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CONTROLLING PRESSURE DIFFERENCES ACROSS THE BUILDING ENVELOPE - COMPLIANCE WITH THE R-2000 HOME PROGRAM TECHNICAL REQUIREMENTS

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INTRODUCTION

The R-2000 Super Energy Efficient Home Program is a joint Canadian government and industry initiative aimed at producing houses that meet high standards of energy efficiency and quality. Houses built under the program must comply with the R-2000 Home Program Technical Requirements[1]

The Technical Requirements set a combined energy performance target for space and water heating. In addition, they also specify minimum requirements for the building envelope, ventilation systems and combustion equipment.

The Requirements are such that R-2000 houses are significantly more airtight than conventional houses. Each R-2000 house must be tested using the Fan Depressurization Method[2] (CGSB Standard CAN2-149.10 M86) and found to either have a Normalized Leakage Area (NLA) of less than 0.7 cm2/m2 or an Air Change Rate of less than 1.5 ACH at 50 Pa.

Because of the tightness of the building envelope, combustion devices in R-2000 houses must have an outside air supply capable of supplying the total requirements of that device for combustion air; only sealed or forced-draft combustion devices are allowed in R-2000 houses. The only exceptions to these requirements are fireplaces and woodstoves, which must be equipped with a combustion air supply and tight-fitting doors.

Mechanical ventilation systems must be installed in all R-2000 houses in accordance with the R-2000 Home Program "Design and Installation Guidelines for Residential Ventilation Systems"[3] (hereafter referred to as the Ventilation Guidelines.) The Ventilation Guidelines address system design, installation, and compliance issues.

One important issue that was addressed in the Ventilation Guidelines was the issue of pressure differences across the building envelope. It was proposed to limit pressure differences to 10 Pa. on a continuous basis to assist in controlling the ingress of soil gasses (principally radon). The Guidelines allow higher pressure differences (up to 20 Pa.) on an intermittent basis provided they do not cause combustion devices to spill byproducts of combustion into the living space. These pressure differences are higher than those which would be appropriate in conventional houses but the fact that no naturally aspirating combustion devices (except fireplaces) are permitted in R-2000 houses was considered when the pressure limits were set.

This paper examines the compliance issues and procedures developed to ensure that pressure differentials in excess of the limits are not created across the envelopes of R-2000 houses.

COMPLIANCE ISSUES

R-2000 Requirements. The limits placed on pressure difference were part of comprehensive set of changes made to the R-2000 Technical Requirements made for the 1986-87 construction season. One of the key issues which was identified on a review[4] of the old R-2000 Program Technical Requirements was the need to be more flexible in terms of types of ventilation systems considered acceptable.

The new Requirements are more flexible in that unbalanced ventilation airflows (such as those caused by exhaust fans) are allowed. The ventilation system must not contribute to increasing the pressure difference across the building envelope by more than 10 Pa. during continuous operation and by more than 20 Pa. during intermittent operation.

The R-2000 Approval Process. To assure compliance with these requirements it was necessary to develop design aids and procedures which would allow R-2000 houses to be assessed.

All R-2000 houses are examined on at least two occasions: firstly, the design is reviewed prior to construction and modelled using the computer program HOT-2000[5] (which is largely based on the NRC program HOTCAN)[6] to determine if the design complies with the Technical Requirements and meets the energy performance target; secondly, the house is visited once constructed to ensure that aspects of the building, specified at the plans review stage, are in place in the finished building. Procedures were needed to provide assistance in determining compliance with limits on pressure differentials at both stages of the approval process.

It was also considered desirable to avoid the need for a separate compliance test (though one would be provided for cases where verification of compliance is needed.) In view of the fact R-2000 houses are already tested for airtightness as part of the approval process, another test was considered onerous and, therefore, desirable to avoid.

Available Data. Much is known about how an R-2000 house responds to unbalanced air flows from the airtightness test. It was recognized that the information in this test could be used to assess whether makeup air was required.

The CGSB Fan Depressurization Test defines the term Equivalent Leakage Area (ELA) to describe the leakage characteristics of the building envelope. ELA divided by envelope area defines the Normalized Leakage Area (NLA) of the building so, along with NLA, ELA of the building envelope is one of the standard outputs available from the depressurization test. ELA is directly related to the flow which will cause a 10 Pa. pressure difference across the building envelope.

Other Considerations. Having depressurization test data available, though, implies that the building is built and leakage characteristics are known. If a makeup air inlet is required, it would be necessary to retrofit it into the building. Some builders expressed the desire to include a makeup air inlet in the building design which would assure, at the design stage, pressure differentials at the post-construction stage would not be excessive. Design aids and procedures were needed assist builders who wanted to assure, at the design stage, retrofits and/or call-backs would not be required.

Approach. To satisfy each of these needs it became apparent that three alternative procedures for determining compliance with the Ventilation Guidelines were needed. Appendix A of the Guidelines was produced detailing the following alternative procedures considered acceptable for that purpose:

1. The first alternative uses Depressurization Test data to assess the need for and size of makeup air inlets based on building leakage area and installed ventilation equipment characteristics.
2. The second alternative specifies a makeup air inlet capable of supplying all the makeup air required to limit pressure differences caused by unbalanced fan flows.
3. The final alternative is a simple pressure difference test.

Proof of compliance can be demonstrated by any one of the above procedures. To explain the basis these procedures, it is necessary to examine the theoretical concepts used in their development.

THEORETICAL BASIS FOR DETERMINING COMPLIANCE

Definitions in CGSB/CAN2-149.10-M86 Fan Depressurization Test Standard. When a depressurization test is performed on a building, a characteristic curve is developed from test data where flow is related to the pressure difference across the building envelope using an equation of the form:

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

where,

- Q, is flow in (L/s)
- C, is the flow coefficient
- ΔP, is the pressure difference in (Pa)
- n, is the flow exponent ($0.5 \leq n \leq 1.0$)

Also in the standard, the term Equivalent Leakage Area (ELA) is defined. It assumes the leakage characteristics to be approximated by flow through a single sharp-edged orifice. ELA is defined as follows:

$$ELA = .001157 \, \rho_r \, C \, 10^{n-0.5} \qquad (2)$$

where,

ρ_r, is the density of air at reference conditions

(ρ_r = 1.204 kg/m3)

Because of the way ELA is defined, if one sets a pressure limit (eg. 10 Pa.) and plots airflow (Q) against ELA, it can be seen that a straight line relationship exists between airflow and ELA. Therefore it is possible to define an unbalanced airflow which will cause a depressurization of 10 Pa. knowing only the ELA of the building.

Further, it is possible to define a flow to cause 20 Pa. depressurization provided that the flow exponent is known. This was the principle behind a simple compliance check developed for R-2000 houses.

A flow exponent of 0.75 was selected as representative of the depressurization characteristics of R-2000 houses and the unbalanced airflows which would cause a 10 and 20 Pa. pressure difference across the building envelope were plotted against the ELA. This plot appears as Figure 1 in this paper and as Figure A-1 in Appendix A of the Ventilation Guidelines. Therefore, by consulting this chart, knowing the ELA of the building envelope, builders and program authorities have available the approximate unbalanced airflows which will cause a 10 and 20 Pa. pressure difference across it.

Theoretically, if one considers that a flow exponent of 0.5 is possible, then consulting Figure 1 would produce an estimate of flow which is 20 percent too large; normally, for the range of flow exponents usually encountered in R-2000 houses, the error is less than 10 percent.

ALTERNATIVES FOR DETERMINING COMPLIANCE

This allows some simple alternatives for determining compliance:

Alternative 1: Determining Compliance from Depressurization Test Data. If the house design primarily uses envelope air leakage to provide makeup air to unbalanced fans, an acceptable method for determining compliance involves using the ELA from the fan depressurization test and consulting Figure 1 to obtain the maximum unbalanced continuous and intermittent airflows which can be tolerated before makeup air will be required. These maximums are compared to the continuous and intermittent flow characteristics of the installed system to determine if makeup air will be required.

Continuous ventilation airflows are measured routinely in R-2000 houses to determine the ventilation rates in the living space so the unbalanced the unbalanced continuous airflow is a measured quantity. To determine compliance, the unbalanced continuous airflow is compared to the maximum allowable unbalanced airflow which will cause a pressure difference of 10 Pa. (taken from Figure 1.) One need only know the ELA from the Fan Depressurization Test to obtain the maximum allowable unbalanced airflow. If the measured flow imbalance is greater that what is allowed, makeup air will be required.

The check is similar when considering unbalanced intermittent airflows, however, defining unbalanced intermittent airflows requires defining the "worst case" for intermittent operation of the ventilation system. The intermittent unbalanced airflow is defined in the Ventilation Guidelines as the largest unbalanced airflow from any ONE installed ventilation device operating alone or in conjunction with the continuous ventilation system since it is extremely unlikely that more than one device will be operating at the same time as combustion devices vulnerable to backdrafting.

Typically, intermittent unbalanced airflows might be caused by a number of common household appliances (eg. a Heat Recovery Ventilator (HRV) in defrost mode or kitchen, bathroom or other exhaust devices such as clothes dryers and central vacuums venting to the outside of the building envelope.) For these devices flow measurements may be impractical so manufacturer's airflow data can be used in determining compliance; in most cases this will provide a significant margin of safety because manufacturer's rated airflows tend to be somewhat optimistic when compared to actual airflows measured in the field. Rated airflows are compared to the maximum allowble unbalanced airflow (obtained from Figure 1) to determine if pressure differences of more than 20 Pa. will be encountered.

In the event that manufacturer's rated airflows for equipment are not available, it is necessary have defined default values for the typical unbalanced airflows produced by household exhaust devices available both as a design aid and so that assessments of compliance can be made. The Guidelines address this need by providing a Table of default airflows from common exhaust devices which is reproduced in this paper as Table 1.

Makeup Air. If either the continuous or the intermittent airflow exceeds the allowable maximums for a house with a given ELA, a makeup air inlet will be required to increase the ELA of the building so that excessive pressures across the envelope are not developed. Another design aid, is provided in the Appendix A of the Guidelines, Table 2, which defines the ELA of various diameter makeup air inlets. The ELA's in the Table are based on conventional duct design principles using a pressure drop of 10 Pa. and an equivalent duct length of 23m (75 ft.) of straight .pa duct. This was done to account for the flow resistance of a hood, minimal ducting and barometric damper or cold trap in the design of the makeup air inlet.

Alternative 2: Assuring Compliance by Specifying a Makeup Air Inlet at the Design Stage. As previously noted, some builders expressed the desire to have a table available listing makeup air inlets for various unbalanced flows which would assure them that the finished building would not exceed the allowable pressure differences across the building envelope regardless of house ELA. In this way, a makeup air inlet could be specified at the design stage assuring them that a retrofit of a larger inlet into the building would not be required; in most cases it will likely be excessive because the design procedure takes little account of envelope air leakage as a source of makeup air.

A table was compiled assuming minimal house ELA (such that 80% of the houses in the Energy Mines and Resources database of 300 homes had more ELA.) Required makeup air inlet diameters were specified to keep house pressures below 10 Pa. for unbalanced continuous flows and below 20 Pa. for unbalanced intermittent flows.

Any builder wishing to assure compliance at the design stage must select the appropriate makeup air inlet diameter from this table, Table 3 (which appears as Table A-3 in the Ventilation Guidelines.) For example, if he is installing an 80 L/s (160 cfm) range fan knowing it would be operating intermittently, a 150 mm (6 in.) diameter makeup air inlet would be required to assure compliance at the design stage. He would not have to calculate the makeup air provided by the house envelope, compliance would be assumed if he installed a 150 mm (6 in.) makeup air duct for that fan.

Alternative 3: Assuring Compliance by Measuring Pressure Differences Across the Envelope. Another acceptable method of assuring compliance is to actually perform a test of pressure differences across the envelope. Because ventilation contractors have suitably accurate pressure measuring equipment (ie. a manometer) on site to perform ventilation flow measurements, this method of assuring compliance may be used when people want to be reassured or wish verification of compliance by an actual measurement.

In designing a method for measuring pressure differences, it was considered necessary to distinguish between combustion air for furnaces, woodstoves etc. and makeup air for unbalanced ventilation flows. A factor of safety was added for calculation purposes in that it was assumed that combustion air provided for combustion devices is not available to provide makeup air for ventilation devices. Therefore, the test procedure requires that chimneys and makeup air inlets for combustion devices be blocked during the test to assure these aspects of the building are not considered in the test of compliance.

Table 4 indicates the preparation of envelope intentional openings required for the test of pressure difference. The openings which are indicated as having to be sealed for the test reflects the concerns raised in the previous discussion.

The actual method for measuring pressure difference is relatively straight forward. The building is prepared as indicated in Table 4 and a remote pressure tap is run from a point inside the building (at grade) to a point 8 m (25 ft.) away from the building. All ventilation equipment is switched off and pressure difference (Po) is measured.

The continuous ventilation system is switched on and the pressure difference (Pc') is measured. The difference in pressure (Pc) represents the increase in pressure difference caused by operation of the ventilation in contiuous mode. That is,

$$Pc = Pc' - Po \qquad (3)$$

For compliance,

$$Pc \leq 10 \text{ Pa}$$

The largest intermittent fan is switched on and the pressure difference (Pi') is measured. The difference in pressure (Pi) represents the increase in pressure difference caused by the intermittent operation of ventilation equipment. That is,

$$Pi = Pi' - Po \qquad (4)$$

For compliance,

$$Pi \leq 20 \text{ Pa}$$

When the test is complete the building is returned to the state is was in before the test. All openings blocked for the test are reopened and combustion devices which may have been turned off are restarted.

SUMMARY

In summary, the R-2000 Program has provided three methods for assuring that pressure differences across the building envelope are not excessive. These alternatives have been provided with the objective not being onerous or requiring a separate pressure test in all cases. Compliance can either be determined from fan test results or from a pressure difference test or by installing a makeup air inlet which should be appropriate in all cases.

Ultimately a builder may choose to avoid "fine tuning" his design either by supplying a makeup air inlet which is adequate in all cases or by supplying only "balanced" ventilation systems, systems in which supply and exhaust flows are equal (eg. as is the case with many Heat Recovery Ventilators.)

The R-2000 program is committed to providing the methods and alternatives for determining the performance of ventilation systems in providing superior air quality to meet market demands.

REFERENCES

1. Canadian Home Builders' Association/Energy Mines and Resources Canada, "The R-2000 Home Program Technical Requirements", Ottawa, November, 1986.

2. Canadian General Standards Board, "Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method", Twelfth Draft, Ottawa, 1986.

3. Canadian Home Builders' Association/Energy Mines and Resources Canada, "The R-2000 Home Program Design and Installation Guidelines for Residential Ventilation Systems", Ottawa, November, 1986.

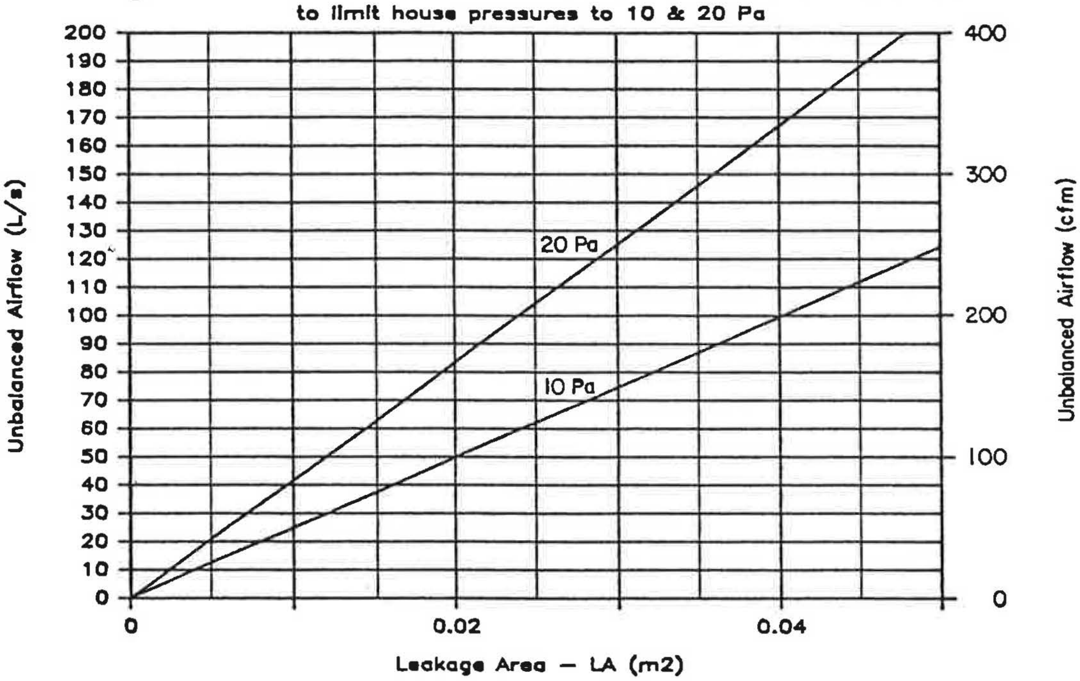
4. Bureau of Management Consultants, for Energy Mines and Resources Canada, "A Review of the R-2000 Home Program Technical Requirements", Ottawa, 1985.

5. Lubun, M, "HOT-2000 Version 1.0", Energy Mines and Resources Canada, Ottawa, November 1986.

6. Lux M.E. et al., "HOTCAN 3.0", National Research Council of Canada, Ottawa, 1985.

Figure 1: Maximum Unbalanced Airflow

to limit house pressures to 10 & 20 Pa



Sample Calculation using Figure 1:

DETERMINING IF A MAKE-UP AIR INLET IS REQUIRED

An exhaust-only ventilation fan is being installed in a house and flows are being set to provide a 50 L/s continuous ventilation rate. Will make-up air be required in that house if it has an Equivalent Leakage Area (ELA) of 0.022 m2?

-Continuous unbalanced flow	50 L/s (100 cfm)
-Required Leakage Area (LA at 10 Pa from Figure 1)	0.020 m2
-Building ELA	0.022 m2

BUILDING ELA IS GREATER THAN REQUIRED ELA SO NO MAKE-UP AIR INLET IS NEEDED

Table 1: Airflows of various air exhaust devices. (Source ref. 3.)

Exhaust Devices	Range of Airflows L/s	(cfm)	Default Value L/s	(cfm)
Bathroom Fans	20-50	(40-100)	25	(50)
Standard Range Fan	50-100	(100-200)	65	(130)
Grille-Top Range Fan	60-150	(120-300)	110	(220)
Clothes Dryer	40-55	(80-110)	50	(100)
Central Vacuums (exhausting to exterior)	45-65	(90-130)	50	(100)

Sample calculation using Table 1:

DETERMINING THE NEED FOR MAKEUP AIR WHEN FLOW IS NOT KNOWN

A stove-top grille range fan is to be installed in a house with an ELA of 0.030 m2. Will makeup air be required?

-Intermittent unbal. flow (Default flow for stove-top grille from Table 1.)	110 L/s (220 cfm)
-Required Leakage Area (LA at 20 Pa from Figure 1)	0.024 m2
-Building ELA	0.030 m2

BUILDING ELA IS GREATER THAN REQUIRED ELA SO NO MAKE-UP AIR INLET IS NEEDED

Table 2: Equivalent Leakage Area (ELA) provided by inlet ducts of various diameters. (Source ref. 3.)

Duct Diameter mm	(in.)	ELA Provided m2
75	(3)	0.0024
100	(4)	0.0052
125	(5)	0.0092
150	(6)	0.0156
175	(7)	0.0240
200	(8)	0.0340

Sample calculation using Table 2:

SIZING A MAKE-UP AIR INLET WHEN ELA IS KNOWN

An exhaust-only continuously operating ventilation fan is being installed in a house with an ELA of 0.010 m2. Flows will be set at 50 L/s (100 cfm), will makeup air be required?

-Continuous unbal. flow	50 L/s (100 cfm)
-Required Leakage Area (LA at 10 Pa from Figure 1)	0.020 m2
-Building ELA	0.010 m2
-Make-up air LA required	0.010 m2

PROVIDE A 150 mm. (6 in.) DUCT -- LA for 150 mm. DUCT is 0.0156 m2 (from Table 2)

Table 3: Required size of makeup air inlet ducts where the Equivalent Leakage Area (ELA) of the building envelope is not known.

Unbalanced Airflow				Required Makeup Air Duct	
Continuous		Intermittent		Duct Diameter	
L/s	(cfm)	L/s	(cfm)	mm	(in.)
10	(20)	20	(40)	75	(3)
20	(40)	30	(60)	100	(4)
30	(60)	50	(100)	125	(5)
50	(100)	80	(160)	150	(6)
75	(150)	125	(250)	175	(7)
100	(200)	170	(340)	200	(8)

Sample Calculation Using Table 3:

SIZING A MAKE-UP AIR INLET WHEN BUILDING ELA IS NOT KNOWN

An exhaust-only ventilation fan will be installed in a house and airflows will be set to provide a 65 L/s (130 cfm) continuous ventilation rate. The builder requires that an adequate makeup air inlet be specified at the design stage to avoid having to retrofit it into the building.

-Continuous unbalanced flow	65 L/s (130 cfm)
-Make-up air inlet diameter required (from Table 3)	175 mm (7 in.)

Table 4: Preparation of intentional openings for test measuring the pressure difference across the building envelope.

Item	Preparation
Windows and Doors	Closed and Latched
Floor Drains	Filled or Sealed
Plumbing Traps	Filled or Sealed
Exhaust Devices and Ventilation Equip.	No Preparation
Chimney Flues and Makeup Air Inlets for any Combustion Device Including those for Fireplaces and Wood Stoves	Sealed and Device Turned Off for the Test