Performance Evaluation of Apple Hill
Energy Efficient Homes

FINAL REPORT

CMHC File No. 176-4-31

PERFORMANCE EVALUATION OF APPLE HILL ENERGY EFFICIENT HOMES

FINAL REPORT

PREPARED FOR:

THE POLICY DEVELOPMENT AND RESEARCH SECTOR

OF

CANADA MORTGAGE AND HOUSING CORPORATION

BY

COGENERATION ASSOCIATES LIMITED
PAR SHELTER ENGINEERING LIMITED
RETROSPECTORS INCORPORATED

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Executive Summary

The subdivision of homes known as "Apple Hill" in Kanata, Ontario represents one of the first attempts by a commercial builder in Canada to incorporate super energy efficient design features into the construction of new houses on a large scale. These features include double wall construction with an insulation value of RSI 7.04, ceiling insulation of RSI 10.56, basement wall insulation of RSI 3.52. Other energy saving features included sealed polyethelene air/vapour barriers, enclosed furnace rooms and heatilator style fireplaces. Many of these design features were based on those demonstrated in the Saskatchewan Energy Efficient Showcase Houses. At the time of construction, this subdivision provided an opportunity to measure the actual performance of commercially constructed energy efficient homes, and gauge the effectiveness of the technology transfer.

The study of Apple Hill Energy Efficient Homes was initiated in the latter part of 1981 with these objectives in mind. However, at that time, there was a very limited number and variety of standard test procedures which could be used to measure energy performance. Airtightness, Air Change, and Thermographic testing standards were in the early draft stages. Revision of these standards are still ongoing to-date. Most of the experience, at that time, with these test procedures, as well as neutral pressure plane measurements, time constants, and even energy monitoring had been confined to controlled research conditions. In order to implement these procedures for large scale testing,

certain modifications and developments were required. Thus, a second objective of the study evolved - to develop and evaluate new testing procedures to measure the performance of houses. Over the course of the study, these procedures were to be refined, the costs documented, and their suitability, for large scale testing evaluated. As a result, the findings of this study cannot be considered scientifically conclusive. The results do, however, provide significant contributions, in an engineering sense, to advancing our understanding of the operation of energy efficient housing; the problems associated with their commercial construction; and the relative merits of various forms of testing.

The study officially began on January 4, 1982, and testing and monitoring was completed by April 30, 1983. The tests which were conducted during this period include:

- Inspection and Appliance Survey
- Air Tightness Testing
- Thermographic Scanning
- Air Change Rate Measurements
- Air Quality Tests
- Thermal Time Constant Tests
- Neutral Pressure Plane Tests

Energy consumption for space heating, domestic hot water and electrical appliances was also monitored on a monthly basis. This data was used to compare actual performance with predicted performance of the houses, using the CMHC-2 model. In addition, the costs of individual tests were documented in an attempt to establish standard costs for each of the test procedures.

A great deal of data has been accumulated over the course of the study, and has been subjected to various forms of analysis. In order to accomodate the volume and diverse nature of this data, this final report is supplemented by a set of appendices. The final report consists of the presentation of summaries of the findings of the individual tasks, as well as some general conclusions about the houses, and test procedures. Detailed results and analysis are presented in the set of appendices, which consist of a series of self-contained reports of the individual tasks.

FINDINGS

In general, the performance of the houses of Apple Hill comes very close to actually being energy efficient homes. The factors which preclude them from this classification are symptomatic of the problems which will likely plague all commercial builders when constructing houses of this type. The major issues are as follows:

Air Leakage

These houses are generally constructed to the specifications advertised by the builder. Air leakage, however, is greater than would be expected for energy efficient homes. Typical leaky areas are the basement, furnace room, fireplace, and attic hatch. These observations are supported by results of air tightness tests, smoke pencil inspections, thermograhic scans, and the location of the neutral pressure planes. Electrically heated homes are generally tighter than gas heated homes because of the absence of the furnace room.

It is obvious from watching the construction of new houses in this subdivision that a training program is required for construction tradesmen; not only dry-wallers and insulators, but electricians, sheet metal workers and plumbers. Likewise, some design features and construction practices require rethinking, especially in the basement header area. A systematic tightening program for these houses could determine to what extent these leaky details contribute to the total leakage area. The design and construction of the heatilator type of fireplaces for these homes also requires re-evaluation to determine whether the function of a fireplace should be solely cosmetic, or if it can make a significant contribution as an energy saving feature.

Air Change/Air Quality

The average air change for these houses is approximately 0.36 air changes (ach) per hour. Electrically heated houses are typically lower. These rates could be lowered significantly through tightening of the major leakage areas. Before tightening work proceeds, some thought should be given to the use of mechanical ventilation to ensure that minimum air change rates are maintained. High humidity in houses with low air change rates supports these findings. Because of the low neutral pressure planes and high humidity levels, there is a possibility of exfiltration/condensation occuring in these houses. Some of the thermographic scans revealed cold spots in the upper ceilings which could be resulting from moisture accumulation. Moisture probing and continuous humidity recording should be initiated to investigate potential moisture problems.

There is also a need to develop or test mathematical models which correlate equivalent leakage areas to air change rates. This may require continuous monitoring of air changes.

Air change rates as determined by tracer gas and time averaged sampling are in the range of 0.2 to 0.5 changes per hour. In most cases the air change rates are below the 0.5 acph level which is being recommended for the 1985 revision of the National Building Code. Despite the low air change rates, the measured concentrations of carbon monoxide, carbon dioxide, and nitrous oxides are below the current recommended levels for these pollutants. The major sources of these pollutants, namely, the furnace and water heater, are isolated in a ventilated, enclosed room. Levels of carbon dioxide were found to be high in a few houses.

Radon and radon daughters concentrations in the Apple Hill houses are greater than expected. In some cases, the levels are high enough to warrant some form of remedial action. The high levels appear to be the result of high radon concentrations in the soil and ground water. The radon appears to migrate through the basement slab and walls and is distributed throughout the house. Very little is known to-date about the long term effects of prolonged exposure to these low levels of radiation. This is currently being investigated further and recommendations will be made in the near future.

Formaldehyde levels were found, in some cases, to be as high as the recommended maxium level set for houses insulated with Uua Formaldehyde Foam Insulation (UFFI), in spite of the fact that UFFI was not used in these houses. The apparent sources of the pollutant appear to be the building materials and furniture. The low air change rates in these houses compound the problem by not allowing for adequate venting or removal of this pollutant.

Energy Use

The annual energy use for the gas-heated Apple Hill homes ranged from 93 to 160 GJ, in terms of equivalent heating value of natural gas and electricity used. This compares to 72 GJ for electrically heated houses. Natural gas consumption, for space heating only, ranged 70 and 85 GJ per year, while electrically heated homes averaged 47 GJ in terms of equivalent heating value of electricity.

Energy usage for domestic hot water ranged between 2.5 and 3.5 GJ, for natural gas water heaters, per month, while electrically heated houses averaged 0.98 GJ per month.

The primary reason for the significant difference in the energy use between the gas and electrically heated houses is centred around the operation of the enclosed furnace rooms. Only the gas heated houses are equipped with enclosed furnace rooms which have the following effects on the energy performance of these homes:

1. The furnace room accounts for more than 30% of the air infiltration in gas heated homes, which are 30 to 70% leakier than comparable electrically heated houses. As a result, air change rates are 60% higher, increasing the heating load of the house during the winter.

2. The temperature in the furnace rooms is typically very close to ambient conditions. This results in higher standby heat losses for the conventional water heaters which are situated there.

3. The efficiency of electrical heating systems are assumed to be 100% because there are no stack losses. The conventional gas furnaces operated at efficiencies in the order of 70%. However, the cold furnace rooms also results in increased radiant losses and short cycling of the furnace reducing its seasonal effective heating efficiency to, in the order of, 50%.

The first phase of testing provided a great deal of information and identified some major issues concerning the design and operation of enclosed furnace rooms. The problems associated with the furnace rooms have been studied in more detail. The results of that study are presented in an appendix to this report.

TEST PROCEDURES

Almost all of the test procedures used were either developed or modified especially for this study. They were continuously refined during Phase 1, as there was a rush to complete testing before the end of the heating season. Unpredictable weather conditions forced re-scheduling of many tests and necessitated the re-testing of many houses to ensure accurate results. Subsequent testing through Phases 2 to 4 was more streamlined and standardized. Between Phases 1 and 4 testing time was cut in half. Information from airtightness air quality and air change testing as well as energy monitoring was the most useful in terms of quantitatively evaluating the performance of these houses. Other testing, such as thermographic scanning, smoke pencil inspection and neutral pressure plane determination provided qualitative data which supported the other findings. The thermal time constant test requires further development in terms of theorical foundation of the test and the test procedure itself before it can be sed with some degree of reliability.

1.0 INTRODUCTION

Since 1973, the cost of energy in Canada has been increasing at rates up to 30% per year. The resulting high, home heating costs have created an interest in energy efficient housing. In order to improve domestic energy use, various levels of government have assisted the housing industry to investigate, more closely, the factors which determine energy use in houses. The findings of this ongoing work have resulted in the development of new designs for energy efficient homes. Some of the more promising designs have been publicized through the construction of 'demonstration' houses across Canada in an attempt to promote acceptance by homeowners and builders. By demonstrating their energy efficiency houses provide a means of transferring technology from the laboratory to the market place. The questions which remained unanswered at the time this study began were, "To what extent could a commercial builder design, build, and sell energy efficient housing; and to what degree would these houses match the energy performance of the demonstration houses?"

The homes constructed by Douglas MacDonald Homes Limited in the Apple Hill subdivision were one of the first attempts to incorporate energy efficient design features into a complete subdivision of homes. These houses were designed and built with energy saving features such as:

A) Double wall construction providing an insulation value of RSI 7.04,

B) Ceiling insulation to a value of RSI 10.56,

C) Basement walls insulated to a value of RSI 3.52,

D) Continuous 0.15 mm polyethylene vapour barrier,

E) Insulated and sealed furnace room with outside combustion air intake,

F) Insulated and weather stripped metal doors,

G) Double glazed wood slider or casement windows.

H) Optional 'heatilator' type fireplaces.

Studying these houses has provided an opportunity to compare their design, construction, and operation to those built by researchers. This comparison should provide the designers and builders, as well as the homeowners, with valuable information which will assist in promoting the development and acceptance of energy efficient housing in the future.

The 'Performance Evaluation of Apple Hill Energy Efficient Houses' started in January, 1982. A total of 35 houses were observed through construction, and monitored for a period of at least one year after occupation. In addition, performance tests, using procedures developed especially for this study, were conducted at four different times of the year in an attempt to measure seasonal variations. The study was divided into a set of tasks. These are:

* Sample Selection
* Appliance Survey and Inspection
* Air Tightness Tests
* Thermographic Scanning
* Air Change Measurements,

* Air Quality Tests,
* Thermal Time Constant Measurements,
* Neutral Pressure Plane Determination,
* Energy Monitoring
* Cost Documentation
* CMHC-2 Analysis

The detailed results of each of these tasks are documented in self contained reports which make up the Appendices to this report. This final report summarizes the findings of each of these tasks, and presents the overall conclusions of the study.

Two additional sub-studies resulted from some of the initial work in Apple Hill. These are:

1) The Study of Furnace Room Design and Operation in Apple Hill Homes.

2) Time Averaged Air Quality and Air Change Measurements.

The findings of these two studies are documented in two reports which form additional appendices to this main report.

2.0 OBJECTIVES

The objectives of this project were to:

1. Test a sample of energy efficient houses constructed at Apple Hill by Douglas MacDonald Homes Ltd., as well as three other energy efficient houses constructed by Urbandale Homes Ltd., to determine the performance of these houses with respect to energy utilization.

2. Develop and evaluate the usefulness of several new test procedures and instruments.

3. Determine the cost of these tests done in quantity on an active construction site.

It is important to note that since the test procedures themselves were being evolved and tested, the results obtained cannot be considered conclusive. The test procedures used in the project have been, and are still being, developed under the basic objective of being repeatable, and, once refined, easily assimilated by the housing industry.

In evaluating the performance of these homes, it should also be noted that they were constructed before evaluation procedures were available; while standards were evolving; and without previous experience of large scale construction of these types of home.

3.0 METHODS

The work was divided into twelve tasks:

Task A - Sample Selection

Task B - Inspection and Design Review

Task C - Air Tightness

Task D - Thermographic Scan

Task E - i) Air Change Rate

ii) Air Quality

Task F - Thermal Time Constant

Task G - Neutral Pressure Plane

Task H - Energy Monitoring

Task I - Cost Documentation

Task J - CMHC-2 Documentation

Task K - House Reports

Task L - Reports

Detailed procedures, complete with evaluation and testing results are presented in the Appendices of this report.

In summary, the study began January 1982, and energy monitoring and performance testing were conducted up to April 30, 1983. Negotiations with Homeowners and the Builder were conducted during January, February and March of 1982. Once an agreement had been signed with the homeowner or builder, an inspection of the house was conducted and metering installed. Performance tests, which consisted of Air Tightness, Air Change, Air Quality and Neutral Pressure Plane, were conducted at three month intervals to coincide with seasonal changes.

Thermographic Scans were conducted during the first phase of performance tests, as were the Thermal Time Constant tests.

Energy consumption for space heating, domestic hot water and general appliance use was recorded once a month from the start of the project. Homeowners were provided with quarterly reports concerning the performance of their house. The costs of testing were recorded throughout the project, and a computer program developed by CMHC, called CMHC-2, was used to conduct a heat loss analysis of the houses.

4.0 SAMPLE SELECTION

The purpose of this task was to select houses suitable for this study, and to obtain approvals from the homeowners and builders to conduct tests on the houses.

The homeowners were first contacted by letter, followed by a personal interview. If they were willing to take part in the study, they were asked to sign an agreement to permit testing. In return for their participation, they received quarterly reports presenting the results of testing on their house.

Approval to test unoccupied houses was obtained from the Builder.

Negotiations with the Homeowners and Builder resulted in the selection of 33 houses from the Apple Hill subdivision. Three houses were also selected from outside of the subdivision to provide a base for comparison. In the Apple Hill subdivision there are eight different models of homes. The distribution of these models within the study sample is:

Model	Number
Regent	8
Russet	9
Cortland	6
Willow	4
York	2
Fireside	2
Westfield	1
Baldwin	1
Urbandale *	3

(* = not in Apple Hill)

5.0 INSPECTION AND DESIGN REVIEW

After approval was obtained from the Builder or Homeowner the next task was to inspect the house and review the design specifications. In addition, an appliance survey and furnace efficiency test was conducted. The builders drawings and specifications were reviewed in order to obtain pertinent design details concerning insulation levels, envelope areas, and volumes which would be required for testing and energy analysis.

5.1 Design Review

The basic energy saving features in these houses include:

- basement walls insulated with RSI 3.52 glass fibre insulation,
- above grade walls insulated to a value of RSI 7.4 through double wall construction and rigid glass fibre cladding,
- ceiling insulated to a value of RSI 10.56 with blown in glass fibre,
- a continuous 0.15 mm polyethelene air/vapour barrier
- enclosed furnace room with combustion air supply.

Other pertinent data concerning each of the models is presented here:

Model	Type	Volume sq. meters	Envelope Area cubic meters
Regent	2-storey	730	360
Russet	2-storey	625	315
Cortland	Bungalow	660	305
Willow	2-storey	790	375
York	Side Split	445	266
Fireside	2-storey	930	410
Westfield	2-storey	635	330
Baldwin	2-storey	730	375

5.2 Appliance Survey

Of the 36 houses involved in the study, 30 used natural gas for space conditioning and domestic water heating. The remaining 6 were heated electrically. In all cases the space heating was provided by a central forced air furnace. Fireplaces were constructed in 24 of the houses. All fireplaces were the 'heatilator' type with combustion air being supplied from outdoors and all were equipped with glass doors. The average number of occupants per household during the study was 3.

5.3 Furnace Efficiency

All of the 2 storey houses were equipped with natural gas furnaces rated at 35 kw (120,000 BTUH) fuel input capacity. The remaining bungalows and sidesplit houses were equipped with natural gas furnaces rated at 24 KW (82,000 BTUH) fuel input capacity. The results of furnace efficiency testing indicate combustion efficiencies in ranging from 68.8% to 78.9%.

5.4 Furnace Rooms

One major area of concern highlighted during the house inspections was the operation of the furnace rooms. Homeowners reported unusually low temperatures in these rooms, resulting in: the formation of frost; frozen water tanks; and cold air from the warm air ducts. These low temperatures raised concerns about the possibilty of condensation and freezing of exhaust vapours in the flue. As a result of these concerns, a study was initiated to evaluate the design and operation of these enclosed furnace rooms, and make recommendations for improvements, if required. The results of this study can be found in the report entitled "The Study of Furnace Room Design and Operation in Apple Hill Homes".

6.0 AIRTIGHTNESS TESTS

The purpose of the air tightness testing was to measure the degree to which unintentional openings had been avoided in the construction of the homes; and to evaluate the usefulness of various air tightness testing techniques.

A total of 36 houses were tested at three month intervals, over a period of one year. The tests were conducted in three configurations:

1. A depressurized test in accordance with the third draft procedures of the CGSB Standard 14A GP 10M.
2. A pressurized air tightness test following the same procedures as the CGSB Standard.
3. A depressurized test with all intentional openings sealed. These include the furnace room, bathroom vents, dryer vents, and fireplace.

Based on these tests, the normalized equivalent leakage area (NELA), and air change rates at 50 Pa (Ac@50Pa) for gas heated houses are:

	NELA(cm2/m2)	AC@50Pa
CGSB	3.2	3.86
Pressurized Unsealed	3.4	4.07
Depressurized Sealed	1.8	2.43

The normalized ELA's and air changes at 50 pascals are compared between the various models in Table 6.1. and illustrated graphically in Figure 6.1.

The Apple Hill homes are tighter, relative to other new housing in the same area, but not as tight as would be expected for new energy efficient standards. Current standards for R-2000 houses call for AC@50Pa to be less than 1.50. These are standards which only the electrically heated houses come close to meeting. The furnace room in gas heated houses appears to be the major contributor to the air leakiness of these houses. The gas heated houses are 30 to 70% leakier than the comparable electrically heated houses.

Both CGSB, and depressurized sealed tests provide reliable and reproducible results. The pressurized test is impractical, due to inconveniences to the homeowner during winter tests. The depressurized sealed test provides a useful measure for assessing the vapour barrier integrity only, while the current CGSB Standard provides a measure of the overall tightness of the above grade envelope.

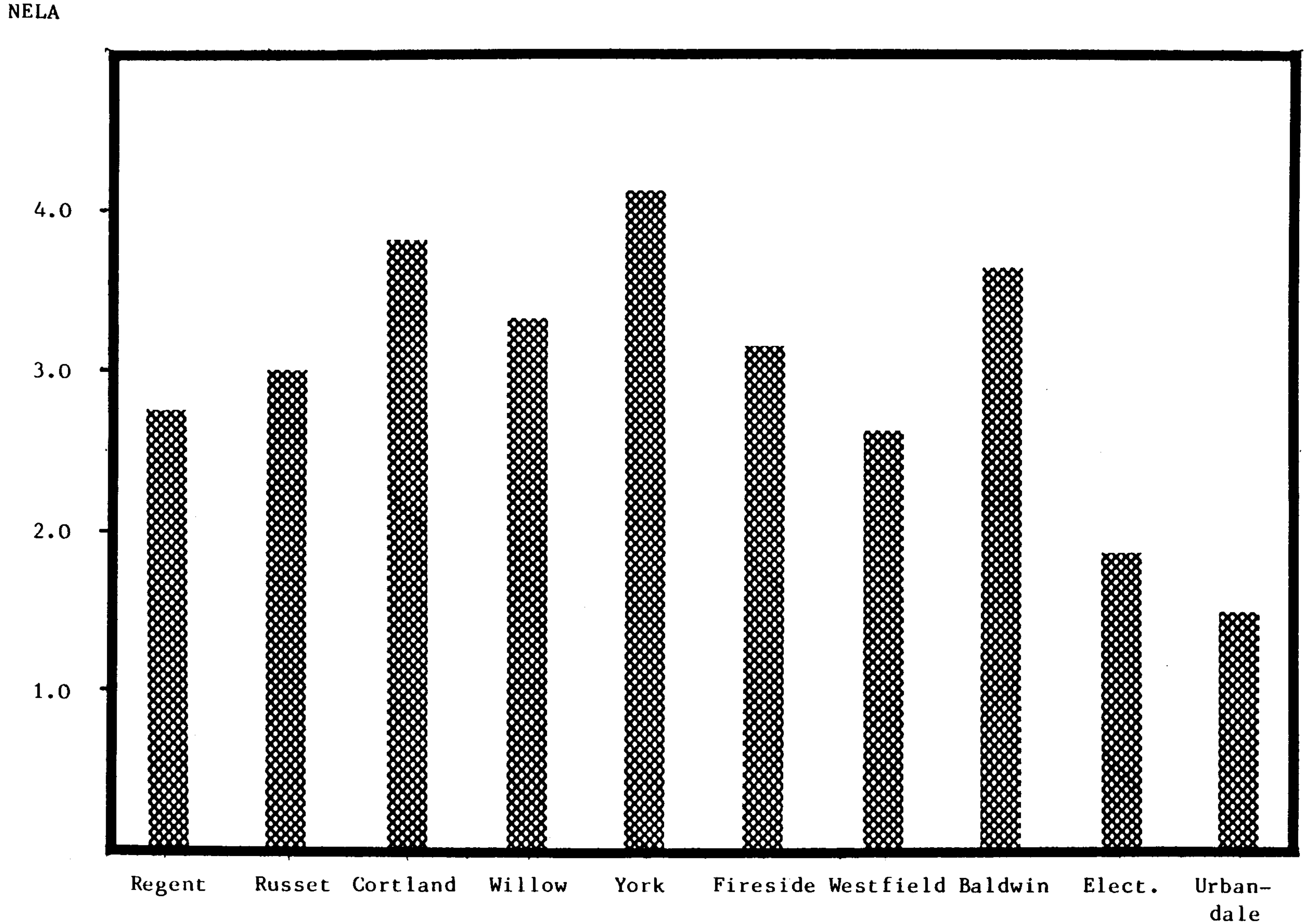
TABLE 6.1
COMPARISON OF AIRTIGHTNESS BY HOUSE MODEL
CGSB TEST PROCEDURE

HOUSE MODEL	NO. OF HOUSES	VOLUME (M^3)	ENVELOPE AREA (M^2)	MEAN NELA (CM^2/M^2)	MEAN AC@50 PA
REGENT	8	730	360	2.77	3.49
RUSSET					
GAS	6	626	315	3.02	3.84
ELECTRIC	2	626	315	1.85	2.44
CORTLAND					
GAS	5	660	330	3.80	4.20
ELECTRIC	1	660	330	1.40	1.58
WILLOW	4	790	375	3.33	3.94
YORK					
GAS	1	454	266	4.10	6.17
ELECTRIC	1	454	266	2.40	4.09
FIRESIDE	2	930	410	3.18	3.56
WESTFIELD	1	635	330	2.63	3.34
BALDWIN	1	730	375	3.67	4.20
#50	1	923	500	1.50	2.53
#51	1	921	520	0.97	1.45
#52	1	864	292	2.00	1.78

Figure 6.1

COMPARISON OF NORMALIZED ELA'S BY HOUSE MODEL

(CGSB TEST RESULTS)



Leak location checklists were filled out for 22 houses identifying leaks with a smoke pencil during airtightness testing. This checklist revealed several areas with a high frequency of observed leaks. In summary, these are:

1/ Drywall dicontinunity such as outlets, ceiling fixtures and baseboards.

2/ A/V barrier detail at the ceiling/partition walls.

3/ Window and exterior doors.

4/ Fireplace/wall construction.

5/ Basement Wall/joist, basement wall/sill and furnace room door.

6/ Attic hatch

7/ Bathroom ceiling vent

Although the Apple Hill homes are identified as energy efficient homes, it is clear that not enough attention was given to A/V barrier detail in the critical areas such as partitions, windows doors, fixtures etc. The leakage sites are characteristic of ommissions in A/V barrier.

7.0 THERMOGRAPHIC SCANNING

The purpose of the thermographic scanning was to identify specific anomalies such as air leakage, moisture accumulation, insulation voids, and thermal bridges; and to evaluate the applicability of the thermographic technique used.

The procedure employed by the thermographer corresponded with the requirements of the CGSB 149-GP-5MP provisional standard for infra-red thermographic survey work in studying frame residential buildings. An exception to section 3.4.2 of this standard was necessary. During the course of the scan the house was constantly depressurized to maintain a difference of 25 to 35 pascals. This depressurization combined with a temperature difference of not less than 20 degrees celcius helped offset the effect of solar radiation on the scans. Some exterior scans were performed, but with notably poor success. The residual solar effects on the brick veneers distorted the thermal image even after an eight hour cooling period following sunset. The bricks glowed, indicating heat loss, while many of the airleaks and voids visible from the interior thermographic scan, were no longer visible. In some cases the exterior scan did provide information of structural problems that would have otherwise have been missed by an interior scan. An example of this is failing brickwork and ties under a windowsill.

For the objectives outlined previously, the interior scanning with depressurization is a useful diagnostic technique. The synergistic effect between depressurizing the house and thermographic scanning was extremely useful because the negative pressure created by the door fan accelerates the air leakage into the house, thereby exhancing the contrast and "visibility" of most thermal expressions. Moreover, the door fan ensures that all air leakage is infiltrating, otherwise, approximately half of the air leakage would consist of warm air leakage out of the house. Exfiltration is impossible to see on an interior infrared scanner because there is no temperature difference; it also serves to partially warm the building envelope and thereby warm the cavities and building materials regardless of their thermal resistance.

This is an especially dangerous trap in new house inspections, where most of the anomalies involve some amount of air leakage. The focus should not be on voids in insulation materials, but on air leakage, thermal bridging, moisture and structural problems. As a general rule, infrared analysis of houses is best combined with the use of a door fan and an interior inspection. Potential moisture problem areas should be inspected further with the use of moisture probes.

In several test houses, the building was pressurized with the fan while the thermographer conducted an infrared inspection from the attic space. This technique did not prove very useful because of the large amount of loose fill insulation in the attic (approximately 400mm) which filtered and diffused air leakage thus obscuring most of the leaks. For example the "stripes" across the ceiling that occurred in most houses (the ceiling strapping spaces provided a direct passage for air leakage from walls and windows) were only visible in the attic after the insulation was moved away.

The thermographic investigation has raised a number of issues about design features employed by the builder. Several examples are briefly described below and illustrated in Figures 7.1 to 7.4

1. The homes incorporate a double stud wall frame with 38 x 140mm (2" x 6") wood studs on the exterior wall, and 38 x 64mm metal studs on the interior. The air vapour barrier is sandwiched between these walls against a layer of 13mm asphaltic fiber board sheathing. Because the exterior 38 x140mm wall is the load bearing wall, all the floor joists and partition walls must first penetrate the air vapour barrier before they are tied into the 38 x 140mm wall. The leakage is considerable at these junctions. The 38 x 64mm cavity also complicates the installation of duct work resulting in occasional tearing or cutting of the air vapour barrier.

2. The structural steel I beams in the basement were constantly leaking air at the junction with the exterior wall. They also function as a thermal bridge. These beams could have been supported with a metal post on the inside of the insulated foundation.

3. The fireplaces are a major weak spot in these energy

efficient homes. Although these fireplaces were installed to meet the special requests of buyers, it is unlikely the homeowners realized the full ramifications. Considerable leakage exists along the chimney/ceiling joint. The dampers leak. The "heatilator" unit also leaks very badly, sucking air from around the flue cavity and directly from out of doors. The glass doors mounted across the fireplace openings leak badly. The location of a fireplace against the outside wall means the masonry materials constitiute a major thermal bridge in the envelope; moreover, much of the thermal mass of the fireplace, when in use, will not benefit the house. A more efficient fireplace design may be possible.

4. A major trouble spot on all of the homes was the header/joist area at the top of the foundation wall. A foam gasket was used underneath the sill plate which continues wherever there is rough concrete, window frames, plumbing or wiring penetration, ductwork, and partition walls at jogs and corners. The amount of air leakage into the finished wall cavity is such that all basement wall outlets and trimwork are very leaky.

The difficulty of firmly attaching a polyethelene air vapour barrier along the joist/sub-floor topography should not be underestimated. The evidence of condensation problems along the header joist (band joist) suggests that a considerable amount of vapour is diffusing into this area. Any moisture that does reach the band joist is likely condensing, and has accumulated for several reasons:

A. The band joist is inadequately insulated with 37mm of glass fibre exteriors sheathing insulation;

B. The polyethyene air vapour barrier from the first floor walls appear to be lapped around the outside of the band joist, preventing proper drying;

C. The basement wall AV barrier is applied to the warm side of the header space fibreglass which creates partial vapour lock. This last condition requires immediate corrective action to maintain the integrity of the header joist. A detailed cross section of the header joist area is presented in Figure 7.5.

Figure 7.1

Thermographic Scan

VISUAL

LOCATION:

Second Floor Ceiling

THERMOGRAM

PROBLEM:

Cold details in ceiling indicate possible air or condensation. The result of a poor A/V Barrier.

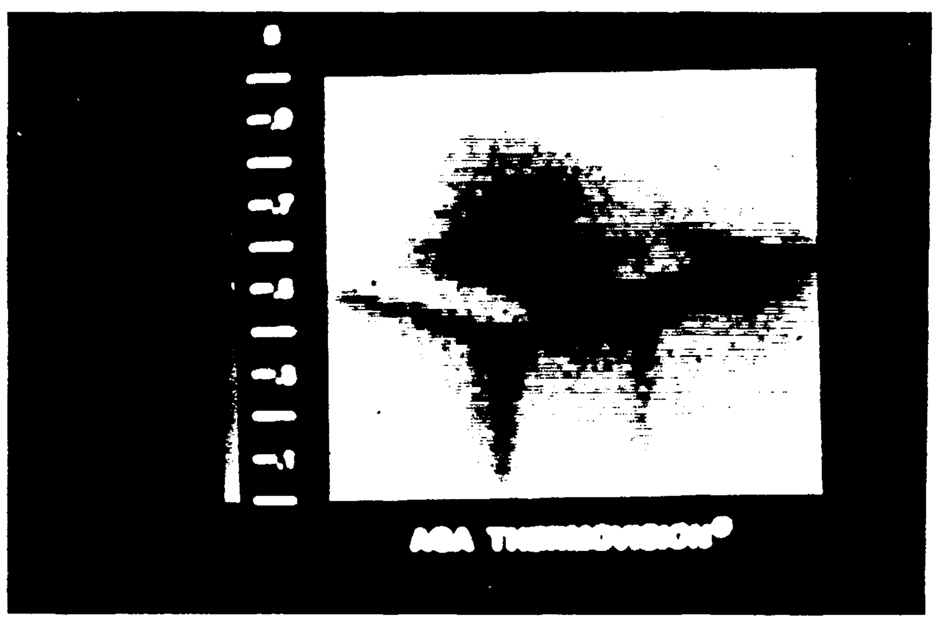
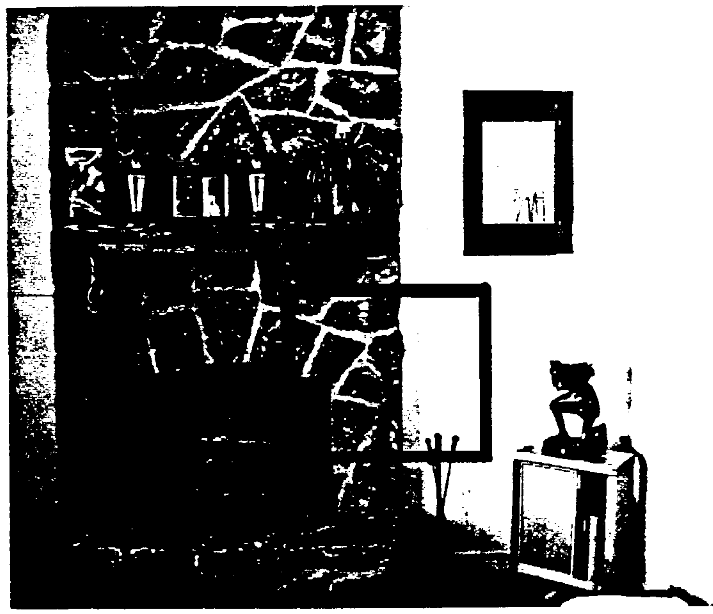


Figure 7.2

Thermographic Scan

VISUAL



LOCATION:

Living Room wall/Fireplace

PROBLEM:

Air leakage at fireplace-wall joint, probably due to poor A/V barrier seal where wall meets fireplace

THERMOGRAM

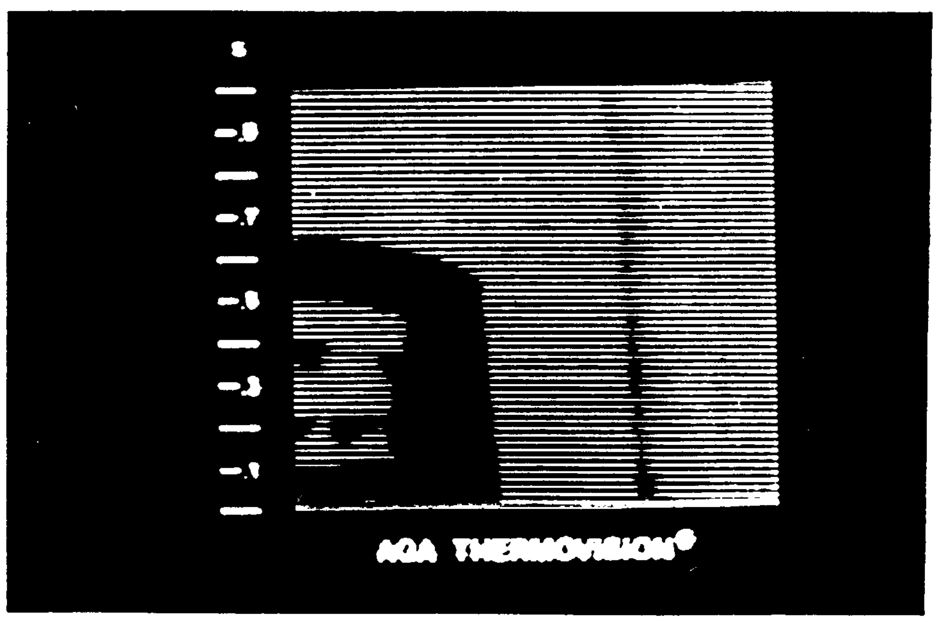
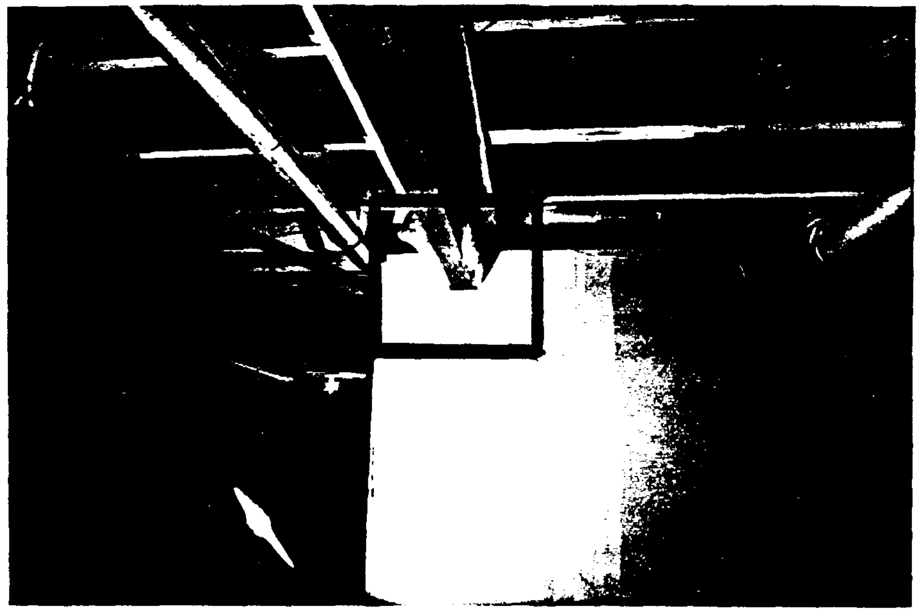


Figure 7.3

Thermographic Scan

VISUAL

LOCATION:
I-Beam into basement wall



THEROGRAM

PROBLEM:

Cold spot at I-Beam intersection with basement wall is the result of insufficient insulation and no air/vapour barrier seal.

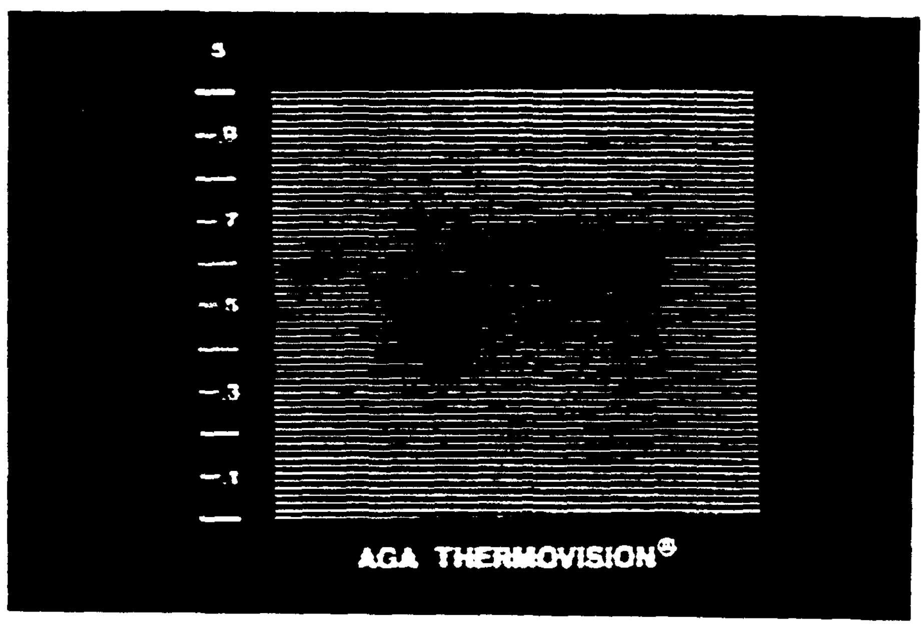


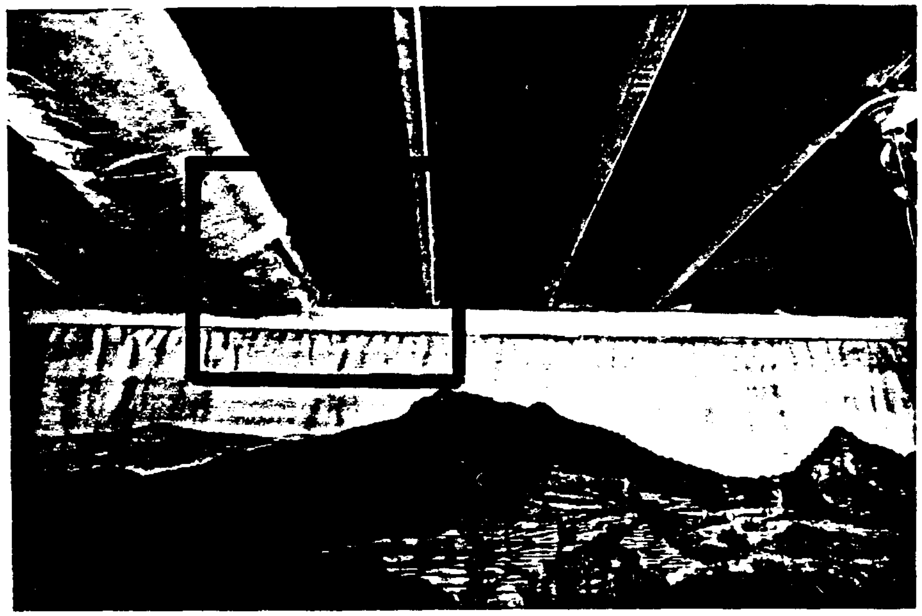
Figure 7.4

Thermographic Scan

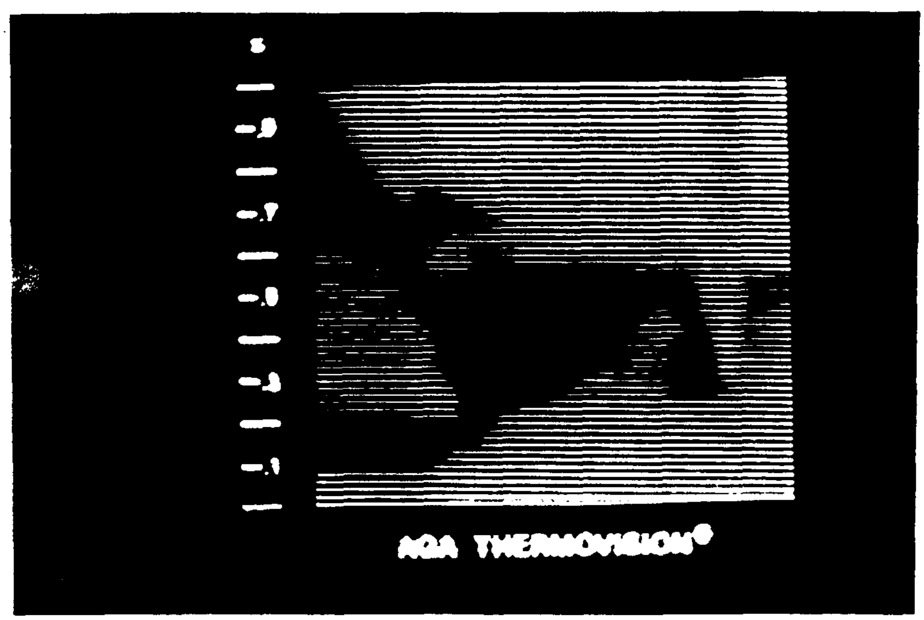
LOCATION:

Basement Header

VISUAL



THERMOGRAM

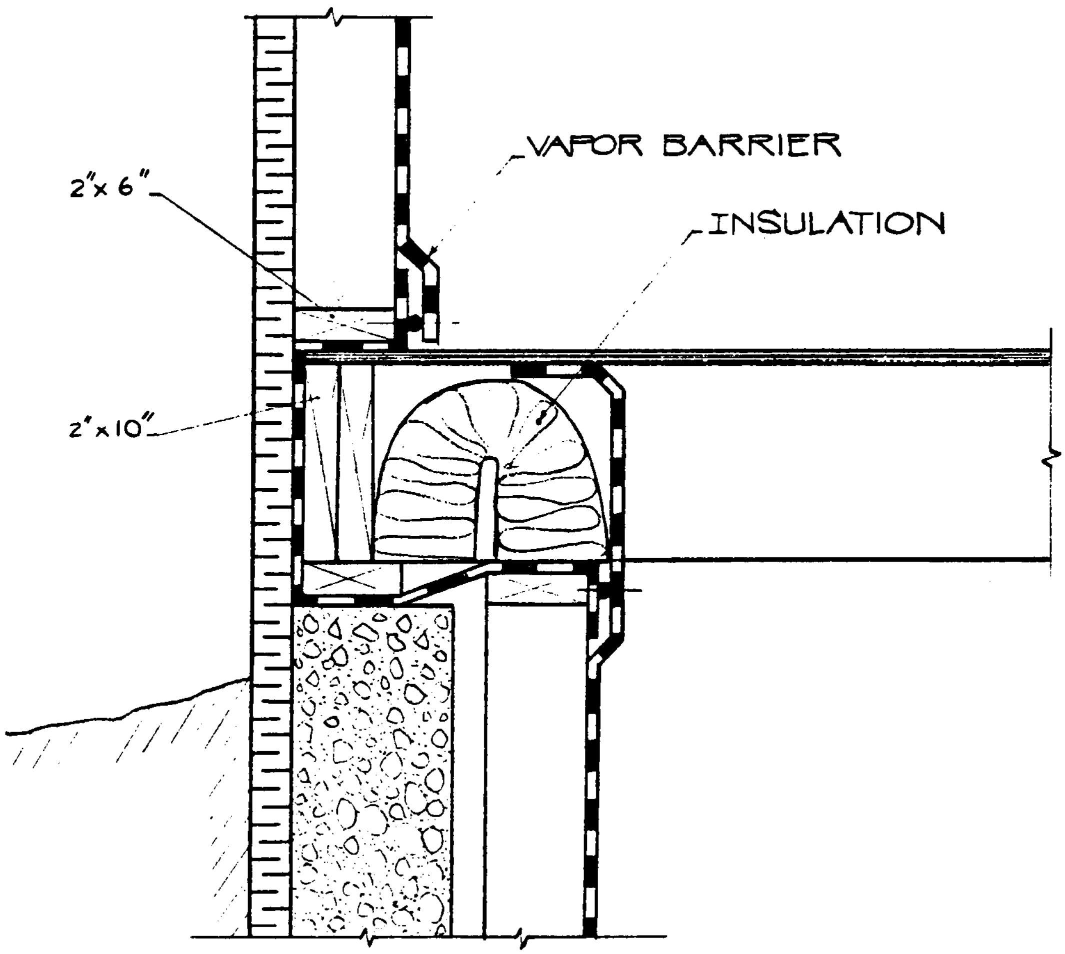


PROBLEM:

Cold spots at insulated vent and joist header resulting from poor A/V Barrier seal.

Figure 7.5

Cross Section of Header Joist



8.0 AIR CHANGE MEASUREMENTS

Tracer gas decay tests were conducted in all houses, in each testing phase. A measured sample of a non-toxic gas (sulpher hexafluoride, SF6), was injected into the cold air return of the furnace. With the furnace fan operating continuously, to keep the house air well mixed, samples were taken at regular intervals. Analysis of the decreasing concentrations of SF6 allowed the calculation of its exfiltration rate and hence the infiltration of fresh air through the envelope. A summary of the results for these tests are shown in Table 8.1. These results show that the gas-heated houses averaged about 0.35 air changes per hour (ACPH) with a range of 0.18 to 0.55 ACPH. Electrically-heated houses averaged 0.21 ACPH, with a range of 0.09 to 0.31 ACPH during winter testing. These lower rates are probably due to the absence of furnace flues and furnace room inlets. During the hour of sampling, the furnace was shut off, but the furnace fan was left on. Attempts were made to ensure that windows were closed, and door openings were minimal. A comparison of air change rates as measured using SF6 technique for gas and electrically heated houses is shown in Figure 8.1.

Some houses showed the same air change rates in each season, independent of the driving factors. Others showed correlation between the driving factors such as temperature and wind, and observed air change rates. The lack of fluctuation in air change rates could be partially due to the constant flow of air drawn through the fresh air inlet which is connected to the return air duct of the furnace. In retrospect, a set of tests should have been conducted with this inlet sealed in order to determine the effect, if any, of the natural driving forces on air change rates.

The second test method employed, was the time averaged perfluorocarbon tracer (PFT) technique. In this procedure, developed by Brookhaven National Laboratories, sources of a perflourocarbon tracer (PFT) were placed around the house. The level of PFT in the house is measured by capillary absorption tube samplers (CATS). The CATS, small glass tubes about the size of cigarettes, were changed every two weeks, and analysed. The average CAT concentration in the house was used to determine the time average change rate during the two week period.

This test method was used on only seven gas-heated houses in the Spring of 1983. The results, as presented in Table 8.2, show air change rates of about 0.18 ACPH, with a range of 0.09 to 0.39 ACPH. These results probably underestimate the actual infiltration rates, due to omission of basement air monitoring. This circumstance makes the comparison of SF6 results to PFT results difficult. The PFT results for all houses showed a direct correlation between air change rates and ambient driving forces.

The results of both the tracer gas and the time averaged tests indicate air change rates in the general range of one third of an air change per hour. ASHARE the American Society of Heating, Refrigerationn and Air Conditioning Engineers recommends one half an air change per hour for residential applications. The low air change rates in the Apple Hill homes raises some concerns about possible air quality problems. In other Apple Hill testing (Section 9) concentration of most common pollutants were found to be well below the recommended maximums. Humidity was a problem in some houses, especially electrically heated ones, resulting in condensation of windows and walls. This situation was rectified to a certain extent through increased mechanical ventilation.

The testing techniques each had advantages, and each require modification for useful results. SF6 testing is relatively inexpensive and quick, but requires further on-site testing to create the guidelines necessary for a variety of house styles, and air handling systems. PFT testing is a promising alternative. Both tests could benefit from extensive stratification and zone testing.

TABLE 8.1
SUMMARY OF AIR CHANGE MEASUREMENTS

HOUSE NO	PHASE 1 TIN	PHASE 1 TOUT	PHASE 1 WIND(KPH)	PHASE 1 ACPH	PHASE 2 TIN	PHASE 2 TOUT	PHASE 2 WIND(KPH)	PHASE 2 ACPH	PHASE 3 TIN	PHASE 3 TOUT	PHASE 3 WIND(KPH)	PHASE 3 ACPH	PHASE 4 TIN	PHASE 4 TOUT	PHASE 4 WIND(KPH)	PHASE 4 ACPH
1	20.90	3.30	17.00NW	0.32	23.00	24.00	19.00S	0.19	24.00	20.00	11.00SW	0.13	18.50	3.20	4.00SE	0.22
2	20.40	5.00	33.00W	0.40	24.00	22.00	20.00W	0.60	24.90	25.00	14.00SW	0.30	22.00	-14.00	15.00SW	0.45
3	20.90	6.00	17.00E	0.35	23.30	19.00	19.00S	0.29	21.00	14.00	17.00NNW	0.39	17.00	-10.00	33.00NW	0.54
4	20.10	5.00	9.00S	0.45	23.50	20.00	0.00	0.20	20.00	16.00	9.00W	0.17	20.00	-11.00	10.00W	0.27
5	20.00	0.60	30.00ENE	0.30	19.00	14.00	10.00S	0.37	20.00	7.00	7.00E	0.30	16.40	-13.00	6.00WSW	0.39
6	19.00	6.00	20.00E	0.45	23.90	18.00	5.00SE	0.50	22.00	17.00	15.00SE	0.83	18.00	-10.00	17.00E	0.38
7	15.90	4.60	7.00NW	0.39	21.00	20.50	7.00N	0.45	18.40	12.00	10.00SE	0.45	17.00	-9.00	15.00NW	0.46
8									21.00	16.00	20.00NW	0.21	20.30	4.00	17.00S	0.25
MEAN	19.60	4.36	20.14	0.39	22.53	19.64	11.43	0.38	21.41	15.88	12.00	0.37	18.65	-8.48	14.63	0.37
10					20.00	20.00	7.00S	0.45	22.00	16.00	18.00SW	0.31	22.90	-15.00	13.00W	0.29
11	17.90	0.50	20.00W	0.30	22.20	24.00	13.00S	0.31	20.40	2.00	13.00N	0.20	18.00	2.00	20.00SW	0.33
12	20.60	2.50	10.00W	0.37	23.00	17.10	26.00NW	0.34	18.00	7.50	9.00W	0.18	19.00	-14.00	10.00NW	0.31
13	22.40	5.30	7.00E	0.26	23.00	22.40	10.00S	0.50	21.30	11.00	12.00SW	0.24	20.00	0.00	10.00E	0.24
14	19.10	-0.60	7.00NW	0.01	22.70	20.00	18.00SW	0.27	21.00	10.00	20.00E	0.14	18.90	-19.00	17.00NW	0.30
E15	21.50	-4.00	17.00E	0.26	28.50	30.80	30.00SW	0.15	20.00	10.90	4.00SW	0.08	19.00	-17.00	26.00NW	0.31
16	20.00	0.30	20.00NE	0.34	21.80	19.00	9.00NW	0.29					17.40	-19.00	4.00W	0.30
E17	18.60	6.30	17.00WNW	0.14	21.00	24.60	7.00SE	0.12	18.00	11.00	10.00NNW	0.12	17.00	6.00	10.00N	0.14
18	20.80	10.00	7.00SE	0.20	27.70	29.60	26.00SSW	0.24	20.00	11.00	0.00SW	0.24	19.50	1.80	18.00SW	0.25
MEAN	17.26	3.71	11.29	0.34	22.91	21.73	15.57	0.34	17.53	8.21	11.43	0.19	19.39	-9.14	14.29	0.30
20	22.60	2.60	0.00SW	0.34	20.80	14.00	7.00W	0.21					18.20	1.00	0.00	0.26
21	19.90	2.60	15.00SW	0.22	20.50	20.50	19.00S	0.23	19.00	11.00	7.00S	0.21	19.80	1.00	20.00SW	0.27
22	18.50	2.60	20.00E	0.46	21.00	21.40	30.00SW	0.22	19.00	13.00	7.00W	0.12	17.20	-18.00	20.00NE	0.40
E23	22.50	7.40	13.00NE	0.12	21.00	18.00	22.00W	0.09	18.10	3.00	11.00NE	0.14	14.00	-22.00	24.00NW	0.09
24	20.90	2.70	7.00E	0.18	25.80	24.20	15.00W	0.20	19.00	11.00	6.00SE	0.19	17.50	-1.00	20.00E	0.18
25					18.70	18.00	7.00W	0.18	20.00	19.00	8.00W	0.13	17.00	-14.80	13.00E	0.26
MEAN	20.48	2.63	12.50	0.30	21.34	19.69	16.51	0.21	19.25	13.50	7.00	0.16	17.94	-6.36	14.60	0.27
27	20.60	7.40	13.00NE	0.20	23.00	20.00	5.00E	0.46	16.90	6.70	30.00SW	0.30	17.00	-15.00	26.00NW	0.20
28					19.00	17.90	15.00W	0.39	20.00	14.00	28.00NW	0.24	18.50	-14.00	2.00NW	0.33
29	21.80	7.80	7.00S	0.26	20.20	21.00	7.00SW	0.20	18.00	14.00	15.00NE	0.26	18.60	-22.00	11.00E	0.54
30					24.00	22.70	19.00SW	0.17	18.00	10.50	0.00	0.19	17.60	-17.20	20.00W	0.48
MEAN	21.20	7.60	10.00	0.27	21.55	20.40	11.50	0.33	18.23	11.00	20.25	0.27	17.93	-17.05	16.75	0.39
E31	19.80	7.00	11.00E	0.37	21.40	23.00	15.00E	0.10	19.00	6.00	40.00NW	0.36	20.00	-6.00	19.00E	0.22
32	19.30	2.60	19.00E	0.44	23.00	23.30	15.00S	4.00	22.00	19.00	17.00E	0.39	20.90	-7.00	9.00SE	0.30
MEAN	19.30	2.60	19.00	0.44	23.00	23.30	15.00	4.00	22.00	19.00	17.00	0.39	20.90	-7.00	9.00	0.30
34	18.80	-4.60	31.00NW	0.51	21.00	16.00	17.00NW	0.61	20.00	15.00	15.00SW	0.22	17.70	-15.00	20.00NE	0.34
35	15.60	3.30	17.00NW	0.26	24.50	21.10	28.00SW	0.15	21.40	11.00	0.00	0.21	19.00	0.70	11.00SE	0.29
MEAN	17.20	-0.65	24.00	0.39	22.75	18.55	22.50	0.38	20.70	13.00	7.50	0.22	18.35	-7.15	15.50	0.32
37	21.50	5.30	7.00E	0.27	22.90	22.00	19.00SE	0.43	22.00	12.20	19.00NE	0.25	19.50	-1.70	11.00W	0.27
39	21.30	-4.00	15.00E	0.35	17.00	15.70	12.00SW	0.21	18.00	13.00	11.00NE	0.20	19.60	-1.00	3.00NW	0.33
50					29.00	27.00	12.00NW		19.00	1.00	7.00S	0.09	18.70	1.00	7.00S	0.22
51									19.00	12.00	5.00NE	0.09	16.70	-10.00	22.00NW	0.20
ELECTRIC	20.60	4.30	14.50	0.22	22.90	24.10	20.50	0.14	18.90	7.73	18.25	0.10	17.50	-9.75	19.75	0.19
GAS	19.73	2.69	14.07	0.34	21.75	20.13	15.44	0.78	19.89	13.32	13.26	0.26	19.03	-7.23	12.35	0.33

TABLE 8.2

SUMMARY OF INFILTRATION RESULTS

House No.	Volume (m^3)	AVERAGE AIR CHANGE RATE (ACPH)				
		(1) 2/15-2/28	(2) 2/28-3/15	(3) 3/15-3/30	(4) 4/19-4/29	(5) 4/29-5/17
8	730	0.16 (± 33%)	0.14 (± 41%)	0.18 (± 41.4%)	0.12 (± 44%)	0.12 (± 53%)
10	625	0.13 (± 18%)	0.11 (± 17%)	0.14 (± 18%)	0.11 (± 8%)	0.10[3] (N/A)
20	660	0.21 (± 4%)	0.20 (± 8%)	0.28 (± 8%)	0.16[2] (± 46%)	0.12[2] (± 74%)
28	789	0.12 (± 15%)	0.10 (± 12%)	0.13 (± 43%)	0.21[2] (± 63%)	
32	455	0.29 (± 30%)	0.24 (± 28%)	0.38 (± 26%)	0.39 (± 17.7%)	
34	930	0.13 (± 17%)	0.12 (± 22%)	0.14 (± 22%)	---- 0.13 (± 43%) ----	
39	731	0.19 (± 20%)	0.18 (± 25%)	0.20 (± 21%)	0.16 (± 62%)	0.18 (± 28%)

NOTES:

1) Air change rates calculated using basement volumes.

2) Additional CAT samplers placed in basement.

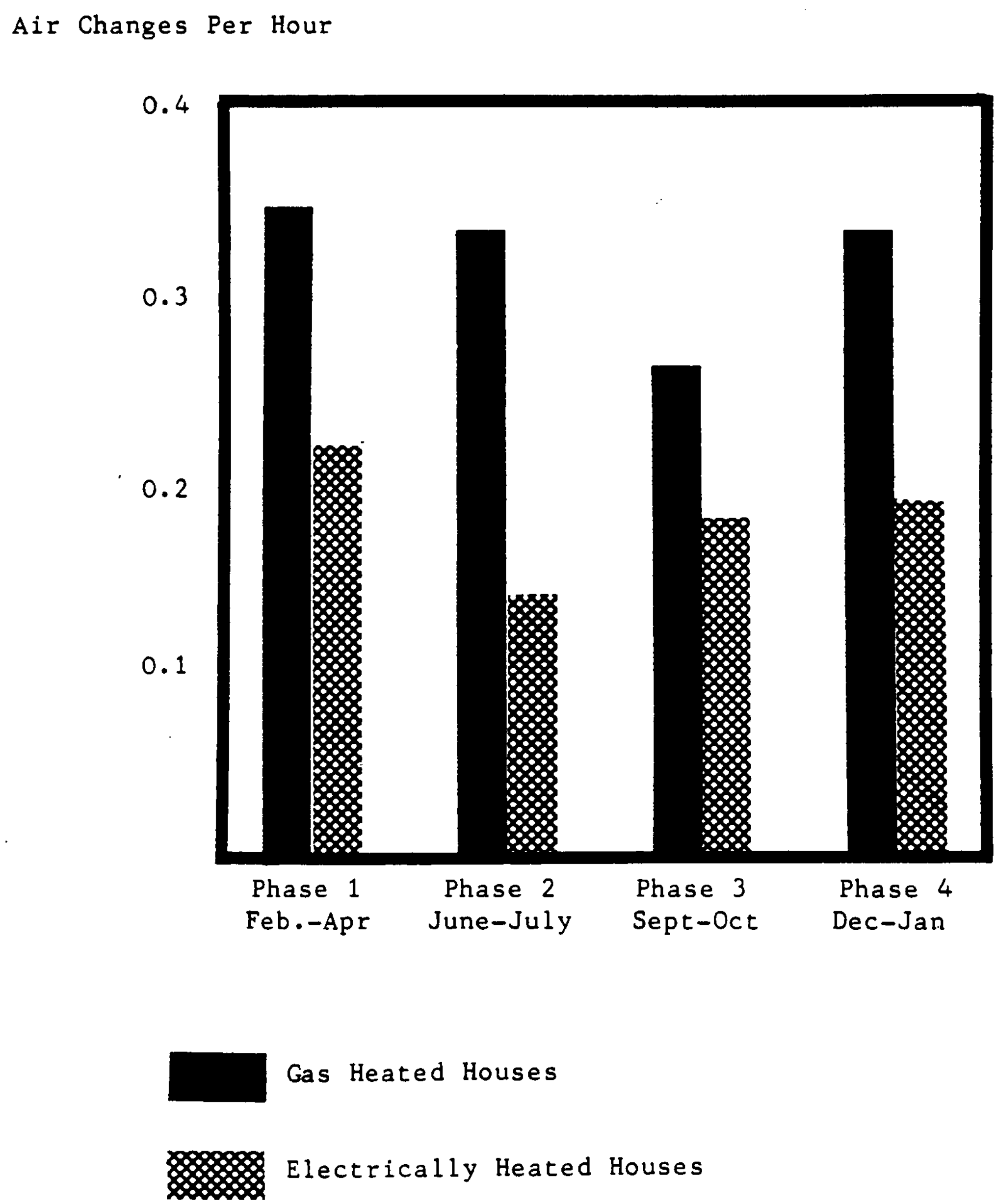
3) Additional CAT sampler and PMCH source placed in basement.

WEATHER CONDITIONS

	PERIOD				
	Feb. 15-28	Feb.28-Mar.15	Mar.15-30	Apr.15-29	Apr.29-May17
Degree Days	272	255	317	194	163
Mean Temperature (°C)	-2.9	1.1	-3.2	4.2	9.4
Mean Wind (KPH)	11.4	16.3	18.3	15.2	13.6

Figure 8.1

COMPARISON OF SEASONAL AIR CHANGE RESULTS



9.0 AIR QUALITY MEASUREMENTS

The Apple Hill Project allowed an opportunity to monitor several potentially dangerous pollutants which a typical homeowner may be exposed to in an airtight house. Pollutants, such as carbon monoxide, carbon dioxide and oxides of nitrogen were measured over three distinct seasons. These gases were measured using a Draeger Multi Gas Detector System, which allows for quick on site evaluation of pollutants levels. The system proved to be a quick and cost effective tool for assessing pollutant levels. A summary of the results of air quality testing is presented in Table 9.1.

Both CO and NO were well below recommended dangerous levels. The geometric mean of carbon dioxide levels in the three test periods range from approximately 500 to 600 ppm. This substance is largely produced by the human metabolism an indicates, in most cases, the presence of a number of people in the immediate vicinity. High CO2 levels are indicative of poor ventilation or circulation in a home and thus suggests that possible improvements in the air circulation of the homes could be made. These levels of carbon dioxide are significantly below the levels recommended by ASHRAE, however, they border on levels commonly found to cause complaints of poor air quality in office buildings(MOL,1983).

Radon and Radon Daughter levels were independently monitored by the Radiation Protection Bureau of the Federal Department of Health and Welfare using both grab sampling and time average techniques. The Apple Hill subdivision, located in March Township has been characterized by high radon levels. These homes represented an excellent opportunity to assess the degree of the radon concentration associated with tighter homes in the area, as well as, supply a substantial test data base for the Bureau. This data base was used to cross-check the montoring equipment. The results revealed stratification of the radon throughout the house. Basement levels were generally higher than those of the upper floors. It is suggested that these higher levels are attributed to radon being carried by soil gas and ground water which generally migrate through foundation and basement slab. The Apple Hill testing showed annual geometric means of radon gas levels in the basement of the houses to be in the order of 2.5pCi/L. Testing also showed the annual WL data for the homes to have a geometric mean of the order of 0.01 WL. This would imply that over 50% of the homes could be classified in th investigative level as defined by the AECB (1977). Furthermore, 15% of the homes exceed the annual average primary criterion of 0.02 WL. These high levels suggest remedial action, on th Apple Hill houses, and consideration of the hazard for future housing and in particular, energy efficient housing located in the proximity of known naturally occurring uraniferous materials.

In a similiar manner to pollutants and radon build-up in tighter homes, due to insufficient fresh air, the build up of moisture in the air is also a serious concern. Unlike other pollutants high relative humidity is much more visible in the home. Significant moisture accumulation on windows, peeling paint, and mold deposits were frequently observed in many Apple Hill homes. These problems were most prevalent during early fall and winter. Many houses had Relative Humidity levels well above recommended levels. A summary of the moisture levels recorded in Apple Hill homes is presented in Table 9.2. It has been suggested that moisture stored within the house structure is released during the fall and winter as outside relative humidities drop with the cooler temperatures. One other major source suggested is the basement slab. It is recommended that in a similiar manner to pollutants, the sources and levels of this moisture be further evaluated such that proper remedial action can be implemented.

The monitoring and evaluation of air quality in tighter homes is a fundamental concern before proper cost-effective remedial action can be implemented. The results of such monitoring could represent not only guidelines for regulatory committees but also an important source of information to enhance the knowledge of the occupants in airtight houses. Furthermore, this information will allow them to more fully understand their own environment and give them more control over the remedial action available to them. It is recommended that standard indoor air quality test procedures be developed so that all tests undertaken in the residential environment will be done on the same basis.

SUMMARY OF APPLE HILL AIR QUALITY RESULTS

PHASE 2

HOUSE NO	CO (PPM)	CO2 (PPM)	NO2 (PPB)	RADON DAUGHTERS BSMT	RADON DAUGHTERS UPSTRS
1	0.50	500.00	12.50	14.90	0.50
2	0.50	700.00	12.50	3.50	0.30
3	0.50	500.00	12.50	15.90	0.50
4	1.00	900.00	12.50	27.40	5.60
5	0.50	800.00	12.50	5.00	0.50
6		800.00	12.50	10.40	0.80
7	0.50	900.00	20.00	2.10	0.50
8					
MEAN	0.50	728.57	13.57		1.24
10	0.50	600.00	15.00		4.90
11	0.50	400.00	12.50	11.60	1.20
12	0.60	600.00	12.50	17.10	7.00
13	0.70	400.00	12.50	13.90	0.40
14	0.50	900.00	12.50	13.90	0.40
E15	0.50	800.00	12.50	25.50	7.30
16	1.00	500.00	0.50	12.90	0.70
E17	0.50	400.00	12.50	15.00	1.20
18	0.60	1000.00	12.50	1.70	1.30
MEAN	0.63	628.57	11.14		2.27
20	0.50	900.00	12.50	20.00	9.70
21	0.70	400.00	12.50	0.70	0.20
22	3.00	600.00	12.50	3.40	1.60
E23	0.70	1000.00	12.50	7.70	6.90
24	0.50	600.00	12.50	20.50	1.70
25	0.50	400.00	12.50	10.90	4.10
MEAN	1.04	644.94	12.31		3.44
27	0.70	500.00	12.50	2.90	0.50
28	0.50	400.00	12.50	12.20	5.10
29	1.00	400.00	12.50	6.00	2.70
30	0.50	600.00	12.50	10.30	1.00
MEAN	0.60	475.00	12.50		2.53
E31	0.50	400.00		12.10	1.00
32	0.90	1000.00	12.50	0.90	0.50
MEAN	0.90	1000.00	12.50		0.50
34	0.50	1000.00	12.50	11.00	0.30
35	0.50	500.00	12.50	1.00	0.50
MEAN	0.50	750.00	12.50		0.40
37	0.00	1000.00	12.50	30.00	1.00
39	0.50	300.00	12.50	14.40	1.90
50					
51					
ELECTRIC	0.55	650.00	9.30		4.10
GAS	0.70	691.14	12.44		1.66

PHASE 3

HOUSE NO	CO (PPM)	CO2 (PPM)	NO2 (PPB)	RADON DAUGHTERS BSMT	RADON DAUGHTERS UPSTRS
1	0.50	500.00	12.50	25.50	1.30
2	0.50	600.00	12.50	17.90	2.40
3	0.50	400.00	12.50	12.30	1.40
4	0.50	600.00	12.50	4.50	2.30
5	0.50	800.00	12.50	3.50	1.10
6	0.50	600.00	12.00	17.00	2.70
7	0.50	400.00	12.50	3.30	1.70
8	0.50	400.00	12.50	71.40	12.10
MEAN	0.50	537.50	12.44		3.13
10	0.00	800.00	12.50	49.20	46.40
11	0.50	400.00	12.50	16.50	4.40
12	0.50	400.00	12.50	12.50	10.20
13	0.50	600.00	12.50	14.10	1.50
14	0.50	600.00	12.50	49.00	6.40
E15	0.50	400.00	12.50	1.70	1.60
16					
E17	0.50	400.00	12.50	20.20	2.70
18	0.50	600.00	12.50	9.30	8.00
MEAN	0.47	485.71	10.71		10.99
20				16.00	3.40
21	1.00	600.00	12.50	3.00	0.60
22	0.50	600.00	12.50	6.30	2.20
E23	0.50	400.00	12.50	5.30	7.90
24	0.50	600.00	12.50	25.50	2.20
25	0.50	600.00	12.50	12.40	2.20
MEAN	0.63	600.00	12.50		1.00
27	0.00	400.00	12.50	3.50	1.40
28	1.00	400.00	12.50	13.30	3.20
29	0.50	800.00	12.50	10.40	3.70
30	0.50	600.00	12.50	10.10	1.00
MEAN	0.70	550.00	12.50		2.53
E31	1.00	400.00		1.40	0.30
32	0.50	400.00	12.50	10.00	2.00
MEAN	0.50	400.00	12.50		2.00
34	0.50	600.00	12.50	24.00	4.00
35	0.50	400.00	12.50	5.90	4.70
MEAN	0.50	500.00	12.50		4.75
37	0.50	600.00	12.50	27.40	7.10
39	0.50	200.00	12.50	12.30	0.90
50	2.00	1000.00	25.00	5.60	3.90
51	1.00	600.00	12.50		
ELECTRIC	0.63	400.00	9.30		3.13
GAS	0.54	484.15	12.27		4.25

PHASE 4

HOUSE NO	CO (PPM)	CO2 (PPM)	NO2 (PPB)	RADON DAUGHTERS BSMT	RADON DAUGHTERS UPSTRS
1	0.00	600.00	12.50	10.00	7.30
2	0.50	400.00	12.50	6.30	4.00
3	0.50	600.00	12.50	15.10	9.00
4	0.50	600.00	12.50	5.70	2.30
5	0.50	400.00	17.50	7.50	4.20
6	0.50	400.00	25.00	4.60	2.20
7	0.70	500.00	12.50	4.60	3.90
8	0.50	600.00	42.50	10.00	7.30
MEAN	0.56	512.50	10.44		5.13
10	0.50	600.00	12.50	43.20	33.00
11	0.50	600.00	42.50	7.50	1.70
12	0.70	400.00	12.50	6.60	3.40
13	0.50	400.00	12.50	7.60	2.10
14	0.60	500.00	12.50	20.00	15.10
E15	0.50	500.00		10.00	7.40
16	0.50	400.00	12.50	4.10	1.00
E17	0.70	400.00	12.50	12.30	7.90
18	1.00	600.00	12.50	10.70	2.30
MEAN	0.61	500.00	16.79		8.49
20	0.50	500.00	12.50	20.20	12.00
21	0.00	600.00	12.50	10.70	5.50
22	0.90	400.00	12.50	0.20	2.00
E23	0.70	400.00	12.50	4.40	3.50
24	0.50	500.00	12.50	26.50	14.90
25	0.50	500.00	12.50	3.20	2.40
MEAN	0.64	500.00	12.50		7.52
27	0.90	400.00	12.50	6.20	5.70
28	0.50	400.00	12.50	1.00	1.40
29	2.00	400.00	30.00	12.10	3.00
30	0.50	400.00	12.50	5.00	2.50
MEAN	0.90	400.00	10.00		3.35
E31	1.00	400.00	12.50	3.10	5.90
32	1.00	500.00	2.50	5.30	4.40
MEAN	1.00	500.00	2.50		4.40
34	0.50	500.00	12.50	12.30	7.60
35	0.60	600.00	12.50	2.20	1.60
MEAN	0.55	550.00	12.50		4.60
37	0.50	700.00	12.50	15.50	11.00
39	0.50	500.00	20.00	13.20	4.90
50	3.50	800.00	50.00	20.10	23.90
51	0.50	500.00	12.50	2.90	0.40
ELECTRIC	0.73	425.00	9.30		6.10
GAS	0.67	520.31	14.26		6.17

APPLE HILL RELATIVE HUMIDITY AND TEMPERATURE SUMMARY

HOUSE NO	PHASE 1 RH(IN) %	PHASE 1 RH(OUT) %	PHASE 1 T(IN) C	PHASE 1 T(OUT) C	PHASE 2 RH(IN) %	PHASE 2 RH(OUT) %	PHASE 2 T(IN) C	PHASE 2 T(OUT) C	PHASE 3 RH(IN) %	PHASE 3 RH(OUT) %	PHASE 3 T(IN) C	PHASE 3 T(OUT) C	PHASE 4 RH(IN) %	PHASE 4 RH(OUT) %	PHASE 4 T(IN) C	PHASE 4 T(OUT) C
1	46.00	84.00	20.90	3.30	62.00	41.00	23.00	24.00	60.00	78.00	24.00	20.00	42.00	93.00	18.50	3.20
2	41.00	64.00	20.40	5.00	66.00	53.00	24.00	22.00	70.00	45.00	24.90	25.00	27.00	44.00	22.00	-14.00
3	38.00	36.00	20.90	6.00	57.00		23.30	19.00	55.00	59.00	21.00	14.00	36.00	40.00	20.50	-16.00
4	42.00	81.00	20.10	5.00	69.00	70.00	23.50	20.00	70.00	59.00	20.00	16.00	40.00	40.00	20.00	-11.00
5		61.00		0.60	50.00	63.00	19.00	14.00	65.00	93.00	20.00	7.00	35.00	85.00	16.40	-13.00
6	34.00	36.00	19.00	6.00	59.00	59.00	23.90	18.00	60.00	59.00	22.00	17.00	30.00	67.00	18.00	-10.00
7	45.00	36.00	15.90	4.60	57.00	50.00	21.00	20.50	56.00	67.00	18.40	12.00	32.00	62.00	17.00	-9.00
8									70.00	82.00	21.00	16.00	41.00	93.00	20.30	4.00
MEAN	41.00	56.84	19.53	4.36	61.14	57.33	22.53	19.64	63.25	70.25	21.41	15.00	35.38	65.75	19.09	-0.23
10					64.00		20.00	20.00	62.00	55.00	22.00	16.00	35.00	46.00	22.90	-15.00
11	46.00	76.00	17.90	0.50	62.00	30.00	22.20	24.00	50.00	50.00	20.40	2.00	60.00	69.00	18.00	2.00
12	44.00	56.00	20.60	2.60	64.00	45.00	23.00	17.10	60.00	81.00	18.00	7.50	35.00	66.00	19.00	-14.00
13	43.00	56.00	22.40	5.30	74.00	70.00	23.00	22.40	67.00	66.00	21.30	11.00	55.00	93.00	20.00	0.00
14	40.00	36.00	19.10	-0.60	61.00	60.00	22.70	20.00	65.00	82.00	21.00	10.00	34.00	65.00	18.90	-19.00
E15	30.00	60.00	21.50	-4.00	65.00	59.00	20.50	30.00	60.00	94.00	20.00	10.90	42.00	55.00	19.00	-17.00
16	30.00	61.00	20.00	0.30	64.00	52.00	21.00	19.00	70.00	71.00	18.00	11.00	33.00	70.00	17.40	-19.00
E17	60.00	84.00	18.60	6.30	57.00	30.00	21.00	24.60					46.00	60.00	17.00	6.00
18	32.00	52.00	20.00	10.00	66.00	59.00	27.70	29.60	60.00	80.00	20.00	11.00	42.00	80.00	19.50	1.00
MEAN	34.71	48.14	17.26	3.55	65.00	48.57	22.91	23.04	62.00	70.43	20.18	9.93	42.00	69.86	19.39	-8.33
20	43.00	60.00	22.60	2.60	60.00	76.00	20.00	14.00					33.00	75.00	18.20	1.00
21	46.00	55.00	19.90	2.60	60.00	36.00	20.50	20.50	50.00	64.00	19.00	11.00	53.00	86.00	19.00	1.00
22	46.00	45.00	18.50	2.60	60.00	60.00	21.00	21.40	70.00	100.00	19.00	13.00	29.00	50.00	17.20	-10.00
E23	40.00	65.00	23.00	7.40	70.00	64.00	21.00	18.00	63.00	56.00	18.10	3.00	45.00	55.00	14.00	-21.00
24	49.00	60.00	20.90	2.70	69.00	61.00	25.00	24.20	72.00	100.00	19.00	11.00	44.00	93.00	17.50	-1.00
25					75.00	59.00	18.70	18.00	75.00	60.00	20.00	19.00	52.00	66.00	17.00	-14.00
MEAN	44.00	55.00	20.40	3.50	68.00	57.00	21.53	19.35	68.75	81.50	19.25	11.40	42.20	74.00	17.94	-8.00
27	57.00	65.00	20.60	7.40	73.00	83.00	23.00	20.00	56.00	57.00	14.90	6.70	36.00	42.00	17.00	-15.00
28						64.00	19.00	17.90	70.00	80.00	20.00	14.00	37.00	51.00	18.50	-14.00
29	17.00	40.00	21.00	7.00	61.00	60.00	20.20	19.00	60.00	82.00	18.00	16.00	20.00	53.00	18.60	-22.00
30					72.00	65.00	24.00	22.70	71.00	94.00	18.00	18.50	33.00	65.00	17.60	-17.20
MEAN	37.00	56.50	21.20	7.60	68.67	60.00	21.55	19.90	64.25	80.25	18.23	11.00	33.50	52.75	17.93	-17.05
E31	51.00	56.00	19.00	7.00	60.00	29.00	21.40	23.00	50.00	49.00	19.00	6.00	51.00	86.00	20.00	-6.00
32	41.00	73.00	19.30	2.60	72.00	73.00	23.00	23.30	60.00	56.00	22.00	19.00	54.00	100.00	20.90	7.00
MEAN	41.00	73.00	19.30	ERROR	72.00	73.00	23.00	23.15	60.00	56.00	22.00	12.50	54.00	100.00	20.90	0.50
34		86.00	18.00	-4.60	63.00	63.00	21.00	16.00	70.00	80.00	20.00	15.00	40.00	42.00	17.70	-15.00
35		84.00	15.60	3.30	72.00	64.00	24.20	21.10	75.00	100.00	21.40	11.00	37.00	86.00	19.00	0.70
MEAN		85.00	17.20	-0.65	67.50	63.50	22.60	18.55	72.50	94.00	20.70	13.00	38.50	64.00	18.35	-7.15
37	43.00	56.00	21.50	5.30	64.00	69.00	22.90	22.00	65.00	80.00	22.00	122.00	46.00	86.00	19.50	-17.00
39	20.00	60.00	21.30	-4.00		60.00	17.00	15.70	60.00	82.00	18.00	13.00	44.00	93.00	19.60	-1.00
50					65.00	39.00	29.00	27.00	66.00	100.00	19.00	1.00	66.00	100.00	18.70	1.00
51									63.00	56.00	19.00	12.00	36.00	79.00	16.70	-10.00
ELECTRIC	49.25	60.25	20.73	4.30	63.00	45.50	22.90	24.10	45.25	49.75	14.40	4.90	46.00	64.00	17.50	-9.50
GAS	33.04	62.31	19.72	ERROR	58.29	63.15	21.75	19.91	64.47	77.00	20.21	26.19	41.95	75.67	19.09	-8.30

10.0 Time Constant

The time constant is a factor which relate the rate of heat flow and heat storage to the changing temperature conditions inside and outside of the house. Embodied in this time constant are factors such as conductive heat loss, convective heat loss, and thermal storage. In reality, the structure and composition of a house is made up of almost an infinite number of time constants forming various pathways and mechanisms for energy to flow. The time constant test assumes this complex network can be represented as one lumped circuit with only one or two major time constants. The purpose of this task, as part of the Apple Hill Study, was to develop the time constant theory further including the development of test procedures and analytical techniques.

The time constant test is based on the premise that the thermal transient response of the inside temperature of a house can be expressed by the following equation

$$
\begin{aligned}
Tin(t) &= T1(o)exp(-t/t1* \\
&+ (Q(t)/G1)\ (1-exp(-t/t1* \\
&+ T2(o)exp(-t/t2*)+ \\
&+ Q(t)/G2(1-exp(-t/t2*)+TE
\end{aligned}
$$

where:

Tin(t) = inside temperature

T1(o) = intial difference between the structural temperature and the inside temperature

T2(o) = initial temperature difference between the structure and TE

TE = equivalent outdoor temperature which should be a weighted average of above and below grade temperature

Q(t) = heat input

G1 = thermal conductance related to short time constant

G2 = thermal conductance related to long time constant.

C1 = thermal capacitance related to short time constant

C2 = thermal capacitance related to long time constant

t1* = short time constant

t2* = long time constant

These terms are illustrated grphically in Figure 10.1 which shows an electrical circuit analogy; and Figure 10.2 which presents a temperature vs. time response for a house which is subjected to a constant heat input of Q1 resulting in a heating curve, and then a no heat cycle which results in a cooling curve. Through log-linear regression analysis of the heating and cooling curves, the long time constant (t*2), and the steady state temperature (Tinf) can be calculated. The results of this analysis or cooling curves from fifteen tests are presented in Table 10.1 .

Figure 10.1

ELECTRIC CURCUIT ANALOGY

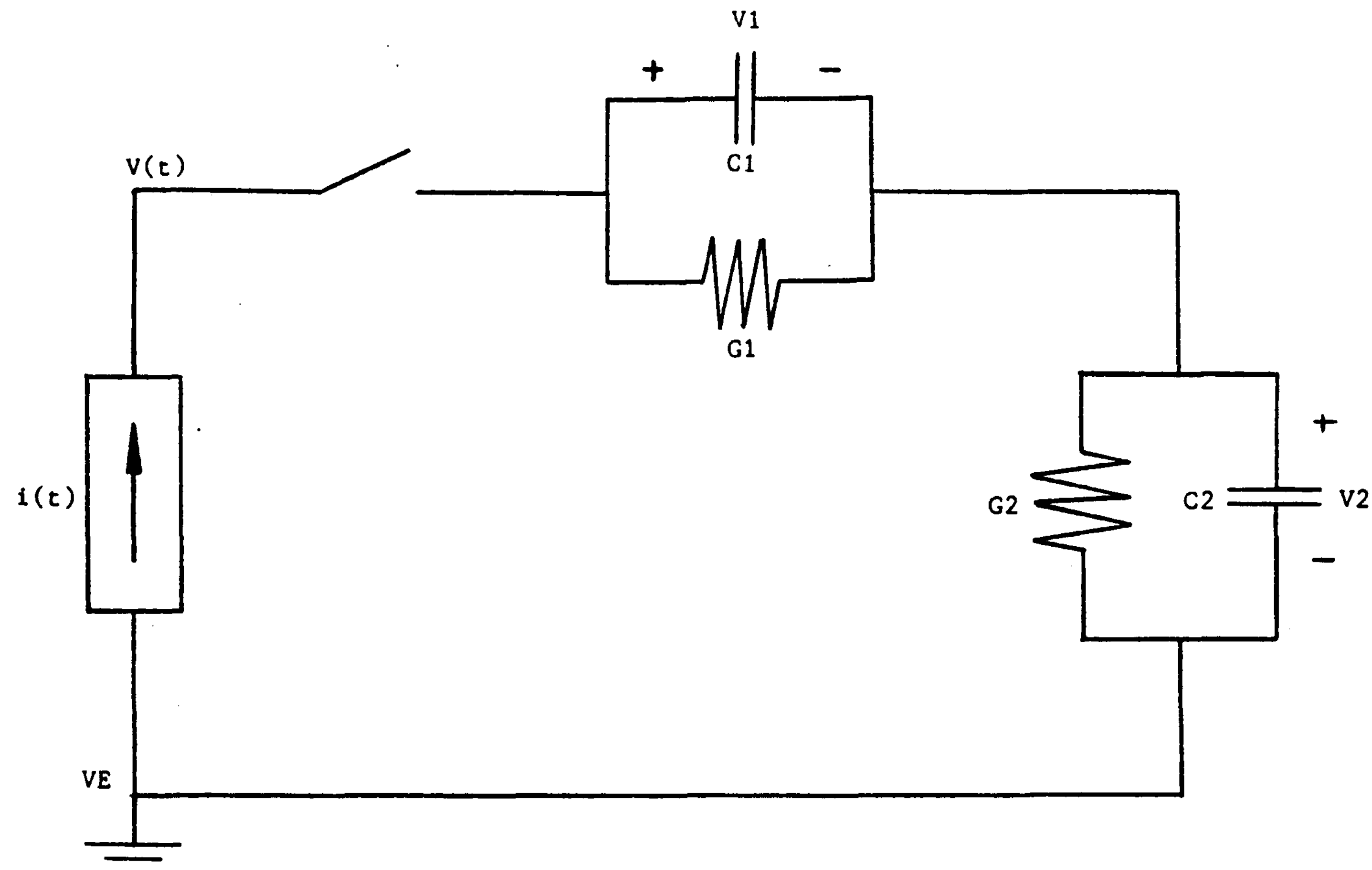
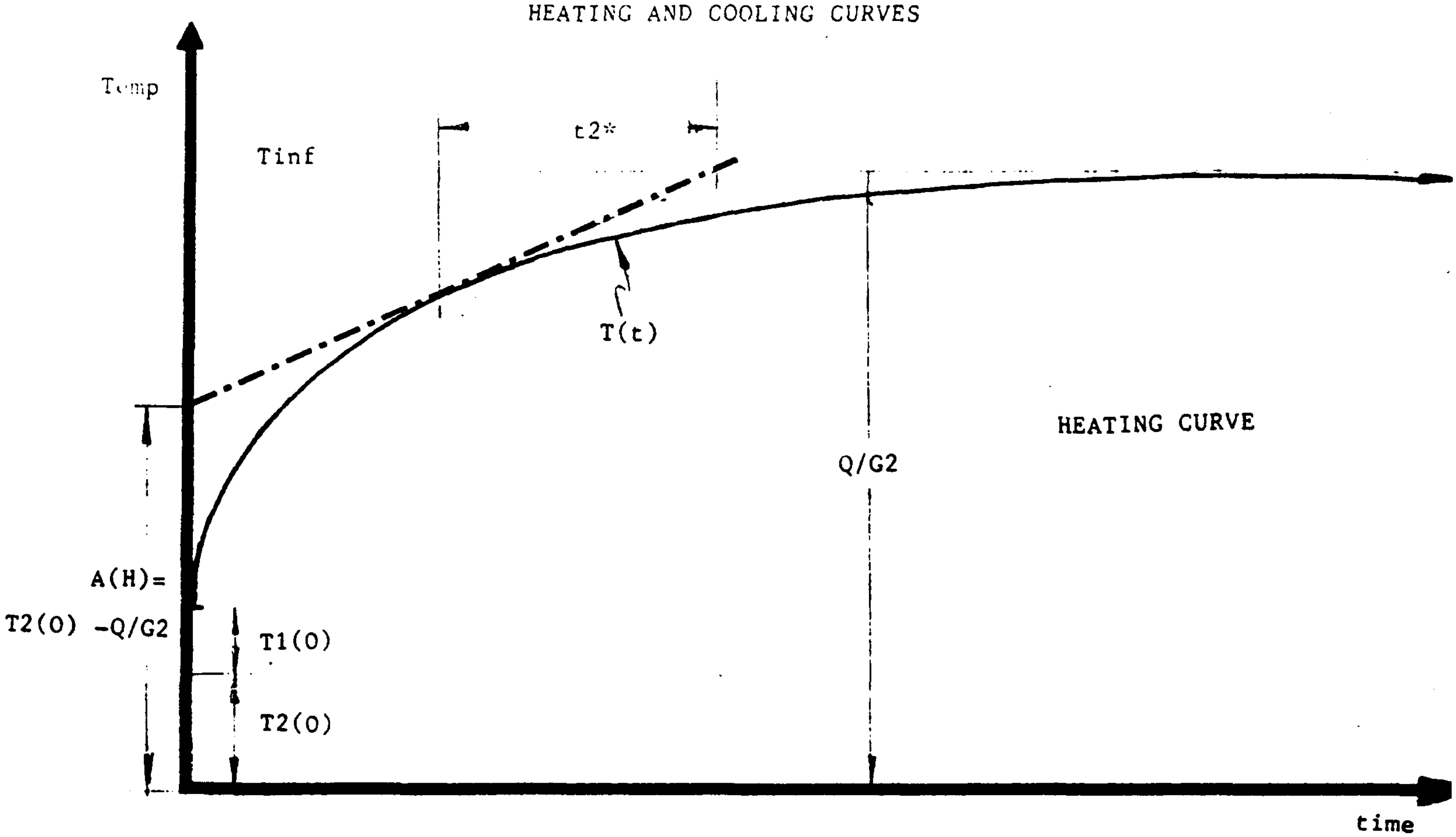


Figure 10.2
TEMPERATURE DISTRIBUTION FOR THE
HEATING AND COOLING CURVES



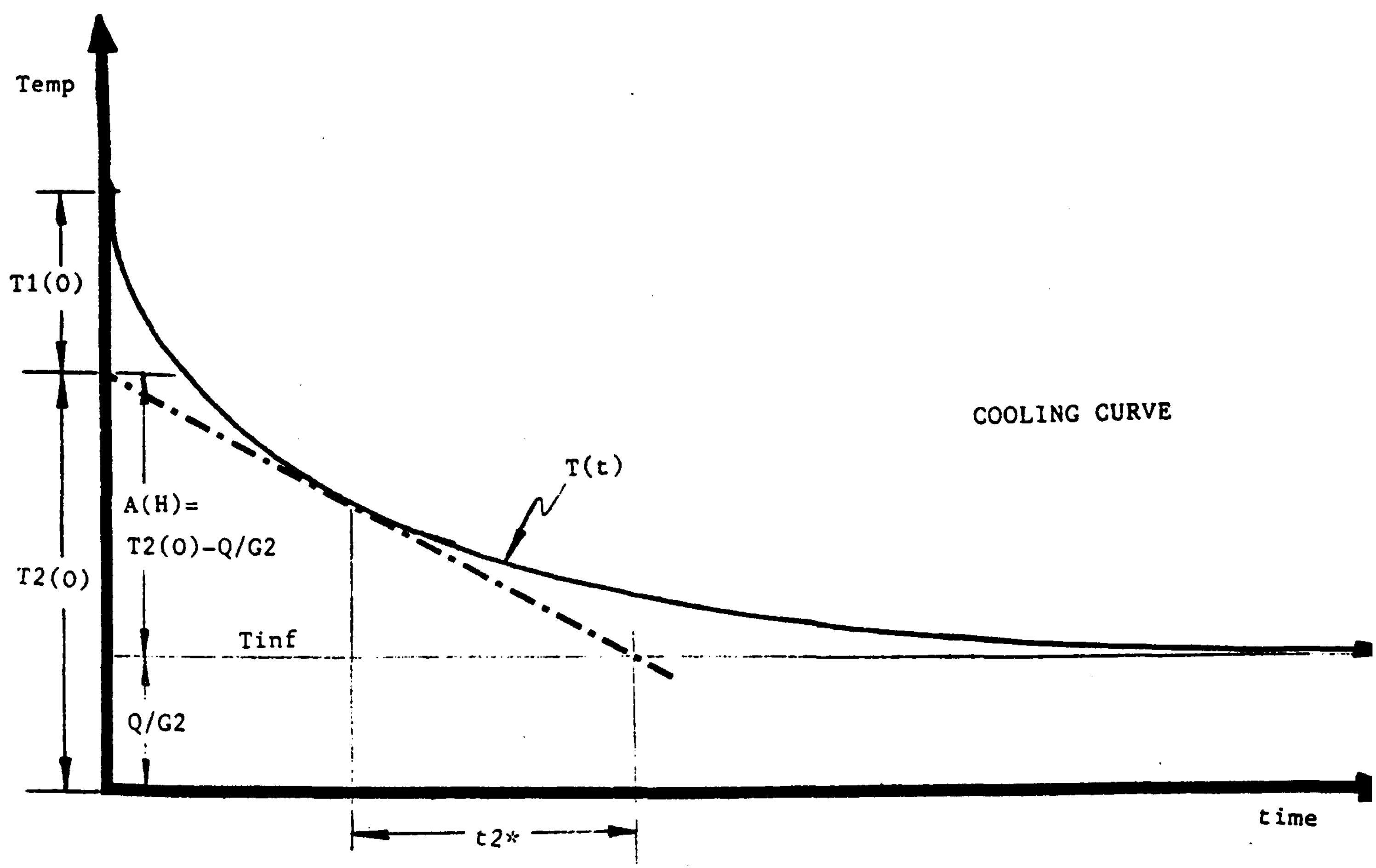


TABLE 10.1
SUMMARY OF TIME CONSTANT TEST RESULTS

HOUSE NO.	MODEL	DATE	TEST NO.	TIME CONST. (MIN.)	TINF COOLING (C)	TIME CONST. (MIN.)	TINF HEATING (C)	TEMP. AMBIENT (C)
19	RUSSET		5	368	19.3			10.3
			6	1138	13.7			12.8
			7	447	22.6			12.8
			13	348	19.6			8.3
			14	1966	-2.1			5.3
			15	1282	9.2			6.7
23	CORTLAND		2	801	13.2			4.0
25	CORTLAND		10					2.0
			12	537	12.8			4.0
29	WILLOW		3	717	14.1	185	32.7	3.0
31	YORK		8	867	14.6			12.8
			9	447	22.6			12.8
			11					
35	FIRESIDE		4	1451	0.8	378	34.6	
39	BALDWIN		1	692	13.7	505	34.3	-1.3

11.0 NEUTRAL PRESSURE PLANE DETERMINATION

The measurement of leakage area in the house envelope can be quantitatively expressed through an air tightness test. Smoke pencil and thermographic tests are useful in isolating specific leakage sites. The neutral pressure plane (N.P.P.) test is used to determine which parts of the house are experiencing infiltration and which parts are exposed to exfiltration. At the neutral pressure plane there is no inside-outside pressure differential, and no air movement through the envelope. Above the neutral pressure plane, exfiltration occurs; and below, infiltration. The location of this plane is highly dependent on outside conditions.

The neutral pressure plane is determined by measuring the pressure differentials across the house envelope at various points. The windows at basement, first, and second floor levels were found to be ideal locations to measure these differentials. neutral pressure plane tests were performed during all four phases of tests. Initial review of the results revealed a difficulty in finding a common neutral pressure plane between similar houses, or the same house over four phases. This considerable variation is primarily due to wind effects on the house. Varying wind speeds and directions make comparitive analysis almost impossible. A summary of the test results is presented in Table 11.1.

In an attempt to extract some quantitative information from the results, tests performed in low or windless days were compared.

These results reflect low neutral pressure planes in the proximity of the first floor level. This substantiates the findings of smoke pencil and thermographic tests which identified major leakage sites along the basement sill area and furnace rooms.

The results of these low wind or windless day tests were also compared with predicted stack effect pressures. The equations predict the overall stack induced pressure across the envelope for a given height. The results obtained from the field tests appear to fit the predicted curve fairly well, substantiating the test technique. However this comparison is only possible on windless days.

Neutral pressure plane testing is a useful method of graphically revealing pressure differentials across building envelopes. Large scale application of this technique would be limited to relatively calm days if any useful information is to be extracted. The sensitivity of the pressures to wind effects and the variability of wind about a building envelope makes the tests very restrictive and unwarranted for large scale testing. There appears to be some usefulness in measuring the change in pressure diffenentials resulting from the operation of combustion appliances or exhaust fans. This is especially of interest in situations where backdrafting of combustion appliance may be a potential problem. The results of testing in Apple Hill show this type of testing to be feasible within the sensitivities and accuracies required.

Table 11.1

SUMMARY OF NEUTRAL PRESSURE PLANE TEST RESULTS

			PHASE 1				PHASE 2				PHASE 3				PHASE 4			
HOUSE NO.	GAS OR ELECTRIC	FIRE-PLACE	T(I)-T(O) DEG. CEL.	WND SPD KPH	N.P.P. (METERS) FRONT	BACK	T(I)-T(O) DEG CEL	WND SPD KPH	N.P.P. (METERS) FRONT	BACK	T(I)-T(O) DEG CEL	WND SPD KPH	N.P.P. (METERS) FRONT	BACK	T(I)-T(O) DEG CEL	WND SPD KPH	N.P.P. (METERS) FRONT	BACK
1	GAS	NO	14.00	17.00	1.00	3.00	2.00	7.00			-3.00	21.00	2.00		16.00	10.00	1.20	2.20
2	GAS	YES									2.00	12.00	1.30	0.10	33.00	16.00		1.60
3	GAS	YES	16.70	17.00			3.00	13.00			6.00	11.00	-2.20	3.50	30.00	26.00	0.40	2.20
4	GAS	YES					4.00	8.00			3.00	9.00	1.00	0.20	32.00	0.00		1.10
5	GAS	YES	19.50	30.00	-0.50	-0.60	5.00	12.00			9.00	0.00	4.70	0.00	29.00	0.00	0.72	1.70
6	GAS	YES	12.00	7.00	-0.90	2.30	-1.00	5.00			3.00	0.00	-1.30	-0.10	26.00	17.00	0.20	
7	GAS	YES	15.50	7.00			1.00	0.00			4.00	20.00	3.20	-1.00	25.00	15.00	2.00	0.10
8	GAS	YES									5.00	10.00	7.00	0.00	16.00	15.00		2.20
10	GAS	NO					2.00	11.00			6.00	10.00		3.10	36.00	13.00	0.00	0.60
11	GAS	NO	15.50	5.00	3.40	2.90	-2.00	22.00			6.00	12.00	-1.50	2.00	10.00	18.00	2.00	1.80
12	GAS	YES	17.50	0.00	0.40	1.70	6.00	22.00			5.00	9.00	4.70	0.00	30.00	10.00	1.00	1.00
13	GAS	NO	14.50	7.00	1.20	1.70	3.00	0.00	-5.00	0.70	5.00	0.00	1.00	0.10	20.00	10.00	-0.30	1.50
14	GAS	YES	12.00	10.00	0.40	2.70	0.00	10.30	-1.50	-4.00	10.00	25.00		3.70	36.00	11.00	0.90	1.90
15	ELEC	YES	24.00	17.00	2.40	3.90	4.00	20.00			6.00	11.00	3.10	0.50	35.00	26.00	3.60	1.30
16	GAS	NO	19.00	20.00		3.50	1.00	15.00							34.00	4.00		1.20
17	ELEC	NO	16.50	12.00	1.10	1.30	-3.00	7.00			7.00	19.00	-2.60	-4.00	23.00	7.00	1.00	1.70
18	GAS	NO	17.50	13.00	-0.20	1.50	-7.00	26.00			7.00	0.00	-1.40	2.00	17.00	18.00		1.60
20	GAS	YES	17.50	10.00		1.10	0.00	13.00							16.00	0.00		1.10
21	GAS	YES	17.50	15.00		-0.90	4.00	10.00			4.00	13.00		0.90	19.00	10.00		0.30
22	GAS	YES	17.00	7.00		-0.10					6.00	10.00		-0.40	34.00	15.00		2.70
23	ELEC	NO	12.50	11.00		3.00		25.00			4.00	6.00		-0.20	36.00	30.00		0.40
24	GAS	YES	14.50	7.00		0.10	-1.00	30.00			7.00	0.00		-0.50	10.00	20.00		0.90
25	GAS	NO					-1.00	9.00			0.00	0.00		0.70	29.00	15.00		0.30
27	GAS	YES	12.50	13.00	2.00	5.00	3.00	10.00			10.00	35.00	0.00	-2.00	31.00	30.00	1.40	
28	GAS	YES					2.00	12.00		0.72	4.00	20.00	1.90	1.40	27.00	6.00		0.80
29	GAS	YES	15.00	15.00	1.30		2.00	11.00	-0.70	0.00	5.00	15.00	-0.30	7.00	35.00	11.00	0.40	2.10
30	GAS	YES					-2.00	15.00			6.00	13.00	2.70	1.20	35.00	20.00		
31	ELEC	YES	16.50	5.00	1.70	2.60	-2.00	0.00			-1.00	7.00		-0.45	24.00	19.00	2.70	
32	GAS	YES	17.50	19.00			2.00	10.00	-0.00	4.90	1.00	20.00	3.00	7.00	30.00	17.00		4.20
34	GAS	YES					1.00	10.00			5.00	16.00	6.00	0.00	31.00	20.00	5.90	1.40
35	GAS	YES	29.00	20.00	-0.10	-1.00					9.00	0.00	0.05	2.45	10.00	5.00	1.50	2.10
37	ELEC	NO	17.00	7.00	1.30	1.10	0.00	15.00	-0.30	-5.00	9.00	17.00	1.00		20.00	15.00	2.00	1.30
39	GAS	YES	24.00	15.00	1.60	4.00	3.00	10.00	1.70	1.00	3.00	7.00		-1.40	17.00	0.00	1.80	1.10
50	ELEC	YES									10.00		7.40		30.50	0.00		
51	GAS	YES									5.00	5.40	2.90		26.00	26.00		
52	ELEC	WD STV									12.00		1.60	1.30	33.00	12.00		

12.0 Energy Monitoring

The purpose of the energy monitoring in the Apple Hill Homes was to:

- Record total energy consumption, as well as energy used for space heating, domestic hot water and appliance usage on a monthly basis.

- Monitor furnace operation in order to determine average operating time and duty cycle.

- Correlate space heating requirements and furnace operation with parameters such as degree days.

- Compare actual energy consumption to that predicted by heat loss models.

Utility billing meters were used to measure total gas and electricity usage. In homes heated by natural gas, additional gas meters were installed to record energy consumed for domestic hot water heating. These additional meters were installed by Ottawa Gas. In electrically heated homes, two additional watthour meters were installed to monitor the energy consumption on the furnace and the hot water tank,

On all houses time totalizers and impulse counters were connected in parallel with the furnace thermostat. The time totalizer logged the number of hours the furnace operated during the month, while the impulse counter recorded the number of times the furnace came on. These meters were read on the last day of each month. Utility meters outside the house were read by a technician. Inside meters were read at the same time if access to the house was possible. Otherwise, the homeowner was contacted by phone and asked to read the meter for us.

Most of the metering was installed on occupied houses during February, March and April of 1982. Additional meters were installed as test houses became occupied throughout the year. A comparison of the total average annual energy use for each house model type in the subdivision is presented graphically in Figure 12.1. A summary of annual energy use for each house is shown in Table 12.1. Annual energy use ranges from 93 GJ to 159 GJ in the gas heated house, compared to an average of 72.3 GJ in the electrically heated houses.

The space heating, or furnace energy use, for each model follows monthly degree-day variations. Furnace use does not go to zero in the summer due to operation of the pilot light, and sporadic operation on cool days.

Energy used for hot water is slightly higher, in the winter, for electrically heated houses; and much higher, in the winter, for gas heated houses. This is probably due to the effect of the cold furnace rooms, and higher standby losses of the hot water tank.

Appliance use is generally steady throughout the year. Slight peaks occur in midwinter, due to increase use of lights; and another peak in mid-summer, due to the use of air conditioners. Linear regression analysis was used to correlate total energy use with monthly degree days. This analysis produced an energy requirement factor in terms of gigajoules per degree day. (GJ/DD) The energy use expressed in gigajoules represents the equivalent heating value of the fuel consumed.

A summary of these values for each model are presented here:

MODEL	Total Energy Use GJ/DD	Furnace Energy Use GJ/DD
REGENT	0.0266	0.0241
RUSSET	0.0213	0.0211
CORTLAND	0.0217	0.024
WILLOW	0.0320	
YORK	0.0210	
FIRESIDE	0.0333	
WESTFIELD	0.0204	
BALDWIN	0.0350	
ALL-ELECTRICS	0.0161	0.0130

The heating requirements for gas heated houses ranges from 0.0204 to 0.0350 GJ/DD; while the electrically heated houses required

almost half, at 0.016 GJ/DD.
The difference in energy use is probably due to additional heat losses created by the furnace rooms in gas heated houses. The total energy use factor can be used as a rough estimate of the heat loss factor of a house.

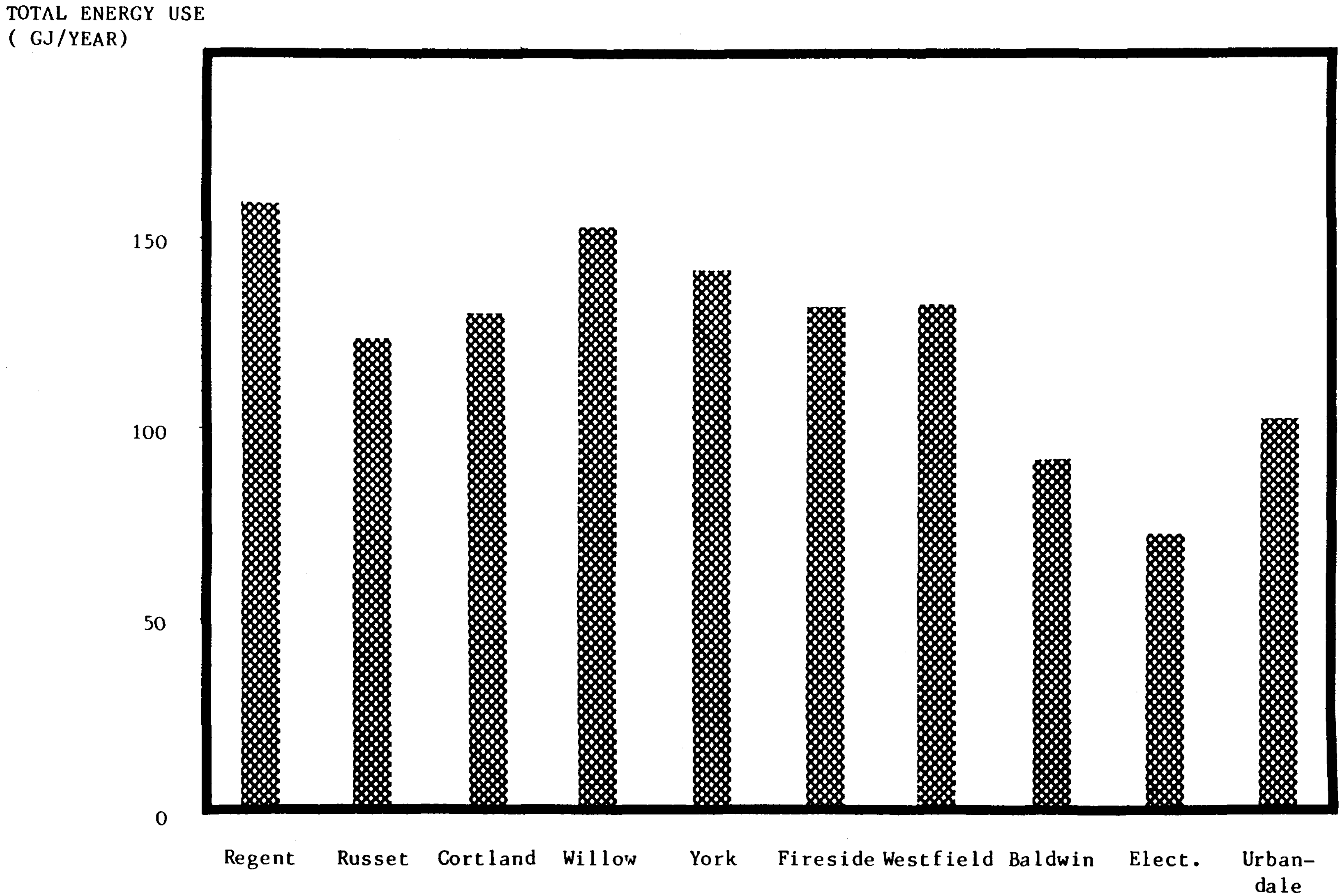
Based on analysis of data obtained from the furnace counters and timers, for the period of September 1982 to February 1983, the actual fuel consumption of the larger furnaces in the subdivision (rated at 120,000 BTU/h or 0.127 GJ/hour) ranged from 0.113 to 0.160 GJ/hour. The smaller furnaces, which are rated at 0.084 GJ/h, have actual consumption in the range of 0.080 to 0.0.83.
The average run time of the furnaces during this period ranges from 1.7 to 2.4 minutes per run.

TABLE 12.1
APPLE HILL STUDY
ENERGY SUMMARY TABLE

HOUSE NUM.	PRIMARY FUEL	TOTAL ENERGY GJ	TOTAL		
			FURNACE	HOT WATER	APPLIANCES
REGENT					
1	GAS	159.06	72.07	52.11	34.88
2	GAS	180.84	91.99	47.49	41.35
3	GAS	151.55	98.23	35.13	18.21
4	GAS	155.98			
5	GAS	160.88	77.12	34.60	48.86
6	GAS	160.36	76.59	45.60	38.09
7	GAS	152.53	79.03	34.10	39.15
RUSSET					
10	GAS	119.38			
11	GAS	107.82	67.49	24.73	15.63
13	GAS	137.08	89.37	31.88	15.86
14	GAS	120.65	73.76	28.79	18.10
15	ELEC	96.81			
16	GAS	103.85			
17	ELEC	62.70			
18	GAS	143.42			
CORTLAND					
20	GAS	128.40	73.85	32.83	21.72
21	GAS	153.36	74.60	35.25	43.51
22	GAS	139.10	81.46	22.57	35.07
23	ELEC	58.71			
24	GAS	110.78	63.08	28.08	19.61
25	GAS	112.26			
WILLOW					
27	GAS	142.41	86.93	35.55	19.93
28	GAS	136.72			
29	GAS	159.01			
YORK					
31	ELEC	74.30	43.04	11.94	19.32
32	GAS	143.13	83.87	33.98	24.05
FIRESIDE					
34	GAS	132.74	92.21	24.28	16.27
WESTFIELD					
37	GAS	133.13	67.84	36.95	28.18
BALDWIN					
39	GAS	93.34			

Figure 12.1

COMPARISON OF TOTAL ANNUAL ENERGY USAGE BY HOUSE MODEL



13.0 COST DOCUMENTATION

The purpose of this task was to develop standard costs for each of the test procedures used in this study.

In order to determine standard costs for each test conducted in this study, the tests were broken down into the following cost components:

A. Manpower
B. Materials
C. Equipment
D. Analysis
E. Travel
F. Overhead
G. Contingency

The manpower component of the test cost is the actual on-site labour charge for a technician or team of technicians. This is further broken down into set-up, calibration, testing, repacking and reporting time. For the purpose of this analysis, an hourly rate of $12.50 has been assumed. This does not include any overhead charge.

The second component is materials. These are the consumable materials such as duct tape, tracer gas, smoke pencils, vacutainer tubes, and film, which can only be used once.

Equipment charges are based on recovering the capital cost of the equipment within a reasonable amount of time. For the purpose of this analysis, it is assumed to be recovered over 200 tests.

The analysis component is the amount of work which is subcontracted to other scientific authorities. This is primarily the case in the analysis of SF6 for tracer gas measurements.

Travel consists of both manhours and mileage charge required to get to the test site. For the purpose of this analysis 0.7 hours of time and 64 km round trip was assumed.

The charge for overhead is included to cover items such as administration, rent, insurance, telephones, utilities, promotion etc. For the purpose of this analysis it was assumed to be equal to manpower charges.

A contingency of 25% has been built into the cost of each test. This has been included to reflect the possibility of retests required, when poor results are obtained due to bad weather conditions or analysis problems.

A summary of the costs to conduct each of the tests, on a one time only basis, is presented in Table 13.1. The amounts shown for energy monitoring are based on a one year monitoring period for a gas and an electrically heated home. The spot tests range in cost from $100.00 to $400.00 per test, while it costs about $1000.00 to monitor a house for one year. When each of the spot tests can be repeated on several houses in the same subdivision on the same day some economies come into play. These economies result is cost savings of 15 to 30% per test. This is also shown in Table 13.1 as the Multi-Test cost.

During the one year period of field testing, air tightness. air quality, air change and neutral pressure plane tests were conducted on each house at quarterly intervals. Approximately 16 hours¢ is required for one person to complete these four tests and analysis on one house in one day¢. The times for each test are based on the assumption that equipment and procedures are familiar to the technician, but that each house is new to the technican. These on-site times were estimated from the time requirements for each test.

In Apple Hill testing, two technicians worked together. This would increase the total time per house to about 20 person hours. However, travel hours for two people have to be taken into account. It did result in reduced on-site time per house, as shown in Figure 13.1. This also resulted in greater homeowner acceptance of tests.

In the first phase of testing, there were frequent equipment problems, and familiarization delays. Prohibitively high winds on site caused aborted tests, and necessitated numerous retests due to invalid results. Such problems contributed up to an additional 40% to the time required for testing.

Using these estimates, a two person team testing 36 houses would require 125 person days for completion. In contrast, the entire Phase 4 testing series for the four above mentioned tests on 36 houses took only 60 person days. This reduction can be attributed to increased efficiency in test methods, and familiarization with the houses and procedures.

Table 13.2 shows a comparison of costs of completing the testing involve in the Apple Hill study using the test schedule presented in Figure 13.1 with the costs that would have been incurred if the tests were conducted on a one shot basis. The apparent savings are about 25%.

TABLE 13.1
SUMMARY OF TESTING COSTS

	AIR TIGHTNESS	THERMO GRAPHY	AIR CHANGE	AIR QUALITY	N.P.P.	TIME CONSTANT	ENERGY GAS	MONITORING ELECTRIC
MANPOWER	33.33	46.25	40.83	18.33	47.92	53.13	150.00	150.00
MATERIALS	1.50	18.61	11.32	16.00	0.00	11.82	0.00	0.00
EQUIPMENT	37.50	200.00	0.00	1.50	12.16	23.50	138.00	295.33
ANALYSIS	0.00	0.00	45.00	0.00	0.00	45.00	0.00	0.00
TRAVEL	21.55	21.55	21.55	21.55	21.55	43.10	258.60	258.60
OVERHEAD	42.08	55.00	49.58	27.08	56.67	70.63	117.50	117.50
CONTINGENCY	33.99	85.35	42.07	21.12	34.57	61.79	166.03	205.36
SINGLE	169.95	426.76	210.35	105.58	172.87	308.97	830.13	1026.79
MULTIPLE	144.70	378.91	164.45	75.28	147.62	308.97	830.13	1026.79
SAVINGS (%)	14.86	11.21	21.82	28.70	14.61	0.00	0.00	0.00

NOTES:
1. HOURLY WAGE RATE=$12.50

FIGURE 13.1
TYPICAL PHASE 4 TESTING

```
-----------------------------------------------------------------------------------------------------
:                           0       .5        1      1.5        2      2.5        3      3.5        4
: TIME                      :        :        :        :        :        :        :        :        :
-----------------------------------------------------------------------------------------------------
: TEST                      :    I--AIR CHANGE/AIR QUALITY--I--N.P.P.--I-AIR TIGHTNESS-I            :
: ----                      :                                                                       :
:                           :                                                                       :
: TECHNICIAN 1              :                                                                       :
: ------------              :                                                                       :
: A. GENERAL SET-UP         :I---I                                                                  :
:                           :                                                                       :
: B. AIR CHANGE             :                                                                       :
:    SF6 INJECTION          :    I-I                                                                :
:    SAMPLING               :           I-------------------I                                       :
:    REPACKING              :                               I--I                                    :
:                           :                                                                       :
: C.  N.P.P.                :                                                                       :
:    SET-UP                 :           I-------------------I                                       :
:    TESTING                :                               I----------I                            :
:                           :                                                                       :
: D. AIR TIGHTNESS          :                                                                       :
:    SET-UP                 :           I-------------------I          I----I                       :
:    TESTING                :                                               I----------I            :
:                           :                                                                       :
: E. GENERAL REPACK         :                                                          I------I     :
:                           :                                                                       :
:                           :                                                                       :
: TECHNICIAN 2              :                                                                       :
: ------------              :                                                                       :
:                           :                                                                       :
: A. GENERAL                :                                                                       :
:    SET-UP                 :I----------I                                                           :
:    TEMP READINGS          :           I----I                                                      :
:                           :                                                                       :
: B. AIR QUALITY            :                                                                       :
:    SAMPLING               :                I------------I                                         :
:                           :                                                                       :
: C.  N.P.P.                :                                                                       :
:    HEIGHT & TEMP          :                             I------------I                            :
:                           :                                                                       :
: D. AIR TIGHTNESS          :                                                                       :
:    SET-UP                 :                                          I----I                       :
:    TESTING                :                                               I----------I            :
:                           :                                                                       :
: E. GENERAL REPACK         :                                                          I------I     :
-----------------------------------------------------------------------------------------------------
```

TABLE 13. 2
ESTIMATE OF TESTING COSTS - FULL STUDY
COST DOCUMENTATION

MANPOWER	MANHOURS	RATE	$/TEST
TOTAL LABOUR	1920.00	12.50	24000.00
MATERIALS			
AIR TIGHTNESS $1.50X 144 TESTS			216.00
AIR CHANGE $11.32 X 144 TESTS			1630.08
AIR QUALITY $16.00 X 144 TESTS			2304.00
TOTAL MAT'L			4150.08
EQUIPMENT			
AIR TIGHTNESS $37.50 X 144 TESTS			6400.00
AIR QUALITY $1.50 X 144 TESTS			216.00
N.P.P. $12.16 X 144 TESTS			1751.04
TOTAL EQUIP.			8367.04
ANALYSIS			
AIR CHANGE $45.00 X 144 TESTS			6480.00
TOTAL DIRECT EXPENSES			42997.12
TRAVEL: 120 DAYS @ $12.80/DAY			1536.00
OVERHEAD			24000.00
SUB-TOTAL			68533.12
CONTINGENCY (25%)			17133.28
TOTAL			85666.40
THERMOGRAPHY $211.76 X 22 TESTS			4658.72
TIME CONSTANT $273.65 X 7 TESTS			1915.55
ENERGY MONITORING: $737 X 31 HOUSES			22847.00
$1026.79 X 5 HOUSES			5133.95
			120221.62

14.0 CMHC-2 ANALYIS

CMHC-2 is a computer program developed by Canada Mortgage and Housing Corporation to perform heat loss analyses on new housing design, as well as to rank various alternative design features in order of thermal performance and cost effectiveness. The CMHC-2 program has been used here to compare the actual energy performance of the Apple Hill houses with the performance predicted by the CMHC-2 model. The program is also used to compare the predicted thermal performance of a Saskatchewan built energy efficient home placed in Apple Hill.

The CMHC-2 program can be discussed in two parts. Part 1 presents the heat loss associated with the various elements of the full envelope area of the house including the basement. Additional parameters include the natural air change rate, and any controlled ventilation. In addition, heating system and passive solar design considerations are also presented.
Part 2 of the program presents a detailed heat balance for the house. The "Net Heat Load" represents the required auxillary space heating load for each month, based on average monthly weather data. By taking into account an efficiency factor of the furnace, actual consumption values can be compared.Steady-state efficiencies were found to be 68-79% for Apple Hill furnaces. A seasonal efficiency of 62% was applied to all gas furnaces.

Additional output provided by the program is:

- a summary of component heat balances for the year,
- a thermal energy analysis, energy required by the house,
- a cost benefit analysis for the furnace and hot water tank,

A special note concerning energy required by the house is that auxiliary space heating load is the only value predicted by the program. The energy required by the hot water tank and electrical appliances are entered by the program user.

Most of the physical parameters describing the different models were obtained directly from the detailed floor plans. The only estimated values are the R-values of the doors and windows, which are based on the program guidelines. Gross, above sill, wall areas include all doors and windows (including bsmt. windows). Window areas include all framing.

Nominal infiltration rates are based on actual grab samples generated from Apple Hill data. The actual input represents a seasonal average from the four phases of the project. Electrical and hot water consumption are based on the average values obtained from energy monitoring.

Table 14.1 compares the total annual energy required for space heating as predicted by CMHC-2, and as actually measured in Apple Hill. Also shown, is a comparison between the CMHC-2 suggested heating system capacity, and the actual installed furnace capacity.

The CMHC-2 program uses an Ottawa mean (normal) weather data base, which reflects a colder heating season and less sunshine hours than actually experienced in 82/83 heating season. As a result, the CMHC-2 model predicts greater than expected auxiliary space heating requirements.

The results discussed are restricted primarily to the heating season, space heating load. In reference to the non- heating season (May to Sept.), CMHC-2 predicts a zero space heating in constrast to the 1 to 7 GJ range actually observed. This is primarily due to pilot lights, occasional cold weather, and other quirks of nature that often contribute to some of the off season consumption. These are difficult if not impossible to model and do not justify serious analysis.

As outlined earlier in the report, air change rates are a user defined variable, and represent between 20% to 40% of the gross heat loss associated with the house. Because of the sensitivity of the model to air change rates, a re-evaluation of air change input was prompted. It is suggested that future modelling might emphasize heating season air change rates, as opposed to the seasonal air change rate. This is because summer air change rates which tend to be lower than the heating season, reduce the seasonal average. As a result, the model predicts less than expected auxiliary space heating requirements.

The analysis of the Saskatchewan Energy Efficient showcase house placed in Apple Hill shows a much lower required space heating load than Apple Hill homes. Although this may be due to higher R-values in the house, the most significant factor is the very small air change rate associated with the home (0.05ACPH). This is in contrast to the 0.20 to 0.45 ACPH range associated with the Apple Hill houses which accounts between 20% to 40% of the space heating load.

The CMHC-2 computer program calculates an approximate heat loss factor based on the insulating properties of the building materials and components of the house. This factor is expressed in terms of Watts/C. An indicative measure of the actual heat loss on each house was made by correlating total monthly fuel, and electricity consumption, with monthly degree days. The resulting slope of a linear regression analysis provides a measure of the energy use per degree day in terms of equivalent heating value of the consumed. Dividing by 24 hours and converting from gigajoules to watts provides the energy use in Watts/C. These values were computed for houses where a complete heating season of data (September to April) was available and compared with the CMHC-2 heat loss factors in Table 14.2. For gas heated houses, the CMHC-2 heat loss factors are 69.5% less than energy use factors on average. Furnace efficiencies were measured in March 1982. These are also shown in Table 14.2. The average furnace efficiency measured at that time was 72.8%
For electrically heated houses, where the efficiency of the heating system is assumed to be 100%, the actual energy use, or heat loss factor, was the same as the CMHC-2 factor for House 17. There was only a difference of 6% in House 15. In House No. 23,

the actual energy use factor was 45% less than the predicted. This is because a heat pump was installed in this house in the early fall.

In general, the CMHC-2 program has been reasonably good in predicting heat loss factors as shown here. Parameters which have not been included in this analysis, which could affect these results are:

- monthly variations in air change rates
- additional heat gains from occupants and solar radiation
- net contribution to heating from hot water heaters and electrical appliances
- degree days based on actual thermostat setting

Table 14.1

Furnace Size and
Seasonal Consumption Summary

House No.	Heated Volume m^3	CMHC-2 Sugg. Heating Cap. Watts	Actual Heating Cap. Watts	ACPH Seasonal	Seasonal Consumption CMHC-2 Gj*	Actual Gj
1	730	9786	35150	0.22	67.1	72.1
2		12339		0.43	89.7	92.0
3		11367		0.35	98.2	98.3
4		9907		0.23	77.4	N.A.
5		11731		0.38	80.8	77.1
6		12461		0.44	97.9	76.6
7		12461		0.44	97.6	79.0
8		9907		0.23	72.7	N.A.
10	626	10467	35150	0.35	76.9	N.A.
11		9166		0.28	73.4	67.5
12		9365		0.30	73.2	70.3
13		9424		0.25	73.1	89.4
14		9035		0.24	67.1	73.8
15		8767		0.24	63.2	N.A.
16		10063		0.34	89.7	N.A.
17		7671		0.13	57.6	N.A.
18		10114		0.25	67.6	N.A.
20	660	9008	24000	0.27	77.1	73.9
21		8679		0.24	56.5	74.6
22		9227		0.29	69.8	81.5
23		6744		0.11	34.2	19.2
24		7582		0.19	57.1	63.1
25		7742		0.19	60.5	N.A.
27	790	11196	35150	0.33	93.5	86.9
28		11400		0.32	89.7	N.A.
29		11005		0.29	86.9	N.A.
30		9821		0.20	80.2	N.A.
34	930	15177	35150	0.42	141.0	92.2
35		12234		0.23	96.0	N.A.
37	730	9895	35150	0.31	70.5	67.9
39	635	10186	35150	0.27	83.2	N.A.

* Auxilary Load/0.62 adjustment for furnace efficiency

NOTE: Season refers to monitoring year March 31, 1982 to March 30, 1983.

Table 14.2

Comparison of Heat Loss Factors

HOUSE NO.	HEAT LOSS FACTORS Watts/°C CMHC-2	ACTUAL	RATIO CMHC-2 / ACTUAL	FURNACE EFFICIENCY
1	197	307.9	0.640	71.9
2	244	375.0	0.651	68.9
3	226	262.7	0.860	70.6
4	199	383.1	0.519	76.4
5	233	298.6	0.780	73.5
6	246	357.6	0.688	70.1
7	246	310.2	0.793	69.6
10	209	254.6	0.821	N/A
12	195	259.3	0.752	74.7
13	189	278.9	0.678	74.8
14	185	283.6	0.652	75.2
15E	183	194.4	0.941	N/A
16	205	338.0	0.607	74.0
17E	162	162.0	1.000	N/A
18	209	235.0	0.888	N/A
20	184	245.4	0.750	75.1
21	178	309.0	0.576	74.0
22	188	283.6	0.663	71.4
23E*	146	100.7	1.450	N/A
24	162	218.7	0.741	70.6
25	161	250.0	0.644	N/A
27	226	340.3	0.664	70.3
28	226	349.5	0.647	N/A
29	219	608.8	0.360	N/A
34	298	339.1	0.879	76.0
37	194	262.7	0.738	74.0
MEAN			0.695	72.8

E - ELECTRICALLY HEATED

* - HEAT PUMP INSTALLED IN EARLY FALL

15.0 CONCLUSIONS

Specific conclusions corresponding to each of the tasks in this study are presented in the respective Appendices to this final report. This section presents a summary of these findings, and conclusions under the following general subject areas:

- Design and Construction
- Energy Performance
- Air Quality
- Testing Procedures

15.1 Design and Construction

The basic energy efficienct design of the Apple Hill homes is that of a double wall, wood-frame, platform construction. The wood-frame platform construction is fairly standard in Canadian housing. For conventional housing, this type of design offers many advantages which facilitate construction. However, there are a couple of areas which require careful consideration in the design and construction of energy efficient housing. Specifically, these problem areas result in thermal bridging of the envelope, and unnecessary air leakage due to discontinuities in the air vapour barrier.

Fireplace

One major problem area is the fireplace. In most of the Apple

Hill homes, the fireplace is located on an exterior wall, and forms a part of that wall. This resulted in problems during construction, of trying to seal the air vapour barrier to the masonary construction of the fireplace. Also, a thermal short circuit to the outside is created through the uninsulated materials. The fireplaces's inherent low efficiency, combined with air supply and thermal bridging problems, make them net energy losers in these energy efficient houses.

First Floor Header and Sill Plate

The first floor header and sill plate was also a problem area, both in terms of insulating and air sealing. Although the air vapour barrier and insulation had been applied as specified, this area was found to be very leaky during air tightness tests. Thermography also revealed it to be a high heat loss area and potential location for moisture accumulation.

Furnace Rooms

The furnace rooms in the gas heated houses were also a major source of air leakage. This is due partly to the design and construction of the heating system and furnace room. The heating equipment for these houses is oversized by factors of up to 4 to 1, with respect to the required heating capacity. This results in oversized combustion and ventilation air openings which were required by the Gas Code at that time. This, combined with the problems of completely air sealing the furnace room in order to isolate it from the rest of the house, resulted in excess air leakage into the heated space. The design, construction, and operation of the furnace rooms has resulted in poor heating system efficiencies, comfort problems in terms of cold air infiltration, and operational problems in terms of frozen water pipes and condensation in the flues.

Sub-trades

In most of the observed cases, the air vapour barrier was installed properly by drywallers. The subsequent damage and resulting air leakage was inflicted by other sub-trades; primarily electricians, plumbers, and heating contractors. After installation of the air vapour barrier was complete, the installation of wiring, electrical boxes, panels, pipe fixtures and duct work necessitated various penetrations and lacerations of the polyethelene. Most of this damage was never repaired.

15.2 Energy Performance

Total annual energy use for the gas-heated Apple Hill homes ranged from 93 to 159 GJ, in terms of equivalent heating value of natural gas and electricity used. This compares to 72 GJ for electrical heated houses. Natural gas consumption, for space heating only, ranged 70 and 85 GJ per year, while electrically heated homes averaged 47 GJ, in terms equivalent heating value of electricity.

Energy usage for domestic hot water ranged between 2.5 and 3.5 GJ, for natural gas water heaters, per month; while electrically heated houses averaged 0.98 GJ per month.

The primary reason for the significant difference in the energy use between the gas and electrically heated is centred around the operation of the enclosed furnace rooms. Only the gas heated houses are equipped with enclosed furnace rooms. The furnace room accounts for more than 30% of the air infiltration in gas heated homes, which are 30 to 70% leakier than comparable electrically heated houses. As a result air change rates are 60% higher, increasing the heating load of the house during the winter.

The temperatures measured in the furnace rooms are typically very close to ambient conditions. This results in higher standby heat losses for the conventional water heaters, which are situated there.

5.3 Air Quality

Air change rates as determined by tracer gas and time averaged sampling are at, or below, 0.3 changes per hour. Despite the low air change rates, the measured concentrations of carbon monoxide, carbon dioxide, and nitrous oxides are well below the current recommended levels for these pollutants. The major sources of these pollutants, namely, the furnace and water heater, are isolated in a ventilated, enclosed room. Levels of carbon dioxide were found to be high in a few houses.

Radon and radon daughter concentrations in the Apple Hill houses are greater than expected. In some cases, the levels are high enough to warrant some form of remedial action. The high levels appear to be the result of high radon concentrations in the soil and ground. The radon appears to migrate through the basement slab and walls and is distributed throughout the house. Very little is known to-date about the long term effects of prolonged exposure to these low levels of radiation. This is currently being investigated further, and recommendations will be made in the near future.

Formaldehyde levels were found, in some cases, to be as high as the recommended maxium level set for houses insulated with Urea Formaldehyde Foam Insulation (UFFI), in spite of the fact that UFFI was not used in these houses. The apparent sources of the pollutant appear to be the building materials, and furniture. The low air change rates in these houses compound the problem by not allowing for adequate venting, or removal of this pollutant.

High humidity levels were found to be a problem, especially in electrically heated houses. To some extent, this problem was alleviated by increasing air change rates through mechanical ventilation. However, humidity levels could still present a problem, as the upper floors of many of the houses operate a positive pressure relative to outside. This creates the potential problem of exfiltration/condensation over those portions of the envelope subjected to positive inside pressure. Although the degree of danger or threat to the structural integrity of the houses cannot be determined at this time, it is an area which requires further consideration.

15.4 Test Procedures

Many of the test procedures used were developed especially for this study. In some cases, such as air tightness, and thermography, existing draft standards were used or modified to fit the requirements. In other cases, such as the neutral pressure plane and the time constant, test procedures were developed from theoretical concept.

Airtightness Testing

Airtightness testing was conducted in three configurations: CGSB Standard Third Draft Pressurized Sealed and Depressurized Sealed. Both the depressurized tests provided reliable and reproducible results. The pressurized test was found to be impractical in occupied houses in the winter. The depressurized sealed test provides a useful measure for assessing vapour barrier integrity only, while the CGSB test measures the overall tightness of the envelope. The results were found to be fairly repeatible over the one year period of testing. This suggests that airtightness testing can provide a benchmark for comparison of houses. For the purpose of comparing the relative tightness of houses, a normalized ELA, or air changes at 50 pascals, should be used. For the purpose of comparing houses for ventilation compliance, a more useful measure would be the absolute ELA.

Thermography

The interior thermographic scan conducted under depressurization was found to be an excellent diagnostic technique for identifying air leakage, and thermal bridges. The negative pressure created by the door fan enhanced the visibility of the thermal expressions, reduced the testing time, and made the test procedure less dependent on climatic conditions.

Air Change

Air change rates were determined by using the SF6 tracer gas technique, and the Brookhaven time averaged perflourocarbon tracer (PFT) technique. The SF6 tests provide a spot measurement of air change rates under controlled conditions while the PFT provides an average measure for a period of normal operation. A problem with both techniques is the time required to have samples analysed. This waiting period is in the order of weeks to months. Some means of active monitoring is required in order to make air change testing an even more effective diagnostic tool for ventilation problems.

Air Quality

The most cost-effective technique for detecting dangerous levels of carbon monoxide, carbon dioxide, and nitrous oxides was found to be the Draeger Multi-Gas Detector System.

Time average measurements of Radon, using Terredex Trach-Etch detectors, were found to be a cost effective means of monitoring this pollutant. Some questions still remain in the correlation of Trach-Etch measurements with grab samples; and time averaged measurements taken by Health and Welfare Canada.

Neutral Pressure Plane

The test procedure developed for measuring pressure differentials across the envelope worked well. However, many questions were raised about the validity of the results obtained from a spot measurement. Since there are so many driving factors, such as wind speed, wind direction, temperature difference, and mechanical ventilation, which affect the location of the neutral pressure plane; there was very little consistency in the measurements. Some form of integrated measurement is required to determine the length of time, and the degree to which, portions of the envelope are subjected to negative and positive pressure differentials.

Time Constant

The time constant test requires further development in terms of the background theory, test procedures, and analysis. Additional testing is required in order to determine the repeatibility of the test, and the effects of forces such as wind, solar, and changing temperature conditions.

Energy Monitoring

Energy monitoring, using standard utility meters is an effective low cost means of monitoring, if data is required on a monthly basis. Home owners were cooperative and provided reliable meters readings, after instruction on how to do so. This techinque requires periodic inspection of the meter to verify readings. If energy data is required on a more frequent basis, such as weekly, or daily, a more elaborate remote monitoring system may be justified.