STUDY OF RESIDENTIAL VENTILATION DUCT ENERGY LOSSES

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EXECUTIVE SUMMARY

This report presents the findings of a study undertaken to investigate the impact of energy transfer from a conditioned air space into the ductwork of a residential heat recovery ventilator. The study was undertaken because some of EMR's field testing indicated poor performance for installed HRV systems. This work was intended to investigate whether poor installation practices could significantly deteriorate the performance of heat recovery equipment.

The study identifies typical installed duct configuration and quantifies the performance effects of energy losses to the HRV ducting system. The report introduces the term Sensible Heat Recovery System Efficiency which adjusts for duct energy losses. This term is equivalent to the commonly used "system efficiency" often used in field monitoring reports, since the energy efficiencies are based on indoor and outdoor temperatures. Using the new terminology, a typical ductwork and HRV would have its -25°C performance rating reduced from 59% for the baseline case to 50% for the "best" ducting system tested, and to 41% for the "worst" ducting system tested. For 0°C ratings, the corresponding values are: 83% baseline, 75% "best" case and 71% "worst" case.

Development and incorporation of appropriate duct energy losses into the procedure, HOT 2000 software, are recommended.

RÉSUMÉ

Le présent rapport décrit les résultats d'une étude portant sur les conséquences d'un transfert d'énergie d'un espace à air conditionné dans le réseau de conduits d'un échangeur de chaleur résidentiel. L'étude a été entreprise parce que certains essais sur le terrain réalisés par EMR ont mis en évidence une mauvaise performance des échangeurs de chaleur installés. Le but de ce travail était d'examiner si de mauvaises techniques d'installation pouvaient réduire de façon notable la performance des échangeurs de chaleur.

La configuration classique des conduits installés a été déterminée et les effets des pertes d'énergie vers le système de conduits de l'échangeur de chaleur sur la performance ont été quantifiés. Le *pouvoir de récupération de la chaleur sensible* est un paramètre qui a été introduit pour tenir compte des pertes d'énergie dans les conduits. Ce terme est équivalent au paramètre appelé "rendement du système", couramment utilisé dans les rapports de surveillance sur le terrain, puisque les rendements énergétiques sont basés sur les températures intérieure et extérieure. Avec la nouvelle terminologie, un échangeur de chaleur et un système de conduits ordinaires verraient leur performance nominale à -25 °C réduite de 59 % dans la configuration de base à 50 % pour le "meilleur" système de conduits vérifié, et à 41 % pour le "pire" système de conduits. Les valeurs correspondantes pour les performances nominales à 0 °C sont les suivantes : 83 % pour la configuration de base, 75 % pour la "meilleur" configuration et 71 % pour la "pire" configuration.

Il est recommandé de déterminer et d'intégrer dans les calculs (logiciel HOT 2000) les pertes d'énergie dans les conduits appropriées.

1.0 INTRODUCTION

ORTECH International has undertaken an investigation into the energy losses associated with ducting for residential ventilation systems. This work was initiated due to data from field monitoring projects indicating HRV system efficiencies below expected levels. The same field data indicates energy gains and losses in the ductwork connected to the HRV and the conditioned space. It has been suspected that the overall energy performance of installed HRVs is greatly influenced by the connecting ductwork. The scope of this project was to undertake limited tests to investigate the energy losses associated with typical residential ventilation duct systems.

2.0 TECHNICAL DISCUSSION - Development of Testing Method

In order to quantify the energy gains and losses associated with HRV ductwork, the following steps were undertaken.

Step 1: Identify the sections of ventilation ductwork which impact the overall energy performance of an HRV.

Step 2: Determine the recommended and actual configuration of these sections.

Step 3: Determine the performance of these sections through laboratory simulations.

2.1 Definition of Terms

The performance of an HRV is defined in the CAN/CSA Standard C439-88, "Standard Methods of Test for Rating the Performance of Heat Recovery Ventilators". Field monitoring data focusses on sensible heat recovery; therefore to evaluate the HRV we refer to Section 9.3.3.1 of the Standard.

$$E_{shr} = \frac{(M_{si} \times C_p \times (t_{5i} - t_{1i}) \times T) - Q_{sf} - Q_{sh} - Q_c - Q_d}{(M_{maxi} \times C_p \times (t_{3i} - t_{1i}) \times T) + Q_{ef} + Q_{eh}}$$

where:

E_{shr}	=	sensible heat recovery efficiency
M_s	=	mass flow rate of air measured at Location 2, kg/s
i	=	i^{th} time that data are recorded
C_p	=	specific heat of air, 1.0 KJ/kg·K
t_5	=	net supply airflow temperature at Location 2, °C, before mixing with air from the exhaust stream (as calculated in Clause 9.3.3.7 of CSA C439)
t_1,t_3	=	dry bulb temperature at Locations 1 and 3 respectively, °C
T	=	time interval represented by i'th reading, seconds
Q_{sf}	=	energy input into supply airstream attributed to fan(s), KJ
Q_{sh}	=	energy used by heater in supply airstream, KJ
Q_c	=	casing heat gain, as calculated in Clause 9.3.3.4, KJ
Q_d	=	defrost energy use, as described in Clause 9.3.3.5, KJ
M_{max}	=	maximum of M_s or M_e
Q_{ef}	=	energy input into exhaust airstream attributed to fan(s), KJ
Q_{eh}	=	energy used by heater in exhaust airstream, KJ

Temperature locations are identified in Figure 1.

To evaluate the HRV and ductwork performance as a system, parameters in the equation must be reviewed. In laboratory rating tests, measurements are taken at all four of the HRV inlet and outlet collars for temperature, humidity ratio, airflow and static pressure. Air leakage between the exhaust stream and supply stream is also measured, and performance ratings are then calculated. These laboratory ratings do not include the effects of energy transfer to and from the duct systems.

However, energy losses and gains from a conditioned space to the warm side ductwork of a ventilation system would have only minor net impact in a residential energy balance. The energy impact of the cold side ductwork would affect both the heating load of the residence and the energy recovery in the HRV, since the temperature difference across the HRV will be affected.

The sensible heat recovery of an HRV system can be adjusted to include the effects of this energy transfer to the ductwork. The potential flow of energy is indicated in Figure 1. Any energy gains in the cold supply ductwork act as a preheater. In the standard equation, a term for cold supply ductwork energy gain, Q_{cs} could be included.

Any energy gains in the cold exhaust ductwork would be lost from the structure to the exhaust airstream and impose an additional space heating energy requirement. In the equation, a term for cold exhaust ductwork energy gain, Q_{ce} could be included.

Therefore to evaluate the effects on sensible heat recovery caused by the ventilation ductwork, the equation for determining the above for an installed HRV system may be changed. The equation for Sensible Heat Recovery System Efficiency, E_{shrs} would then become:

$$E_{shrs} = \frac{(M_{si} \times C_p \times (t_{5i} - t_{1i}) \times T) - Q_{sf} - Q_{sh} - Q_c - Q_d - Q_{cs} - Q_{ce}}{(M_{maxi} \times C_p \times (t_{3i} - t_{1i}) \times T) + Q_{ef} + Q_{eh}}$$

where Q_{ce} = cold exhaust duct energy losses
Q_{cs} = cold supply duct energy losses

Figure 2 illustrates the section of ventilation ducting to be evaluated as having an impact on total system energy recovery performance. It should be noted that the performance of an HRV is affected by the mass airflow balance of the supply and exhaust air passing through it. The impact of imbalance is quantified by the M_{si} over M_{max} term. For the purpose of this investigation balanced airflows will be assumed.

2.2 Identification of Ducting Characteristics

Having identified the cold supply and exhaust ducting as critical to ventilation performance, the next activity was to determine typical characteristics of this ducting.

This was done by a review of manufacturers' recommendations and actual installation practices. The Heating, Refrigeration and Air-Conditioning Institute of Canada's "Installation Manual for Residential Mechanical Ventilation Systems", 1991 edition and the Home Ventilating Institute's "Installation Manual for Heat Recovery Ventilators", 1990 edition were also reviewed.

The recommended installation practices were found to be consistent. In summary, they suggest the following:

duct run	as short as possible
duct diameter	sized for required ventilation airflow
duct sealing	tape or caulking
Number of bends	as few as possible
insulation	minimum R4 (RSI 0.5)
duct type	preformed ridged or optionally flex duct
vapour barrier	poly or metalized film on cold side ducting

Generally, recommended installation practices stressed keeping the duct resistance as low as possible and ensuring that there are no leaks in the system. Cold side ducting must be insulated and a vapour barrier applied over the insulation with care taken to ensure the continuity of the vapour barrier. A minimum insulation level of R4 (RSI 0.5) is specified in the HRAI installation manual. Insulation and airtight vapour retarding membranes are primarily specified to prevent condensation on or in ductwork. So, as an HRAI guideline in absence of a specific R value, a minimum duct surface temperature of 14°C is recommended to prevent condensation.

To determine the actual installation practices of installers, several steps were taken. First, HRAI was contacted for a list of certified ventilation system installers. Installation of HRV's by a certified installer was an R2000 home registration requirement. From the list of over 600 installers a random sampling was picked from across Canada.

A total of 53 installers were contacted of whom 15 replied. The results of the survey are summarized in Table 1, Appendix A. The data were reviewed to determine "typical" cold side ducting on HRVs. It was found that two basic categories of systems are used. One utilizes flex ducting and the other uses rigid steel ductwork. In both systems other characteristics were the same. The typical system, according to the installers, is identified in Table 2.

TABLE 2

Characteristics of Typical HRV Cold Side Ducting

Type of Duct	Insulated Flexible Duct with Integral Foil Vapour Barrier
Diameter of Duct	6 inches
R-Value	6 (see note)
Insulation Thickness	1 inch fiberglass
Length of Duct from Unit to Outside Wall	10 feet
Distance between Supports	4 feet
Airflow of HRV	175 cfm (see note)
Number of Bends/Elbows	4
Type of Joint Sealing	Duct Tape / Caulking

Note: The information in this table is interesting. The installers believe that the systems have R6 insulation value with 1" fiberglass. Manufacturers claim an R value more like R4 for 1" fiberglass, which is the most common thickness used. Similarly, the claimed installed flow rate of 175 cfm also appears suspiciously high.

For laboratory test purposes, the typical system characteristics were simulated using 6 inch steel ductwork with insulating pipe sleeves and metalized foil backed insulated flex ducting. Appendix C contains a manufacturer's description of the insulated pipe sleeves (NFX60) and flexible duct (NFX30) used in the simulations. An additional simulation using rigid duct with no insulation was also conducted. This approximates a worst case installation where perhaps a poor vapour barrier had allowed water to soak the insulation. Figures 4 and 5 represent the various flexible and rigid ducting configurations selected for simulation.

As part of the test matrix, an appropriate range of airflow and temperatures had to be defined. By reviewing ORTECH's historic HRV performance test data with 0°C to -40°C outdoor temperatures, the following was found. Most HRVs had a cold exhaust discharge temperature between +10°C to -10°C. Cold supply temperatures (at outdoor vent) would be those used for typical performance rating test purposes (i.e. -25°C, -40°C)

2.3 Laboratory Test Matrix

Using typical cold side ventilation ducting characteristics, ORTECH's HRV test and development facility was modified as in Figure 3. The following is the final test matrix.

Test Matrix

Duct	Configuration	Temp (°C)	Airflow (L/s)
Insulated flex duct with metalized vapour barrier	10 ft straight, no sags	- 40 to + 10	30 to 75
Insulated flex duct with metalized vapour barrier	4, 90° bends 4 ft between supports 10 ft total straight sections	- 40 to + 10	30 to 75
Steel duct with insulation, poly vapour barrier	10 ft straight	- 40 to + 10	30 to 75
Steel duct with no insulation	10 ft straight	- 40 to + 10	30 to 75
Steel duct with insulation, poly vapour barrier	10 ft straight, total 4 - 90° elbows	- 40 to + 10	30 to 75
Steel duct with discontinuous vapour barrier	10 ft straight, total 4 - 90° elbows	- 25	55

Based on these tests, values for typical cold exhaust and supply energy losses were determined.

3.0 RESULTS

The results were analyzed to identify duct heat gain and static pressures for the various configurations tested.

The appendices contain tabulated and plotted test results.

Some general results were obtained from the test matrix. Initially it was observed that there were only marginal differences in duct energy gains between the flexible and rigid ducts when both were insulated at the same level.

A comparison of the energy gains recorded for the various straight duct configurations is given below:

10 ft Straight Duct Energy Gains

Supply Temp. °C	Airflow Nominal L/s	Energy Gain (Watts)		
		Rigid No Insulation	Rigid Insulated	Flexible Insulated
- 25	30	296	127	112
	55	355	135	165
	75	394	171	150
- 10	30	164	112	90*
	55	212	116	128
	75	256	164	134

* interpolated from Figure 11a, Appendix B

Secondly, it was observed that the configuration of the duct (i.e. number of bends or elbows) had minimal effect on the energy gains at constant airflows. This is best illustrated in Figure 9A (Appendix B), Flexible Duct Heat Gains, in three configurations.

The heat gain of the uninsulated rigid duct can be viewed as a 'worst case' for energy gain.

A comparison was also done of the static pressures resulting from the different rigid and flexible duct configurations. In general it was found that in straight configurations the flex duct would produce approximately two times the static pressure of the rigid duct. In configurations with bends or elbows, the flexible duct had about one and one-half times the static pressure. A larger bend radius in the flex duct may possibly account for a lower static pressure ratio in the rigid duct than found in straight configurations.

In addition to bends, the flexible duct was configured straight with sags to simulate bad installation practices. With sags, the flex duct had approximately four times the static pressure of the rigid duct.

The following is a table of the test results:

Comparison of Duct Static Pressure (Pascals)
for 10 ft Lengths

Airflow L/s	Straight Duct Configuration		
	Rigid	Flexible	Flexible with Sags
30	1	2	4
55	3	7	15
75	6	12	27

Airflow L/s	Rigid 4 - 90° Elbows	Flexible 3 - 90° Bends
30	5	7
55	17	24
75	30	47

A plot of the test results may be found in Figures 5a and 10a, Appendix B.

An additional duct configuration was chosen to simulate a poor installation of an HRV. The rigid duct, insulated with 4 elbows, was used at -25°C and 55 L/s. The vapour barrier was slit at all joints. Over a three day period the supply air temperature was changed between -25°C and +15°C to promote moisture formation in the insulation. At the end of the test a heat gain in the duct of 178 watts was recorded vs a 135 watt gain with the vapour barrier intact.

4.0 CONCLUSIONS

The test matrix results indicate that for a given insulation level, combined with an effective vapour barrier, duct energy gains can be expected to be the same for different duct configurations of approximately equal length. It was also seen that the effectiveness of the vapour barrier can have a significant impact on energy gains.

This may be an important factor, based on limited observed actual installations which showed considerable moisture permeation of the insulation.

A typical HRV was chosen to evaluate the effect of the cold side duct energy gains at both -25°C and 0°C.

A previously tested 55 L/s plate type unit operating at -25°C and 0°C entering temperature had the following performance, totalized over a 12 hour period in ORTECH's Laboratory:

	-25°C	0°C
Sensible Energy Recovered	83,786 KJ	58,152 KJ
Sensible Energy Exhausted	126,456 KJ	63,468 KJ
Supply Fan Energy	3,113 KJ	2,926 KJ
Exhaust Fan Energy	3,113 KJ	2,926 KJ
Defrost Energy	4,685 KJ	0°C
Cold Supply Temperature	-25°C	0°C
Cold Exhaust Temperature	-3°C	8°C

From this data, we can calculate:

	-25°C	0°C
Net Energy Recovered	75,989 KJ	55,226 KJ
Net Energy Exhausted	129,568 KJ	66,394 KJ
Sensible Recovery Efficiency E_{shr}	= 59%	= 83%

From the test matrix, cold side duct energy gains, KJ over 12 hours amount to:

	-25°C		0°C	
	Best Case	Worst Case	Best Case	Worst Case
Supply	7,128 KJ	15,336 KJ	3,758 KJ	5,400 KJ
Exhaust	4,320 KJ	7,360 KJ	1,555 KJ	2,549 KJ

Using a simplified analysis procedure, we can estimate the Sensible Heat Recovery System Efficiency as follows:

@ -25°C

Without Duct System Adjustment, $E_{shrs} = \dfrac{75,989 \text{ KJ}}{129,568 \text{ KJ}} = 59\%$

With "Best Case" Duct System, $E_{shrs} = \dfrac{(75,989 - 7,128 - 4,320) \text{ KJ}}{(129,568) \text{ KJ}} = 50\%$

With "Worst Case" Duct System, $E_{shrs} = \dfrac{(75,989 - 15,336 - 7,560) \text{ KJ}}{(129,568) \text{ KJ}} = 41\%$

@ 0°C

Without Duct System Adjustment, $E_{shrs} = \dfrac{55,226 \text{ KJ}}{66,394 \text{ KJ}} = 83\%$

With "Best Case" Duct System, $E_{shrs} = \dfrac{(55,226 - 3,758 - 1,555) \text{ KJ}}{66,394 \text{ KJ}} = 75\%$

With "Worst Case" Duct System, $E_{shrs} = \dfrac{(55,226 - 5,400 - 2,549) \text{ KJ}}{66,394 \text{ KJ}} = 71\%$

The Sensible Heat Recovery System Efficiency can be viewed as the portion of sensible space heating energy associated with the ventilation airstream, which is recovered by the system. Note that the system efficiency and normally quoted sensible recovery efficiency are identical, before adjustment for the duct system energy flow.

5.0 RECOMMENDATIONS

During the course of this project, test data were generated which suggest that typical HRV system installations are subject to sufficient heat transfer through the cold side ducting to have a significant effect on their energy performance.

Furthermore, testing suggests that the energy loss into the ducting may be mostly a factor of insulation level and length, regardless of number of bends or elbows.

This could lead to the development of a general per foot adjustment factor to be applied to the HRV performance. This factor could be based on cold supply and exhaust temperatures, R value and airflow rate.

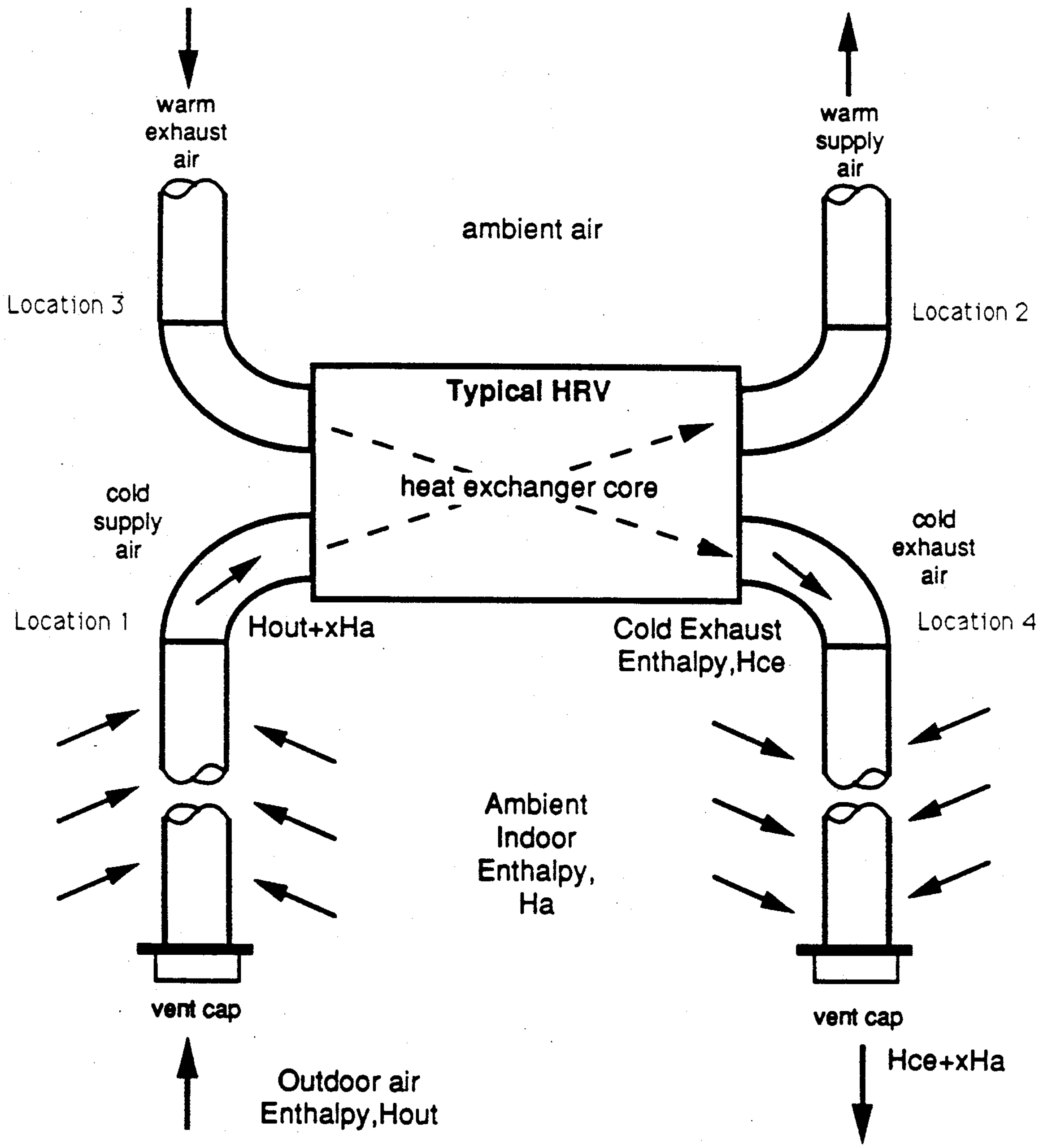
By applying the duct loss values, a more accurate estimation of energy savings attributed to the HRV may be developed.

Another recommendation results from setting up the various duct configurations. It was found that flex duct was much easier to install properly than the rigid duct. Particularly, if a continuous flex duct section is used from the HRV to the outdoor vent, the increased static resistance of flexible duct may be offset by a reduced chance of incontinuity in the vapour barrier. In other words, the energy impact of reduced airflow caused by the increased static pressures for the flex duct are offset by the reduced potential for thermal losses.

Finally, we recommend that appropriate correction factors be developed and incorporated into the HOT 2000 energy analysis program to adjust the HRV performance estimates for the effects of duct energy transfers.

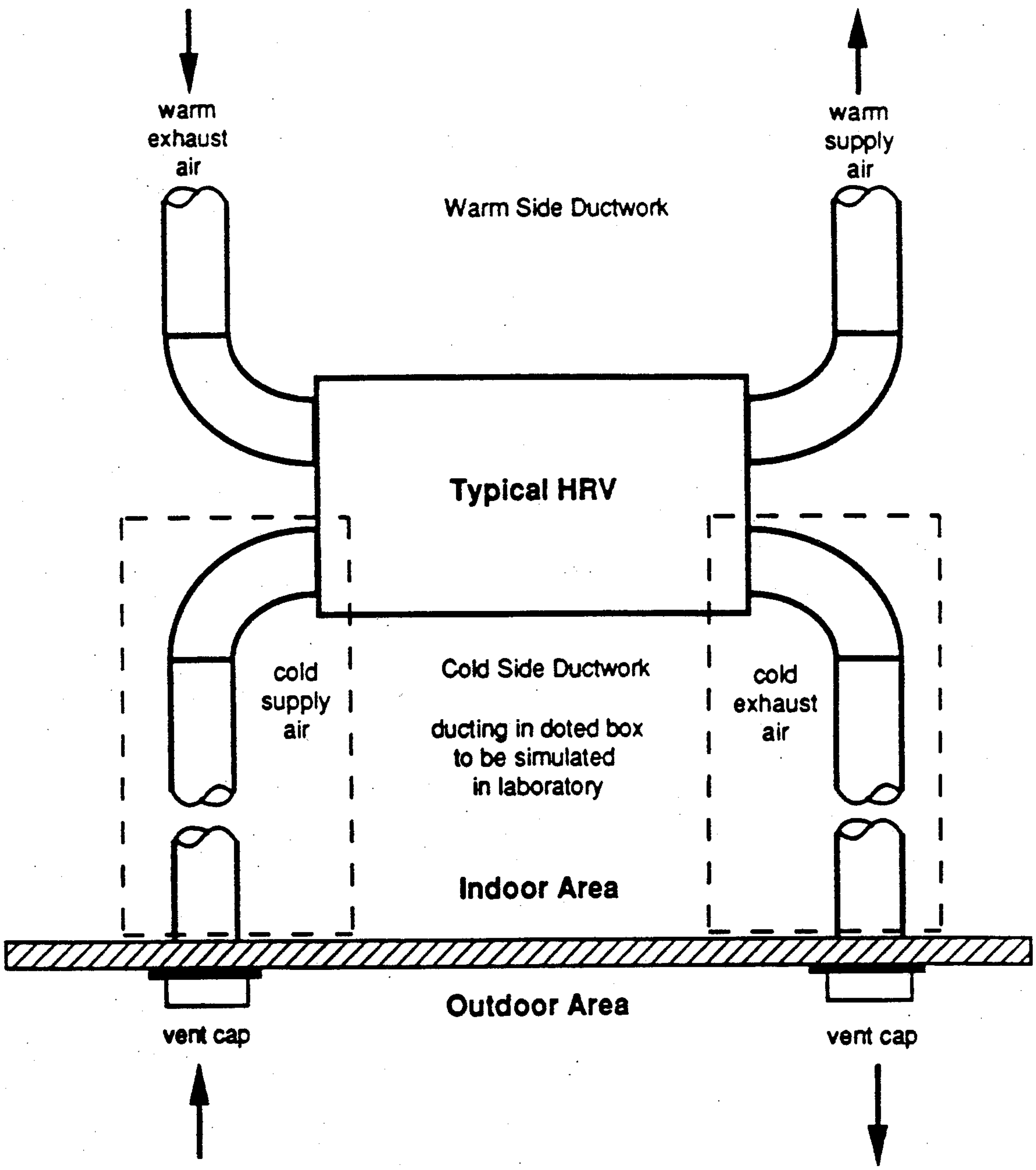
P. Edwards, Manager
HVAC Technologies

FIGURES



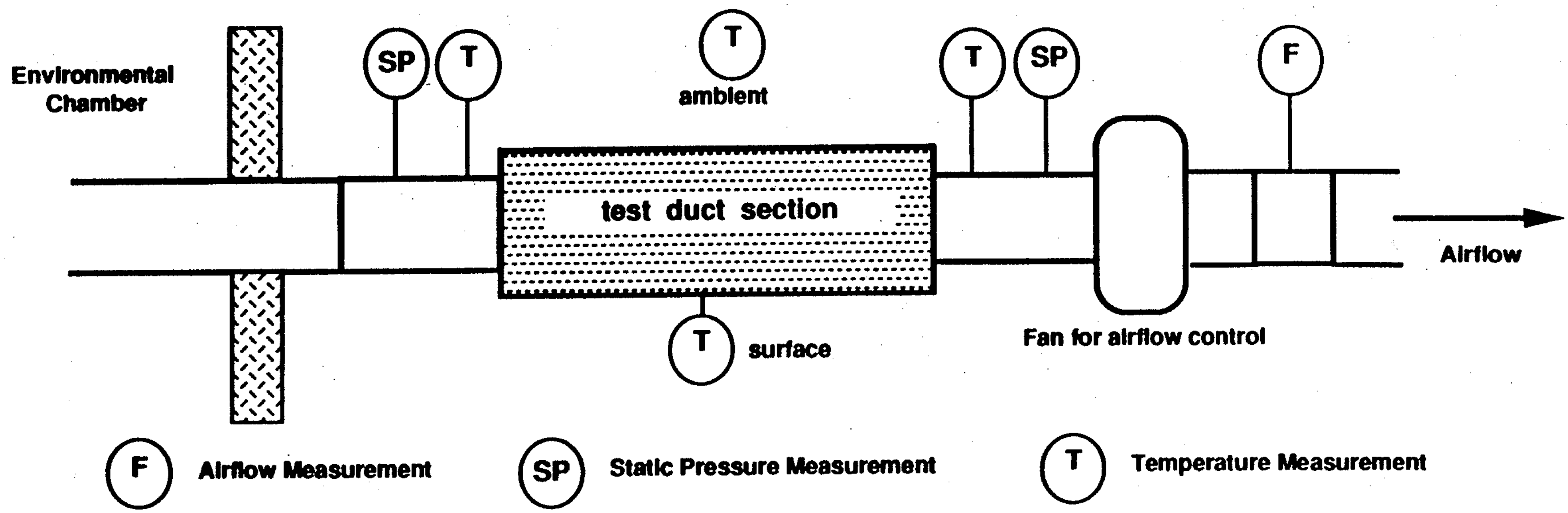
Residential Ducting Heat Loss Simulation
Energy Flow

Figure 1



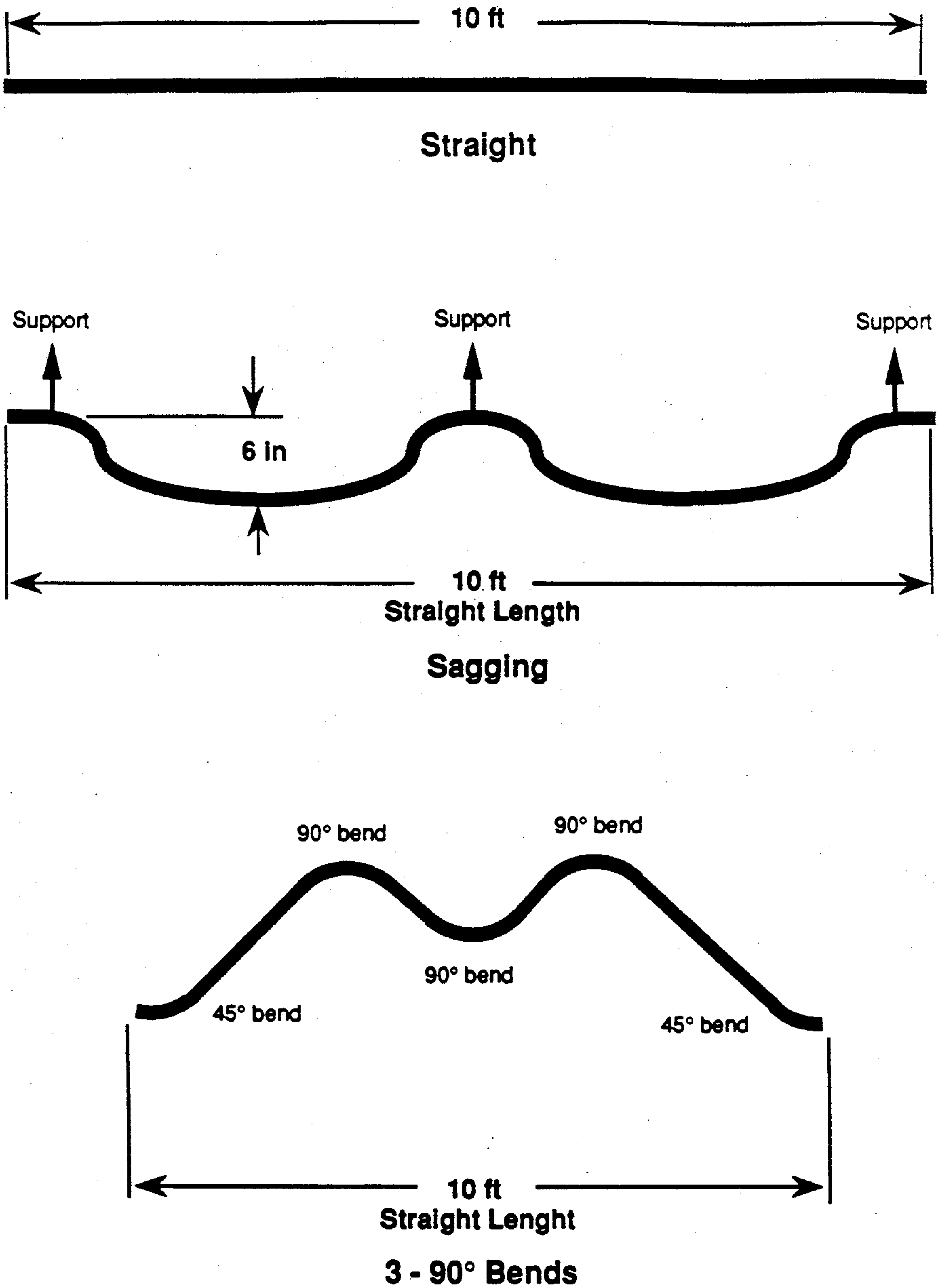
Residential Ducting Heat Loss Simulation
Critical Duct Locations

Figure 2



Simplified Facilities Setup, Residential Duct Energy Loss Simulation

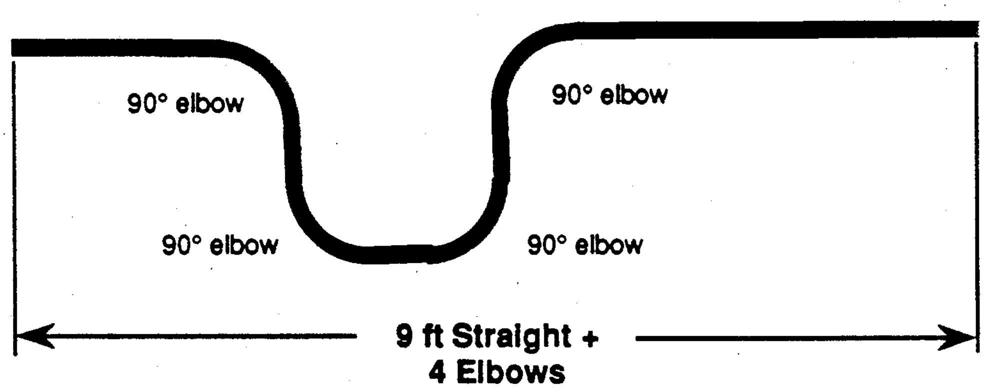
Figure 3



FLEXIBLE DUCT CONFIGURATIONS

Figure 4

Straight
(insulated with vapour barrier and uninsulated)



4 - 90° Elbows
(insulated with vapour barrier)

RIGID DUCT CONFIGURATIONS

Figure 5

APPENDIX A

Table 1 - HRV Cold Side Ducting Survey Results

Results of HRV Cold Side Ducting Survey

Brand name	Airflow CFM	Type of Duct	Size	Length feet	Insulation Brand	R-Value	Thickness	Number of Bends	Type of vap. Bar	Length Between supports(feet)	Type of Joints	Province
Vanee	150-200	Flex. Insulated	6-8	15-20	-	6-8	1.5	3	-	8	Duct Tape	Ontario
Carrier	150-250	Flex. Insulated	6-8	15-20	-	6	1	3	-	7-8	Duct Tape	Ontario
Venmar	150-350	Solid/Steel	6	10-15	Foil back	N/A	1	2	Alum. Foil	-	Duct Tape	Ontario
Lifebreath	100-140	Flex. Insulated	6-8	6-8	-	5-6	1	3	Alum. Foil	2-3	Taped	Ontario
Lifebreath	100-200	Flex. Insulated	6	-	-	6-8	1	2-3	Alum. Foil	2	Caulking	Manitoba
Lifebreath	96-100	Flex. Insulated	6	12-15	-	5	1	4	Alum. Foil	3	Caulking	Manitoba
Vanee	200-210	Flex. Insulated	6	4	-	6-8	1	4	Alum. Foil	8	Caulking	Saskatchewan
Vanee	200-240	Flex. Insulated	6-7	15-20	-	6-8	1	4	Alum. Foil	6	Caulking	Saskatchewan
Lifebreath	100-200	Galv. Steel	6	4-6	Fiberglas	6-8	1	2	Alum. Foil	N/A	Tape/Caulk	Alberta
Vanee	200	Flex. Insulated	6-8	5	-	6-8	1	4	Alum. Foil	2	Duct Tape	Alberta
Vanee	200	Flex. Insulated	6	6	-	5	1	1	Alum. Foil	2	Duct Tape	BC
Venmar	100-200	Mixed	7	6-8	-	5-6	1	6-10	Foil/poly	2-3	Duct. Tape	Newfoundland
Lifebreath	60-220	Flex. Insulated	6-8	7	-	6-8	1	4	Foil	3-4	Tape/Poly	Nova Scotia
Vanee	200	Flex. Insulated	6	15-20	-	5-6	1	2	Foil	1-2	Tape/Caulk	PEI
Lifebreath	100-200	Flex. Insulated	6-8	5-6	-	6-8	0.5	1-2	Foil	2-3	Screw/Tape	Newbrunswick

TABLE 1

APPENDIX B

Cold Side Ventilation Simulation Results

Table 1a: Tabulated Test Results

Supply Temp. °C	Ambient Temp. °C	Surface Temp. °C	Airflow L/S	Heat Gain Watts	Temp. Gain °C	Duct Static Pa
Rigid Duct, Insulated, Straight						
9.9	16.5	16.1	31	47	1.3	1
9.4	17.7	16	56	59	0.9	3
9.1	17.5	15.8	74	69	0.8	6
0	17.3	15.6	32	77	2.0	1
0.2	17.1	14.7	54	84	1.3	3
-0.3	16.8	15.1	75	142	1.6	6
-10.3	16.8	13.3	31	112	2.9	1
-9.3	16.5	13.1	56	116	1.7	4
-9.7	16.4	13	75	164	1.8	7
-24.4	17.8	12.3	30	127	3.4	1
-24.9	17.3	12.1	55	135	1.9	3
-24.3	17.6	12	74	171	1.8	6
-38.3	17.8	11.6	30	178	4.5	1
-39	15.8	9.5	73	117	1.2	6
-40.7	16.3	9.5	29	138	3.6	1
-39.1	16.7	9.9	54	159	2.2	3
-40.3	16.2	8.7	73	192	2.0	6
Rigid Duct, Uninsulated, Straight						
-10.7	19.4	7.6	31	164	4.4	1
-10.3	19.4	4.3	56	212	3.1	4
-10.4	19.7	2.9	76	256	2.7	6
-25.7	18.9	3.6	31	296	7.7	1
-26.1	18.9	-0.2	55	355	5.1	3
-25.6	18.3	-3.2	75	394	4.1	6
-40	18.4	0.3	30	411	10.7	1
-40	17.8	-6.1	55	476	6.6	3
-38.9	17.5	-8.6	74	486	5.0	7
Rigid Duct, Insulated, 4-90° Elbows						
-1.1	18.3	16.9	30	82	2.2	
-0.6	18.5	16.5	57	91	1.3	
-0.2	18.5	16.1	73	80	0.9	
-24.4	16.9	13.2	30	145	3.9	5
-24.2	17.6	13.2	53	144	2.1	17
-24.1	17.5	13.9	74	84	0.9	30
-39.9	17.2	11.1	31	135	3.3	
-40.6	17.7	12.4	54	156	2.2	
-38.7	17.7	12.2	75	79	0.8	
Flexible Duct, Straight						
9.9	20.0	18.4	74	18	-0.2	0
10.1	20.2	18.3	56	14	-0.2	0
10.3	20.4	18.5	30	0	0.0	0
0	20.1	16.7	30	75	2.0	2
0	20.2	16.1	56	87	1.3	7
-0.1	19.7	15.8	76	100	1.1	13
-24.4	19.9	12.3	29	112	3.0	2
-24.4	19.4	11.2	52	165	2.5	7
-25.2	18.9	10.3	74	150	1.6	12
-39.8	18.4	9	30	131	3.3	2
-40.6	18.3	7.7	53	146	2.1	6
-39.7	17.9	7.5	76	150	1.5	11
Flexible Duct, Sags						
-26.2	19.5	11.8	30	100	2.6	4
-26.5	19.4	11.5	55	146	2.1	15
-26.4	18.9	11.1	74	152	1.6	27
Flexible Duct, 3-90° Bends						
-26.2	19.2	10.7	31	115	3.0	7
-26.1	18.2	10.4	53	114	1.7	24
-26.8	17.8	10.1	75	152	1.6	47

Figure 1a: **Rigid Duct, Uninsulated, Straight**

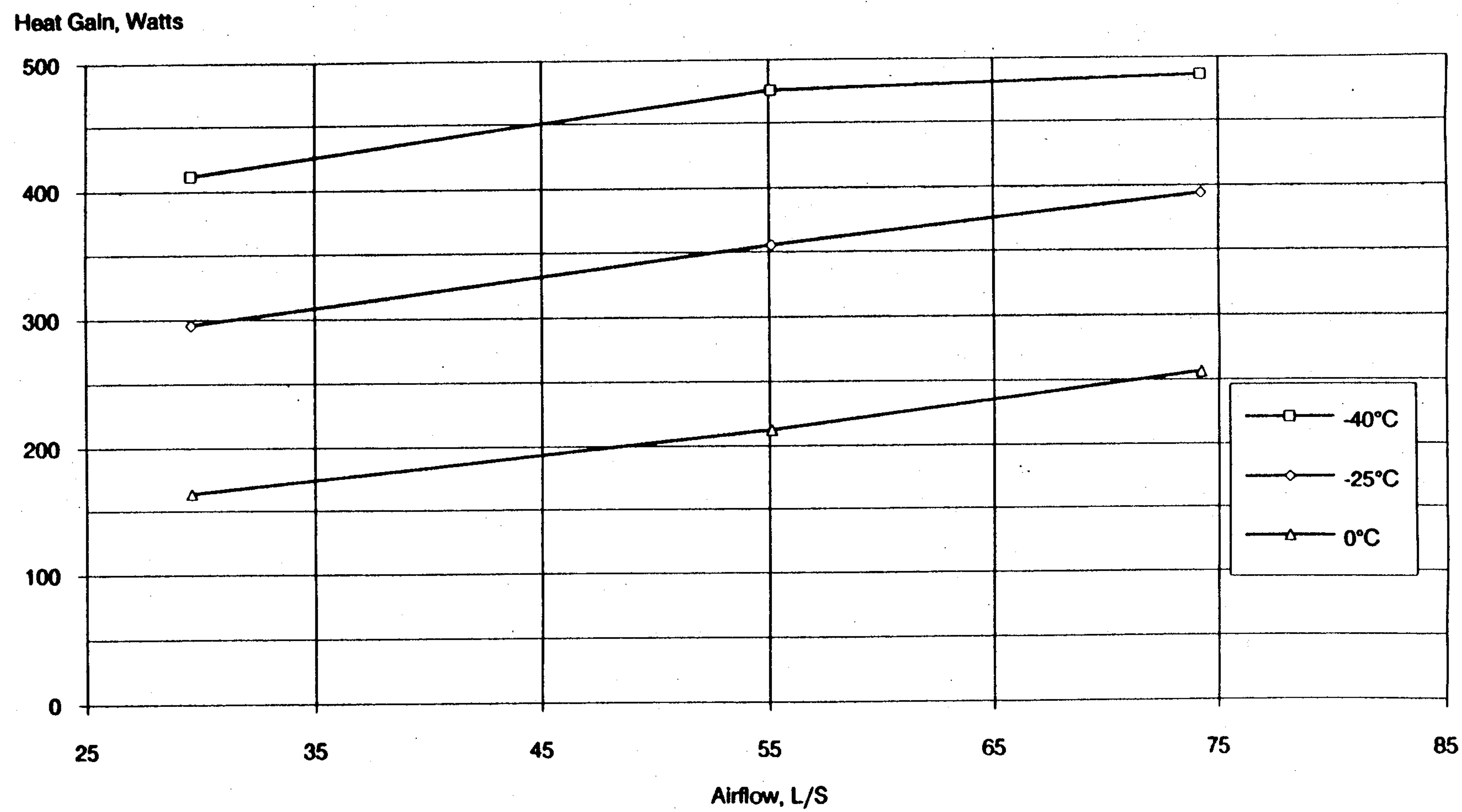


Figure 2a: **Rigid Duct, Uninsulated, Straight**

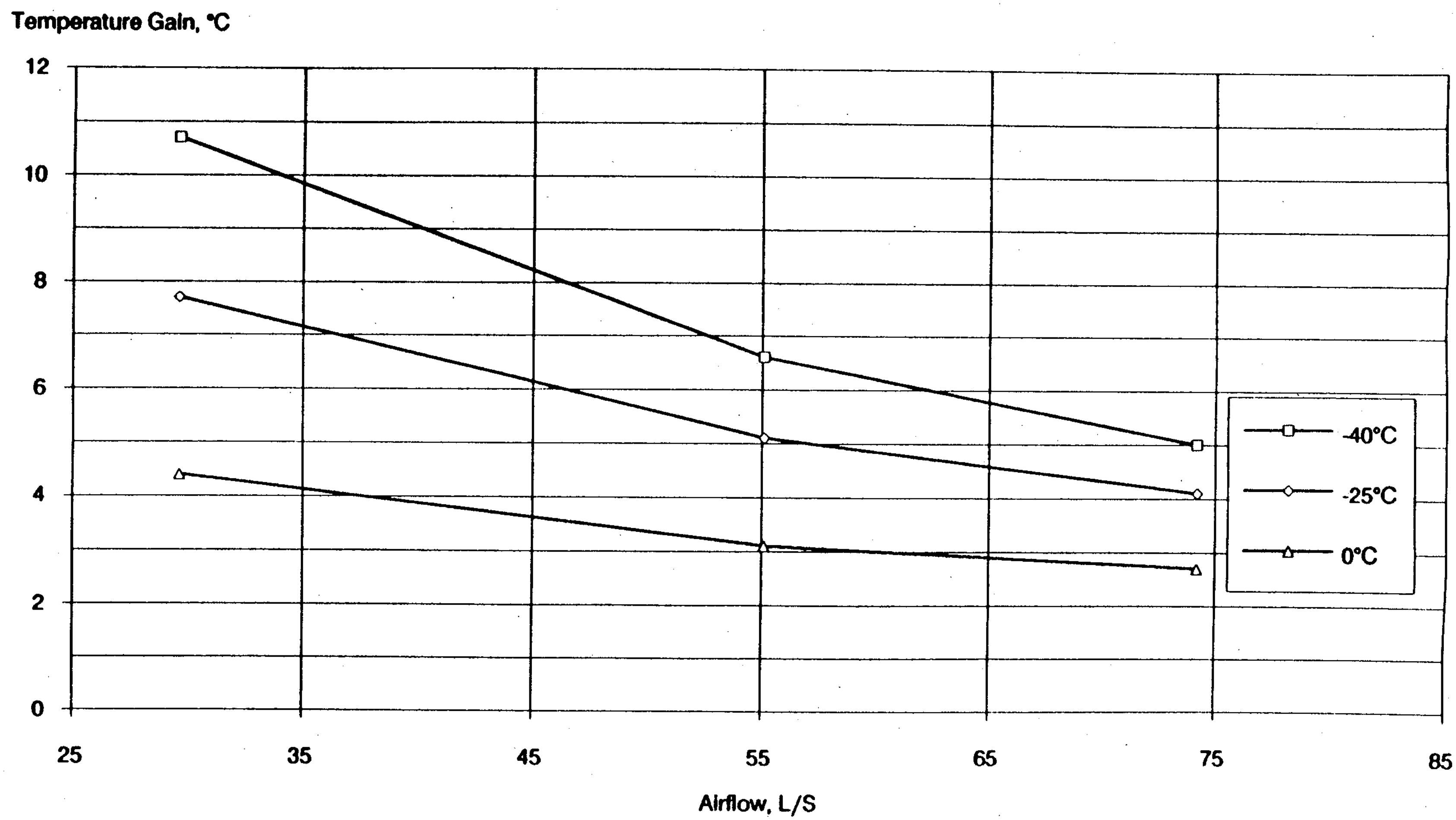


Figure 3a: **Rigid Duct, Insulated, Straight**

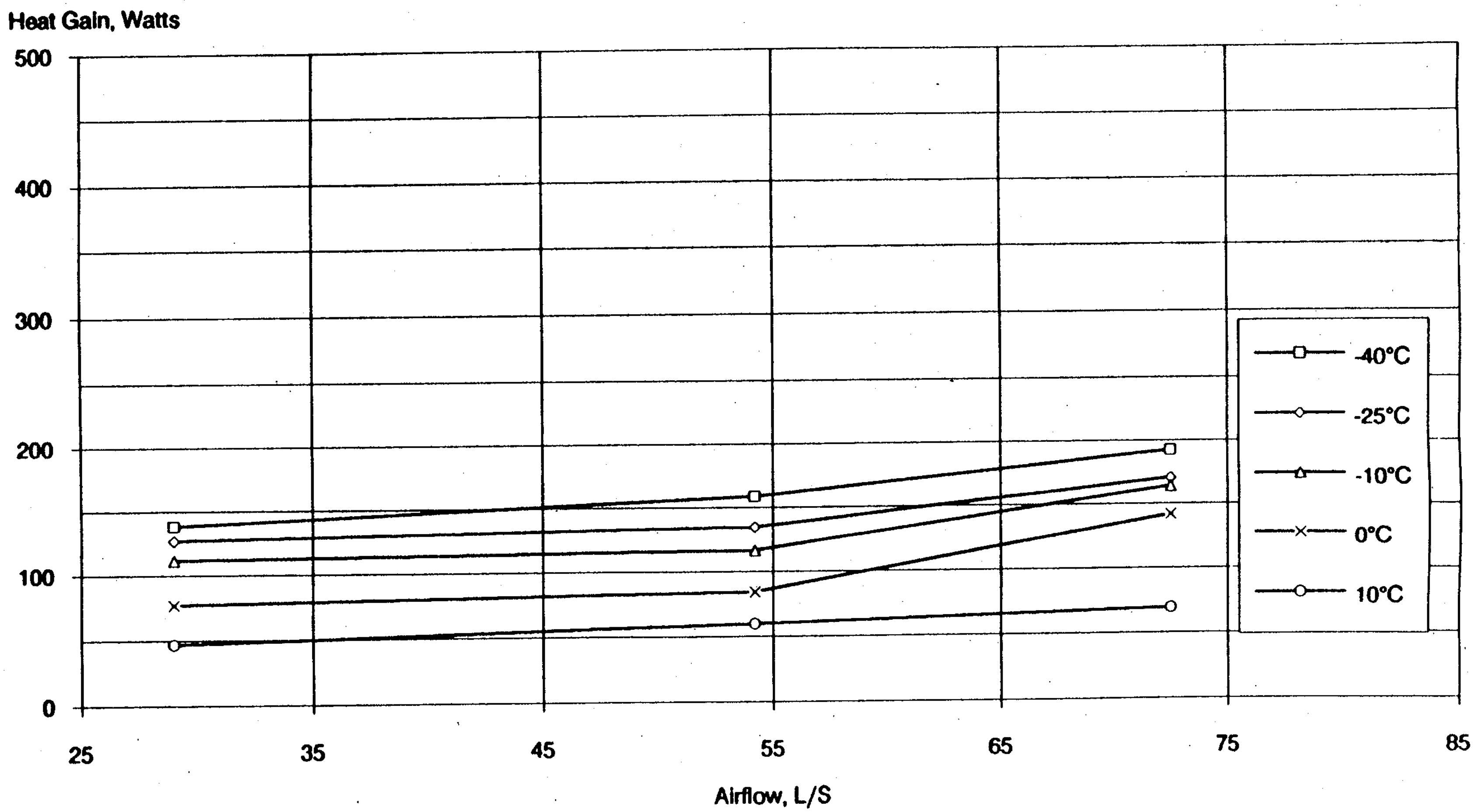


Figure 4a: **Rigid Duct, Insulated, Straight**

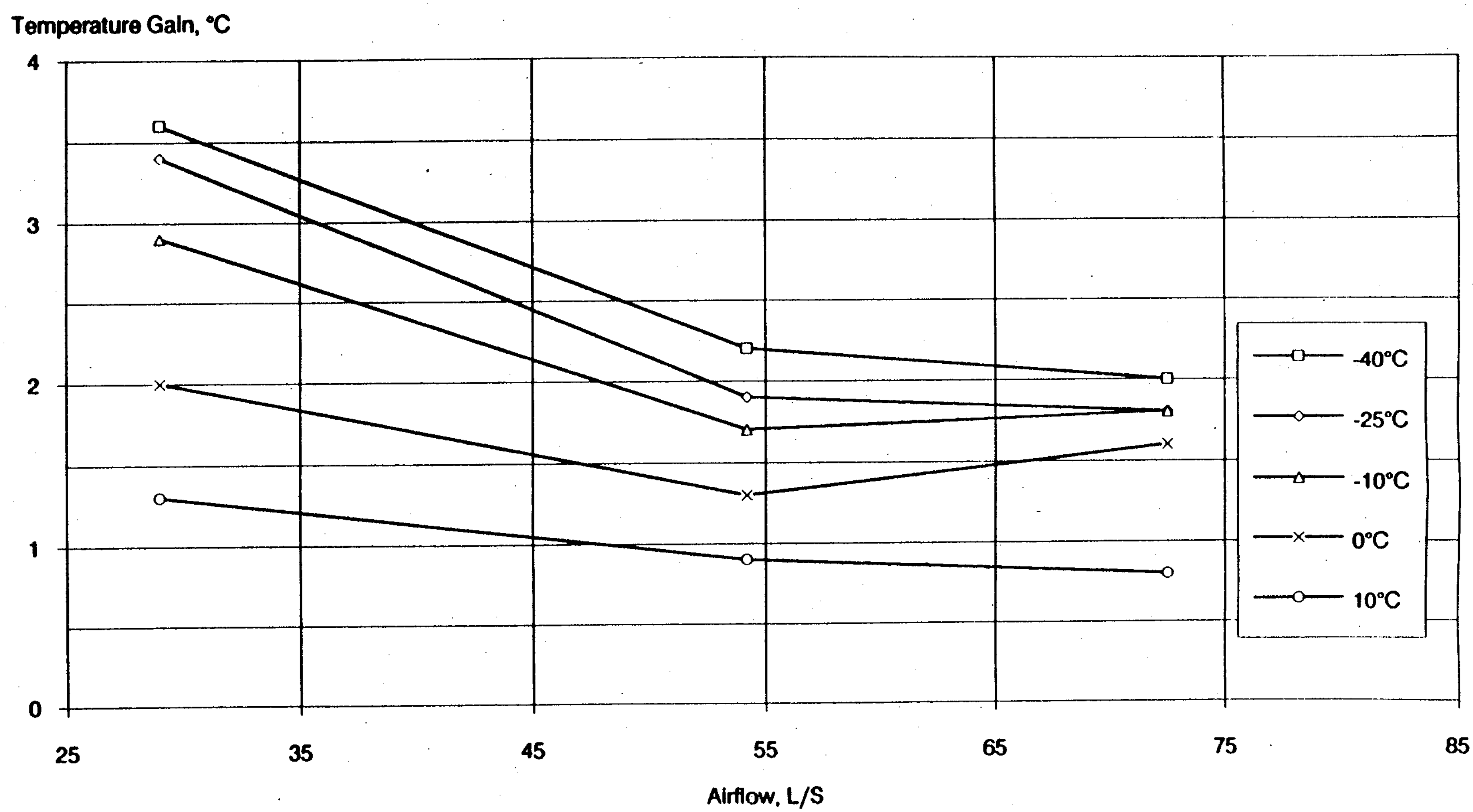


Figure 5a: **Steel Duct, Insulated, Straight**

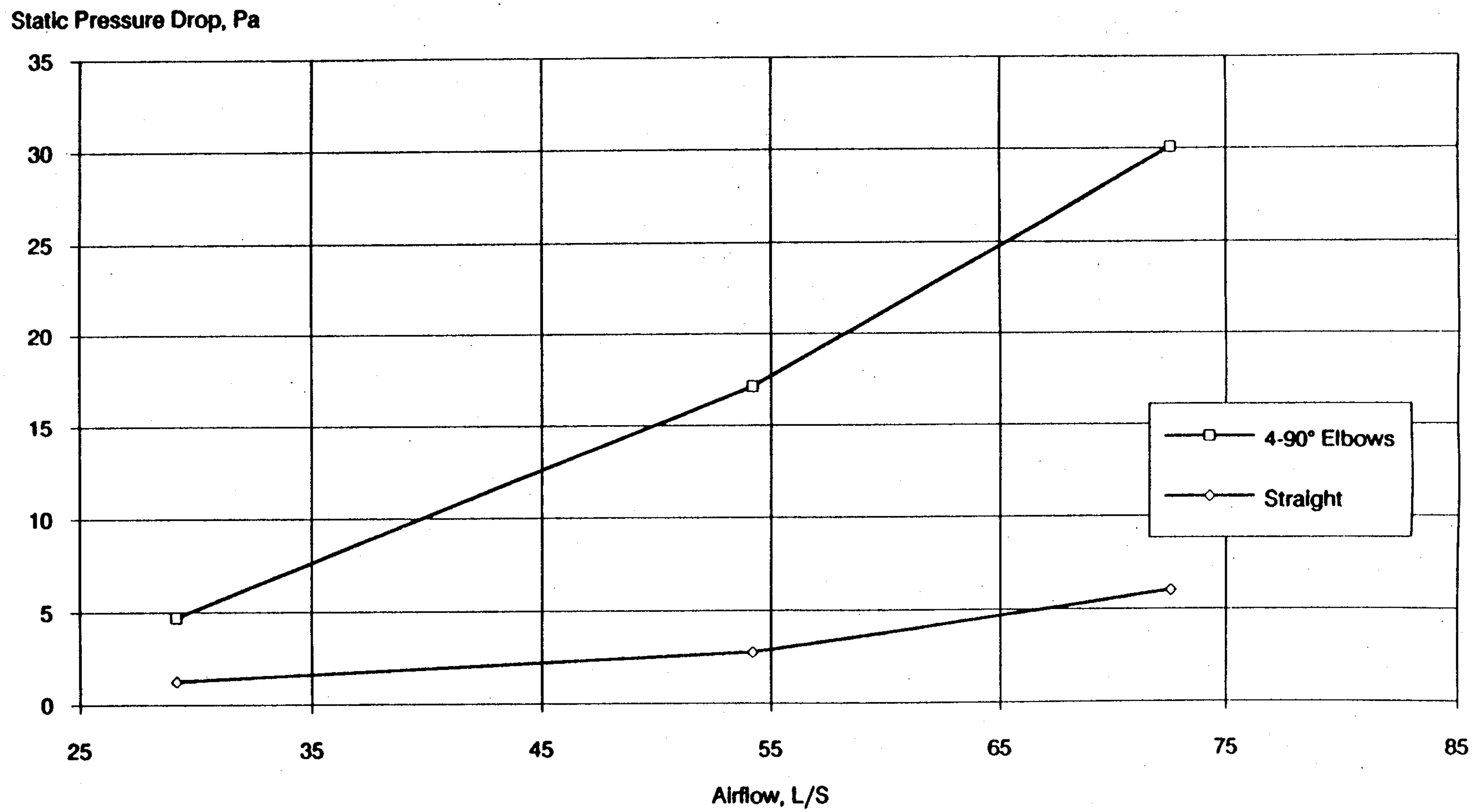


Figure 6a: **Rigid Duct, Insulated, 4-90° Elbows**

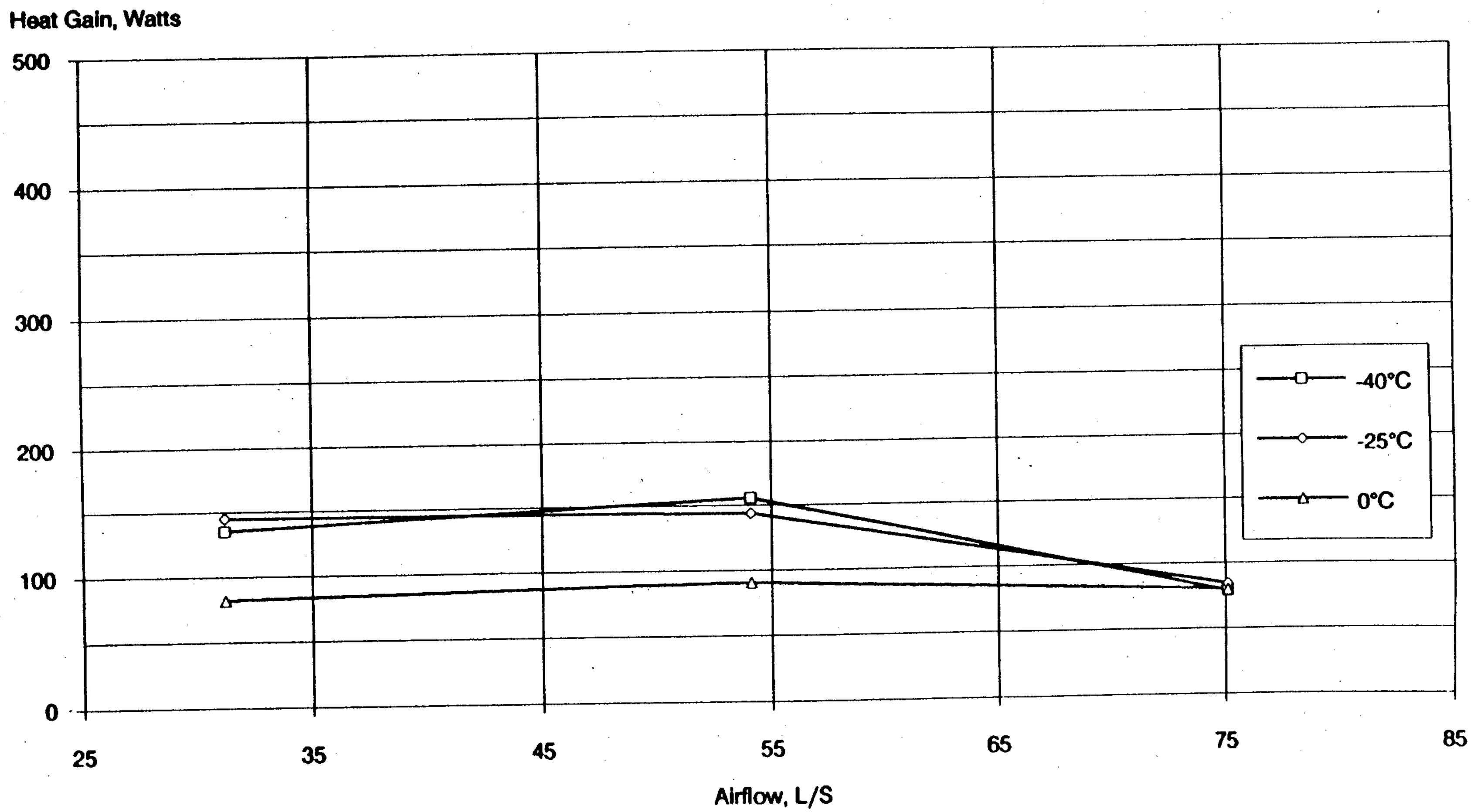


Figure 7a: **Flexible Duct, Insulated, Straight**

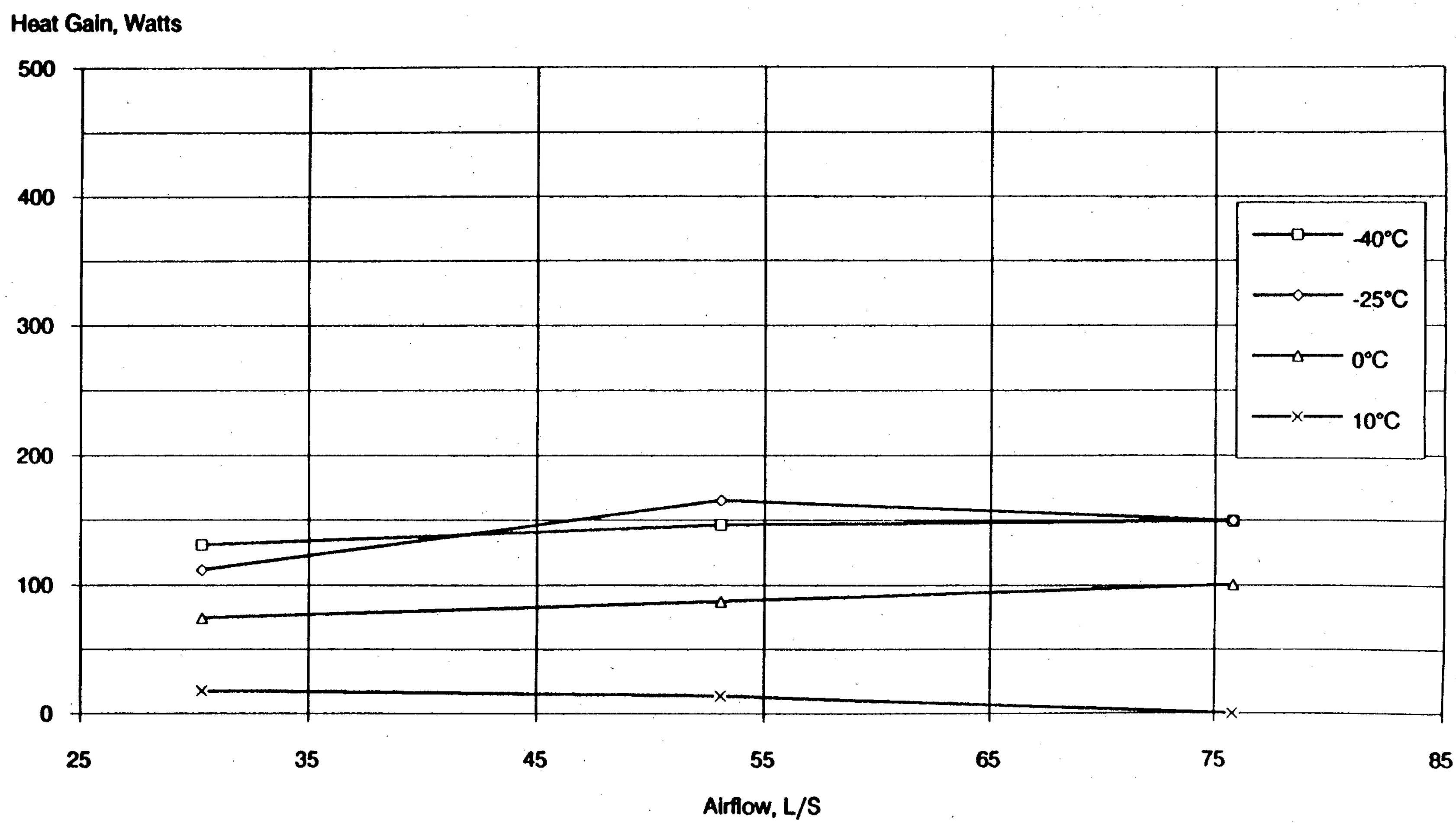


Figure 8a: **Flexible Duct, Insulated, Straight**

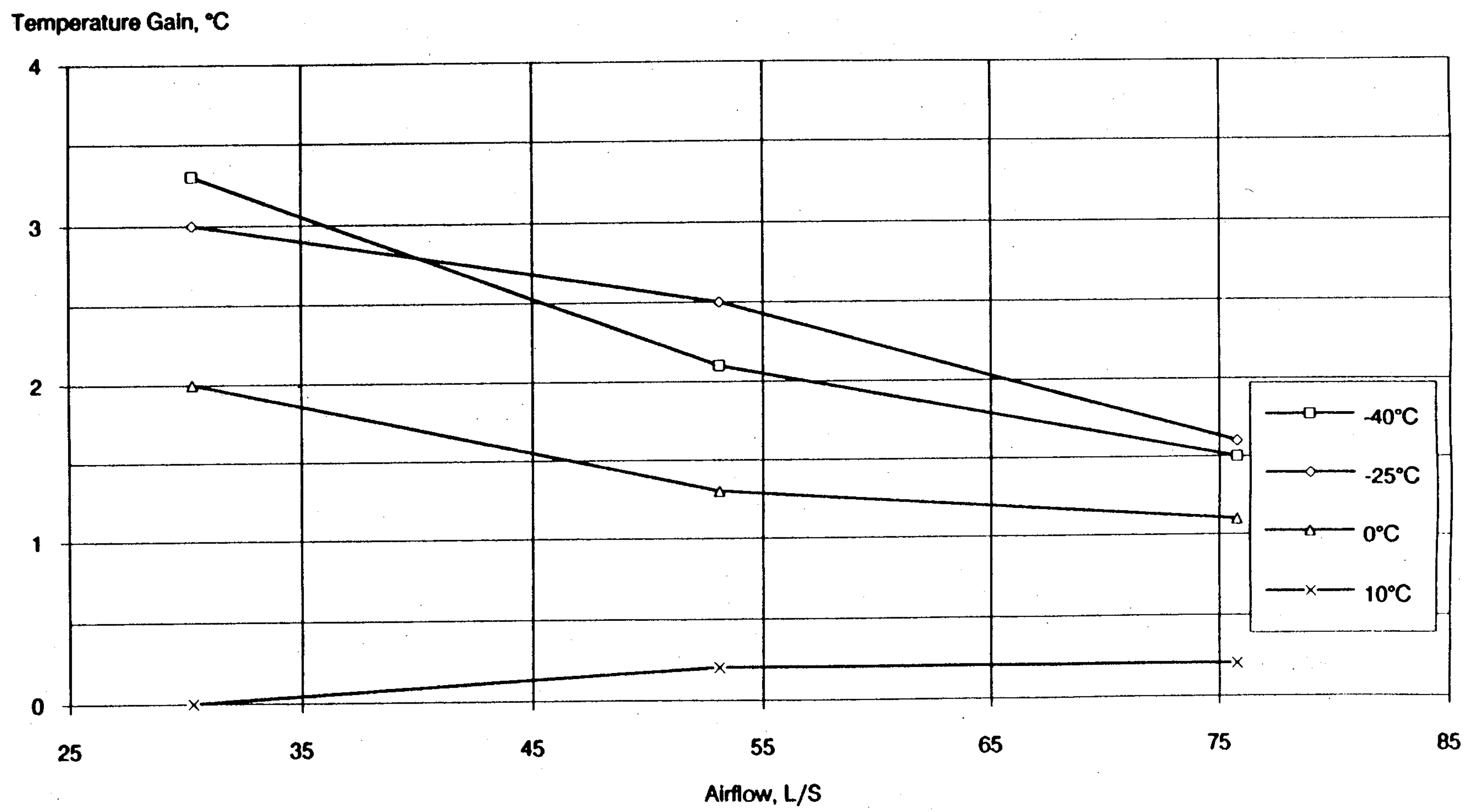


Figure 9a: **Flexible Duct, -25°C, Insulated**

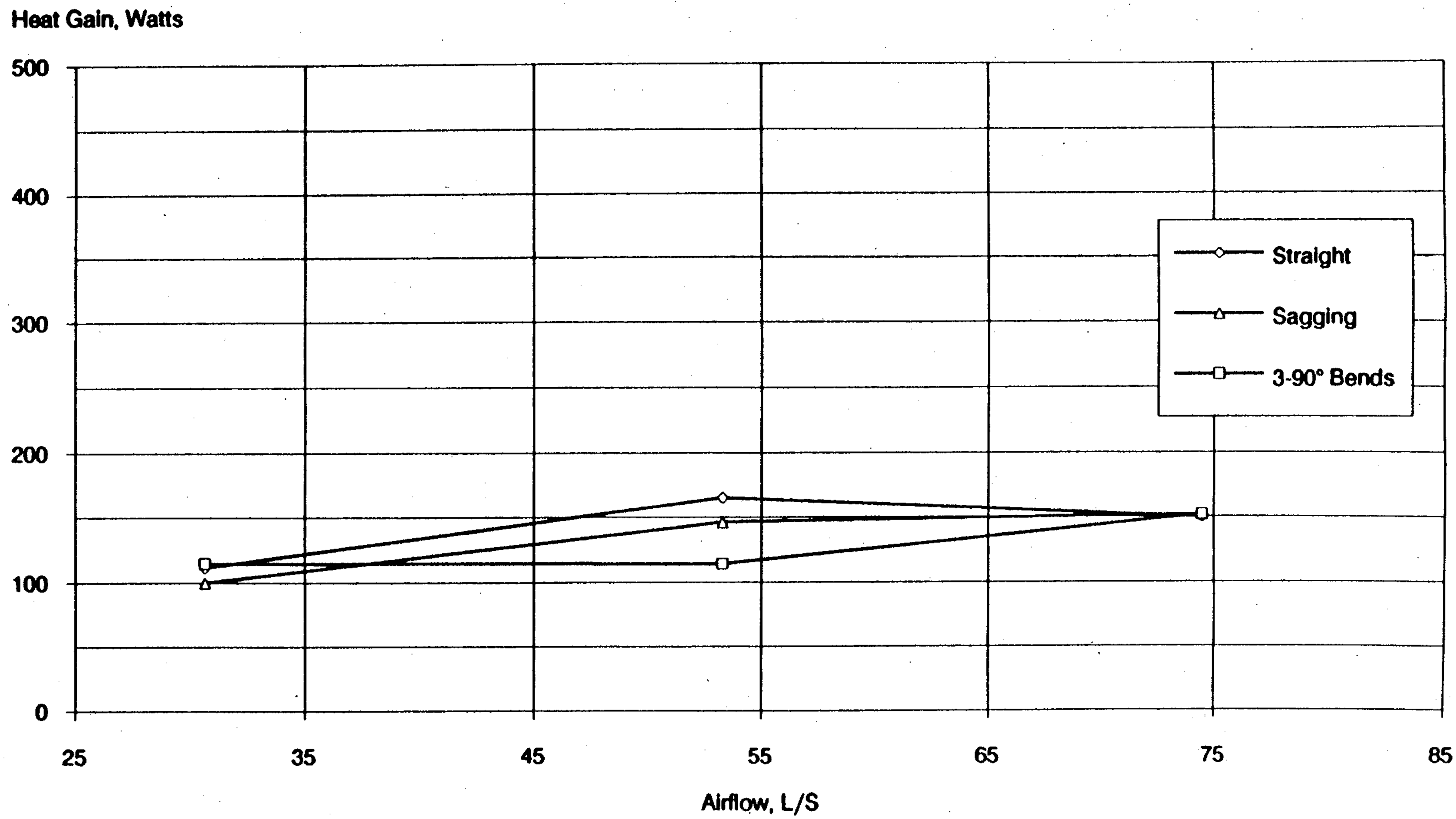


Figure 10a: **Flexible Duct, -25°C, Static Pressures, 3 Configurations**

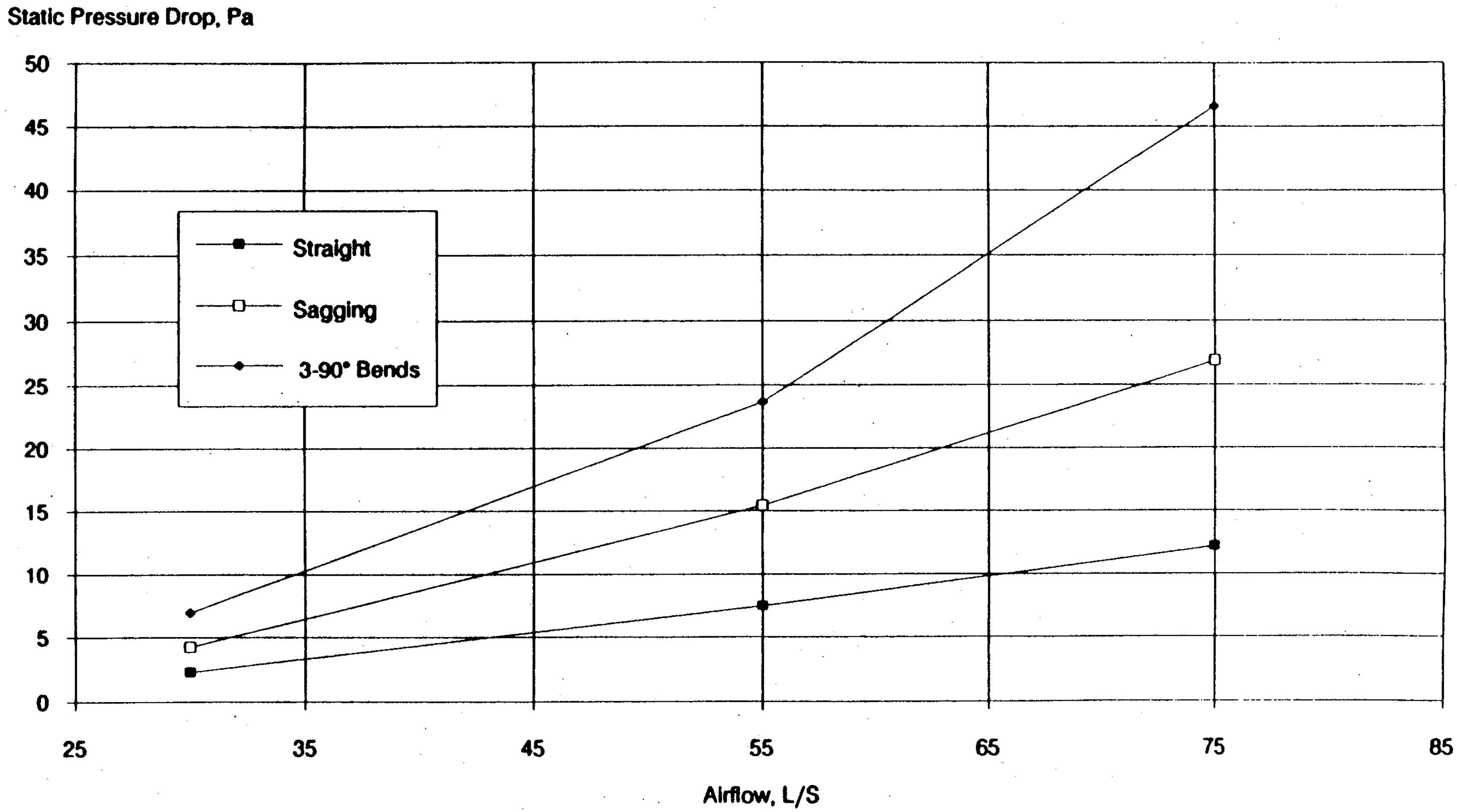
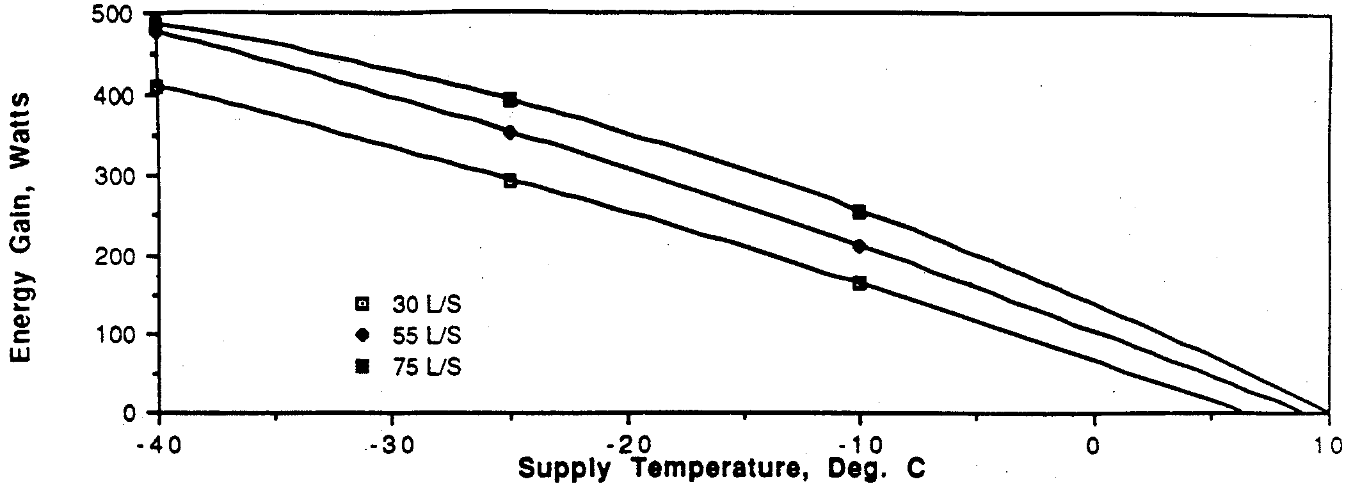
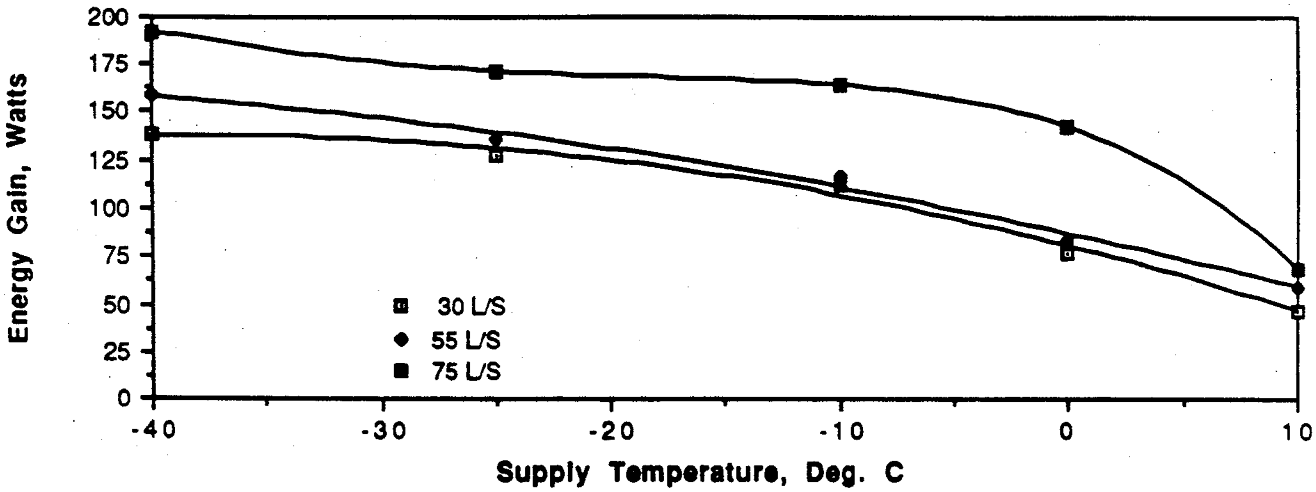


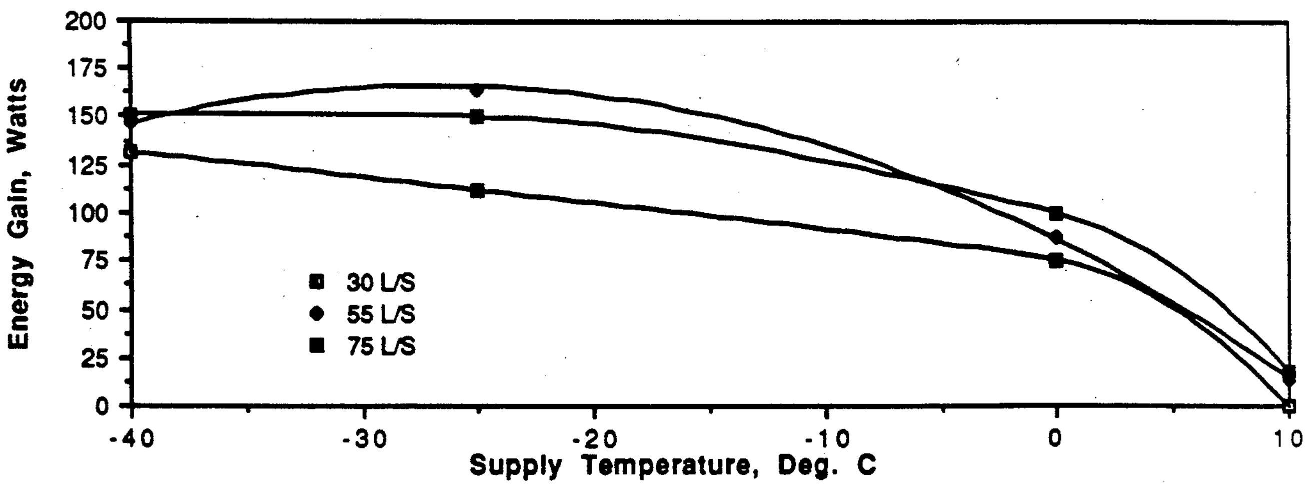
Figure 11a: **Rigid Duct, Uninsulated, Straight**



Rigid Duct, Insulated, Straight



Flexible Duct, Straight



APPENDIX C

Test Duct Specifications

[redacted]

Flexible Ducting Systems

NFX 10

Description: FOIL NON-INSULATED UL 181 CLASS 1 CONNECTOR

Construction: Multiplies of aluminum foil/polyester laminate and metalized polyester film encapsulating a steel wire helix.

Appendix

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NFX 20

Description: UL 181 CLASS 1 CONNECTOR PRODUCT FOR GENERAL PURPOSE USE.

Construction: Double lamination of tough polyester encapsulates a steel wire helix; high density fiberglass insulation; and sheathed in a durable polymer vapor barrier.

PERFORMANCE DATA

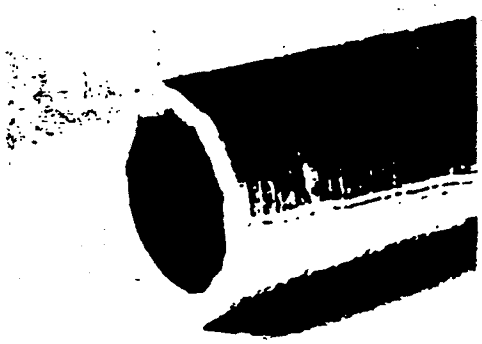
Temperature Range: −20°F to 250°F intermittant (½" pos. w.g. max.), −20°F to 180°F continuous (2" pos. w.g. max.), −20°F to 140°F continuous (max. pressure)

Working Pressure: 4" w.g. pos., 4"-10" dia.; 2" w.g. pos., 12"-20" dia.; 3/4" w.g. neg., all dia.

Velocity: 5,000 FPM

R Value: 5.79

Standard Diameters: 4"-20"



NFX 30

Description: QUALITY LEADER WITH REINFORCED METALIZED VAPOR BARRIER PROVIDES HIGHEST THERMAL PROPERTIES, UL 181 CLASS 1 DUCT.

Construction: Double lamination of tough black polyester encapsulates a steel wire helix for the core; high density fiberglass insulation; and a metalized spirally reinforced vapor barrier.

PERFORMANCE DATA

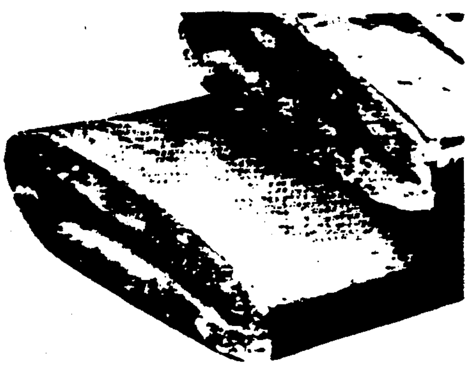
Temperature Range: −20°F to 250°F intermittant (½" pos. w.g. max.), −20°F to 180°F continuous (2" pos. w.g. max.), −20°F to 140°F continuous (max. pressure)

Working Pressure: 6" w.g. pos., 4"-12" dia.; 4" w.g. pos., 14"-20" dia.; 3/4" w.g. neg., all dia.

Velocity: 5,000 FPM

R Value: 6.0

Standard Diameters: 4"-20"



NFX 60

Description: LABOR SAVING 5' PIPE SLEEVES

DATA

10 Series: Energy-efficient 1¼" fiberglass blanket insulation encapsulated in a metalized vapor barrier, provides an R value of 5.79 and vapor transmission of .05 perms.

11 Series: Tough polyethylene vapor barrier encloses 1" fiberglass insulation blanket to provide an R value of 4.3 and vapor transmission of .10 perms.

Packaging: 4"-12" diameter, 20 pieces per carton; 14"-16" diameter, 10 pieces per carton. Starter cap is enclosed with each carton of pipe sleeve.

NUTECH ENERGY SYSTEMS INC