microclimate around the building by means of a remote weather station (measuring temperature, relative humidity, direct and diffuse solar radiation, wind direction and speed), (6) temperature and heat-flow monitoring for thermal resistance and time-lag calculations of typical enclosure assemblies (Colantonio and Frisk 1985). The interrelationships between performance requirements and test procedures are charted in Table 2. Most of the test procedures either require or cross-reference data from one test to another. By conducting these tests almost simultaneously, common data are used for a number of procedures, which improves the accuracy of test results.

Testing Strategies

Field testing was scheduled in two field trips, both approximately two weeks in duration. Detailed test schedules were drawn up prior to both field trips. The first was used to obtain data on winter operations, while the second was used to to gather nonseasonal and outstanding data not previously recorded. In order to reduce the time required to carry out field testing, a number of building enclosure tests were conducted simultaneously. Since pressure measurements were required by both architectural and mechanical disciplines for a number of purposes, pressure tubes were installed at the beginning of each field trip and left in place for use when required.

Air-leakage testing, consisting of a number of related tests, was identified as the most complex and labor-intensive field test. One complete evening was set aside and other tests were planned around it. A large calibrated external fan was used to carry out depressurization testing to determine the leakage characteristics of the enclosure and the supply air dampers when closed mechanically and manually. It was also used to maintain a constant pressure during tracer gas testing and to calibrate airflow through the numerous building exhaust fans.

Two infiltration rate tests using propane as the tracer gas were conducted for correlation with the depressurization air-leakage test. During both of these tests pressure differentials were monitored every 15 minutes at 12 separate locations throughout the building. A slight wind (2.5 m/s) was present all evening and the resulting pressure effects on all four elevations were monitored and referenced to the average pressure being recorded continuously on a strip chart.

Thermographic investigations were conducted during the tracer-gas testing to take advantage of the constant pressure differential across the enclosure. Investigations were conducted from the interior to better observe air-leakage patterns. During the second tracer-gas test, exterior thermographic investigations were conducted to determine infiltration effects on the rainscreen wall assembly.

At the start of the first field trip, a remote weather station was set up on the roof of the building to measure weather data. It was left to gather digitally recorded hourly data to the end of the second field trip. Parameters for data collection were dictated by the requirements of the DOE 2.1B program. A hard-copy printout of these data was used as reference material for thermal comfort analysis, thermal resistance measurements, mechanical system performance testing, and air-leakage tests.

Throughout both field trips, data-logging equipment was set up to monitor heat flow and through-wall temperatures at predetermined cross sections for calculation of time-averaged thermal resistances of typical enclosure assemblies. This testing was conducted during normal operational conditions.

Pressure Monitoring

The Winnipeg Taxation Data Center is a long two-story office building with 11 exterior stairwells with ground-level fire exits. These, along with the main entrance, were used as openings for pressure tubes to the exterior. During the first field trip, individual pressure readings were obtained from the stairwell locations, while average pressures were obtained with tubing from four elevations to a common manifold, pressure transducer, and strip chart. Tubing, set up to measure average pressures, was used to record measurements during air-leakage testing, standard and nonstandard mechanical system operation, and testing of mechanical system ventilation rates. Tubing, set up in the stairwells, was used to obtain individual pressure readings at spot locations on the enclosure. These readings were correlated with wind data from the weather station on the roof. This monitoring was conducted at high pressure differentials during tracer-gas infiltration testing.

During the second field trip, only tubing for average pressure measurement was installed. Given a total building height of approximately 11 m, stack effect during field testing was calculated to be a maximum of 7 Pa from grade to roof level. Pressure monitoring was used for determination of pressure measurements during thermographic inspections, pressure measurement monitoring during standard mechanical system operation, and during ventilation rate testing.

During working hours, average pressure readings during standard mechanical system operations (partial to full fresh air supply) ranged from 5 to 50 Pa, indicating that the building was being maintained constantly at a slightly positive pressure. During evenings (midnight to 6:00 a.m.) average pressure readings ranged from -5 to -10 Pa, indicating that the building was maintained on minimum fresh air throughout the night. Mechanical system settings are well established, since their operation is monitored by a central in-house computer with hourly log printouts.

Mechanical system testing showed that, with air dampers fully open ("full fresh air" setting) pressure readings ranged from 53 to 32 Pa (positive building pressure). With supply air dampers in the "partially open" setting, readings ranged from 18 to 5 Pa. With supply air dampers in the "minimum fresh air" position, readings ranged from 0 to -13 Pa. Finally, with supply air dampers in the "fully closed" setting, readings ranged from -8 to -20 Pa (negative building pressure). During the minimum fresh-air ventilation-rate test, pressure readings ranged from -3 to -13 Pa, with an average of -8 Pa.

These data were used to characterize the operation of mechanical systems in order to produce an accurate energy simulation model. This knowledge is also beneficial to the building scientists studying causes of specific enclosure deterioration.

Air-Leakage Testing: Pressurization Method

The building has a completely open second floor, a full building-height main-entrance atrium, and a partitioned ground floor with open office space throughout two-thirds of the floor area. Equal pressurization throughout the building was easily achieved.

An external vane axial-type fan with manually adjustable variable pitch blades having a potential flow rate of 0 to 19.5 m^3/s was used to depressurize the building. Airflow rates were measured upstream of the fan intake using total pressure averaging Pitot tubes for high airflow rates and an orifice plate for low airflows. Readings were recorded on a strip chart.

All supply air intake louvres were sealed with plywood and tape. With the external fan off and sealed, all exhaust air fans were turned on and then turned off individually. The pressure drops were identified with the corresponding fans on the strip chart. With exhaust and relief louvres sealed, the calibrated fan was turned on and adjusted to flow rates producing pressure differences similar to those recorded with various exhaust fans.

With the supply, return, and exhaust louvres sealed, depressurization air-leakage testing was carried out per CGSB Standard CAN 2-149.10-M84 and ASTM Standard E 779-81 to determine the leakage characteristics of only the enclosure. With the mechanical systems on full recirculation and the seals removed, maximum flow rates and corresponding pressures were recorded when all dampers were closed mechanically by the the central controller. The pressure and flow rate were also recorded after all dampers were closed manually.

The original plans for air-leakage testing included pressurization with the external fan. Equipment checks the evening prior to testing indicated that insufficient pressure could develop from the fan alone; thus this testing was not included in the final test schedule. This equipment check was later proved to be incorrect, but insufficient time was left to make alternate plans to include pressurization testing in the final test plans.

The air-leakage characteristics were defined using standard flow-rate equations found in CGSB Standard 2-149.10-M84. The flow coefficient, C, was calculated to be .16 $L/s{\cdot}m^2\ (Pa)^{.65}$. National Research Council of Canada air leakage studies on eight high-rise office buildings indicated flow coefficient value ranges from 0.09 to 0.36, with the average being about 0.22 $L/s{\cdot}m^2\ (Pa)^{.65}$ (Shaw and Tamura 1976). The results indicate that this building enclosure is relatively airtight.

When the calibrated fan was adjusted to the same pressure as achieved by all the building exhaust fans, a flow rate of 14.05 m^3/s was recorded. Nameplate data from the building's exhaust fans provided a total building exhaust capacity of 16.95 m^3/s.

Air Infiltration Testing: Tracer Gas Method

This test was carried out per ASTM Standard E 741-83. With all supply louvres sealed, the building was manually seeded throughout the office areas with propane levels of 15 to 20 ppm. Half an hour after seeding, the building was depressurized to 95 Pa by means of building exhaust fans and the calibrated fan. Every half hour, by means of hand pumps and two-litre plastic air bags, air samples were obtained from the eight return air ducts and analyzed the same evening. Using the calibrated fan with all supply, relief, and exhaust air louvres sealed, the procedure was repeated with the building depressurized to 33 Pa.

The data indicated an infiltration rate at 95 Pa of 0.82 ACH (air changes per hour) and 0.52 ACH at 33 Pa (negative building pressure). Data based on the air-leakage characteristics determined by fan depressurization testing produced an air-leakage rate of 0.72 ACH at 95 Pa and 0.35 ACH at 33 Pa. The accuracy of the air leakage testing was reduced by the lack of a pressurization test. The accuracy of the infiltration testing was questioned after detailed analysis of air samples. Analysis of the decay rates indicated much greater decay rates between the first group of samples than the last group. Due to the design of the return air system, it was felt that samples should have been obtained from the office spaces rather than from the return air ducts.

Thermal Resistance

Prior to selection of wall and roof sections for thermal resistance testing, thermographic investigations were conducted to choose locations free from thermal anomolies and representative of the typical assemblies. Sensors were installed in the same horizontal and vertical planes throughout the assemblies, and exterior ambient, exterior surface, interior surface, and interior ambient temperatures as well as heat flow through the section (measured at the interior surface) were monitored.

T-type thermocouples were used to obtain temperature data while a resistance-type heat-flow meter was used to measure heat flow. These were wired to a data logger. Surface thermocouples and heat-flow meters were imbedded into the exterior surfaces using silicone and underneath interior wallcoverings to reduce effects of emissivities. Ambient temperature thermocouples were protected with masking tape cones from sudden wind activities and direct radiant influences. Data recording was to take place for a minimum of 72 continuous hours, but operational problems with the data logger reduced the sample time by half.

The procedure for analysis was based on a "running average" relationship in which the basic steady-state equation is slightly modified to account for time. Rather than using the instantaneous value, an accumulated average is used (Burch and Kritz). Using this procedure, the in-situ thermal resistance for a typical south wall assembly was 3.65 RSI. When determined by summation of the thermal resistances of each component of the assembly, the theoretical steady-state resistance value for the section was 3.66 RSI. The in-situ thermal resistance of a typical roof assembly was 5.54 RSI, while the theoretical steady state thermal resistance value was 5.11 RSI. The actual resistance value was higher than the calculated value because of the additional thermal resistance of the sprayed-on fireproofing and potentially higher R value for the gravel ballast. These measured values were input into DOE 2.1B and used to determine the overall building resistance.

Thermographic Inspections

At least three prior thermographic inspections had been carried out on this building. Available reports identified problem areas and analyzed as-built documents. This information was used to plan procedures for detailed inspections and to focus on areas where retrofit work had taken place. The thermographic inspection during the infiltration test was conducted to observe air-leakage patterns during high-pressure conditions of 95 Pa (Colantonio, 1985). Due to the "rainscreen" design of the building enclosure, interior investigations were preferred for inspection of air leakage anomalies with the building depressurized. An infrared shortwave (2 - 5.6 micron) scanner and imaging system was used on the top floor, while an infrared longwave (8 - 12 micron) scanner and imaging system was being used simultaneously on the ground floor. The open spaces on the interior allowed for easy thermographic scanning of exterior walls.

During the second tracer-gas air-infiltration test (negative building pressure of 33 Pa) the exterior surfaces of the south and east elevations were inspected with the long wave infrared system for experimental purposes only. The second field trip was used to carry out a detailed thermographic investigation of areas not previously inspected (hidden from sight), problem areas identified from past inspections, previously retrofitted areas, and other areas identified as potential problem areas from the as-built documents. This involved removal of convector covers and ceiling tiles and inspection of unused exterior stairwells. Interior inspections with shortwave infrared imaging systems were carried out with the building depressurized to 33 Pa by building mechanical systems.

The exterior unpressurized stairwells exibited the most serious air leakage faults. Air leakage was observed around the windows in the stairwells, around the interior and exterior doors, and at the wall junction of the main building and the stairwells. Air leakage was observed on the west wall in a few locations where precast panel supports pass through the air and vapor barrier. Minor air leakage was observed at various points of the wall-to-roof junction. The northeast corner of the ground floor, retrofitted earlier, showed no signs of air leakage along the base and under the windowsills. Air-leakage patterns were documented at different pressures for future development of infrared thermal anomaly pattern recognition.

The results of these inspections were qualitative and could not be input directly to the energy analysis program. They were used to identify major areas of air leakage and to generate solutions; the cost payback implications were determined by energy consumption simulation analysis. In most of the cases that dealt with sealing of air leakage through the enclosure, energy savings proved minimal compared to the high costs of repair due to unchecked deterioration of enclosure assemblies.

Weather Data Collection

Weather data were collected for input to the DOE 2.1B weather file to run the energy-simulation model. The design model is run on a typical reference year, obtained from manipulation of 30-year data tapes from Atmospheric Environment Services (AES) of Environment Canada. Actual energy-consumption models use digital weather data gathered from a local weather station as well as the test building. The accuracy of the design model is verified by its correlation to the actual model.

A remote weather station was installed on the main roof to record data on an hourly and accumulated daily basis. Data included average dry bulb temperature, average relative humidity, average total incoming radiation, average reflected radiation, and average wind vector data (wind speed, vector magnitude, vector direction and standard deviation of direction). Weather data were collected on hard-copy printout and on cassette tape for direct input into a minicomputer. The printout data were immediately used by team members studying thermal resistance, thermal comfort, mechanical engineering, and energy analysis.

Digital weather data were obtained from the local weather station for a three-month period from the beginning of the first field trip. Energy simulations were run using these data and compared with similar runs using data obtained from the weather station on the test building for the same time period. A 2% difference in energy consumption was recorded.

DISCUSSION

Procedures for collecting building enclosure data were successful in obtaining data for DOE 2.1B input. Many improvements to the building's total performance and to test methodologies were recommended as a result of qualitative and quantitiative enclosure analysis.

Automation of pressure-measurement collection techniques through the use of pressure transducers, current transmitter and central automatic data logging equipment was recommended as the solution to reduce labor-intensive manual methods and to collect data over a longer period of time with greater accuracy. More pressure transducers could be installed for correlation of wind speeds and directions to pressure profiles. This type of data is required to develop more accurate energy-analysis models. Without these data, assumptions have to be made in the LOADS program for air-infiltration characteristics and pressure profile patterns during specific environmental conditions. Although assumptions may prove reasonably accurate, field data improve the accuracy of the energy model.

Through the use of a calibrated external fan, substantial data were obtained on the air-leakage characteristics of the building and the supply air dampers. Results indicated that the building enclosure was relatively airtight and, apart from isolated locations of air leakage (identified by thermographic inspections and thermal comfort complaints), did not warrant large-scale retrofit solutions. Testing indicated that 35% of the total air leakage, with mechanical systems off, was through the supply air dampers. With minor modifications to the related mechanical equipment this could be reduced easily to 15%.

Air-infiltration test methodology using the tracer-gas decay-rate method requires further study. Further tests should include simultaneous sampling from the return air plenum and seeded office spaces. Although the thermographic inspections identified specific locations of air leakage, only the locations where deterioration occurred to the building enclosure as a result of condensation build-up were considered for retrofit recommendations.

Energy-analysis simulations using weather data from the local weather station and the weather data gathered at the test building showed a 2% difference in energy consumption. This good correlation was attributed to the fact that the test building was not subjected to extraordinary local environmental influences. A better case for remote weather stations could be made with test sites that have substantial environmental influences around them (such as large buildings and vegetation, abnormal grade conditions).

The thermal-resistance testing had to be conducted under normal operating conditions and therefore could not be integrated easily with the other tests. The weather data collection, on the other hand, was used primarily to cross-reference other tests.

The most significant aspect of the overall testing of the building enclosure is the interrelationship of data from all the tests mentioned in this paper. Performance requirements have been developed, in some situations, from a number of related test methodologies. Data from most of the building enclosure tests utilized by ABS in this building were required to be cross-referenced to other test procedures for analysis of chosen performance requirements. The correlation of data from different tests makes it critical that the tests be carried out under similar environmental conditions.

CONCLUSION

Test procedures have been carried out simultaneously in order to obtain valuable quantitative data on the building enclosure for development of an accurate energy-simulation model using DOE 2.1B. The data obtained included (1)time-averaged in-situ thermal resistance values for major wall and roof assemblies, (2) specific pressure differential measurements for the various operational mechanical settings, (3) microclimate weather data that includes dry-bulb air temperature, relative humidity, total incoming radiation, reflected radiation, and wind speed and direction, (4) enclosure-infiltration rates for specific pressure differentials, and (5) air-leakage characteristics for the enclosure and supply air dampers.

Time-averaged in-situ thermal resistance values for wall and roof assemblies were similar to theoretical values. This quantitative information can be used to calibrate thermal images of the building enclosure but will require additional work to yield adequate quantifiable results.

Thermographic investigations during high-pressure conditions were used to identify locations of air leakage. Energy-analysis simulations indicated that reduced energy consumption from lowered infiltration rates due to substantial enclosure retrofit is not cost-effective. At the same time, the cost benefit from reduced maintenance over the life of the building was much higher.

Data quantifying air-leakage and infiltration rates are required in order to produce an accurate energy simulation model. Although ranges can be quoted for these parameters, only in-situ testing can determine specific values. Test methodologies for large buildings require further analysis and development.

Long-term weather data collection (one year or longer) is recommended when a very detailed DOE 2.1B energy analysis is being conducted and where there are extraordinary local microclimate influences.

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TABLE 1

Levels of Diagnostic Measurement

1. Plan/Archive Analysis
   a. Plans, specifications, photographs
   b. Building budgets, implementation, history
   c. Occupancy/Management records

2. Expert walkthrough analysis
   a. ear: listening
   b. eye: seeing
   c. nose: smelling
   d. hand, body: touching, feeling
   e. mouth: tasting

3. Occupancy and use analysis
   a. questionnaire
   b. interview
   c. behavioural mapping, physical traces

4. Simple instrumentation analysis

5. Complex instrumentation analaysis

(Mill et al. 1985)

TABLE 2

Interrelationship Between Field Testing Procedures and Performance Requirements

LEGEND

- ● - essential to providing specific data to performance requirement
- ▲ - provides additional background data for performance requirement
- □ - does not effect performance requirement, can be scheduled with other testing.
- ⬡ - affects other tests used to determine performance requirement therfore cannot be scheduled with other testing.

TEST PROCEDURES	PERFORMANCE REQUIREMENTS: - DOE 2.1B specific input	- development of an accurate energy simulation model	- thermal resistance of major wall and roof components	- infiltration rates for specific pressure differences	- air leakage characteristics of enclosure and mechanical louvres	- pressure differences across the envelope for specific thermostat and mechanical system settings	- pressure profiles for specific wind speeds and directions	- identification of thermal anomolies on the enclosure	- accurate interior, exterior ambient temperature, relative humidity, wind speed and direction, direct and diffuse solar radiation data.	COMMENTS
- tracer gas decay rate testing to measure infiltration rates	▲	●	⬡	●	□	▲	▲	▲	□	- air change rates: 0.82 ARC at 95 Pa; 0.52 ARC at 33 Pa - suspected error due to sampling through the return air duct.
- depressurization testing to obtain leakage characteristics of enclosure with and without mechanical louvres	●	●	⬡	□	●	▲	▲	⬡	□	- air leakage curves (mechanical louvres sealed) indicate: 0.72 ARC at 95 Pa; 0.35 ARC at 33 Pa - pressurization testing not completed - $C = .16\ L/s \cdot m^2 (Pa)^{.65}$
- pressure monitoring to determine average pressure differences during specific thermostat and mechanical system settings	▲	●	⬡	▲	▲	●	▲	□	□	- ranged from +50 Pa (full fresh air) to -20 Pa (minimum fresh air) - building generally operated at a slightly positive pressure (3 to 8 Pa)
- pressure monitoring to determine specific pressure profiles through the enclosure due to wind pressure	▲	●	□	▲	▲	▲	●	▲	□	- manual data collection pressure profile technique unrealiable , this test procedure needs to be automated - stack pressure during testing, 7 Pa from top to bottom of building
- temperature and heat flow monitoring for thermal resistance and time lag calculations of typical enclosure assemblies	●	●	●	⬡	⬡	⬡	□	●	▲	- typical south wall assembly: 3.65 RSI - typical roof assembly: 5.54 RSI - in-situ values similar to theoretical steady state values
- thermographic inspection of enclosure during high pressure conditions	▲	▲	●	▲	▲	□	□	●	▲	- air leakage was visible at window sills, around stairwell walls and doors, a few locations at the wall roof junction - misplaced insulation noticed on west wall
- constant monitoring of the micro-climate around the building by means of a remote weather station	●	●	●	▲	▲	▲	●	▲	●	- 2% difference in energy consumption was noted between data recorded at test building and that from local weather station