

RESEARCH REPORT



Demonstration of Duct Installation in Houses Previously Without Ducting



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Demonstration of Duct Installation in Houses Previously Without Ducting

R. Clarke Designs Ltd.
3 Sheffield Court
Oromocto, NB E2V 2N1

for
Don Fugler
CMHC Policy and Research Division

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Note: Canada Mortgage and Housing Corporation uses SI (metric) units, or a combination of SI and Imperial units, in all its research reports. This report is an exception. All the calculation sheets used by the contractor in the duct design and sizing used Imperial units. The report text presents the results in Imperial units without conversion to SI units.

EXECUTIVE SUMMARY

Natural gas has recently become available in New Brunswick and other Maritime Provinces, and home owners are slowly beginning to convert from traditional fuels of electricity, oil and wood. Not only are these homeowners considering a change in fuel, but the availability of new technology is prompting them to consider alternate heating distribution system types. This project involved working with a heating contractor in Fredericton, New Brunswick to monitor the installation of new forced air heating systems in three older houses previously without such systems. Air flows were measured, recorded and compared with design air flows and measured air capacity of the blower. A photographic record illustrates obstacles faced by the heating contractor, which can force deviation from original system design.

The objectives of this project were:

- (a) to record those obstacles and challenges faced by heating contractors engaged to install forced air heating systems in houses previously without such systems;
- (b) to evaluate the effect of such obstacles on the ability of the forced air system to deliver design airflows throughout the house;
- (c) to illustrate the importance of detailed duct design in retrofit installation projects.

With the recent introduction of gas to the Province, it was decided to approach a local gas company to identify a heating contractor involved in heating system conversions to be a participant in this project. The participating contractor was contacted in early fall of 2002 to begin selection of suitable houses. The unpredictable nature of the retrofit market lead to difficulties on the selection of houses for the project and on-site work by the contractor was not completed until autumn 2004. A high proportion of quotations prepared by contractors in the retrofit market do not result in contracts. There were also a number of successful contracts on houses not deemed suitable for this project. There were also houses that would have served as good example; however the homeowners decided not to proceed.

“House One” is a bungalow constructed in the early 1990's originally equipped with electric baseboard resistance heaters. “House Two” is a slab-on-grade storey and half house built in the mid-1980's and originally equipped with electric radiant ceiling panels. “House Three” is a bungalow constructed in the early 1970's equipped with electric baseboard resistance heaters.

Detailed heat loss, heat gain calculations were completed using Right-Suite Canada, a software program developed by the Wrightsoft Corporation in cooperation with HRAI. Duct sizing calculation were performed using the manual calculation method presented in the HRAI Residential Air System Design manual. For each case study, the heating/cooling consumption estimated by the contractor for the purpose of initial discussions with the homeowner, was compared with heating/cooling loads determined by detailed calculation. Each case study contains a comparison of duct sizes installed by the contractor to the sizes suggested by the detailed design process. In each case, duct sizes used by the contractor often vary from those resulting from the detailed design. Rather than install ducts of various diameters as determined by detailed design, it is common practice in the industry to use one common branch duct size throughout. This practice depends fully on distribution dampers for control of airflow. The contractor consistently installed fewer and smaller ducts than suggested by the detailed design method.

Air-flow measurements are presented for each case study house. As a rule, air-flows measured using the capture hood were significantly lower than the value recorded using the flow collar insert into the duct. In

some respects this reduction in recorded value can be attributed to configuration of the hood and back pressure the hood places on the system causing the airflows to re-balance. Air leakage into/from ducts are also a contributing factor in this difference. Attempts to seal ducts were not consistent through each test house. Supply air flow measurements collected do not match return air flows. Air flows measured using the saddle style flow collar do not correlate well with air flows measured using the capture hood placed over a grille. Even though the methods of measurement are industry approved and used in R-2000 commissioning, the range of flows observed reduces ones confidence in the indicated results and the methods used for measuring.

The contractor tended to oversize on both heating and cooling equipment. The contractor usually oversized on the supply branch ducts, selecting a single diameter rather than varying sizes as per design; however trunk duct sizes were usually undersized on both supply and return. The return system was consistently undersized with fewer return branches, and smaller grilles installed than were suggested in the detailed design.

The contractor has not provided costing data, but has indicated no specific costing factor was used, each project was estimated based on issues presented. Houses One and Three were judged to be very straightforward; however, House Three has resulted in a higher than usual rate of callback. House Two was estimated to be more difficult primarily due to the challenges presented by the slab on grade construction and limited access to ceiling spaces and lack of conditioned space to accommodate new equipment.

Although training programs exist (through HRAI) and recently NRCan has offered cash incentives to encourage contractors to take these courses, there is little incentive for contractors to follow through with use of the detailed duct sizing design methods. There is also a lack of consumer awareness of the benefits of detailed heat loss/heat gain and design calculations that could be performed by their heating contractor. Further, there is a lack of awareness by the consumer that the contractor is not using such detailed support calculations.

RÉSUMÉ

Le réseau de gaz naturel dessert depuis peu le Nouveau-Brunswick et les autres provinces maritimes, si bien que les propriétaires d'habitations commencent lentement à se tourner vers cette ressource énergétique au détriment de l'électricité, du mazout et du bois. Non seulement les propriétaires envisagent-ils de remplacer leur source d'énergie, mais la disponibilité de la nouvelle technologie les incite à adopter d'autres types de systèmes de distribution de la chaleur. Pour les besoins de la présente recherche, il fallait travailler en collaboration avec un entrepreneur en chauffage de Fredericton, au Nouveau-Brunswick, pour surveiller l'installation d'un nouveau système de chauffage à air pulsé dans trois anciennes maisons qui en étaient dépourvus. Après coup, les débits d'air ont été mesurés, consignés et comparés aux débits d'air de calcul et à la capacité du souffleur. Des photographies montrent les obstacles auxquels était confronté l'entrepreneur, qui pourraient le contraindre à dévier du plan d'origine.

La recherche poursuivait les objectifs suivants :

- a) consigner les obstacles et défis auxquels sont confrontés les entrepreneurs de chauffage dont les services ont été retenus pour installer des systèmes de chauffage à air pulsé dans les maisons qui en étaient dépourvues;
- b) évaluer l'effet de ces obstacles sur la capacité du système à air pulsé à distribuer les débits d'air de calcul dans toute la maison;
- c) illustrer l'importance de la conception approfondie du réseau de conduits lors des travaux de rattrapage.

Vu que la province est depuis peu desservie par le réseau de gaz naturel, il a été décidé de communiquer avec une compagnie de gaz locale en vue de trouver un entrepreneur s'occupant du remplacement de systèmes de chauffage intéressé à participer à la recherche. L'entrepreneur participant a été rejoint au début de l'automne 2002 pour commencer la sélection de maisons convenables. La nature imprévisible du marché du rattrapage a rendu difficile la sélection de maisons aux fins de la recherche, de sorte que l'entrepreneur n'a pas pu terminer les travaux sur place avant l'automne 2004. Une proportion élevée des offres présentées par les entrepreneurs du marché du rattrapage n'aboutissent pas à des contrats. Des contrats ont effectivement été passés à l'égard de maisons qui n'ont toutefois pas été jugées convenables pour les besoins de la recherche. Il y avait également des maisons qui auraient pu constituer de bons exemples, sauf que les propriétaires ont décidé de ne pas aller de l'avant avec les travaux.

La maison n° 1 est un bungalow construit au début des années 1990, équipé à l'origine de plinthes électriques. La maison n° 2 comporte un niveau aménagé sur une dalle sur terre-plein et une petite habitation construite au milieu des années 1980, équipée à l'origine de panneaux électriques rayonnants au plafond. La maison n° 3 est un bungalow bâti au début des années 1970, chauffé par des plinthes électriques.

Des calculs détaillés des pertes et gains de chaleur ont été effectués à l'aide de Right-Suite Canada, logiciel mis au point par Wrightsoft Corporation en collaboration avec HRAI. Les calculs de dimensionnement des conduits ont été effectués selon une méthode

manuelle énoncée dans le guide Residential Air System Design de l'organisme HRAI. Pour chaque étude de cas, la consommation de chauffage/climatisation estimée par l'entrepreneur en vue d'amorcer les discussions avec le propriétaire, a été comparée aux charges de chauffage/climatisation établies par voie de calculs détaillés. Chaque étude de cas contient un tableau comparatif des dimensions des conduits mis en place par l'entrepreneur et de celles qu'indiquent les calculs détaillés. Dans chaque cas, les dimensions des conduits retenues par l'entrepreneur varient bien souvent de celles qui découlent de calculs détaillés. Plutôt que de mettre en place des conduits de différents diamètres selon ce qu'indiquent les calculs détaillés, il est pratique courante de recourir à un diamètre de conduit de dérivation partout. Cette pratique dépend tout à fait des registres de distribution pour le contrôle du débit d'air. L'entrepreneur a systématiquement installé moins de conduits et des conduits de dimensions inférieures par rapport à ce qu'indiquait le mode de calcul détaillé.

Les mesures des débits d'air sont présentées pour chaque maison faisant l'objet d'une étude de cas. En règle générale, les débits d'air mesurés au moyen du capuchon de saisie étaient beaucoup moins importants que la valeur consignée à l'aide de la buse insérée dans le conduit. À certains égards, cette réduction de la valeur consignée peut s'expliquer par la forme du capuchon et la contre-pression que le capuchon exerce sur le système, amenant le rééquilibrage des débits d'air. La différence s'explique également par les fuites d'air (par infiltration et par exfiltration) des conduits. Les tentatives destinées à rendre les conduits étanches n'ont pas été uniformes dans toutes les maisons soumises aux essais. Les mesures des débits d'air d'alimentation recueillis ne correspondaient pas aux débits d'air de reprise. Les débits d'air mesurés à l'aide de la buse en dos d'âne ne correspondent pas bien aux débits d'air mesurés à l'aide du capuchon de saisie disposé par-dessus une grille. Même si les méthodes de mesure sont approuvées par l'industrie et employées pour la mise en service des maisons R 2000, la plage des débits observés réduit la fiabilité des résultats indiqués et des méthodes de mesure.

L'entrepreneur surdimensionnait généralement les appareils de chauffage et de climatisation. Il a généralement surdimensionné les conduits de dérivation d'alimentation, en choisissant un seul diamètre de conduits plutôt qu'en faisant varier le diamètre selon les calculs; par contre, les dimensions des gaines de dérivation étaient généralement sousdimensionnées aussi bien pour les bouches d'alimentation que pour les bouches de reprise. Le circuit de reprise était systématiquement sousdimensionné, comptant moins de conduits de dérivation de reprise et des grilles plus petites que ce qu'indiquaient les calculs détaillés.

L'entrepreneur n'a pas fourni de données sur le coût de revient, mais a indiqué n'avoir eu recours à aucun facteur précis pour l'établir; l'estimation a été établie dans chacun des cas selon les enjeux présentés. Les maisons nos 1 et 3 ont été considérées comme posant aucune difficulté particulière, même si la maison n° 3 a nécessité un nombre beaucoup plus élevé de rappels qu'en temps normal. La maison n° 2 présentait davantage de difficultés en raison surtout des défis que présentait la dalle sur terre-plein, l'accès limité aux espaces sous plafond et au manque de locaux conditionnés pouvant recevoir de nouveaux appareils.

Bien qu'il existe des programmes de formation (par l'intermédiaire de l'HRAI) et que RNCan offre depuis peu des mesures financières pour inciter les entrepreneurs à suivre ces cours, les entrepreneurs sont peu enclins à suivre les modes de calculs détaillés des conduits. De plus, les consommateurs sont peu conscients des avantages que procurent les calculs détaillés des pertes et gains de chaleur que pourraient effectuer l'entrepreneur en chauffage. En outre, les consommateurs sont peu sensibilisés au fait que les entrepreneurs n'effectuent pas de calculs détaillés.



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INTRODUCTION

This project involved working with a heating contractor in Fredericton, New Brunswick to monitor the installation of new forced air heating systems in three older houses previously without such systems. The project involved completing calculations of heating and cooling loads and sizing of duct systems. Air flows were measured, recorded and compared with design air flows and measured airflow of the blower. A photographic record illustrates obstacles faced by the heating contractor, which can force deviation from original system design.

BACKGROUND

Natural gas has recently become available in New Brunswick and other Maritime Provinces, and home owners are slowly beginning to convert from traditional fuels of electricity, oil and wood. Not only are these homeowners considering a change in fuel, but the availability of new technology is prompting them to consider alternate heating distribution system types.

A large number of older homes in New Brunswick were subject to heating system conversions in the 1970's as part of a government funded "off-oil" program. Many of these homes had duct systems removed in favour of electric baseboard systems, while some retained their duct systems opting to change only the furnace. A large number of homes of more recent vintage are heated with electric baseboard systems with no previous duct systems having been installed. These houses present a particular challenge to homeowners wishing to convert fuels as well as the method of the heat distribution.

Detailed heating system design is not a requirement to get a building permit in New Brunswick. As a consequence, "rule-of-thumb" design and sizing practices are most common, and research has shown that across Canada, systems are most often oversized. In a retrofit situation, it is suspected "rules-of-thumb" sizing choices result in inefficient system operation and fuel consumption, as well as higher than necessary equipment costs. Couple this with the compromises that must be made when fitting a duct system into older houses and the effects on expected airflow rates can be significant.

With the recent introduction of gas to the Province, it was decided to approach a local gas company, TryCo Gas, to identify a heating contractor involved in heating system conversions to be a participant in this project. Air-Care Inc., a heating and ventilation company of Fredericton that carries out system conversions for TryCo Gas in the Fredericton area, indicated an keen interest to participate in the project.

OBJECTIVES

The objectives of this project were:

- (a) to record those obstacles and challenges faced by heating contractors engaged to install forced air heating systems in houses previously without such systems;
- (b) to evaluate the effect of such obstacles on the ability of the forced air system to deliver design airflows throughout the house;
- (c) to illustrate the importance of detailed duct design in retrofit installation projects.

PROJECT DESCRIPTION & TASKS

This project involved working with a heating contractor to select three existing homes which were having new ducted, forced air heating systems installed, where no ducting previously existed. The author of this report served as a consultant to the heating contractor, providing heat loss/gain load calculations as well as duct layout and sizing design. There was not a requirement on the part of the contractor to use the design. This report presents the results of the project as three case studies, each comprised of several tasks.

Each case study included the following tasks:

- (1) house selection;
- (2) house measurement and preparation of plan;
- (3) calculation of heating/cooling loads;
- (4) comparison of design condition loads calculations and contractor estimates;
- (5) comparison of installed equipment capacities to design condition loads;
- (6) comparison of estimated energy consumption resulting from choices;
- (7) comparison of contractor installed duct sizes with sizes resulting from detailed design;
- (8) measurement of air-flows;
- (9) provision of a photographic record of solutions & challenges encounters on site.

GENERAL NOTES

(1) House Selection

The participating contractor was contacted in early fall of 2002 to begin selection of suitable houses, but activity in the retrofit market was slow. It seems most work in the autumn involves installation of systems in new homes, while those considering system changeovers or conversions typically wait until faced with problems in their existing system. Although the contractor was continually quoting new and changeover installations, all estimates do not result in a contract. Many equipment changeovers involved use of existing duct systems and this project specifically targeted houses without existing duct systems.

It was originally intended that project houses would be converted to gas forced air heating, but the gas conversions did not occur. Each of the three study houses were in fact converted from electric baseboard or radiant heating systems to air source heat pump systems with integral electric resistance supplemental heat. The lack of timely availability of appropriate case study houses lead to unexpected delays. However, as the issues surrounding duct sizing and selection would be the same, regardless of whether the conversions were to gas forced air or heat pump forced air, it was decided to not wait for gas fuel conversions to present themselves.

Concern for the future of the project occurred when one of the owners of the heating firm bought out his partner. Assurances were made that there would be no problem, and as a good working relationship existed with the firm, it was deemed best to continue with them through the difficult period.

A significant delay occurred when a homeowner had a change of mind. The homeowner had committed to the contractor, system sizing calculations had been completed along with house and systems layout plans and the contractor was scheduled to begin work when the homeowner backed out. This is mentioned as a reminder of the uncertainties faced by contractors on a regular basis in the field.

“House One” is a bungalow constructed in the early 1990's originally equipped with electric baseboard resistance heaters. “House Two” is a slab-on-grade storey and half house built in the mid-1980's and originally equipped with electric radiant ceiling panels. “House Three” is a bungalow constructed in the early 1970's equipped with electric baseboard resistance heaters.

(2) House Measurement and Preparation of Plan

Measurements were taken of each house and floor plans were prepared to form a basis for heating and cooling load calculations and duct layouts. Plans for the case study houses are included in Appendix A for House One; Appendix B, House Two; Appendix C, House Three.

(3) Calculation of Heating/Cooling Loads

Heating and cooling load calculations were performed using Right-Suite Canada, a software program developed by the Wrightsoft Corporation in cooperation with HRAI. Calculated loads are included in Appendix A for House One; Appendix B, House Two; Appendix C, House Three.

(4) Comparison of Design Condition Loads Calculations and Contractor Estimates

For each case study, the heating/cooling consumption estimated by the contractor for the purpose of sizing the system and for initial discussions with the homeowner, was compared with heating/cooling loads determined by detailed calculation.

(5) Comparison of Installed Equipment Capacities to Design Condition Loads

Each case study indicates size of heating equipment required to meet the design condition heating and cooling loads and compares this to the size of equipment proposed by the contractor and the size of equipment actually installed.

(6) Comparison of Estimated Energy Consumption Resulting from Choices

When the project began, it was thought gas appliances would be used and if oversized equipment were selected, there may be some impact on fuel consumption. It was the intention to estimate the impact on gas consumption of oversizing gas furnaces, relative to furnaces which were closely matched design heat loss of the houses. However, since the houses ended up being heated electrically, it was determined such a calculation would no longer be valid within the scope of the project.

(7) Comparison of Contractor Installed Duct Sizes with Sizes Resulting from Detailed Design

Each case study contains a comparison of duct sizes installed by the contractor to the sizes suggested by the detailed design process. In each case, duct sizes used by the contractor often vary from those resulting from design. Rather than vary sizes, it is common practice in the industry to use a common branch duct size and control airflow with distribution dampers. The contractor consistently installed fewer and smaller ducts than suggested by the detailed design method.

(8) Measurement of Air-Flows

Air-flow measurements are presented for each case study house. Measurements were recorded using saddle style flow collars inserted into round branch ducts and a digital manometer. Air-flow measurements were also collect through the use of a capture hood, equipped with a round flow collar which was placed over supply and return grilles. As a rule, airflows measured using the capture hood were significantly lower than the value recorded using the flow collar insert into the duct. In some respects this reduction in recorded value can be attributed to configuration of the hood. Note that the percentage difference in the value is not consistent. A Report of comparative test completed on the air flow measurement equipment used in the project is included in Appendix D.

(9) Provision of a Photographic Record of Solutions & Challenges Encounters On Site

An important aspect of this project was identification of obstacles encountered by the heating contractor in a retrofit project, challenges which make it difficult to achieve a satisfactory installation, challenges which often require deviation from the intended design. Photographs for each case study are located in Appendix A for House One; Appendix B, House Two; Appendix C, House Three. Photographs illustrating the flow measuring equipment are contained in Appendix D.

CASE STUDIES

House One

This bungalow style house, constructed in 1992 with a walk-out basement to the backyard, was originally equipped with electric baseboard resistance heaters. The current homeowner had a wood stove installed in the Family Room in the basement, and it is used consistently through the winter. The interior of the basement is partially finished with several frame partitions in place with only one partition finished with drywall. The attic is insulated to R40, main walls and back walkout basement wall are R20, while the remaining basement walls are insulated to R12.

The heating contractor's challenge in this case was to add an air source heat pump system with new duct work to all rooms. The existing interior basement plan limited placement of the air handler to a corner on one end of the basement. Other challenges were presented by existing wiring, plumbing and structural framing. Even though the new heat pump system contained electric resistance back-up heating elements, the homeowner elected to maintain the original electric baseboard heating. As a consequence, additional electrical capacity had to be added to the electric panel.

The owner was interested in having air conditioning for the summer months as well as being able to take advantage of the forced air system to circulate wood heated basement air throughout the house. In discussions with the contractor, the owner decided on an air source heat pump to handle their cooling needs and also look after their heating needs for much of the winter. Also, in the future when heating with wood becomes less feasible, the heat pump will continue to provide an economic heating source. The home owner chose a single speed system, rather than the more expensive new variable speed motor technology.

The contractor completed the installation in the spring of 2003. The home owner has been through a cooling season and is now in the first heating season. There has been limited feedback as to the customer's level of satisfaction, which probably indicates there have been no notable problems with the new system.

House Measurement and Preparation of Plan

Measurements were taken and floor plans were prepared to form a basis for heat loss calculation. Floor plans can be found in Appendix A.

Calculation of Heating/Cooling Loads

Heating and cooling load calculations were performed using Right-Suite Canada. Results of the calculations are included in Appendix A. Design condition loads were calculated to be 47766 Btuh for heating, and 24008 Btuh for cooling. A copy of the computer printout is attached in Appendix A.

Comparison of Design Condition Loads Calculations and Contractor Estimates

The contractor estimated that meeting the heating and cooling loads would require a 3 ton heat pump with a 20 kW electric resistance back-up system. Based on the detailed design condition calculations, the recommended installed size would be 15 kW or 51195 Btuh of electric heat and 2 to 2.5 tons of cooling. The contractor installed equipment which met his load estimates.

Comparison of Installed Equipment Capacities to Design Condition Loads

According to detailed calculations mentioned above, the 68260 Btuh output of the 20 kW electric back-up exceeds the 40% over-sizing limit recommended in heating standards. The 3 ton heat pump has a cooling output of between 33000 and 36000 Btuh, which is 37% to 50% more than estimated by the detailed design condition heat gain calculations.

Comparison of Contractor Installed Duct Sizes with Sizes Resulting from Detailed Design

Duct sizing calculation were performed using the manual calculation method presented in the HRAI Residential Air System Design manual. The calculations were based on an airflow of 933 cfm. This was

based on 400 cfm per ton delivered ton of cooling, for a 2.5 ton heat pump rated at 28000 Btuh cooling capacity. A copy of the manual calculation is attached in Appendix A.

In the detailed design, supply branch duct sizes vary from 3 to 6 inches in diameter. All branch ducts installed by the contractor were 6 inches in diameter. The main supply trunk duct size in the detailed design was 20"x8" reducing to a 16"x8". The supply trunk duct installed was the same, except the vertical supply plenum above the air handler was 14"x18".

The following Table 1-H1 draws comparison between the available cross sectional area of supply ducts selected in the detailed design and those installed by the contractor. Table 2 - H1 draws a comparison between the available free area of the diffusers selected by detailed design and those installed by the contractor.

Table 1 - H1
Available Free Area Comparison
Cross Sectional Area of Supply Ducts

Detailed Design Area

Duct Dia.	Quan.	@	Sq. In.	Area	Sq. In.
3"	1	@	7.1	7.1	Sq. In.
4"	3	@	12.5	37.5	Sq. In.
4.5"	3	@	16	48	Sq. In.
5"	4	@	20	80	Sq. In.
5.5"	2	@	24	48	Sq. In.
6"	1	@	28	28	Sq. In.
Available Free Area				248.6	Sq. In.

"As-Built Area

Duct Dia.	Quan.	@	Sq. In.	Area	Sq. In.
6"	14	@	28	392	Sq. In.
Available Free Area				392	Sq. In.

Table 2 - H1
Available Free Area Comparison
Supply Diffuser Free Area

Detailed Design Area

Size	Quan.	@	Sq. In.	Area	Sq. In.
4X10	14	@	24	336	Sq. In.
Available Free Area				336	Sq. In.

"As-Built Area

Size	Quan.	@	Sq. In.	Area	Sq. In.
4X10	9	@	24	216	Sq. In.
None	3	@	28	84	Sq. In.
6" Rd.	2	@	20	40	Sq. In.
Available Free Area				340	Sq. In.

The detailed design for the return side called for branch sizes between 5.5 and 7.5 inches in diameter. The contractor actually "panned" in the joist spaces, which could accommodate higher airflow. There were two exceptions, R-5 was designed as a 7" diameter and R-6 was designed as a 5.5" diameter, a 6" diameter was duct was installed in both cases. See cross sectional area comparison as follows in Table 3 - H1.

Table 3 - H1
Available Free Area Comparison
Cross Sectional Area of Return Ducts

Detailed Design Area

Duct Dia.	Quan.	@	Sq. In.	Area	Sq. In.
5.5"	2	@	24	48	Sq. In.
7"	1	@	38	38	Sq. In.
7.5"	3	@	44	132	Sq. In.
Available Free Area				218	Sq. In.

"As-Built Area

Duct Dia.	Quan.	@	Sq. In.	Area	Sq. In.
"pan"	3	@	134	402	Sq. In.
6"	2	@	28	56	Sq. In.
Available Free Area				458	Sq. In.

** - "pan": 2" X 10" joists @ 16" o.c.

The detailed design showed four 6"x12" trussed steel return air grilles for the main floor, and two 6"x8" for the basement. The contractor installed four return air grilles on the main floor level, these were 4"x10" pressed steel diffusers identical to the supply diffusers. In the basement, the contractor chose to install one 6"x8", while the remaining return duct was left open without a grille. Although the installed return air capacity may be deemed deficient from the main floor, there was not feedback in this regard from the home owner to the contractor. This may be due, in part, to the owner usually leaving the basement door open. See available free area comparison as follows in Table 4 - H1.

Table 4 - H1
Available Free Area Comparison
Return Grille Free Area

Detailed Design Area					"As-Built Area				
Size	Quan.	@	Sq. In.	Area Sq. In.	Size	Quan.	@	Sq. In.	Area Sq. In.
6X8	2	@	40	80 Sq. In.	4X10	4	@	24	96 Sq. In.
6X12	4	@	62	248 Sq. In.	6X8	1	@	40	40 Sq. In.
					None	1	@	28	28 Sq. In.
Available Free Area				328 Sq. In.	Available Free Area				164 Sq. In.

** Truss Steel Floor Grilles used in Detailed Design

** Pressed Steel Supply Air Diffusers used in As-Built

Measurement of Air-Flows

Air-flow measurements are presented in Tables in Appendix A. Measurements were recorded using a 6" diameter saddle style flow collar inserted into round branch ducts and a digital manometer. Air-flow measurements were also made using a capture hood with a 4" diameter round flow collar, placed over supply and return grilles. A Report of comparative test completed on the air flow measurement equipment used in the project is included in Appendix D. Photographs illustrating the flow measuring equipment are contained in Appendix D.

It will be noted the airflow volumes recorded through the use of a hood are significantly lower than values recorded through use of the flow collar insert into the duct. Reasons for these differences are discussed in the "Conclusions" section of this report.

As can be observed in the photographs, joints have not been sealed, so some reduction in measured air flow may be due to leakage; however, main trunk ducts have been sealed. It will also be noted in the return system that metal panning has been sealed to the joist; however, end blocking has not been sealed. It is suspected resistance to return air flow caused by fewer return grilles increases leakage into the system through unsealed end blocking of panned joist spaces.

Air-Handler Capacity

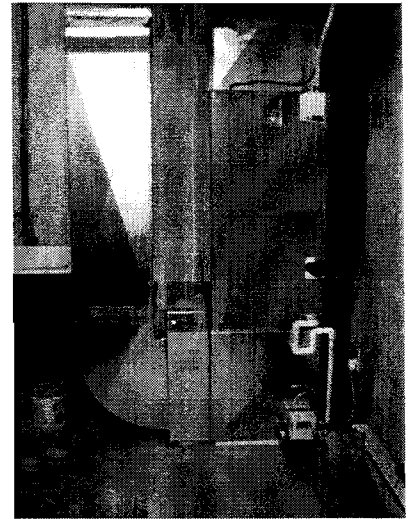
Measurements were taken to determine the airflow capacity of the air-handler. This was done by measuring the temperature rise through the air-handler with the system operating on back-up electric heating. Using the formula: $CFM = BTU / \text{Temperature Rise} \times 1.08$; the calculation indicates an air flow capacity of 1200 cfm.

The average return-air temperature was 65.75 F., and the average supply temperature measured 118.4 F., resulting in a temperature rise of 52.65 F.. The output of the 20 kW electric back-up heating systems is 68,280 Btuh. The temperature rise used in the detailed design was 50 F, with a 15 kW electric back-up with an output of 51,195 Btuh.

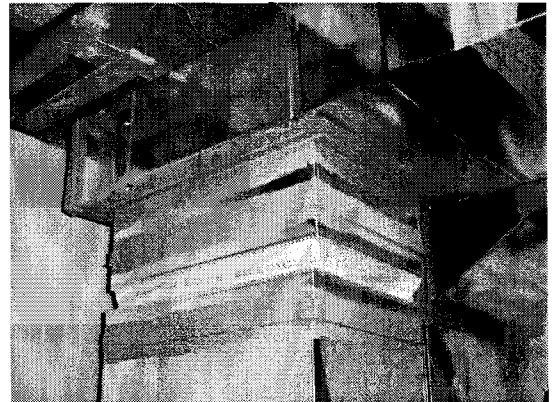
Photographic Record of Solutions & Challenges Encounters On Site

Photographs identified in observations below, and presented in a reduced form, can be seen in full size format in Appendix A

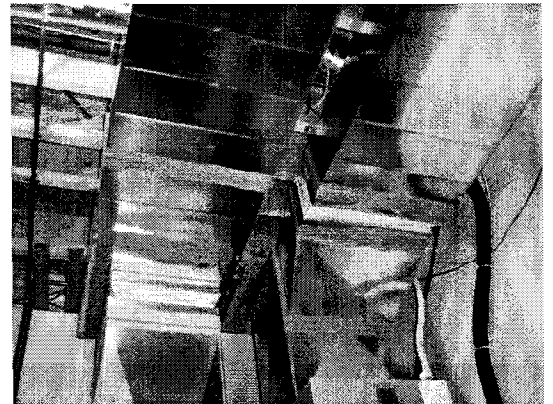
Picture, H1,001.jpg, shows the air-handler located in the corner of the basement, in fairly restricted quarters. Notice the utility sink to the left of the return-air drop. Although the contractor has put forth a good effort in sealing the main trunk ducts, connects at the air-handler have very typically been left unsealed.



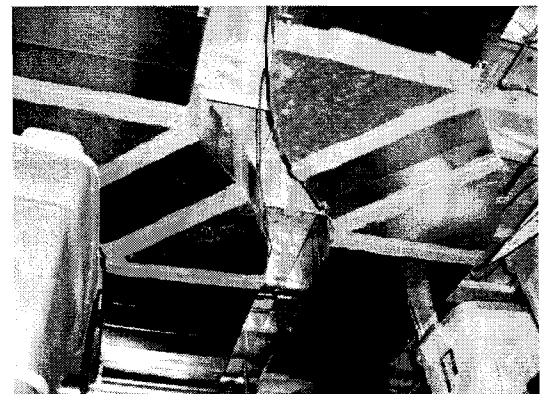
Picture, H1,002.jpg, shows the 14"x20" return-air drop with sealed connection to from 20"x8" return trunk. Photo also shows the sealed connection on both sides of the vibration isolation collar installed in the drop.



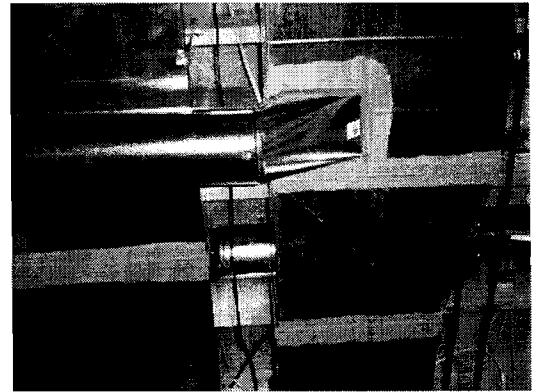
Picture, H1,003.jpg, shows the sealed joints in a continuation of return and supply trunks, both of which are 20"x8", the vibration collar located in the supply-air trunk is also shown.



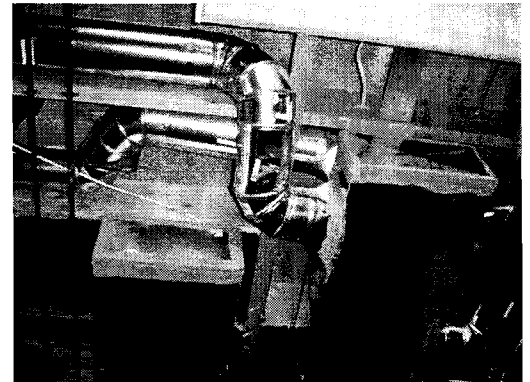
Picture, H1,004.jpg, shows the sealed joints in the off-set required in both supply and return trunks necessary to avoid plumbing drop and connections to city service, as well as location of electric domestic water heating tank connections.



Picture, [H1,005.jpg](#), shows a typical branch take-off from the main supply trunk. This style take-off was used for both top and bottom connections to the trunk, and sealed in the manner shown. Also visible is the reduction in the supply trunk from 20"x8" to 16"x8". Existing water supply piping can also be seen to the right of the supply trunk. No water piping was relocated during this installation.

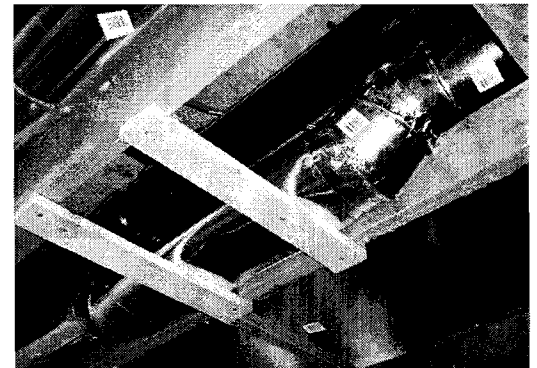


Picture, [H1,006.jpg](#), shows a complicated take-off arrangement at the end of the supply-air trunk. The contractor was challenged to avoid both framing and plumbing. The branch with the top take-off travels between the floor joist, but elbows were required to avoid a water pipe which is shown making its own connection up through the frame floor.



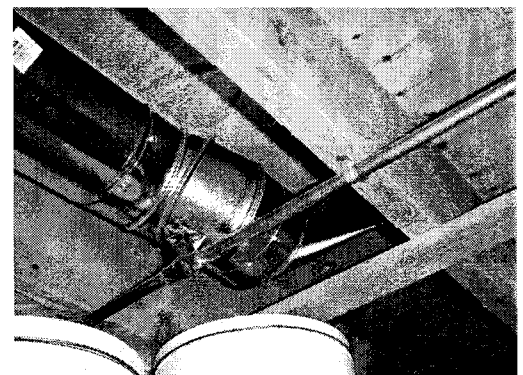
In order to avoid an existing light fixture the supply trunk was not extended and blocking to hold the light fixture was also in the way of a top take-off so a side take-off was used requiring an additional 3-90 deg. elbows.

Picture, [H1,007.jpg](#), shows a complex arrangement around a plumbing connection. This is the same branch referenced first in the photo above. A 45 deg. elbow was required to lower the branch and also the 6" round duct was squashed slightly to avoid an unseen plumbing connection to this main drain pipe. There was not enough room for a rectangular or square section of duct.

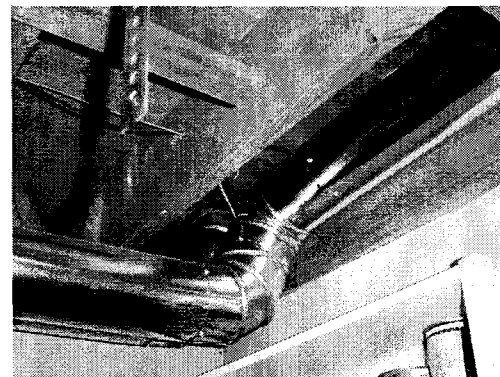


Return-air joist panning is also shown, note sealant used between sections of metal pan and between pan and joists.

Picture, [H1,008.jpg](#), shows the warm-air supply to the main floor bathroom. The existing valve controlling an outdoor hose bib required the branch to be offset with a couple 45 deg. elbows.

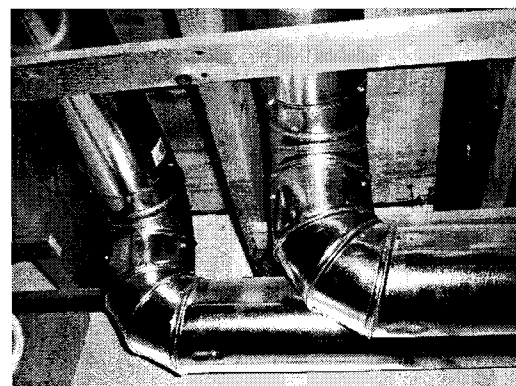


Picture, [H1,009.jpg](#), the two branches shown can also be seen on the right side of H1,006 above as they take-off from the main supply trunk. Due to the light fixture shown in H1,006 the main trunk was terminated requiring at least 3 additional 90 deg. elbows in each of these two branches.

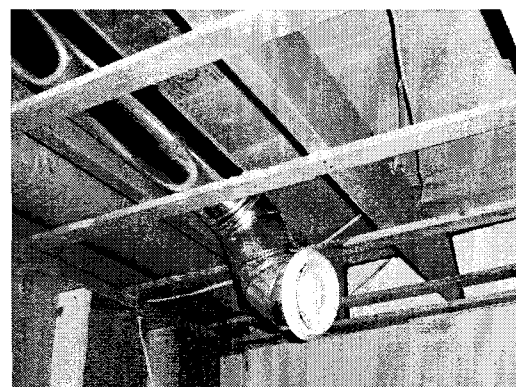


It is also noted, duct sealant was not used on any joints of supply branches.

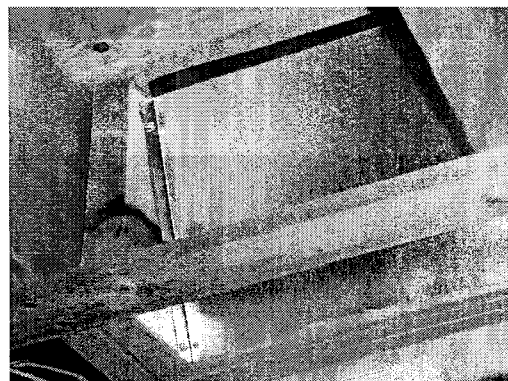
Picture, [H1,010.jpg](#), shows a very typical direction change encountered on site. In this case two supplies are required in rooms on main floor rooms located behind the garage. If the designer is not familiar with framing layout, the two extra 90 deg. elbows required, may be missed in the duct design process.



Picture, [H1,011.jpg](#), shows a supply-air branch serving a workshop space in the basement. Rather than using the expected end boot termination for this branch the contractor, at the homeowner's request, installed 2 extra 90 deg. elbows and a round plastic diffuser. It is noted this style of round plastic diffuser creates much more resistance to airflow than the standard metal rectangular diffuser.



Picture, [H1,012.jpg](#), shows an end block of a panned joist return air branch. Note that although care was taken to seal metal pan to floor joists, as seen in other photos, no sealant has been used around this block. Air leakage into the return duct around such an end block can reduce volume of air intended to be returned from a nearby floor grille.



CASE STUDIES

House Two

This storey and half slab-on-grade house was built in 1986 and was originally equipped with electric radiant heating panels in the ceilings of habitable rooms. The flat ceiling portion of the house is insulated to R40, while the 2"x10" rafter sloped ceiling is insulated to R32. The main walls are insulated to R20. The concrete slab was constructed with 1.5" thick (R7.5) rigid foam insulation applied to the top surface and covered with a plywood subfloor. The current homeowner requested an air source heat pump be installed primarily to provide summer cooling. The homeowner also wanted to improve air filtering and circulation and it seemed appropriate to take advantage of the heating potential as well. The homeowner chose a heat pump with the new variable speed motor technology. Even though the air-handler contains supplementary electric resistance heaters, the original electric radiant heating panels were to remain operational.

The primary challenge in this house was to find a suitable location for the air handler, and the routing of ducts throughout the house. One major obstacle to duct installation was the existence of insulation and electric radiant heating panels in the main floor ceiling beneath the finished upper floor area. There was also no conditioned space within the finished portion of the house in which to locate the new mechanical equipment. A proposal to renovate an unfinished attic space located above a portion of the main floor family and living room adjacent to the finished area on the upper floor into a conditioned space mechanical room was accepted by the homeowner. This also provided additional storage space for the house. This addition of surface area to the home added to the original heating loads. Insulation levels similar to those existing in the remainder of the home were used in this renovation.

An unexpected challenge arose when the homeowner was unable to secure a contractor to renovate the attic space in the peak of the construction season. In order to expedite the project, the heating contractor arranged for preparation of the attic space to a stage where installation of the new system could proceed.

In order to provide heating/cooling to one section of the house, a portion of the duct work was required to pass through the attic above the unheated garage. This raised two concerns: (a) the possibility of intrusion of vehicle related pollutants into the duct system, and (b) the effect of outdoor seasonal temperatures on the ability of the duct to deliver the desired air temperature. In response to these concerns, the contractor used insulated flex duct to minimize joints and seams in duct material and sealed those duct penetration of the main house wall and ceiling surfaces. Although best practices suggest this situation be avoided, it is indicative of the situations that face heating contractors on a regular basis. Temperature measurements listed with picture H2,011 indicate summer heat gain in this unconditioned attic do indeed significantly affect the temperature of air passing through the insulated flex duct.

The contractor completed the installation in the summer of 2003, the home owner has been through a cooling season and is now in the first heating season. The contractor has been called by the homeowner on occasion during the summer concerning fine tuning of the distribution of cooling air.

House Measurement and Preparation of Plan

Measurements were taken and floor plans were prepared to form a basis for heat loss calculation. Floor plans can be found in Appendix B.

Calculation of Heating/Cooling Loads

Heating and cooling load calculations were performed using Right-Suite Canada. Results of the calculations are included in Appendix B. Design condition loads were calculated to be 52019 Btuh for heating and 21520 Btuh for cooling. A copy of the computer printout is attached in Appendix B.

Comparison of Design Condition Loads Calculations and Contractor Estimates

The contractor estimated that meeting the heating and cooling loads would require a 2 to 2.5 ton heat pump with a 20 kW electric resistance back-up system. Based on the detailed design condition calculations, the

recommended installed size would be 15 kW or 51195 Btuh of electric heat (because the owner was retaining the original electric radiant ceiling panels) and 2 tons of cooling. The contractor installed the 2.5 ton equipment.

Comparison of Installed Equipment Capacities to Design Condition Loads

The contractor installed a 15 kW or 51195 Btuh of electric back-up heat as recommended in the detailed design. The 2.5 ton heat pump has a cooling output of approximately 30000 Btuh, 39% more than the cooling requirement estimated through detailed design.

Comparison of Contractor Installed Duct Sizes with Sizes Resulting from Detailed Design

Duct sizing calculations were performed using the manual calculation method presented in the HRAI Residential Air System Design manual. The calculations were based on an airflow of 900 cfm. This was based on 450 cfm per ton delivered ton of cooling, for a 2 ton heat pump, as the actual delivered output per ton was not known at time of design. A copy of the manual calculation is attached in Appendix B.

In the detailed design, supply branch duct sizes vary from 4 to 6 inches in diameter, with 5 and 6 inch diameter recommended on the plan. All branch ducts installed by the contractor are all 6 inches in diameter. The main supply trunk duct size in the detailed design was 22"x8" reducing to a 13"x8" and an 8" diameter solid duct section across the garage attic. The supply trunk duct installed was an 18"x8" reducing to 12"x8" and then to an 8" diameter insulated flex across the garage attic.

The following Table 1-H2 draws comparison between the available cross sectional area of supply ducts selected in the detailed design and those installed by the contractor. Table 2-H2 draws a comparison between the available free area of the diffusers selected by detailed design and those installed by the contractor.

Table 1 - H2
Available Free Area Comparison
Cross Sectional Area of Supply Ducts
"As-Built Area

Detailed Design Area

Duct Dia.	Quan.	@	Sq. In.	Area	Sq. In.
4"	1	@	12.5	12.5	Sq. In.
4.5"	3	@	16	48	Sq. In.
5"	3	@	20	60	Sq. In.
5.5"	4	@	24	96	Sq. In.
6"	2	@	28	56	Sq. In.
Available Free Area				272.5	Sq. In.

Duct Dia.	Quan.	@	Sq. In.	Area	Sq. In.
6"	14	@	28	392	Sq. In.
Available Free Area				392	Sq. In.

Table 2 - H2
Available Free Area Comparison
Supply Diffuser Free Area
"As-Built Area

Detailed Design Area

Size	Quan.	@	Sq. In.	Area	Sq. In.
4X10	8	@	24	192	Sq. In.
6" Rd.	5	@	20	100	Sq. In.
Available Free Area				292	Sq. In.

Size	Quan.	@	Sq. In.	Area	Sq. In.
4X10	8	@	24	192	Sq. In.
6" Rd.	6	@	20	120	Sq. In.
Available Free Area				312	Sq. In.

In the detailed design, the return branch ducts vary in size between 6 and 8 inches in diameter. The contractor actually used the enclosed ceiling joist spaces, which could accommodate higher airflow. Vertical stud spaces were also used to return air from low wall grilles. See cross sectional area comparison as follows in Table 3 - H2.

Table 3 - H2
Available Free Area Comparison
Cross Sectional Area of Return Ducts

Detailed Design Area

Duct Dia.	Quan.	@	Sq. In.	Area	Sq. In.
6	2	@	28	56	Sq. In.
6.5	1	@	33	33	Sq. In.
7"	2	@	38	76	Sq. In.
7.5"	1	@	44	44	Sq. In.
8	1	@	50	50	Sq. In.
Available Free Area				259	Sq. In.

"As-Built Area

Duct Dia.	Quan.	@	Sq. In.	Area	Sq. In.
"stud"	4	@	50.75	203	Sq. In.
6"	2	@	28	56	Sq. In.
Available Free Area				259	Sq. In.

** "stud": 2" x 4" studs @ 16" o.c.

Nominal 4"x10" supply air diffusers were selected by the detailed design and were also installed by the contractor. The detailed design showed four 6"x10" return air grilles on the main floor and two on the upper floor. The contractor installed three 6"x14" return air grilles on the main floor Livingroom, and one 6"x14" on the upper wall of the stairwell. In the Parlor, the contractor converted a 6" diameter branch and plastic diffuser, which has served as a fresh air supply from the HRV, into a return-air branch. A similar solution was used to create a return air from the Master Bedroom. Floor plans showing duct and grille sizes as per design are contained in Appendix B. See available free area comparison as follows in Table 4 - H2.

Table 4 - H2
Available Free Area Comparison
Return Grille Free Area

Detailed Design Area

Size	Quan.	@	Sq. In.	Area	Sq. In.
6X10	6	@	52	312	Sq. In.
Available Free Area				312	Sq. In.

"As-Built Area

Size	Quan.	@	Sq. In.	Area	Sq. In.
6X14	4	@	71	284	Sq. In.
6" Rd.	2	@	20	40	Sq. In.
Available Free Area				324	Sq. In.

** Truss Steel Floor Grilles used in Detailed Design

** Pressed Steel Supply Air Diffusers used in As-Built

Measurement of Air-Flows

Air-flow measurements are presented in Tables contained in Appendix B. Measurements were recorded using a 6" diameter saddle style flow collar inserted into round branch ducts and a digital manometer. Air-flow measurements were also made using a capture hood, equipped with either a 4" or 6" diameter round flow collar, placed over supply and return grilles. A Report of comparative test completed on the air flow measurement equipment used in the project is included in Appendix D. Photographs illustrating the flow measuring equipment are contained in Appendix D.

It will be noted the airflow volumes recorded through the use of a hood are significantly lower than values recorded through use of the flow collar insert into the duct. Reasons for these differences are discussed in the "Conclusions" section of this report.

As can be observed in the photographs most joints have been sealed, some reduction in measured air flow may be due to leakage. It will also be noted in the return system that the main trunk ducts are sealed and where accessible return-air branches were sealed. However, those return branches that were comprised of enclosed joist or stud spaces were not sealed and negative pressures may draw some return-air from the house structure.

Air-Handler Capacity

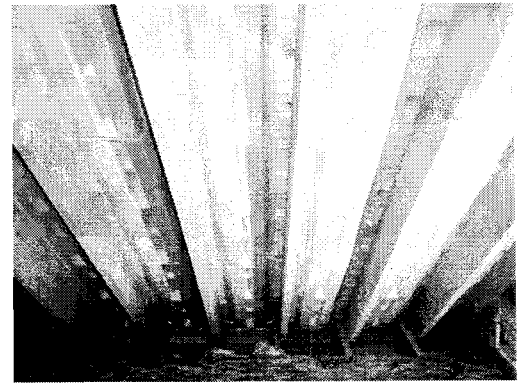
Measurements were taken to determine the airflow capacity of the air-handler. This was done by measuring the temperature rise through the air-handler with the system operating on back-up electric heating. Using the formula: $CFM = BTU / \text{Temperature Rise} \times 1.08$; the calculation indicates an air flow capacity of 998 cfm.

The average return-air temperature was 72 F., and the average supply temperature measured 119.5 F., resulting in a temperature rise of 47.5 F.. The temperature rise used in the detailed design was 50 F., with a 15 kW electric back-up with an output of 51,195 Btuh.

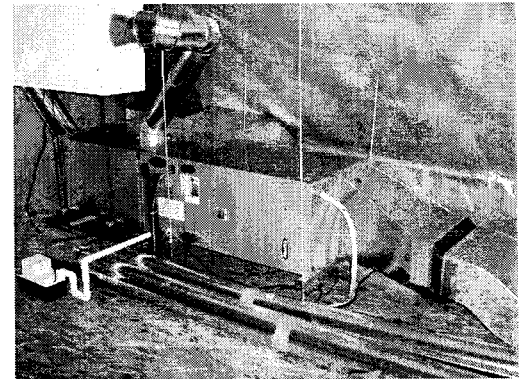
Photographic Record of Solutions & Challenges Encounters On Site

Photographs identified in observations below, and presented in a reduced form, can be seen in full size format in Appendix B.

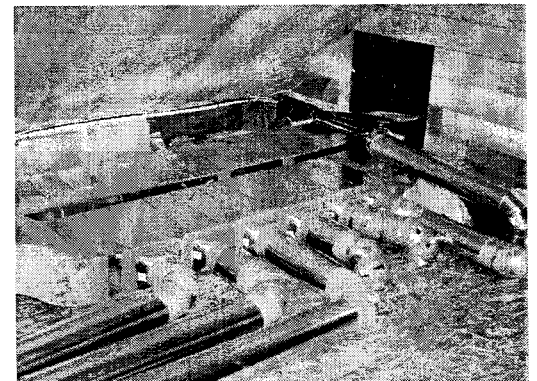
Picture, H2.001.jpg, shows installation of “tru-vents” between rafters of attic space during renovation to conditioned mechanical room.



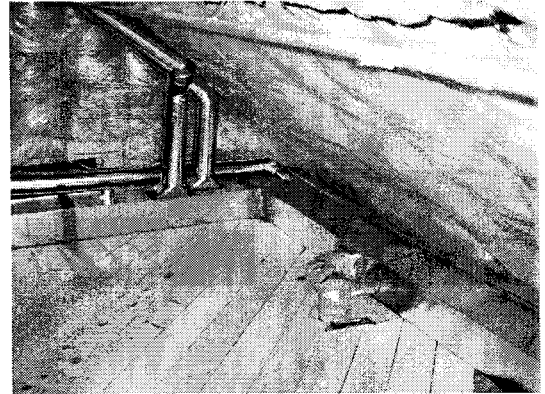
Picture, H2.002.jpg, shows the air-handler located in the corner of the newly created attic mechanical room. The unit was suspended in a horizontal position on adjustable threaded rods from the roof rafters. A by-pass filter system can be seen in the upper left of the picture. A vibration collar can be seen in the main supply-air trunk at the right side of the picture.



Picture, H2.003.jpg, shows the main supply trunk in the foreground with several 6" diameter branches attached. Distribution dampers can also be seen in sections of straight duct near the main truck. Note brush-on duct sealant has been used. The original end-wall separating the finished upper floor from the un-conditioned attic space can be seen at the right of the picture. The original attic access from a conditioned storage space was used as a duct passage.



Picture, [H2.004.jpg](#), shows the main supply trunk as it travels around the perimeter of the original conditioned attic storage area. Note the two 6" dia. ducts rising from the trunk, these were previously supply-air leads from the HRV serving two bedrooms, and were converted to warm-air supplies from the heat pump. It was impossible to serve the two bedrooms with warm-air ducts in the floor/ceiling, as this space was full of insulation above existing electric radiant ceiling panels. A warm-air supply to the Master Bedroom can be seen passing through the board floor.



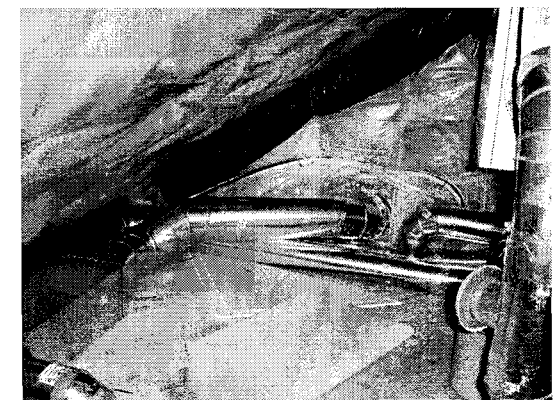
Picture, [H2.005.jpg](#), shows view of conditioned attic storage space prior to installation of system. Note ducts previously used by the HRV can be seen following the roof profile.



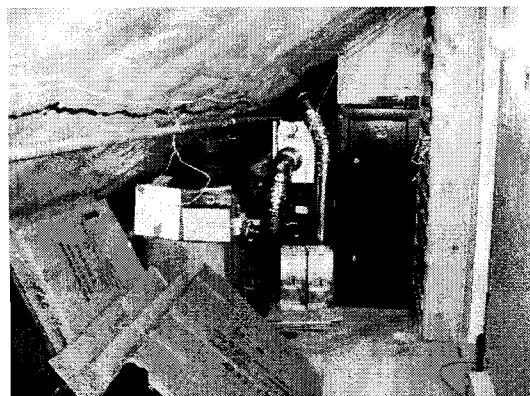
Picture, [H2.006.jpg](#), shows the warm-air supply boot passing through the ceiling of the Master Bedroom below. The boot appears to be located just beneath the edge of the main trunk duct, note the elbows required to make the connection. Location of warm-air supplies in the ceiling was made difficult by the presence of electric radiant heating panels. The contractor took advantage of 4" wide ceiling strapping locations as a position to cut through the ceiling and avoid the panels. It is noted the trunk duct connection was not sealed.



Picture, [H2.007.jpg](#), shows the opposite end of space shown in H2, 004.jpg. The HRV can be seen in the upper right side of the picture. The end of the rectangular warm-air supply trunk can be seen on the left side of the picture. The 8" diameter warm-air supply duct is shown passing through the attic wall to the un-conditioned garage attic space. It is noted joints in the 8" diameter duct were not sealed at time of this photograph. Also seen is the connection of the round metal duct to the insulated flex duct used in the adjoining attic space. At time of photograph, end wall vapour barrier had not been re-sealed.



Picture, H2,008.jpg, shows the original condition of the conditioned attic storage space shown in the previous picture.



Picture, H2,009.jpg, shows the 8" diameter insulated flex duct used as the supply air duct passing through the unconditioned garage attic space. It was originally intended this duct track along side the end wall of the conditioned space to minimize effective duct length; however, it was decided to pass over top of the space in order to avoid disrupting the homeowners current use of space.

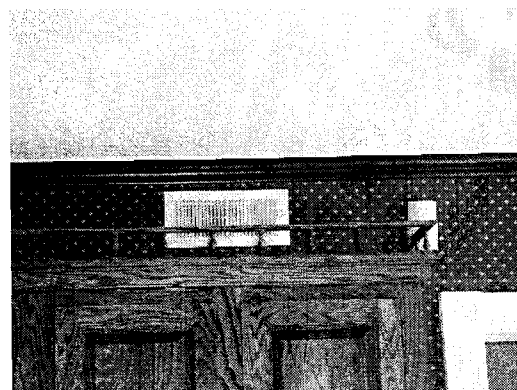


Picture, H2,010.jpg, shows the 8" diameter insulated flex duct passing over the garage attic space, and following the roof down to a space above the conditioned rooms behind the garage. Temperatures were measured on a hot summer afternoon with the following result:

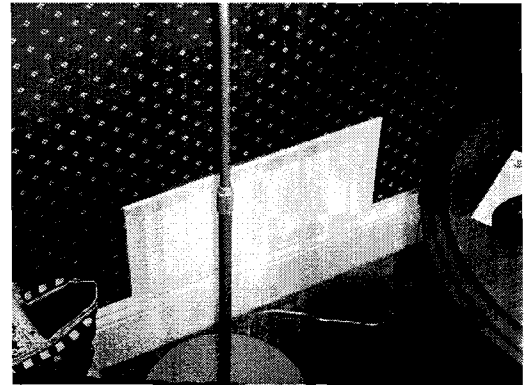
- Temperature in duct before leaving conditioned space: 54 F.
- Temperature at ceiling diffuser at end used point: 58.6 F.
- Temperature in garage attic space: 107 F.
- Temperature in attic between roof sheathing and duct: 126 F.
- Outdoor temperature: 84 F.



Picture, H2,011.jpg, shows warm-air supply diffuser located in kitchen above wall cabinets. As mentioned with H2, 004.jpg, the kitchen could not be supplied through the ceiling. The diffuser shown is supplied through the flex duct shown in the previous picture. Unable to place diffusers in low wall, at this end of the house diffusers are all high, making it difficult to maintain a comfortable temperature for heating at floor level. Owner will rely on original radiant heating panels. High wall diffuser placement will be an advantage during the cooling cycle.



Picture, [H2,012.jpg](#), shows typical low wall return-air grille which allowed air into the stud cavity to be drawn up and through a joist cavity back to the return-air trunk.



Picture, [H2,013.jpg](#), shows plate opening at top of stud space, alignment of studs and joists does not always allow for a full stud pass to be open to a single joist space. Insulation required for the radiant heating panels had to be removed from those cavities used for passage of return air and cavities had to be sealed from neighbouring spaces. Insulation was still required above that portion of the ceiling containing radiant ceiling panels.



Picture, [H2,014.jpg](#), shows ceiling cut-outs to receive diffusers. In all main floor rooms served from the ceiling, it was necessary to avoid existing electric radiant ceiling panels. Portions of 4" wide ceiling strapping were removed to make room for the diffusers. As a consequence, the diffusers were limited to location and not always able to be placed close to the outside wall.



CASE STUDIES

House Three

This bungalow style house was constructed in 1973 by the current homeowner, and was originally equipped with electric baseboard resistance heaters. The interior of the basement is partially finished around the perimeter. The master bedroom, livingroom, diningroom and kitchen have a cathedral ceiling. The bathroom, central hallway and middle and front bedroom are topped by a flat ceiling. Since construction, ceiling insulation was increased to the current R40. The main wall construction consists of a 2"x4" frame, with an outer cladding of 1.5" T&G plank, and a 3/4" cedar board interior finish. It will be noted in the pictures presented below, insulated portions of the basement did not have a vapour barrier or gypsum board installed.

The heating contractor's challenge in this case was to add an air source heat pump system with new duct work to all rooms. Potential location of the new air handler was limited to the end of the basement between existing water tanks and a planned future outdoor entrance to the basement. The location of the air handler required that the main supply and return air trunk ducts be located on the side of the beam opposite the "L" extension of the basement, requiring installation of a secondary supply air trunk. Other challenges were presented by an existing fireplace foundation, stairwell opening, wiring, plumbing and a 5" deep steel beam spanning the junction of the "L" to the main basement. Even though the new heat pump system contains electric resistance back-up heating elements, the homeowner opted to maintain the original electric baseboard heating as back-up.

The owner was interested in having air conditioning for the summer months and decided on an air source heat pump to handle the cooling needs as well as look after their heating needs for much of the winter. The home owner in this case decided to install the new variable speed motor technology.

The contractor completed the installation work in the early fall of 2003. At the time of writing this report, the home owner has not been through a cooling season and was in the first heating season. The contractor has been responding to comfort concerns expressed by the home owners. Although the contractor has established the house to be warm, the home owner expressed dissatisfaction about a draft past favorite sitting areas. The contractor continues to make revisions to the return air system, adding branches left out of the original installation, but which were included in the detailed duct design.

House Measurement and Preparation of Plan

Measurements were taken and floor plans were prepared to form a basis for heat loss calculation. Floor plans can be found in Appendix C.

Calculation of Heating/Cooling Loads

Heating and cooling load calculations were performed using Right-Suite Canada. Results of the calculations are included in Appendix C. Design condition loads were calculated to be 60368 Btuh for heating and 23961 Btuh for cooling. A copy of the computer printout is attached in Appendix C.

Comparison of Design Condition Loads Calculations and Contractor Estimates

The contractor estimated that meeting the heating and cooling loads would require a 2.5 ton heat pump with a 20 kW electric resistance back-up system. Based on the detailed design condition calculations, the recommended installed size would be 20 kW or 68260 Btuh of electric heat and 2 tons of cooling. The contractor installed the initially estimated equipment.

Comparison of Installed Equipment Capacities to Design Condition Loads

According to detailed calculations mentioned above, the 68260 Btuh output of the 20 kW electric back-up is within the 40% over-sizing limit recommended in heating standards. The 2.5 ton heat pump has a cooling output of approximately 30000 Btuh, is on the 25% limit above the Btuh requirement estimated by the detailed design condition heat gain calculations.

Comparison of Contractor Installed Duct Sizes with Sizes Resulting from Detailed Design

Duct sizing calculations were performed using the manual calculation method presented in the HRAI Residential Air System Design manual. The calculations were based on an airflow of 900 cfm. This was based on 450 cfm per ton delivered ton of cooling, for a 2 ton heat pump, as the actual delivered output per ton was not known at time of design. A copy of the manual calculation is attached in Appendix C.

In the detailed design, supply branch duct sizes vary from 3 to 6 inches in diameter. All branch ducts installed by the contractor were 6 inch, except one 5 inch diameter. The main supply trunk duct size in the detailed design was 24"x8", reducing to a 20"x8", and to 11"x8". The supply trunk duct installed was 16"x8", reducing to a 14"x8", and to a 10"x8". The secondary supply trunk duct installed was 12"x8", reducing to an 8"x8".

The following Table 1 - H3 draws comparison between the available cross sectional area of supply ducts selected in the detailed design and those installed by the contractor. Table 2 - H3 draws a comparison between the available free area of the diffusers selected by detailed design and those installed by the contractor.

Table 1 - H3
Available Free Area Comparison
Cross Sectional Area of Supply Ducts

Detailed Design Area

Duct Dia.	Quan.	@	Sq. In.	Area	Sq. In.
3	1	@	7.1	7.1	Sq. In.
4"	2	@	12.5	25	Sq. In.
4.5"	3	@	16	48	Sq. In.
5"	5	@	20	100	Sq. In.
5.5"	3	@	24	72	Sq. In.
6"	3	@	28	84	Sq. In.
Available Free Area				336.1	Sq. In.

"As-Built Area

Duct Dia.	Quan.	@	Sq. In.	Area	Sq. In.
5"	1	@	20	20	Sq. In.
6"	13	@	28	364	Sq. In.
Available Free Area				384	Sq. In.

Table 2 - H3
Available Free Area Comparison
Supply Diffuser Free Area

Detailed Design Area

Size	Quan.	@	Sq. In.	Area	Sq. In.
4X10	16	@	24	384	Sq. In.
2 1/4X10	1	@	13	13	Sq. In.
Available Free Area				397	Sq. In.

"As-Built Area

Size	Quan.	@	Sq. In.	Area	Sq. In.
4X10	11	@	24	264	Sq. In.
None	3	@	28	84	Sq. In.
Available Free Area				348	Sq. In.

The detailed design for the return side called for branch sizes between 5 and 7 inches in diameter. The contractor actually "panned" in the joist spaces, which could accommodate higher airflow. There was one exception, a 6" return-air branch duct was used from the Master Bedroom. The main return-air trunk duct size in the detailed design was 24"x8", reducing to a 20"x8", and to an 11"x8". The installed return-air trunk duct is 20"x8" for its full length to a tapered end section as shown in the photographs. The return-air drop was installed as 16"x18". See cross sectional area comparison as follows in Table 3 - H3.

Table 3 - H3
Available Free Area Comparison
Cross Sectional Area of Return Ducts

Detailed Design Area

Duct Dia.	Quan.	@	Sq. In.	Area	Sq. In.
5"	4	@	20	80	Sq. In.
6.5	5	@	33	165	Sq. In.
7"	3	@	38	114	Sq. In.
Available Free Area				359	Sq. In.

"As-Built Area

Duct Dia.	Quan.	@	Sq. In.	Area	Sq. In.
"pan"	5	@	134	670	Sq. In.
6"	1	@	28	28	Sq. In.
Available Free Area				698	Sq. In.

** "pan": 2" x 10" joists @ 16" o.c.

Nominal 4"x10" supply air diffusers were selected by design and were also installed by the contractor. The detailed design showed six 6"x10" return air grilles on the main floor and three in the basement. The detailed design also showed and three 6"x8" return air grilles on the main floor. The contractor installed 6 return-air grilles, four were 4"x10" (supply diffuser), one was a 10"x12" floor grille and the other was a 6"x24" floor grille. Floor plans showing duct and grille sizes as per design are contained in Appendix C. See available free area comparison as follows in Table 4 - H3.

Table 4 - H3
Available Free Area Comparison
Return Grille Free Area

Detailed Design Area

Size	Quan.	@	Sq. In.	Area	Sq. In.
6X8	3	@	40	120	Sq. In.
6X10	9	@	52	468	Sq. In.
Available Free Area				588	Sq. In.

"As-Built Area

Size	Quan.	@	Sq. In.	Area	Sq. In.
4X10	4	@	24	96	Sq. In.
10X12	1	@	101	101	Sq. In.
6X24	1	@	119	119	Sq. In.
Available Free Area				316	Sq. In.

** Truss Steel Floor Grilles used in Detailed Design

** Truss Steel 10x12 and 6X24 Floor Grilles used in As-Built

** Pressed Steel 4X10 Supply Air Diffusers used in As-Built

Measurement of Air-Flows

Air-flow measurements are presented in Tables in Appendix C. Measurements were recorded using a 6" diameter saddle style flow collar inserted into round branch ducts and a digital manometer. Air-flow measurements were also made using a hood equipped with a 4" or 6" diameter round flow collar, placed over supply and return grilles. A Report of comparative test completed on the air flow measurement equipment used in the project is included in Appendix D. Photographs illustrating the flow measuring equipment are contained in Appendix D.

It will be noted the airflow volumes recorded through the use of a hood are significantly lower than values recorded through use of the flow collar insert into the duct. Reasons for these differences are discussed in the "Conclusions" section of this report.

As can be observed in the photographs, joints in branch ducts as well as those in the main trunk ducts have been sealed. In the return-air system, main trunk ducts have been sealed, although metal panning has not been sealed to the joists, and end blocking has not been sealed. It is suspected resistance to return air flow caused by fewer return grilles increases leakage into the system through unsealed end blocking of panned joist spaces.

Air-Handler Capacity

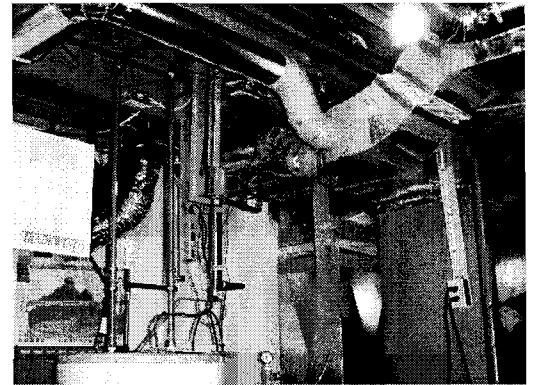
Measurements were taken to determine the airflow capacity of the air-handler. This was done by measuring the temperature rise through the air-handler with the system operating on back-up electric heating. Using the formula: $CFM = BTU / \text{Temperature Rise} \times 1.08$; the calculation indicated air flow capacity of 1350 cfm.

The average return-air temperature was 70.4 F., and the average supply temperature measured 117.26 F, resulting in temperature rise of 46.86 F.. The temperature rise used in the detailed design was 70 F., with a 20 kW electric back-up with an output of 68,280 Btuh.

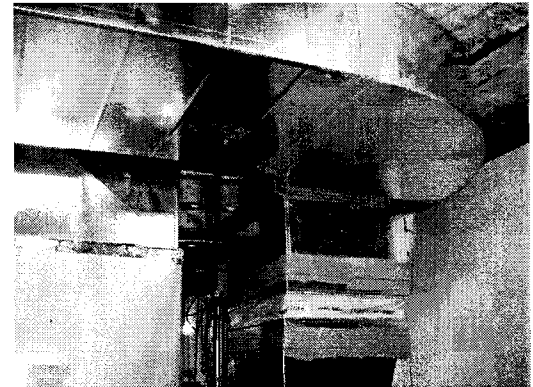
Photographic Record of Solutions & Challenges Encounters On Site

Photographs identified in observations below, and presented in a reduced form, can be seen in full size format in Appendix C.

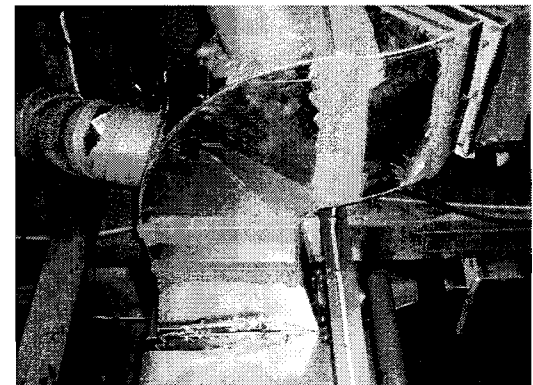
Picture, H3,001.jpg, shows the air-handler located near the end of the basement next the water heater and the central load bearing beam. The return-air drop can be seen between the air handler cabinet and the wall. Also seen in the foreground is a secondary supply trunk serving several spaces on the side of the beam opposite the main supply trunk.



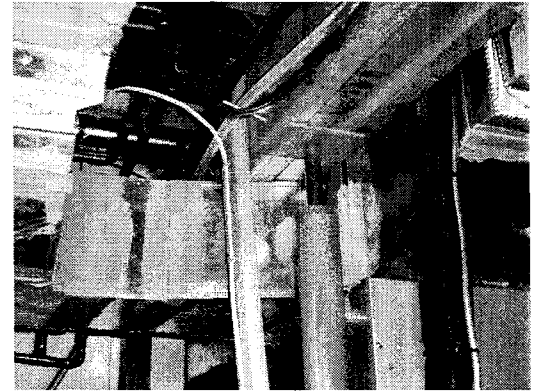
Picture, H3,002.jpg, shows the 20"x8" return-air trunk turning to the back of the air-handler and connecting to the 16"x18" drop. The vibration isolation collar and sealant of trunk joints can be seen.



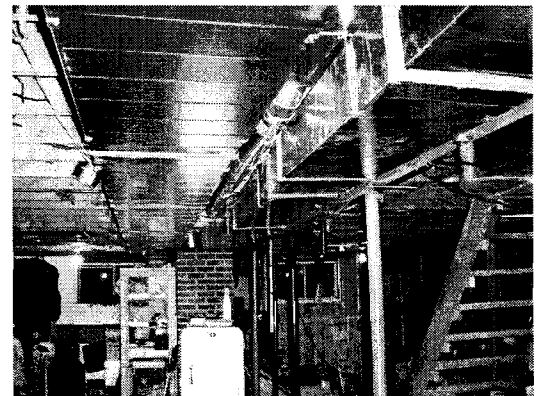
Picture, H3,003.jpg, shows the secondary supply-air trunk passing beneath the beam, and the take-off to the center bedroom and bathroom. Note sealant and vibration isolation collars.



Picture, [H3,004.jpg](#), shows another view of the secondary supply-air trunk connection to the main plenum. Notice the restricted distance from top of air-handler to underside of beam.



Picture, [H3,005.jpg](#), shows the main return-air (left) and supply-air (right) trunks extending along the basement. The foundation for the brick fireplace can be seen in the path of the main trunks. The stair opening can be seen to the right. The load bearing beam and steel posts can be seen next to the warm-air trunk.



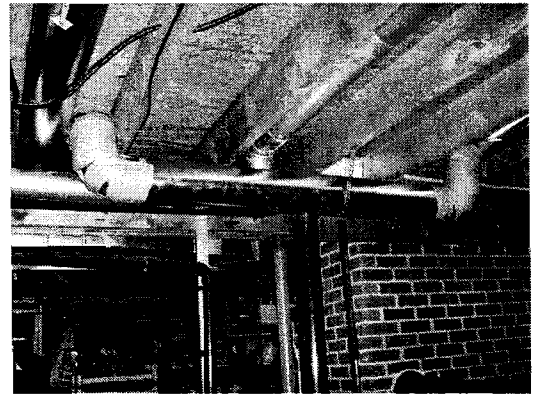
Picture, [H3,006.jpg](#), shows the tapered end on the return-air trunk, used by the contractor to extend the return-air far enough to pick up the floor return-air grille from the living room. The taper was also necessary to enable continuation of the 10"x8" supply trunk.



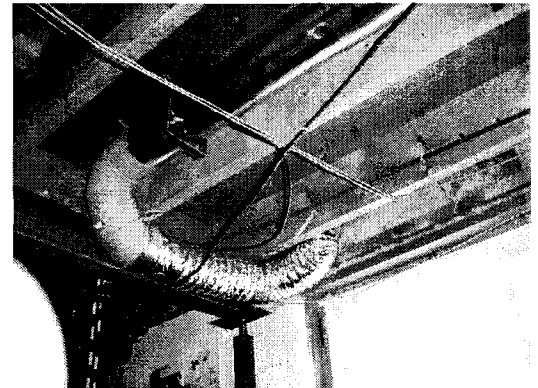
Picture, [H3,007.jpg](#), shows the secondary supply-air trunk as it passes beneath the 5" deep steel beam at the junction of the "L" portion to the main rectangle of the basement. The return-air branch from the master bedroom is also visible as it passes beneath the same steel beam and connects to a section of panned joist. It is noted the panned joist is not sealed, nor is the joint between the joists and the floor sheathing which create the upper portion of the panned space. Also note the change in joist direction.



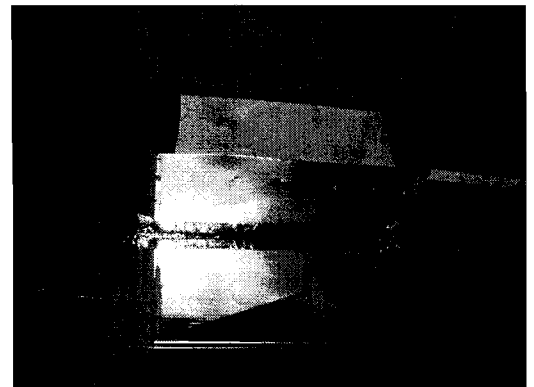
Picture, H3,008.jpg, shows a supply-air branch to the livingroom which connects across and above the center beam, elbows down and extends parallel to the beam and elbows up into floor joist space to extend out to perimeter wall.



Picture, H3,009.jpg, shows the supply-air branch to the bathroom. The contractor kept the branch duct away from the basement window and used a section of flexible duct. This was the only 5" diameter branch to be installed.



Picture, H3,010.jpg, shows a typical section of panned joists with a wooden end block. Although aluminum foil tape was used to seal the pan to the main trunk, no sealant was used between the pan and joist and the end block was also left unsealed.



CONCLUSIONS

The heating retrofit market presents many more challenges to the heating contractor than those faced in new construction. Challenges of a structural system assembled without consideration for the installation of a duct system, results in many more fittings. Other challenges include limited access to portions of the house due to finished ceilings, lack of space to accommodate the mechanical system and in the case of House Two, radiant ceiling panels and insulation.

There is the challenge of client perception. Some early feedback indicated client awareness of air movement (past favorite sitting area, for example) where previously none was felt. This draws attention to the fact that, in a new house unlike in a retrofit, the occupant has no prior experience with respect to how the house operates. The client may be much more prepared to accept such sensations of air movement in a new house, but be more critical of such following a retrofit.

Duct sizing calculations were based on the design heating/cooling loads except in one case where the cooling output of the system was known. The contractor tended to oversize on both heating and cooling equipment. The contractor usually oversized on the supply branch ducts, selecting a single diameter rather than varying sizes as per design; however trunk duct sizes were usually undersized on both supply and return. The return system was consistently undersized with fewer return branches, and smaller grilles installed than were suggested in the detailed design. An observation of the detailed duct sizing calculations, attached for each house, indicates that one square inch of free area is required for each 2.5 and 2.7 cfm of return air. Contractors are not generally aware of the need to provide a larger free area for air flowing at lower velocity and pressure through a return grille.

Measurements and calculations at the air handler confirm airflow were within range of those expected for the size of the equipment installed; however, these were much higher than the total of airflow measurements collected at branches and grilles. Supply airflow measurements collected do not match return air flows. Air flows measured using the saddle style flow collar do not correlate well with air flows measured using the capture hood placed over a grille. It will be noted the airflow volumes recorded through the use of a capture hood are significantly lower than values recorded through the use of the flow collar inserted into the duct.

Capture hoods of the type used provide a reasonably accurate indication of air flow through a grille. However, the back pressure the hood imposes at the grille causes the air flows to re-balance. This can result in a significant reduction in airflow through the grille being tested. The act of measuring the airflow changes the airflow. It is expected that this impact will be much more significant for multi-duct systems (e.g. forced air heating supply ductwork) than for a single duct system (e.g. a dedicated exhaust fan). Even though the methods of measurement are industry approved and used in R-2000 commissioning, the variation in airflow measurements observed reduces ones confidence in the indicated results and the methods used for measuring.

Air leakage into/from ducts is also a contributing factor in this difference. Attempts to seal ducts were not consistent through each test house.

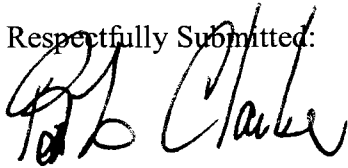
A report by Bert Phillips, P.Eng., MBA, on comparative testing completed on the air flow measurement equipment used in the project is included in Appendix D.

The contractor has not provided costing data, but has indicated no specific costing factor was used, each project was estimated based on issues presented. Houses One and Three were judged to be very straightforward; however, House Three has resulted in a higher than usual rate of callback. House Two was estimated higher

primarily due to the challenges presented by slab on grade structure and limited use of ceiling spaces and lack of conditioned space to accommodate new equipment.

Although training programs exist through HRAI, and recently NRCan has offered cash incentives to encourage contractors to take these courses, there is little incentive for contractors to follow through with use of the detailed duct sizing design methods. There is also a lack of consumer awareness of the benefits of detailed heat loss/heat gain and design calculations that could be performed by their heating contractor. Further, there is a lack of awareness by the consumer that the contractor is not using such detailed support calculations.

Respectfully Submitted:

A handwritten signature in black ink, appearing to read 'Bob Clarke', written over the typed name.

R.G. (Bob) Clarke, CET
President,

R. CLARKE Designs Ltd.

3 Sheffield Court

Oromocto, N.B. E2V 2N1

Tel: 506-357-3377

Fax: 506-357-3378

e-mail: rclarke@nbnet.nb.ca

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