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Appendices

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Introduction

1. This document has been developed to aid in the estimate of the heat lost due to building holes, gaps and cracks. It also covers the general location of these gaps in common building types.

2. The effect of these openings on the capacity required to compensate for this addes load has been established in the ASHRAE Handbood of Fundamentals(1). ASHRAE has not, however, made any serious effort to estimate the heat required for a typical year.

3. This paper presents a method of estimating the cost due to the infiltration. The equations are suitable for low buildings only as the predominant factor is the wind. The infiltration in high rise buildings is primarily affected by stack effects. The equations for low rise buildings are based on:
   1. the ASHRAE formulae for wind effects and stack effects, as described in (1);
   2. the ASHRAE crack method for infiltration effects and stack effects, as described in (1); and
   3. the ASHRAE Degree day method of heating estimates, as described in ASHRAE Systems Handbook (2).

4. The formulae requires information of the weather in the city. This information has been collected for various areas in Canada and is presented in Appendix B; the source of this information is:
   1. degree day records as included in the National Building Code Supplement No. 1 (3); and
   2. wind data as given in the Environment Canada booklet on Wind (4).

2. Considerations

1. ASHRAE'S System Handbook (2) has provided a method of allowing for infiltration by calling for an estimate of the number of "air changes" per hour. This is then converted into heat loss factors and combined with the conduction losses for the balance of the building. The resulting information is used in the heating requirements.

2. The method employed here is to quantify the infiltration by using the area of the holes and prevailing wind speed to calculate the infiltration due to winds. As the infiltration for low buildings is controlled by these factors the formulae presented here account for that mechanism only; infiltration due to the stack effect is negligible for buildings up to 10m high.

3. The calculations on fuel costs allow for heating equipment with a capacity of up to 100 kW operating at average efficiency. If the equipment being used has different efficiency the formulae can be adjusted.

4. The derivation of formulae is covered in Append. A. The formulae divide buildings into classes to cover different types of construction. Caution should be applied when selecting the formulae to ensure that the correct building construction is identified.

Computer Programs

1. The National Research Council (NRC) has developed a computer program for houses with a sub-routine for infiltration that estimates the energy used for heating. The program is described in the NRC booklet 17663 (5) and is "...primarily intended for researchers, designers and consulting engineers This sub-routine uses a variation of the ASHRAE method of establishing instantaneous heating requirements due to infiltration.

2. The ENCORE program utilises the weather data for Canadian Cities that has been collected by the Department of Environment. Part of this information includes the wind data as presented in the Department of Environment booklet(4

3. One Consulting Engineering Group has developed a computer program that enables them to establish the heating and cooling loss from a building. It requires the establishment of the building envelope's characteristics by a single pressure test, and uses this to predict the energy losses through the alogorithms for the flow of heat in the building

4. Where the problem has been established the pressure test can be used with a thermographic scan to establish the location of holes in the building.

. Formulae

1. Infiltration

$Q = k \times (dP)^n \times A$

Where "Q" is the average infiltration rate in litres per second (L/s)

$k = 550$ L/(s.Pa.m^2) For type *1 buildings
$k = 400$ L/(s.Pa.m^2) For type *2 buildings
$k = 300$ L/(s.Pa.m^2) For type *3 buildings

*Note: The building construction for each type of building is discussed in Appendix A with the derivation of the formulae.

"$(dP)^n$" is the pressure differential built up by the wind. The values are shown in Appendix B in terms of pascals (Pa).

"A" is the total area of the holes in the building,calculate in square metres (m^2).

2. Energy Costs

1. Oil cost $= \frac{Q \times °C.d \times \text{Oil price ¢/L}}{26\ 100}$ ($)

Note: °C.d is the measure of weather effects for the area, it is further explained and the values given in Appendix B.

2. Gas cost $= \frac{Q \times °C.d \times \text{Gas price ¢/m}^3}{26\ 700}$ ($)

3. Electrical cost $= \frac{Q \times °C.d \times \text{Energy costs \$/MJ}}{10}$ ($)

Note: The energy lost to infiltration is often partially balanced by other loads including loads, process work, and solar effects. It is further complicated by the mechanical systems and process cooling. The energy cost formulae are applicable only if all these factors are accounted for.

5. Other Factors

1. The total energy requirements for heating must allow for the heat lost through the building shell and the heat lost to air passing through the buildings. All other heating requirements are generally minimal; even the heating required for chemical processes is insignificant since most of the heat is rejected to the air or cooling water.

2. The heat used for lighting and power inside a building does have a significant effect on the building heating requirements. Most large office buildings are self heating during the occupied hours due to the heat from the lights. Similarly it is typical to find that if a warehouse is used continually the heat from the lights must be accounted for in the calculations.

3. In some buildings significant quantities of air are required for process purposes. It is preferable to direct the intake of these systems to fresh air make-up systems, however, it is not uncommon to find exhaust systems installed without make-up systems. This move is generally made on economic grounds; it is cheaper to install one system than two. The complication occurs when the make-up is taken from the working space, because this creates drafty conditions throughout the building.

4. Some energy is supplied to a building through solar heating. This heat is absorbed into the buildings through the walls and windows facing sourth, as well as through the roof. Various methods can be used to increase the proportion of heat from the sun, particularly by increasing the area of the south facing windows. Unfortunately any increase in the size of windows means that the prime heating systems have to be increased to compensate for the extra heat loss at night, etc.

Note: Each of these factors are considered in the calculations shown in Appendix C, and some of them are very complicated and require separate considerations. If an account is also to me made into the dynamics of the building, ie. if greater accuracy is required than a first order estimate, then an hour-by-hour simulation should be considered.

6. Pressure Testing

1. Some testing has been done on buildings to determine the effectiveness of the envelope as a protection against infiltration. Plots have been developed by NRC to classify the wall enclosures on the basis of air leakage versus the air pressure built up.

2. The National Association of Architectural Metal Manufacturerers has developed a specification (6) for testing curtainwall panels for static and dynamic wind conditions. This specification applies to manufacture items only and will require some field inspection and testing to ensure that the panels are installed satisfactorally.

3. The air handling systems can be used in conjunction with thermographic equipment to locate holes in buildings. The investigations of the RCMP North Ottawa barrick areas, the cafeteria and the swimming pool, and the North York Federal Building were all carried out partially using this technique.

4. Another technique has been developed by a group in the U.S. The requirements are limited to the introduction of a trace gas into the building and the opening of an evacuated container a given period later. With the condition of the building, ie. the temperatures and the wind speed, etc., some quantitative factors can be developed. Similar tests have been developed that can be measured instantaneously using electronic snifters.

Note: Any of these arrangements can help to develop an understanding of the severity of the infiltration problem; however, an experienced contractor can point out the problems for many buildings as they recur in similar places in most structures.

Typical Building Faults

1. Various techniques have been developed that allow the completion of buildings with a minimum attention to details. Typical is the fixing of windows and the installation of electrical outlets.

2. Most window manufacturers allow more than twenty-five millimetres clearance between the rough opening for a window and the window frame. The window is generally wedged into place with blochs and these are sufficient to ensure that the window is secure. Good practice calls for the building contractor to caulk the gap, but few complaints are registered by the building user as long as the trim strip covers the open area. The extra energy costs from this are significant.

3. Electrical outlet and switching boxes are generally installed after the wall, trim. The wires are often pulled through the otherwise finished wall and the electrical trade is not responsible for the damage to the air seal or the insulation. The result is an infiltration rate that costs the homeowner in Toronto, using gas heating, about $5.00/a for each electrical box on the outside wall.

4. The installation of mechanical services into the outside wall also leads to damage of the air seal. One generality that could be gleaned from this is that no services should be installed in the outside walls; that would leave the problem of sealing to the building trades.

5. The break of the air seal by the mechanical and electrical services, including the holes left around entrances and by services that have been removed, is still monor compared to the gaps that are left between the building components. Typical problem areas are the sill plate, the seal of the top of walls and the match line between the walls and columns.

6. The gaps at the sill plate are generally narrower than other gaps as the walls tend to settle. With light construction walls, however, the gap may be large.

7. The gap at the top of the wall usually escapes the attention of the user as it cannot be seen and the air exfiltrates from it. The flow of air through this gap can lead to building damage and needs attention for many reasons.

8. Concrete blocks and some brick mortars shrink after a few years; this allows the walls to move away from the steel columns and show gaps along columns and at the top of walls.

9. All the above faults require a caulking seal; the other problem area is the seal around doors and opening windows.

10. The usual action of installing compression gaskets around doors and windows so that the gaps are sealed by forcing the moving item against a stop creates problems of tolerance which are complicated by the expansion and shrinkage of these over the seasons. The film seal described in the next section is a viable alternate.

Remedial Actions

1. General
    1. There are few products on the market that can be recommended for retrofit work; the need for retrofit in this area has not had the attention that it deserve and few innovations have been made.
    2. The standard rubberized products used for new construction are satisfactory; however, they are hard to install. Retrofit work should be completed simply and quickly as most of the work is taking place in areas that are commercially valuable.

2. Polyurethane
    1. The first product is a polyurethane foam. This material can be applied through an opening as small as six millimetres in diametre, and will expand to fill any size hole. This expansion can be controlled, with practice, so that the total void can be filled. (some caution is needed to ensure that the holes are not overfilled, thus causing too much pressure on the building components.) The material can be applied in almost any weather and is not affected by the low temperatures of the building.
    2. This product was used in the remedial actions taken in some Ottawa buildings for the RCMP. Other examples of the use of this product can be listed if required*.
    3. One example of the use of this product is the sealing of electrical outlet boxes, particularly in houses. The action required in removing the electrical hardwar after taking the usual precaution of shutting off the power to the area, is not difficult. The electrical components can usually be drawn out of the box with the wiring still connected. The applicator is then inserted through the electrical box holes and the foam injected into the space. The foam should be inserted on all sides of the box and through the back as well. The electrical connections should be checked before the electrical service is reconnected, with a special check on the tension of the screw connections if aluminium wiring has been used. This procedure has been shown in the sketches of Appendix D.

*Note: Request for information on this should be addressed to Chief, Mechanical Engineering, PWC.

3. Film Seal
   1. This technique requires the installation of a film in the door (or window) jamb so that the door folds the film between its edge and the door frame. This means that the seal will be maintained even if the moving component does not return to exactly the same position when closed.
   2. A polypropylene film, cut to the required width, with a preformed longitudinal notch and an adhesive protected by a peel-away protection is available. This product has the advantage of being applicable in all climates, but other combinations may be available using more common products.
   3. Details on the use of this product are shown in Appendix D.
   4. These products are being tested in various applications and the results are being monitored by Mechanical Engineering.

References

1. ASHRAE Handbook and Product Directory, 1977 Fundamentals American Society of Heating, Refrigeration and Air-Conditioning Engineers Inc., Chapter 21, "Infiltration and Ventilation"; New York 1977.

2. ASHRAE Handbook and Product Directory, 1976 Systems American Society of Heating, Refrigeration and Air-Conditioning Engineers Inc., Chapter 43, "Energy Estimating Methods:, New York 1976.

3. National Building Code of Canada, National Research Council of Canada, "Supplement No. 1 Climatic Information for Building Design in Canada", NRC No. 13986; Ottawa 1975.

4. Winds: Canadian Norms, Volume 3 1955 - 1972, Environment Canada; Downsview Canada.

5. Konrad A. & B.T. Larson, Encore Canada: Computer Program for the Study of Energy Consumption of Residential Building in Canada, DBR Paper No. 859, Division of Building Research NRC 17663; Ottawa 1978.

6. Specification TM-1-68T, National Association of Architectural Metal Manufacturers.

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1. Garden, GK. Use of Sealants, Canadian Building Digest NRC, DBR, CBD 97, Ottawa 1967.

2. Wilson, A.G. Air Leakage in Buildings, Canadian Building Digest NRC, DBR, CBD 23, Ottawa 1961

3. Tamblyn, R.T. Infiltration, the Thief in the Night Toronto, 1978.

4. Tamblyn, R.T. Infiltration Workshop, Toronto, 1978

5. Tanura, G.T. Measurements of Air Leakage Characteristics of House Enclosures, ASHRAE Transactions Volume 81, Part 1; 1975.

This formula has been developed from the instantaneous infiltration rates formula used by ASHRAE (1). The value of "k" has been based on observations of the heating requirements for various buildings.

Building Classification is calculated from the volume of the cavity of the room or building, if there are no partitions.

i.e. $\frac{\text{Volume of cavity (room)}}{\text{area of openings*}}$ = up to 10,000 Type 1 building between 10,000 and 20,000 Type 2 building and above 20,000 Type 3 building.

*NOTE: This area is to allow for the doors that are being opened, i.e. based on an average time of the doors being opened, e.g. if a door is $2M^2$ and it is open 10% of the day, the effective area of this is $0.2m^2$.

Value of Heat Lost

Energy costs are derived from the equations for sensible heat:

Heat Rate

Imperial	SI
1.08 X Flow(cfm) X Δt (°F) (Btu/h)	1.21 X Flow (L/s) X Δt(°C) (W)

Heat Lost per Year

Imperial	SI
1.08 X Flow (cfm) X °F.d X 24 h/d = 25.92 X Flow (cfm) X °F.d (Btu)	1.21 X Flow (L/s) X t(°C) X 24 h/d X3600 s/h = 104 544 X Flow (L/s) X °C.d

Fuel Factors

Natural Gas

Imperial		SI
1000 Btu/ft³	Calorific Value	37.26 kJ/L = 36.26 MJ/m³
"X" $/1000 ft³	Sold at	"Y" ¢/ m³

"X" $/1000 ft³ = "X"/28.3 $/m³
= Y ¢/283m³

"X" \$/1 000 ft³ X 1 000 Btu/ft³ X 0.75 "X" \$/750 000 Btu	Heating Value assuming 75% Efficiency	"Y" ¢/m³ X 37.26 MJ/m³ X 0.75 = "Y" ¢/27.95 MJ

i.e. "X" /750 000 Btu = "X" /791 MJ
& "Y" ¢/26 490 Btu = "Y" ¢/27.95 MJ

168 000 Btu/gal	Calorific Value	39 MJ/L
"Z" ¢/gal	Sold at	"V" ¢/L

"Z" ¢/gal = "V"/4.55 ¢L

"Z" ¢/168 000 Btu X 0.7 "Z" ¢/117 600 Btu	Heating Value assuming 70% efficiency	"V" ¢/39 X 0.7 = "V" ¢/27.31 MJ

i.e. "Z" ¢/117 600 Btu = "Z" ¢/124 MJ
& "V" ¢/25 880 Btu = "V" ¢/27.31 MJ

ELECTRICAL

1 kW.h = 3 413 Btu	Calorific Value	N/A
"E" ¢/kW.h	Sold at	"B" \$/MJ

"E" ¢/kW.h = "E"/3.6 MJ

"E" ¢/3 413 Btu	Heating value assuming 100% efficiency	"B" \$/MJ

i.e. "E" ¢/3 413 Btu = "E" ¢/3.6 MJ
& "B" \$/948 Btu = "B" \$MJ

ENERGY COST FORMULAE

Oil Cost (\$)

$$\frac{25.92 \times Q \times {}^\circ F.d \times \text{"Z"}}{117\,600 \times 100} = \frac{Q \times {}^\circ F.d \times \text{"Z"}}{45370}$$

$$\frac{104\,544 \times Q \times {}^\circ C.d \times \text{"V"}}{10^6\ MJ/J \times 100\ ¢/\$ \times 27.31\ MJ} = \frac{Q \times {}^\circ C.d \times \text{"V"}}{26\,100}$$

Natural Gas Cost ($)

$\frac{25.92 \times Q \times °F.d \times "X"}{750\ 000}$ — $\frac{104\ 544 \times Q\ °C.d \times "Y"}{10^6\ MJ/J \times 100\ ¢/\$ \times 27.31\ MJ}$

$\frac{Q \times °F.d \times "X"}{28\ 900}$ $= \frac{Q \times °C.d. \times "Y"}{26\ 735}$

Electrical Cost ($)

$\frac{25.92 \times °F.d \times "E" \times Q}{341 \times 100}$ — $\frac{104\ 544 \times Q\ °C.d \times "B"}{10^6\ MJ/J \times 100\ ¢/\$}$

$= \frac{Q \times °F.d \times "E"}{13\ 136}$ $= \frac{Q \times °C.d \times "B"}{960}$

Note: 1. The term "Q" has been used for both systems to denote air flow; for Imperial the term denotes flow in cubic feet per minute, (cfm), for SI the term denotes flow in litres per second, (L/s).

2. The constants have been rounded off in the text.

Derivation of formula $Q = k \times (dP)^n \times A$

The theory used is based on the Bernoulli's theorem and the relationship between the pressure and the velocity interchangability:

$p = \frac{\rho \times v^2}{2}$ which is expressed in terms of lb/ft^2 or pascals

Imperial measure	i.e.	SI measure
"ρ" in $slugs/ft^2$	density	"ρ" in kg/m^3
"v" in ft/s	velocity	"v" in m/s
"p" in lb/ft^2	pressure	"p" in pascals

For air at normal temperature and pressure*

"ρ" $= 13.35\ ft^3/lb$ — density — "ρ" $= 1.2\ kg/m^3$

$= 1/13.35 \times 32.2\ slug/ft^3$

Note: $g = 32.2$ slug/lb

$"v"mph = \frac{v\ mph \times 5280\ ft/mile}{3600\ s/h}$ velocity $"v"\ km/h = \frac{v km/h \times 1000\ m/km}{3600\ s/h}$

$= 1.467 \times v\ ft/s$ — $= 0.278 \times v\ m/s$

$\frac{2.326 \times 10^{-3}\ slug \times (1.467 \times v)^2}{2}\ (lb/ft^2)$ pressure $p = \frac{\rho \times v^2}{2}$ — $\frac{1.2\ kg/m^3 \times (0.278 \times v\ m/s)^2}{2}$

$= 2.5 \times 10^{-3} \times v^2\ lb/ft^2$ — $= 0.0464 \times v^2\ Pa$

$= 0.000\ 481 \times v^2$ in of water

*NOTE: The formulae allows for the increased density of air at lower temperature through the "k" factor.

ərivation of formula $Q = k \times (dP)^n \times A$ (cont'd)

ıe total wind pressure would not build up in a building because of the leakage from ıe building; this has been compensated by using the following factors for the alculation of the factor $(dP)^n$ i.e. be varying the value of "n".

ɔr type 1 buildings n= 0.6
ɔr type 2 buildings n= 0.65
ɔr type 3 buildings n= 0.7

ith loosely constructed buildings, ie. with greater opening/cavity ratios, the flow f air will increase, hence the value of "k" increases for the lower quality buildings.

he area factor "A" is based on the total area of the opening. The actual infiltration ath is limited to approximately half the total openings; the user of this text can half he opening area and then double the flow factors if that has greater appeal.

Note on the use of Imperial Units

he value of the pressure build up in a building will be less than the value calculated rom the wind pressure; the use of the interger on the pressure calculated from the SI value f pressure will be reduced for the lower quality buildings which is as expected; however similar calculation using the pressure value in inches will show an increase in pressure. or this reason the values of pressure should not be calculated in Imperial, a straight onversion is to be made from the SI value i.e.

	Infiltration Formulae	
$= 110 \times (dP)^n \times A$	Type 1 buildings	$Q = 550 \times (dP)^{0.6} \times A$
$= 80 \times (dP)^n \times A$	Type 2 buildings	$Q = 400 \times (dP)^{0.65} \times A$
$= 60 \times (dP)^n \times A$	Type 3 buildings	$Q = 300 \times (dP)^{0.7} \times A$

ihere $(dP)^n$ is in pascals for both the Imperial and SI calculations.

ı is in cfm for Imperial
. is in square feet for Imperial

Q is in litres per second for SI
A is in square metres for SI.

City	Wind Speed* k/h (km/h)	Wind Factor (dP)^n (PA) Pa** Building Type 1	2	3	Degree Days*** °C.d
ONTARIO					
Armstrong	12.6	3.31	3.66	4.04	6921
Centralia	18.7	5.32	6.11	7.02	3968
Chapleau	11.3	2.90	3.17	3.49	6056
Earlton	16.1	4.44	5.03	5.69	5996
Geraldton	12.1	3.15	3.47	3.82	6667
Gore Bay	16.4	4.54	5.15	5.84	5085
Grahame	14.2	3.82	4.27	4.78	6577
Kenora	16.0	4.41	4.99	5.64	5998
Kingston	16.4	4.54	5.15	5.84	4291
Mount Forest	14.8	4.01	4.51	5.06	4889
Muskoka	13.7	3.66	4.08	4.54	4866
Nakina	12.4	3.25	3.58	3.95	6649
North Bay	15.3	4.18	4.71	5.30	5376
Ottawa	14.5	3.92	4.39	4.92	4829
Sault Ste. Marie	15.3	4.18	4.71	5.30	5278
Simcoe	15.3	4.18	4.71	5.30	3944
Stirling	11.4	2.94	3.21	3.51	4431
Sudbury	21.4	6.25	7.28	8.48	5333
Thunder Bay	14.2	3.82	4.27	4.78	5781
Timmins	14.3	3.35	4.31	4.82	6333
Toronto	15.3	4.18	4.71	5.30	3793
Trenton	16.1	4.44	5.03	5.69	4172
White River	8.4	2.03	2.16	2.29	6486
Wairton	17.4	4.88	5.56	6.35	4479
Windsor	17.0	4.74	5.40	6.14	3654
QUEBEC					
Bagotville	16.4	4.54	5.15	5.84	5963
Baie Comeau	15.8	4.34	4.91	5.55	5777
Fort Chimo	16.4	4.54	5.15	5.84	8581
Megantic	16.2	4.47	5.07	5.74	5382
Mont Joli	20.3	5.87	6.80	7.88	5513
Montreal	15.8	4.34	4.91	5.55	4557
Nitchequon	15.4	4.21	4.75	5.36	7999
Quebec	16.7	4.64	5.27	5.99	4965
Rivere du Loup	14.0	3.76	4.19	4.68	5500
Roberval	15.6	4.28	4.83	5.45	5845
Ste. Agathe des Monts	10.8	2.75	2.99	3.26	5484
Schefferville	18.0	5.08	5.81	6.66	8267
Sept Iles	18.2	5.15	5.90	6.76	6293
Sherbrooke	11.4	2.94	3.21	3.51	4712
Val d'Or	12.5	3.28	3.62	4.00	6205

* Taken from Ref (4)
** Derived in Appendix A
*** Taken from Ref (2)

Leakage in a Warehouse

The building has been surveyed and the following information gathered:

1. Dimensions 45 m X 55 m X 6 m tall.
2. Crackage, alsong the tope of the wall; continuous, 1 cm wide; alongside three columns; 1.5 cm wide; around the flues, (3 off), 3cm gap around the 20 cm stack; and a hole 15 cm in diameter.
3. The building has partitions and the walls are made of concrete block.
4. There are three windows on the south side; these are 1.5 m X 3 m each.
5. The building is kept lit ten hours per day and has a lighting power comsumption of 70 W/m^2.
6. The building is located in Ottawa.
7. There are no partitions.
8. The building is heated by oil-fired boilers, 70% efficient with a fuel cost of 16¢/L.
9. The walls are 20 cm concrete block; the roof is steel deck, with built up roofing and 5 cm insulation.
10. There are three shipping doors, 3m X 4m and two access doors, 0.8m X 2m; the doors are open 3% of the occupied time.

Calculating the infiltration due to the holes, cracks and gaps.

Area of Holes:

1. Crack at the top of the walls

$$= \frac{1\text{cm} \times (45\text{m} + 55\text{m}) \times 2}{100\ \text{cm/m}}$$

$$= 2\text{m}^2$$

2. Crack alongside column

$$= \frac{1.5\ \text{cm} \times 6\ \text{m} \times 3}{100\text{cm/m}}$$

$$= 0.27\ \text{m}^2$$

3. Gap around flues

$$= \pi \times \frac{(26^2 - 20^2)}{100^2 \times 4} \times 3$$

$$= 0.065\ \text{m}^2$$

4. Hole

$$= \frac{\pi \times 15^2}{4 \times 100^2}$$

$$= 0.018\text{m}^2$$

TOTAL $= 2.3530\ \text{m}^2$

Building is type 1, (large open building with poor seal on walls)

$$(dP)^n = 3.92\text{Pa}$$
$$k = 550\ \text{L/(s.Pa.m}^2\text{)}$$
$$\text{ie. } Q = 550 \times 3.92 \times 2.353$$
$$= 4\,593\ \text{L/s}$$

Calculating the cost of this from the formulae (no.4)

$$\text{Oil Cost} = \frac{Q \times {}^\circ\text{C.d} \times \text{Oil price ¢/L}}{26\,100}$$

$$= \frac{4\,593\ \text{L/s} \times 4\,829\ {}^\circ\text{C.d} \times 16\ \text{¢/L}}{26\,100}$$

$$= \$13{,}597.00$$

This cost is a close enough estimate for this building; however, a closer estimate can be made if all the factors in the heat balance of the building are made. These calculations are normally made by mechanical engineers, the following is an example of the scope of calculations that can be made. These calculations should be made to ensure that the importance of the operating and building changes which can be made are realized by the building manager.

The following summarizes the calculations which have been made for the above building on a monthly basis. To calculate this the values of the wind velocity have been taken from Ref(4) and the values for the temperatures have been taken from Ref (7).

1. Heating Load Summary

MONTH (1980/1981)	Hours Occupied	and Unoccupied	Heating loads Transmission	in kilowatts Building Infiltration	Door Infil.
September	294 h	510 H	52.2 kW	25.6 kW	19.8kW
October	322 h	514 h	109.3 kW	59.2 kW	45.6 kW
November	308 h	500 h	108.0 kW	108.8 kW	83.0 kW
December	294 h	534 h	268.0 kW	160.0 kW	123.6 kW
January	294 h	534 h	294.1 kW	184.5 kW	144.5 kW
February	280 h	472 h	285.4 kW	183.5 kW	141.2 kW
March	308 h	524 h	223.5 kW	145.1 kW	111.8 kW
April	294 h	544 h	139.3 kW	88.4 kW	68.0 kW
May	280 h	544 h	73.5 kW	43.1 kW	33.2 kW

2. Energy Required Summary

MONTH (1980/1981)	Energy (GJ) for Building Infiltration	Total Heating Required for Building a) Unoccupied period	b) Occupied
September	47 GJ	142.8 GJ	0
October	153.8 GJ	311.8 GJ	47.3 GJ
November	279.4 GJ	518.0 GJ	219 GJ
December	430.2 GJ	588.7 GJ	400.1 GJ
January	494.2 GJ	687.1 GJ	476.1 GJ
February	443.9 GJ	631.9 GJ	440.0 GJ
March	388.6 GJ	537.9 GJ	340.5 GJ
April	229.1 GJ	296.8 GJ	129.1 GJ
May	84.4 GJ	119.1 GJ	0 GJ
	2 550.6 GJ	3 844.1 GJ	2 052.1 GJ

A further reduction in the heating requirement will result from the solar effects. During the occupied period the heating requirements will reduce by approximately 10% and the unoccupied period by 4%. Similarly, the heat required to compensate for the building infiltration will drop by about five percent.

ie. the final heating requirements will be:

Infiltration ≃ 2 423 GJ; Unoccupied period ≃ 3690 GJ ; Occupied period ≃ 1 847 GJ

Cost of fuel to compensate for the infiltration:

$$\simeq \frac{2\,423 \text{ GJ} \times \$0.16 \times}{0.7 \times 39 \times 10^{3}} \text{ GJ}$$

Where oil cost 16¢/L and the calorific value of oil is 39 MJ/L; the efficiency is presumed to be 70%.

≃ \$14,200.00, i.e. within ±4% of the value calculated above.

NOTE: The calculations show very close correlation; however, if the door infiltration and the building heat losses were reduced the effects of the infiltration due to the cracks would be reduced as more heat was made available from the internal heating to compensate for the infiltration.

Calculation N - G

Door Infiltration

$Q = k. (dP)^n \times A$

For this example
$k = 550$ L/(s.Pa.m^2)
$(dp)^n = 3.92$ Pa
A= area of doors

An average heat loss rate was established for the energy calculations.

Wall Infiltration

$Q = k. (dP)^n \times A$

k*= 0.08 L/(s.m^2Pa)
A= Wall area

*Note: "K" value compensates for the fact that only half the area is infiltration, the rest is exfiltrating.)

1. GENERAL

1. The energy required by the air-conditioning system as a result of infiltration could be offset by the "free cooling" effect to the space; i.e. the infiltration of cold air will help offset the internal loads.

2. During peak conditions the infiltration will bring excessive fresh air into the space. This will generally be in addition to the design fresh air requirements allowed for in the fresh air components in the air-conditioning system and will add to the peak load.

3. The additional load will add to the installed capacity required (or it will mean discomfort to the occupants) and will raise the peak demand rates for the building.

2. AIR-CONDITIONING LOAD DUE TO INFILTRATION

1. The load from this extra air will be both sensible and latent, ie. the air coming in will require temperature and humidity reduction.

2. The amount of air will depend on the prevailing wind, and because the winds in summer are generally slower than in winter the average wind velocity for the summer months of July and August are to be used.

3. The cooling effects are to allow for the cooling of the air at the 2½ % condition (see ASHRAE Fundamentals (1)) and the room design condition.

4. The following example calculates the increased capacity required for a building in Ottawa and the cost of this in terms of extra capital cost and the increased demand charges for Ottawa Hydro.

Building is a type 2 building with a total opening area of 1.08 ft^2 , i.e. 0.1 m^2

From (4) the average wind velocity in Ottawa is 12.4 km/h.
From (1) the design condition (2½%) 30.5°C d.b. & 23.5°C w.b. (i.e.) 87°F d.b. and 74°F w.b.) Room conditions are 75°F/24°C & 50% R

$((dP)^n$ calculation

$dP = 0.0464 \times 12.4^2$
$= 7.13$ Pa
$(dP)^n = 7.13^{0.65}$
$= 3.59$ Pa (type 2 building)

Air Flow "Q"

$80 \times 3.59 \times 1.08$	$400 \times 3.59 \times 0.1$
$= 310$ cfm	$= 144$ L/s
$1.08 \times \Delta t°F \times$ flow (cfm)	$1.21 \times \Delta t°C \times$ flow L/s
$= 1.08 \times (87°F - 75°F) \times 310$ cfm	$= 1.21 \times (30.5°C - 24°C) \times 144$
$= 4018$ Btu/h	$= 1132$ W

2. Air-Conditioning Load due to Infiltration

0.68 X Δ hr X flow

(Δ hr = change in humidity ratio in gram/lb)

= 0.68 X (111 - 64) grains/lb X 310 cfm
= 9910 Btn/h

Latent Load 0.3 X Δhr X flow (L/s)

(Δhr is the change in humidity ratio in dg/kg)

= 0.3 X 69 dg/kg X 144 L/s
= 2980 W

Total Load

13 930 Btu/h 4110 W

3. Cost Estimate (Capital)

1. The cost of installing air-conditioning will depend on the size of the load, for some project the incremental load calculated for the area under consideration will be meaningless as the air-conditioning unit being proposed will have enough capacity for the infiltration in a standard size unit.

2. A typical cost of air-conditioning has been based on the total capacity; thence the extra cost for the load shown would be:

$2,000/TR

$$\frac{2,000 \text{ X } 13\ 930 \text{ Btu/h}}{12\ 000 \text{ Btu.h}^{-1}\text{/T.R.}}$$

= $2,320

$600/kW
= 600 X 4.11
= $2,470

i.e. the added cost due to a 1.08 ft² total infiltration will be $2,320.

i.e. the added cost for air-conditioning due to a 0.1 m² infiltration path in a building in Ottawa will be $2,470.00

4. Operating Cost.

1. The cost of operating the air-conditioning unit to produce the added cooling required for the space cannot be assessed in terms of the energy costs, the cost can be determined for the increased demand however

2. For buildings that are heated by sources other than electrical heating the added peaks of the air conditioning units will mean an additional hydro cost on the demand meters. For the example used for the Ottawa area the added cost for demand rates would be:

For a system operating at 1.2 kW/T.R.

$$\text{Demand increase} = \frac{13\ 930 \text{ X } 1.2}{12000}$$

= 1.4 kW

With a C.O.P. of 3 (C.O.P. = coefficient of performance)

$$\text{Demand} = \frac{4.11}{3} = 1.4 \text{ kW}$$

For Ottawa the charge for demand is $2.80/kW per month, i.e. the total increased running cost would be

= 1.4 kW X $2.80k/W X 12 months/a = $47.00

i.e. the increased operating cost of a filtration path of 1.08 ft² (0.1m²) is approximately $50.00 per year.