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APPENDIX 8 TO MAIN REPORT

STUDY OF APPLE HILL ENERGY EFFICIENT HOMES

TASK I - COST DOCUMENTATION

Prepared for:

The Policy Development and Research Sector

of

CANADA MORTAGAGE AND HOUSING CORPORATION

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1.0 INTRODUCTION

The study of Apple Hill Energy Efficient Houses required the development and implementation, on a large scale, of many new thermal performance tests. It involved negotiating with homeowners and builders to obtain approval to conduct these tests. Once the approval was obtained, field testing had to be conducted in a manner which would minimize the inconvenience to the homeowner and ensure accurate and workable results.

This required a great deal of planning, managing, coordination and practice before the test procedures were finally optimized. For some tests, such as neutral pressure plane and thermal time constants, a lot of work was required in the initial phases in order to develop a workable test procedure including suitable techniques of analysing data. Some of these problems are dicussed in the test procedure evaluations in the respective appendices.

This appendix, which documents the results of Task I Cost Documentation deals with the actual cost of thermal performance tests for this study. Through analysis of these costs, it may be possible to project future costs of similiar testing, when each test is performed in isolation, or as part of a larger set of tests.

2.0 OBJECTIVES

To develop standard costs for each of the test procedures used in this study.

3.0 METHOD

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 within 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 costs consist 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 retesting, required when poor results are obtained due to bad weather conditions or analysis problems.

Test procedures and schedules were revised and improved over the four test phases. The results presented here show the initial, and final, format of the test procedures and the associated costs.

4.0 FINDINGS

The standard costs for the performance tests conducted at Apple Hill have been prepared in a number of ways in order to make this information useful to the various groups considering both individual testing, and large scale testing programs. The tests are first analysed on the basis of a one time only test. The costs include everything from travel to the site, to reporting the results. The second consideration is conducting each of the tests on a large scale. The third case analyses the effect of conducting multiple tests on one house, and then on a large scale. Incorporated with this analysis are some comments on the "learning curve" aspects which were experienced in the Apple Hill study.

4.1 AIR TIGHTNESS TESTS

The air tightness testing was conducted at the same time as the thermographic scan, building inspection, and householder interview during the first phase of testing. This combination of tests required a three man crew. The total time for an experienced crew ranged from 95 to 125 minutes on-site. Initially these tasks took considerably longer, and ranged in time from 160 to 190 minutes. The crew, consequently managed to test only 2 houses per day at the beginning of Phase 1; whereas at the completion of all testing, they could test up to 4 houses in one long day.

The air tightness testing was the longest single task for the three man crew, because of the necessity to test the building in at least 3 configurations (sealed, unsealed depressurized, and unsealed pressurized). Sealing the house meant a longer set-up time, taping 3 bathroom fans, blocking the fireplace, and plugging the furnace and hot water heater flue, combustion and draft air intakes, clothes dryer vent, and fresh air intake.

Windy days prolong the testing considerably, and manage to destroy at least half the test data by contributing to data correlations below 0.98. Air tightness testing would have taken longer still, if the envelope areas and volumes had not been pre-calculated from the builder's plans. The preparations of a comprehensive air leakage checklist required a thorough inspection of the interior of the building envelope with an air current tester (smoke pencil). The combined use of thermography, however, helped considerably to reduce the time required for such an inspection.

The initial air tightness testing required an additional 15 to 20 minutes over the times listed below due to an unfamiliarity with the location of vents and leaks, and a longer set-up time. The breakdown of time and costs for airtightness testing based on the experience in Apple Hill is presented in Table 4.1. The total cost of testing one house at a time is estimated at $169.96. Conducting airtightness tests on more than one house in one subdivision in one day results in some cost savings. Using the same test procedures

as in Apple Hill, three houses can be tested per day. The major cost saving is in travel. The total cost to test 3 houses per day is $434.10 or $144.70 per house. This represents a 15% cost savings.

TABLE 4.1
AIR TIGHTNESS TESTS
COST DOCUMENTATION

MANPOWER		MINUTES	MANHOURS	RATE	$/TEST
	SET-UP	55			
	CALIBRATION	5			
	TESTING	65			
	REPACKING	10			
	REPORTING	25			
TOTAL LABOUR		160	2.67	12.50	33.33
MATERIALS					
DUCT TAPE					1.50
EQUIPMENT					
DOOR FAN (CAPITAL COST $7500)					37.50
ANALYSIS					
NONE					0
TOTAL DIRECT EXPENSES					72.33
TRAVEL:	MANHOURS	0.70			8.75
	MILEAGE(KM)	32.00			12.80
OVERHEAD					42.08
SUB-TOTAL					135.97
CONTINGENCY (25%)					33.99
TOTAL					169.96

4.2 THERMOGRAPHIC SCANNING

The thermographic scan was completed while the house was depressurized. There was no significant variations in the thermal image as the pressure fluctuated from negative 20 to negative 60 pascals; as a consequence, the air tightness testing could proceed at the same time. The thermograhic testing proved to be much more efficient with two people, rather than one. While the thermographer scanned the building from the inside, room by room, his assistant could record ambient conditions, draw a floor plan, note the locations of thermograms, take visual photographs to accompany each thermogram, corroborate air leakage expressions with smoke pencil tests, and talk to the householder.

The initial thermographic testing required considerably more time to accomplish than estimated. Many unusual thermal expressions had to be investigated. This required burrowing under attic insulation, adjusting isotherms, probing behind the header insulation, checking problem areas with smoke pencils or surface temperature probes. After the first 5 or 6 houses the images began to repeat themselves, and it was possible to concentrate only on the most obvious anomalies thereby saving considerable amounts of time. The thermographer also developed an excellent conception of the building assemblies and construction details. For these reasons, the time required for the 2 man thermography team ranged from a high of 120 minutes, to a more acceptable range of 60 to 90 minutes. The most difficult time requirement to estimate was the

time required to relate with the householder, since many people showed an avid interest in the infra-red images and the air leakage scans. Historical problems and idiosyncracies of the house were described in detail as a way of assisting the thermographer. The breakdown in time and costs is presented in Table 4.2. The total cost to perform one test is $426.76. Again, the major cost savings in testing a number of houses in one day is the travel expense. A total of two houses per day can be tested in a similiar manner to the Apple Hill procedure. The total cost to test two houses is $757.84, or $378.91 per house. This represents a saving of 11%.

TABLE 4.2
THERMOGRAPHY
COST DOCUMENTATION

MANPOWER		MINUTES	MANHOURS	RATE	$/TEST
	SET-UP	10			
	CALIBRATION	2			
	TESTING	80			
	REPACKING	70			
	REPORTING	60			
TOTAL LABOUR		222	3.70	12.50	46.25
MATERIALS					
NITROGEN FOR CAMERA					12.78
FILM & PHOTO PROCESSING					3.83
MAINTENANCE					2.00
EQUIPMENT					
CAMERA RENTAL (CAPITAL COST $40,000)					200.00
ANALYSIS					
NONE					0
TOTAL DIRECT EXPENSES					264.86
TRAVEL:	MANHOURS	0.70			8.75
	MILEAGE(KM)	32.00			12.80
OVERHEAD					55.00
SUB-TOTAL					341.41
CONTINGENCY (25%)					85.35
TOTAL					426.76

4.3 AIR CHANGE

Air change testing, using SF6 tracer gas and vacutainers, was accomplished by one technician, on-site, in a time period of approximately 100 minutes. It was usually possible to conduct at least 2 tests per day, occasionally as many as 4. There is not a lot of activity in this test, consequently, it was possible to accomplish other work simultaneously. Usually, the technicians would measure window locations, and complete recording forms for the neutral pressure plane testing, while waiting for the gas concentrations in the house to decay. The nature of air change testing does not allow the technicians to leave the house between samplings, since this would contribute to air change rates. The breakdown in time, and costs, for this test is presented in Table 4.3. The cost of a one time only test is $210.36.

When multiple houses, or tests, are conducted, up to 4 tests per day can be completed. This reduces the travel component of the total cost. In addition, there is a $2 cost savings in the analysis of each tube, if more than 100 tubes are analysed at one time. The cost of completing four tests per day is $657.78, or $164.45 per test. This is a cost savings of 22% over the individual test.

TABLE 4.3
AIR CHANGE TESTS
COST DOCUMENTATION

MANPOWER		MINUTES	MANHOURS	RATE	$/TEST
	SET-UP	15			
	CALIBRATION	1			
	TESTING	85			
	REPACKING	5			
	REPORTING	90			
TOTAL LABOUR		196	3.27	12.50	40.83
MATERIALS					
SYRINGES					1.09
VACUTAINERS					2.98
SF6					6.10
MISC.					1.15
EQUIPMENT					
NONE					0
ANALYSIS	DESCRIPTION				
SHIPPING					10.00
ANALYSIS					35.00
TOTAL DIRECT EXPENSES					97.15
TRAVEL:	MANHOURS	0.70			8.75
	MILEAGE(KM)	32.00			12.80
OVERHEAD					49.58
SUB-TOTAL					168.29
CONTINGENCY (25%)					42.07
TOTAL					210.36

4.4 AIR QUAILITY

Air Quality testing for CO, CO2 and NOX was completed by one technician using Draegar tubes and hand pumps, in a time period of one and a half hours. The breakdown of time and costs for air quality test is shown in Table 4.4. The cost of a one time only test is estimated here to be $105.58.

The major cost savings in conductinng multiple tests is in the travel expense. Up to 5 houses can be tested per day. The cost to complete these 5 tests in one day is $376.36, or $75.28 per test. This represents a saving of 29%.

TABLE 4.4
AIR QUALITY TEST
COST DOCUMENTATION

MANPOWER		MINUTES	MANHOURS	RATE	$/TEST
	SET-UP	5			
	CALIBRATION	0			
	TESTING	60			
	REPACKING	13			
	REPORTING	10			
TOTAL LABOUR		88	1.47	12.50	18.33
MATERIALS					
DRAEGER TUBES 4 @ $4 EA.					16.00
EQUIPMENT					
DRAEGER PUMPS ($300)					1.50
ANALYSIS					
NONE					0
TOTAL DIRECT EXPENSES					35.83
TRAVEL:	MANHOURS	0.70			8.75
	MILEAGE(KM)	32.00			12.80
OVERHEAD					27.08
SUB-TOTAL					84.47
CONTINGENCY (25%)					21.12
TOTAL					105.58

4.5 NEUTRAL PRESSURE PLANE

Neutral pressure plane testing entailed a considerable amount of activity, and ingenuity, on-site. Each test required a total time for one technician, of approximately 77 to 152 minutes. Initally the testing took as long as 170 minutes, since the equipment was at first very bulky, and difficult to calibrate. The damping mechanisms were finicky, and the procedure was largely untried. After the procedure was ironed out, the tests continued to vary in time for two reasons:

i) Some models did not have windows, or other access points, in the required locations (at least two openings in a verticle line). This reduced the amount of testing;

ii) In other cases the high wind speed, or gusting, would scatter the data, and necessitating a much longer run time to obtain accurate readings on the strip chart recorder. The breakdown of time, and cost, is shown in Table 4.5. The cost of completing one test is $172.87.

Up to 3 tests could be conducted per day. The cost of conducted 3 tests would be 442.88, or 147.62 per test. This represents a cost savings of 15%.

TABLE 4.5
NEUTRAL PRESSURE PLANE TEST
COST DOCUMENTATION

MANPOWER		MINUTES	MANHOURS	RATE	$/TEST
	SET-UP	15			
	CALIBRATION	5			
	TESTING	110			
	REPACKING	10			
	REPORTING	90			
TOTAL LABOUR		230	3.83	12.50	47.92
MATERIALS					
NONE					0
EQUIPMENT					
PRESSURE TRANSDUCER ($1277.92)					
CHART RECORDER ($1090.33)					
MISC. ($27.68)					12.16
ANALYSIS					
NONE					0
TOTAL DIRECT EXPENSES					60.08
TRAVEL:	MANHOURS	0.70			8.75
	MILEAGE(KM)	32.00			12.80
OVERHEAD					56.67
SUB-TOTAL					138.29
CONTINGENCY (25%)					34.57
TOTAL					172.87

4.6 TIME CONSTANTS

Time constant tests require a minimum of twelve hours in the house. This test is conducted overnight to minimize the effects of Solar Radiation on the heating and cooling of the house. Temperature sensors, heaters, fans, controllers, and recording devices are set up in the late afternoon. It is preferred that the house be unoccupied during testing. All instruments are calibrated, meters read, and a standard SF6 tracer gas test conducted, before leaving the house. The heater controls run the house through one five hour continuous heating sequence, and one five hour cooling sequence, during which the temperature is recorded. In the morning, the technician returns to disconnect equipment, and take necessary readings of power consumption. The temperature and energy data is analysed by computer in order to determine the appropriate thermal performance factors. The breakdown of time and cost is shown in Table 4.6.

TABLE 4.6
TIME CONSTANT TEST
COST DOCUMENTATION

MANPOWER		MINUTES	MANHOURS	RATE	$/TEST
	SET-UP	30			
	CALIBRATION	15			
	TESTING	60			
	REPACKING	30			
	REPORTING	120			
TOTAL LABOUR		255	4.25	12.50	53.13
MATERIALS					
AIR CHANGE					11.82
EQUIPMENT					
WEATHER STATION ($2700) CHART RECORDER ($1500) MISC. ($500)					23.50
ANALYSIS					
AIR CHANGE					45.00
TOTAL DIRECT EXPENSES					133.45
TRAVEL:	MANHOURS	1.40			17.50
	MILEAGE(KM)	64.00			25.60
OVERHEAD					70.63
SUB-TOTAL					247.17
CONTINGENCY (25%)					61.79
TOTAL					308.96

4.7 MONITORING

Separate meters were installed in each of the houses to measure:

- space heating energy use
- domestic hot water energy use
- general appliance energy use
- furnace operation

Readings were taken from these meters once a month, on the last day of the month. When possible, the meters were read directly by a technician. If this was not possible, the information was relayed over the phone by the homeowner. Monitoring of each house continued for a period of 18 months. The breakdown of time and costs for this task, on a one year basis, is shown in Table 4.7.

TABLE 4.7
ENERGY MONITORING
COST DOCUMENTATION

MANPOWER (PER MONTH)		MINUTES	MANHOURS *	$/HOUSE GAS	$/HOUSE ELECTRIC
	SET-UP	0			
	CALIBRATION	0			
	TESTING	30			
	REPACKING	30			
	REPORTING	0			
TOTAL LABOUR/HOUSE/MONTH		60	1.00	12.50	12.50
/HOUSE/YEAR				150.00	150.00
MATERIALS					
NONE				0	0
EQUIPMENT					
GAS METERS (ONE/HOUSE)				138.00	295.33
OR					
HYDRO METERS (TWO/HOUSE)					
ANALYSIS					
NONE				0	0
TOTAL DIRECT EXPENSES:				288.00	445.33
TRAVEL:	MANHOURS	0.70(X 12 MO.)		105.00	105.00
	MILEAGE(KM)	32.00(X 12 MO.)		153.60	153.60
OVERHEAD				117.50	117.50
SUB-TOTAL:				664.10	821.43
CONTINGENCY (25%)				166.03	205.36
TOTAL (/HOUSE/YEAR)				830.13	1026.79

* MANHOUR RATE = $12.50

4.8 REPORTS

The following reports were prepared and submitted as part of the reporting requirements of this study.

- Six Progress Reports
- One Interim Report
- One Final Report
- Eight Appendices to the Final Report

Progress reports were submitted after each phase of testing. The interim was submitted in April 1982 to present the findings of the first phase of testing.

At the end of testing, reports were prepared for each major task and included as Appendices to the Final Report. The breakdown of mandays for these reports is as follows.

	Mandays
Progress Reports (6)	30
Interim Report	30
Appendices	80
Final Report	15
Total	155

5.0 LARGE SCALE TESTING

The previous sections discuss the time and expenses for individual tests. 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.

Table 5.1 shows an estimated 16 hours required for one person to perform the four listed 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 previously discussed for each test.

In Apple Hill testing, two technicians worked together. This would increase the total time per house to about 20 person hours, due to increased travel times, and test overlap inefficiencies. It did result in reduced on-site time per house, as shown in Figure 5.1. 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.

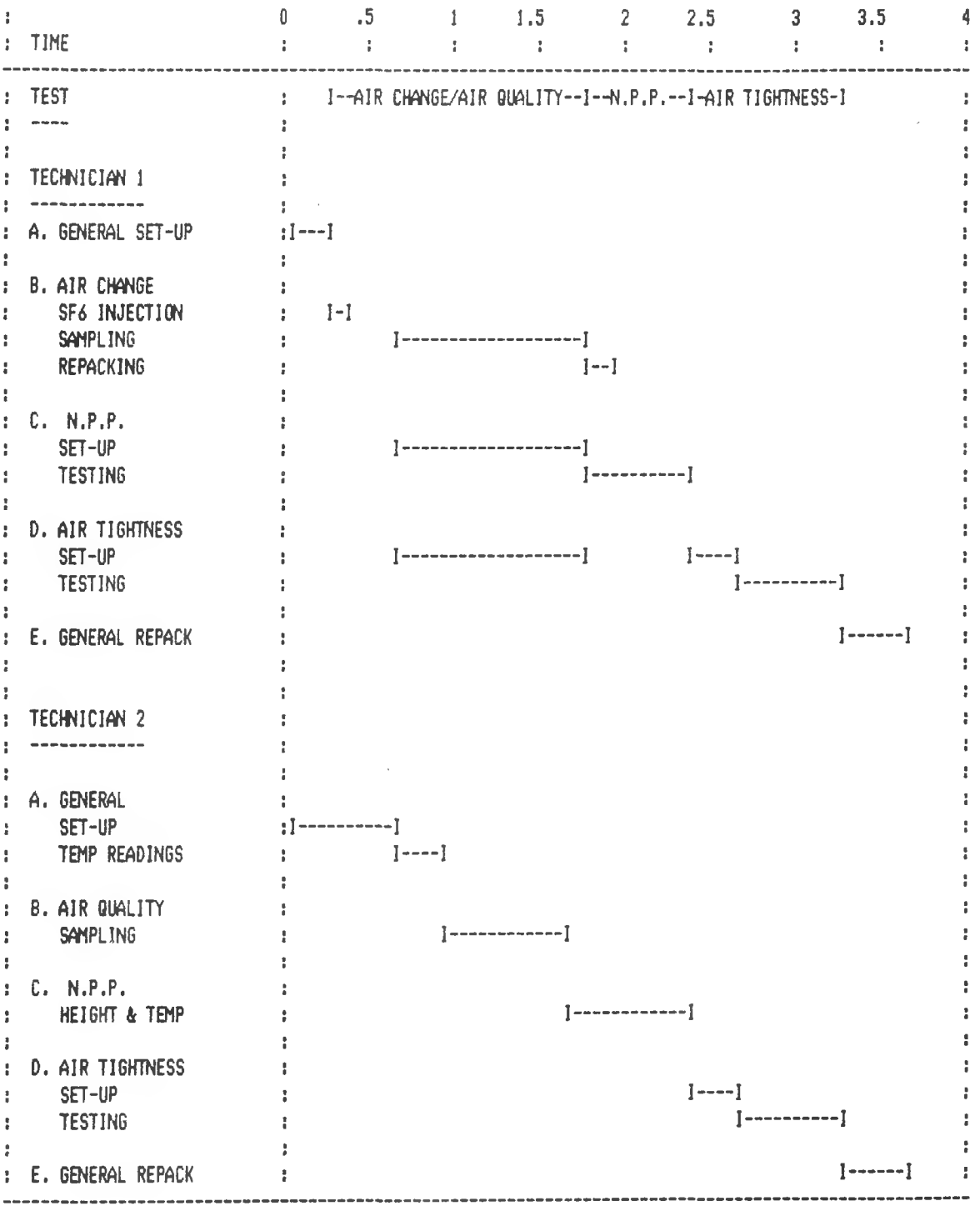
Table 5.1 Approximate Time Requirements

Single Tests

On Site Time for first time of testing

A.T. - for CGSB pres, CGSB Depl., Dep Sealed	= 4.3 hours
A.C. - (1 hour sampling)	= 2.5 hours
N.P.P. (8 window test)	= 2.3 hours
Air Quality (NOX, CO, CO 2 with 2 pumps)	= 1.3 hours
Recording and Analysis (to summary stage)	
A.T. (if volume, envelope area is accurately done)	= 0.4 hours
A.C. (including shipping tubes etc.)	= 1.5 hours
N.P.P. 8 window test	= 1.5 hours
Air Quality	= 0.1 hours
Other'	
Contact with homeowner (scheduling)	= 0.2 hours
Loading equipment @ office per test	= 0.1 hours
Transportation (15 miles to site each way)	= 0.5 hours
Unloading @ office per test	= 1.0 hours
	15.9 hours

TYPICAL PHASE 4 TESTING



6.0 Summary

A comparison of the costs to conduct each of the tests, on a one time only basis, and a multiple house basis, is presented in Table 6.1. The amounts shown for energy monitoring are based on a one year monitoring period for a gas, and an electrically, heated home. The hourly wage rate for a technician to conduct these tests is assumed to be $12.50 per hour. The savings resulting from multiple testing range from 11 to 29%.

Table 6.2 shows the cost of completing the testing using the typical Phase 4 sequencing. The total cost of testing is $103,088.24. This represents a cost savings of 25%, as compared to the cost of conducting all of the tests on a one time basis, which is estimated in Table 6.3 to be $136,504.13.

TABLE 6.1
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

TABLE 6.2
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
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

TABLE 6.3
COST COMPARISONS

TEST	#OF HOUSES	#OF TESTS	$/TEST	TOTAL COST
AIRTIGHTNESS	36.00	4.00	169.95	24472.80
THERMOGRAPHY	36.00	1.00	426.76	15363.36
AIR CHANGE	36.00	4.00	210.35	30290.40
AIR QUALITY	36.00	4.00	105.58	15203.52
N.P.P.	36.00	4.00	172.87	24893.28
TIME CONST.	7.00	1.00	308.97	2162.79
ENERGY MON.				
GAS	31.00	1.00	830.13	25734.03
ELECT.	5.00	1.00	1026.79	5133.95
TOTAL				143254.13