AIR LEAKAGE IN REFRIGERATED VANS

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Prepared For
THE UNITED STATES DEPARTMENT OF ENERGY

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FOREWORD

In conducting this study, B. A. Bodenheimer & Co., Inc. has been fortunate to receive the extensive cooperation of several manufacturers and users of the equipment. These companies have made available both test equipment and trailers or containers for the conduct of the tests covered by this report, and we express our appreciation for their cooperation in this regard and for their willingness to absorb related expenses. We have also received valuable counsel from their personnel.

At the request of these companies, no identification is made in this report as to ownership of either test equipment or vehicles. We share their belief that in this way maximum benefit will be derived from the study.

ABSTRACT

The Air Leakage in Refrigerated Vans Project was initiated by the Department of Energy to assess the impact of air leakage on fuel consumption of highway transport refrigeration equipment. The project, conducted from September of 1977 to December of 1978 collected air leakage data on refrigerated trailers, containers and truck bodies. A Prototype Air Leakage Test Set was developed, designed and constructed to take measurements, and a total of 92 representative vehicles were examined.

The results of the study indicate that air leakage causes a 25% increase in the average refrigeration load. However, the majority of transport refrigeration units are equipped with control systems that require the power to be supplied continuously, so that the potential reduction in fuel consumption that can be expected by reduced air leakage is limited. Alternative control techniques and power sources for the control and operation of refrigeration unit components other than the compressor could reduce fuel consumption by approximately sixty percent.

TABLE OF CONTENTS

TITLE SHEET	i
FOREWORD	ii
ABSTRACT	iii
TABLE OF CONTENTS	iv
LIST OF FIGURES	vi
LIST OF TABLES	vii
EXECUTIVE SUMMARY	viii
1.0 <u>BACKGROUND</u>	1
1.1 Historical Background	1
1.2 Project Background	3
2.0 <u>OBJECTIVES</u>	6
2.1 Primary Objectives	6
2.2 Secondary Objectives	7
3.0 <u>METHODS AND PROCEDURES</u>	8
3.1 Overpressure Air Leakage Test	8
3.2 Air Leakage Test Set Design	9
3.3 Test Plan	13
3.4 Implementation of the Test Plan	15
4.0 <u>RESULTS</u>	23
4.1 Segment 1 Tests - Comparison of Test Equipment	23
4.2 Segment 2 Tests - Air Leakage of In-Service Equipment	25
4.3 Increased Cooling Load Due to Air Leakage	50
4.4 Increased Fuel Consumption Due to Air Leakage	56
4.5 Limitation on Reducing Fuel Consumption	57

5.0	<u>CONCLUSIONS</u>	61
6.0	<u>RECOMMENDATIONS</u>	64
7.0	<u>REDUCTION OF AIR LEAKAGE IN REFRIGERATED VANS</u>	68
7.1	Design	68
7.2	Maintenance	76
	REFERENCES	80
	GLOSSARY OF TERMS	81
	APPENDICES	
A	Data Sheet and Operating Instructions for Prototype Air Leakage Test Set	A1
B	Calculation of Energy Equivalent of Air Leakage	B1
C	Specification for Air Leakage Test Set	C1

LIST OF FIGURES

<u>FIGURE</u>		<u>PAGE</u>
3-1	Test System Schematic	11
3-2	Front View, Prototype Air Leakage Test Set	12
3-3	Installation of Air Supply Connection and Test Body Thermometer in Meat Trailer	17
3-4	Psychrometric Chart	19
3-5	Correction Factors for Regulated Line Temperature and Relative Humidity	21
3-6	Correction Factors for Secondary Pressure	22
4-1	Air Leakage with Open and Closed Drains	38
4-2	Gap in Floor at Junction of Trailer Floor with Interior Elevator	40
4-3	Typical Damage to Insulation and Door Liner	43
4-4	Distortion of Door Frame due to Ladder Mounting	43
4-5	Mounting of Refrigeration Unit on Milk Delivery Truck	45
4-6	Sliding Doors in Driver's Compartment - Milk Truck	45
4-7	Rear Door of Milk Delivery Vehicle	47
4-8	Typical Door and Door Seal Damage	48
6-1	Quality Audit Chart	65
7-1	Floor Drains - Alternate Concepts	69
7-2	Sill Gasket - Alternate Concept	70
7-3	Roll Up Door Gaskets - Alternate Concept	72
7-4	Aluminum Floor Intersection with Shell	74
7-5	Door Seals - Alternate Designs	77

LIST OF TABLES

<u>TABLE</u>		<u>PAGE</u>
4-I	Principal Characteristics of Air Leakage Test Sets	24
4-II	Classification of Vehicles Tested During Tests of In-Service Equipment	26
4-III	Results of Medium Temperature Tests - Group 1	29
4-IV	Results of Low Temperature Tests - Group 1	29
4-V	Results of Medium Temperature Tests - Group 2 Containers	34
4-VI	Results of Low Temperature Tests - Group 2 Containers	34
4-VII	Results of Medium Temperature Tests - Group 2 Trailers	37
4-VIII	Results of Low Temperature Tests - Group 2 Trailers	37
4-IX	Results of Medium Temperature Tests - Group 3	42
4-X	Results of Low Temperature Tests - Group 3	42
4-XI	Inspection Results - Milk Vans	49

EXECUTIVE SUMMARY

Background

It has long been recognized that air leakage into refrigerated transport equipment increases the cooling load, and requires larger refrigeration units than would otherwise be necessary. This project attempted to determine the energy impact of this additional load by testing of in-service equipment, and to recommend means of reducing the consumption of diesel fuel which is usually used to power transport refrigeration equipment.

Objectives

The main objectives were:

- o To provide portable test instrumentation of improved accuracy to be used for conducting air leakage measurements in vans and other installations required to contain a refrigerated atmosphere.
- o To assess the potential for air leakage measurements to identify the sources of air leakage in such vans and bodies, and to assess the energy losses resulting therefrom.
- o To identify those construction features which reduce air tightness in refrigerated vans.
- o To develop design concepts and features which can reduce air leakage in new and existing vehicles.

Test Equipment

Prior to the design and the construction of the test instrumentation a literature survey was made to assess the present knowledge of highway vehicle construction features that permit air leakage, test procedures used, and standards applied by various manufacturer and user groups. Based on this study the overpressure method of testing was selected since it is capable of reproducible results using relatively low cost test apparatus, requires a short time to perform

and has relatively low skilled manpower requirement. This is required so that the use of air leakage testing will be feasible as a manufacturing and maintenance tool.

Comparison of Prototype and Existing Test Equipments

In order to verify that the Prototype Test Set would produce accurate and reproducible results, comparison tests were conducted on the same vehicles using air leakage test equipment currently in use at three different vehicle manufacturers. It has been shown that the Prototype Test Set does give accurate results, whereas the manufacturer's units do not do so, nor give results that can be compared with each other. The deficiencies of the manufacturer's test sets have been identified, and a specification for an instrument of sufficient accuracy for most industrial needs has been developed.

Testing of In-Service Vehicles

A total of 92 in-service van bodies was tested. The test bodies include straight trucks, semi-trailers and containers on chassis ranging in size from 16 feet (4.9 m) to 42 feet (12.8 m) in length. The tests were conducted in the field at the facilities of a trailer operator, a combined trailer/container operator, two supermarket distribution centers and a typical dairy operator.

Results

The impact of air leakage on energy consumption varies with the ambient and cargo temperature, and has been shown to result in an average increase of 25% of the energy required in the absence of such leakage. It is evident that more air tight equipment can be manufactured since wide variations in air leakage were found in the field, with some older units of some manufacturers showing air leakage values one-quarter of that of similar but newer equipment of other builders.

The use of air leakage test equipment to identify the magnitude of air leakage, and to assist in identifying the sources of leakage, was demonstrated.

Whereas visual and smoke bomb examinations identify gross leakage paths, these methods do not provide any indication of the magnitude of air leakage.

Limiting the energy savings that can be achieved is the mode of operation of most refrigeration units, in which the refrigeration unit diesel engine, or other power source is kept running at all times. This requires that the units maintain temperature by alternately heating and cooling the cargo space. The energy wasted by this method of operation is approximately 40 percent of the total consumption, and the combined result of air leakage and control method approaches 65 percent of the fuel consumption.

Although further work must be done to investigate the means by which refrigeration unit performance may be made less energy intensive, the use of air leakage testing in manufacturing, combined with design changes that reduce air leakage, are recommended. The life of vans used in refrigerated transport is from 12 to 15 years, and these units should be procured with as little air leakage as possible to take advantage of control changes that may be made in the future.

1.0 BACKGROUND

1.1 HISTORICAL BACKGROUND

Prior to 1960, there were no standard methods or conditions for testing refrigerated trailers to determine the cooling load. In that year the U. S. Department of Agriculture published Marketing Research Report No. 433, A Rating Method for Refrigerated Trailer Bodies, as part of a program of work directed to improving the marketing procedures for agricultural products. The thrust of this work was to improve the quality of the perishable products delivered to the consumer, by preventing degradation caused by the use of refrigeration equipment of inadequate cooling capacity.

The nineteen-month study leading to the USDA Rating Method identified air leakage as one of the principal causes of increased cooling load on a vehicle above that predicted by calculation or stationary tests. Based on actual road tests, an increase in cooling load ranging from 8 to 35 percent was reported.

Continued effort to define the losses due to air leakage was stimulated by the increased use of van containers in ocean transportation. Longer voyage times associated with this mode of transportation, (four weeks compared to 5 days for a transcontinental trip in the United States) as well as the limited supply of electrical power aboard ocean vessels, dictated that means be found to reduce avoidable losses.

In the period from 1969 to 1975 standards for rating refrigerated vehicles were drafted by the Truck Trailer Manufacturers Association (TTMA)¹, the International Organization of Standardization (ISO)², and the American National Standards Institute (ANSI)³. These standards all include an air leakage over-pressure test preliminary to a thermal test performed to determine static heat transmission losses. The air leakage test results are used to modify the results of the thermal test to account for additional heat loss due to air leakage. Three

distinct levels of air leakage are recognized by the screening test.

1. effect of air leakage estimated to be less than 5 percent of the heat transmission loss -- no adjustment to the measured heat transmission loss is required.
2. effect of air leakage estimated to be between 5 and 10 percent of the heat transmission loss -- application of a 5 percent correction to the heat transmission value is required.
3. effect of air leakage estimated to be more than 10 percent of the heat transmission loss -- the unit may not be rated under the standards.

These tests apply to new equipment only, and are performed at ambient temperature conditions. Thus the various standardization groups (TTMA, ANSI, ISO) recognize the results of air leakage tests as comparative only, and do not attempt to predict actual performance. Their purpose has been to establish a quality standard, that, together with empirical data, will result in a van body and refrigeration unit combination that can maintain an internal transport temperature in a stated environment.

The fuel crisis of 1973 and 1974, together with the rise in real cost of all forms of energy, has brought a new aspect of air leakage in refrigerated vehicles to the forefront. Based on published fuel consumption data and vehicle fleet size data, it is estimated that unnecessary air leakage in refrigerated transport represents an energy loss as high as 70 million gallons of diesel fuel per year.

Estimates of the useful life of refrigerated vehicles is 12 to 15 years, and it is recognized that although hardware improvements may require significant time periods to have appreciable effects on national energy consumption, the size of the refrigerated transportation fleet in the United States makes it a substantial energy consumer, and hardware improvements must be diligently pursued to conserve petroleum fuels.

1.2 PROJECT BACKGROUND

A refrigerated van is a container for the transportation of products that require controlled temperature during transit. Temperature requirements may involve either heating or cooling, or both, depending on the required interior temperature and the ambient temperature encountered during the trip. Implicit in this definition is that the van body is equipped with equipment to maintain the desired temperature. The term "refrigerated van" is used throughout this report in a more general sense which includes both a heating and a cooling capacity.

Even if it were possible to make a van body completely airtight, it would not be prudent to do so. If such a body were loaded with cargo in an ambient of 90° F (32.2°C) and is then cooled to a temperature of 36° F (2.2°C), the volume of air in the van body would contract and produce a negative pressure. The negative pressure would produce stresses that could damage the structure by collapsing the sides or roof. Some refrigerated containers are designed to withstand such pressures, but most are not.

The mechanism by which air exchange occurs in a refrigerated van is complex. Any such structure has imperfections, especially at structural and sheet metal joints, and the quantity of air entering and leaving the body is a function of the size of these openings and the pressure differences between the inside and outside of the body where the openings are located. Thus, for example, during a cooling cycle, and when the van is stationary, all of the openings in the structure are exposed to negative pressure and air flows into the body through all of the openings. If the interior is being heated, the flow through the openings is outward. At steady state, some openings will admit air to the van and others will exhaust air to produce a balance in the mass flow of air. In any case, a net change in the cooling load has occurred.

Air leakage is the result of pressure differences, categorized as follows:

1. Chimney Effect. A pressure difference is caused by the temperature difference between the inside air and the outside air. For a temperature difference of 100°F (55.6°C), this pressure difference for a typical van (interior height of 96 inches (2.44 m)) is 0.024 inches of water column (W.C.) (6 Pa) at the interior floor level of the vehicle.
2. Internal Air Circulation. A pressure gradient exists when air is circulated within the van body by the refrigeration unit. The air is circulated by fans in order to maintain product temperature. Typical pressure gradients in loaded van bodies are from 0.4 inches W.C. (100 Pa) to 1.5 inches W.C. (374 Pa) depending on the type of fan used.
3. Vehicle Motion Effect. The movement of the vehicle creates a pressure difference between front and rear of the vehicle; this pressure difference is a function of speed. At 45 miles per hour (72 Km/h) typical pressures have been measured at 1 inch W.C. (249 Pa) at the front and -0.2 inches W.C. (-50 Pa) behind the van. A gradient thus exists along the entire vehicle.
4. Effect of Wind. Wind causes a pressure difference between the surfaces facing the wind and those leeward of the wind. It is transient in nature and is superimposed on the vehicle motion effect.
5. Effect of Air Exchange Within the Insulation. If the outer surface of a van body is not adequately treated with a vapor barrier, air exchange takes place between the ambient air and the insulation, even if there is no direct leakage of interior air to the outside. This can produce moisture condensation in the insulation.

Due to many factors involved, and the difficulty of interpretation of static overpressure tests, the overpressure test method has heretofore been relegated to a simple screening test to eliminate equipment inadequate for the proper temperature control.

Thus, in August 1977 a program was authorized by the Department of Energy to assess the state of the art of air leakage measurement in refrigerated vans, to estimate the impact of air leakage on fuel consumption of highway transport refrigeration equipment, and to suggest means of reducing air leakage in such vehicles.

2.0 OBJECTIVES

2.1 PRIMARY OBJECTIVES

The Air Leakage in Refrigerated Vans Project was designed to achieve four primary objectives.

1. To provide portable test instrumentation of improved accuracy to be used for conducting overpressure air leakage measurements in vans and other installations required to contain a refrigerated atmosphere.
2. To assess the potential of air leakage measurements to identify the sources of air leakage in such vans and bodies, and to assess the energy losses resulting therefrom.
3. To identify those construction features which degrade air tightness in refrigerated vans.
4. To develop design concepts and features which can reduce air leakage in new and used vehicles, and to assess the potential energy savings of such features.

The following discussion focuses on the rationale involved in formulating the primary project objectives.

There are strong differences of opinion as to the best test methods and acceptance values for air leakage. American industry favors the measurement of air leakage at $\frac{1}{2}$ inch W.C. (125 Pa) overpressure, whereas European investigators favor use of 1 inch W.C. (249 Pa). Further, there is a substantial difference of opinion as to what constitutes acceptable values of air leakage. There is also evidence that current practices in air leakage measurements yield neither comparable nor consistent results. Therefore, accurate, moderately priced and portable test instrumentation was the first objective.

In order to make significant energy savings possible, it is necessary to identify the sources of air leakage. Currently, when refrigerated vans do not

pass an owner prescribed air leakage test, the usual recourse is to caulk seams and take other action to make the deficient unit acceptable rather than to change design. The second objective was thus formulated to extend the use of air leakage test measurements from a production screening tool to a design and maintenance aid.

"Experience has shown that with proper construction leakage is not a consequence of lack of care but is inherent to the mode of construction."⁴ This statement leads to the adoption of objectives three and four, namely, to identify features which cause air leakage, and to develop concepts which abate the energy waste.

2.2 SECONDARY OBJECTIVES

1. To compare air leakage test values obtained with the Prototype Test Set to values obtained with existing instrumentation used by manufacturers.
2. To compare values of air leakage at interior van temperatures lower than ambient to those taken with both interior and exterior temperatures at ambient.
3. To specify the minimum equipment requirements for air leakage testing when used as a test method for determining maintenance frequency.

3.0 METHODS AND PROCEDURES

3.1 OVERPRESSURE AIR LEAKAGE TEST

This test method requires that air be introduced into a vehicle body until a predetermined positive pressure is attained, and air flow is maintained for a period of time to reach equilibrium. The amount of air required to maintain this positive pressure, measured in standard cubic feet per hour, (or standard cubic meters per hour) is recorded. The word "standard" refers to dry air measured at 70° F (21° C) and 14.7 psia. (1 atmosphere). It is accepted practice to seal those openings of the vehicle body which can normally be expected to be sealed in service, such as floor drains, but no other special preparations are permitted.

The literature survey⁵ indicated that while the overpressure test method does not yield results that can be directly related to in-service air leakage, the method does meet all other criteria that are recognized to be of importance. These are:

1. The test should be inexpensive to perform in terms of apparatus, time and skilled labor requirements.
2. The test should provide reproducible results under field conditions if the equipment is properly chosen and used.
3. The test should be applicable to all types of vehicles.
4. The test should provide data that allow discrimination of well-constructed from poorly-constructed equipment.

The literature search also confirmed that there are no alternative test methods that could be used to predict in-service air leakage short of fully instrumented in service tests. The expense involved in such tests is perceived to be too high for general use for design improvement, quality control and maintenance functions.

Further, the literature search indicated that the overpressure test method

could possibly be exploited in pinpointing air leakage sources. While application in industry had been generally limited to measuring air leakage at one value of overpressure, it has been established by various investigators⁶ that the air leakage of a van, when tested at several different overpressures, can be described by the following equation:

$$Q = bp^n \quad (A)$$

where Q is the air leakage
 b is a constant
 p is the overpressure

Exponent "n" of equation A can be expected to be within the range $0.5 \leq n \leq 1.0$, depending on the type of opening through which the air leaks; the limiting conditions are "true" holes and "true" cracks.

In a "true" hole, an orifice, the volumetric flow of air is proportional to the square root of the pressure difference. In a "true" crack (or very small holes) the flow can be likened to flow through short tubes and for laminar flow, the flow rate is directly proportional to the pressure difference. Tests with short "tube" orifice plates have confirmed this⁷, and have shown that (b) increases linearly with the orifice area, and (n) increases rapidly from 0.5 to 1.0 as the orifice diameter is reduced to less than about 0.045 inches (1.14 mm).

The various investigators⁸ have shown that the air leakage values are also a function of the temperatures at which the tests are performed. At a given ambient temperature (T_e), air leakage is observed to increase as the van interior temperature (T_i) is decreased. This suggests that comparison of air leakage values taken on the same body at two different internal temperatures would be necessary to provide useful data.

3.2 AIR LEAKAGE TEST SET DESIGN

The Prototype Air Leakage Test Set designed and constructed under this contract was instrumented to measure the principal factors recognized to have

bearing on the results obtained. Figure 3-1 is a schematic of the Test Set, and Figure 3-2 is a front view of the unit.

Flow meters based on the variable area principle (Rotameters) are calibrated with a specific fluid at a set temperature and downstream pressure. When the flow meter is used with a different fluid, at a temperature and pressure different from those used in calibration, a correction factor must be applied to the scale reading. The equation for this correction factor is:

$$SCFH_{\text{equivalent}} = SCFH_{\text{scale reading}} \times \sqrt{\frac{SG_1 T_1 P_2}{SG_2 T_2 P_1}} \quad (B)$$

where SG is the specific gravity

T is the absolute temperature, $^{\circ}R = ^{\circ}F + 460$

P is the absolute pressure, $P_a = P_{\text{gage}} + 14.7$

Subscript 1 is the calibration condition

Subscript 2 is the condition at which the measurement is made.

In order to calculate the correction factor, the temperature and the humidity of the air supply, as well as the pressure at the flow meter, must all be known. Instrumentation is provided to measure these variables.

A flow control valve is provided in order to control the flow of air into the test body. This is located at the entry of the flow meter, similar to the TTMA Recommended Practice #38-73⁹. In actual practice it was found more convenient to control the flow of air by use of the pressure regulator only. Increasing pressure at the inlet increases the flow throughout the system, and since the Prototype Test Set is equipped with a pressure gage at the flow meter, the proper correction can be made regardless of how the flow is controlled.

Calibrated thermometers are used to determine ambient air temperature and interior vehicle temperature. The thermometers with which the vehicles are normally equipped are usually calibrated at one point only (an ice bath) and are

FIGURE 3-1
TEST SYSTEM SCHEMATIC

FIGURE 3-2
FRONT VIEW - PROTOTYPE AIR LEAKAGE TEST SET

frequently so located that they accurately register the air temperature only when the refrigeration unit is in operation.

A high resolution inclined manometer (± 0.005 inches of water) is provided to measure overpressure. Differential pressure gages are used in many existing test stations. Although such gages are easier to use since they do not require leveling prior to use and have no fluid that can spill, their accuracy is limited to ± 2 percent of full scale. Therefore, a gage with a range of one inch W.C. (249 Pa) can have an error of ± 0.02 inches W.C. (5 Pa), compared to a manometer which is inherently 100 percent accurate. When readings are taken at low overpressures in the range of 0.05 to 0.15 inches W.C. (12 to 37 Pa), the use of a pointer type gage can introduce errors ranging from 40 to 13 percent.

Since it was anticipated that field testing might involve the use of a portable compressor, special care was also taken to provide a coalescing type air filter at the inlet side of the Test Set to protect the instrumentation from the effects of moisture, oil and particulate matter.

3.3 TEST PLAN

A Manual entitled, "Use, Operation, Calibration and Maintenance of the Prototype Air Leakage Test Set", was prepared which includes a detailed plan and procedure for the individual tests, and also includes all formulae and tables needed to correct the data for the different temperatures, pressures and humidity expected in the field.

The Manual also prescribes a standard data sheet, the reverse side of which is provided with logarithmic graph paper to facilitate the immediate plotting of data to verify that the test points do lie on a straight line, and that the relationship $Q = bp^n$ is satisfied. Further, the Test Set is provided with an abbreviated set of Operating Instructions mounted under a plastic protective sheet so that the operator can check procedures rapidly. The Data Sheet and Operating Instructions are reproduced in Appendix A.

The use of formalized procedures and data reporting is designed to provide consistency of the data gathering process regardless of the operating personnel employed.

Two separate test segments were planned in order to meet the project objectives. In the first segment, tests with the Prototype Test Set in comparison with three existing test sets at three different manufacturers or users of equipment were planned. These tests were designed to establish that the data taken in the second segment could be compared to data previously published in various reports.

In the second segment, air leakage tests were planned to be conducted on existing vehicles. This segment was designed to include a variety of equipment to provide a representative picture of the condition of the refrigerated truck fleet in the United States. As the availability of equipment for testing was necessarily dependent on the cooperation of various commercial concerns, the original test plan provided for the following groups of vehicles to be evaluated.

Group 1: A large sample (20 percent or more) from one fleet of trailers or containers of the same design, constructed within the last 18 months and equipped with mechanical refrigeration units. This groups was used to evaluate variation in manufacturing quality control.

Group 2: A sample from a fleet of trailers or containers operated by a single organization, with equipment from different manufacturers of varying age, but all equipped with mechanical refrigeration units. This group was to serve as a means to evaluate equipment aging and design factors.

Group 3: A sample from a typical domestic supermarket distribution system, all equipped with mechanical refrigeration units. This group was to serve as a means to discriminate the effect of roll-up doors,

side doors, elevating mechanisms, etc. on air leakage.

Group 4: A sample from a local delivery fleet, such as a typical dairy operation composed of straight truck bodies rather than semi-trailers, and equipped with eutectic plate refrigeration units.

A minimum of 80 to 85 separate tests was initially planned. As the availability of equipment became known, the plan was revised to cover a total of 92 separate vehicle tests.

3.4 IMPLEMENTATION OF THE TEST PLAN

3.4.1 Field Procedures

Upon arrival at the various test locations a meeting was held with management personnel to explain the objectives of the program. In all cases the meeting included the manager of the maintenance facility where the tests were to be conducted. Assurance of confidentiality of data was repeated and company representatives were informed that they would receive the test results for their own equipment.

Since the Test Set is designed to be operated by a single individual, the maintenance manager had only to arrange for suitable space, an air supply line, and the vans to be made available for testing. No further assistance was required although a high degree of interest was shown by working personnel in all cases. When such interest was apparent, the Test Set was demonstrated fully and as a result, a very high degree of cooperation was obtained.

Time required for setting up the test equipment, including installation of the flow meter float, leveling the equipment, hooking up the air hose, calibration checks, etc. is estimated to require approximately 1 hour per set up. Except for locations where security could not be guaranteed, it was planned to leave the equipment in place overnight, so that only a calibration check would be required prior to the next day's activity.

A brief meeting was held each day with the maintenance manager to identify

equipment available for test that day. As vehicles became available the air supply tubing was installed (usually through a floor drain), the manometer and test body thermometer were installed and the floor drains were subsequently sealed with a temporary sealing compound (duct seal), see Figure 3-3.

Air leakage measurements were then made at three pressure levels with the inside temperature at ambient. The results were plotted on logarithmic graph paper as the measurements were made. In the absence of condensation of water vapor contained in the air supply, the accuracy of the test is implied when the three measurements are co-linear.

The same test was then repeated except that the van temperature was lowered below ambient by the refrigeration unit. The unit was operated until the inside temperature had stabilized, at which time the unit was shut off. Generally, a temperature above 32⁰ F (0⁰C) was chosen so that ice and frost formation would not complicate the test.

3.4.2 Segment 1 Tests - (Comparison Tests)

During Segment 1 the vehicles to be tested were chosen at random, since the objective was to compare the results of different test sets on the same body, rather than establishing specific magnitudes of air leakage. The test sets used for comparison were not all of the same design, although all essentially meet current test standards of TTMA, ISO, and ANSI. The major difference is the use of pointer type, differential pressure gages instead of a manometer.

3.4.3 Segment 2 Tests - (In-Service Equipment Tests)

Segment 2 tests were planned to be conducted on in-service equipment, and a diligent search was made to find vehicles to fit the test groupings considered to be important. In addition to selecting specific equipment types, it was necessary to obtain the cooperation of the operators of the equipment to make the vehicles available for testing at two internal temperatures. This requires that the equipment be available for a substantial time, since the reduction of

FIGURE 3-3
INSTALLATION OF AIR SUPPLY CONNECTION AND TEST BODY
THERMOMETER IN MEAT TRAILER.

the internal temperature below ambient must achieve not only a reduction in air temperature, but the entire structure must be "pulled down". It is usually convenient to perform the test for ambient trailer temperature one day, reduce the internal temperature overnight, and perform the low temperature test on the next day. In some cases this was impractical, since the equipment could be taken out of service for testing for only 12 hours. In several instances the equipment was returned to service before the low temperature test could be conducted.

3.4.4 Data Correction Procedure

The correction factor for rotameter readings;

$$\sqrt{\frac{SG_1}{SG_2} \frac{T_1}{T_2} \frac{P_2}{P_1}}$$

was separated into two functions for ease of calculation, specifically;

$$\sqrt{\frac{SG_1}{SG_2} \frac{T_1}{T_2}} \quad \text{and} \quad \sqrt{\frac{P_2}{P_1}}$$

If the air supply is dry, but at a temperature different from that used at calibration, the factor $\sqrt{\frac{T_1}{T_2}}$ corrects for the change in density due to temperature alone. When the air supply contains moisture, there is also a change in the specific gravity, which is directly proportional to the change in density at the dry condition compared to the humid condition. Accordingly, the ratio of dry air to humid air (SG_1/SG_2) was calculated for different temperatures and relative humidities using the procedures of the ASHRAE "Brochure on Psychrometry".¹⁰

Figure 3-4 illustrates a sample calculation. Assuming air at 84° F and 40% RH, the ratio of the density of dry air at that temperature (point A) to the density of the moist air (point B) was calculated. This ratio was then multiplied by the ratio of the absolute temperature at calibration (70° F, point C) to the absolute temperature of dry air (point A) at use condition, and the square root of the

SEA LEVEL

AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.

FIGURE 3-4
PSYCHROMETRIC CHART

product tabulated for various temperatures and relative humidity (RH) of the supply air. (See Figure 3-5). The measurement of the temperature and RH was taken just prior to the flow meter entrance.

The correction factor for pressure $\sqrt{\frac{P_2}{P_1}}$, was calculated in increments of 1/4 pound pressure, and tabulated as shown in Figure 3-6. Thus, correction of the flow meter readings required no field calculation of the correction factors. It is emphasized that these tabulated correction factors apply only to the specific instruments used in the Prototype Test Set.

CORRECTION FACTORS FOR REGULATED LINE TEMPERATURE AND RELATIVE HUMIDITY

The factors given below are used to correct the flowmeter reading for temperature and relative humidity other than those used for flowmeter calibration..

REGULATED LINE TEMPERATURE (OF)	REGULATED LINE RELATIVE HUMIDITY (PERCENT)										
	0	10	20	30	40	50	60	70	80	90	100
35			1.03				1.04				
40							1.03				
45			1.02								
50							1.02				
55			1.01								
60							1.01				
65											
70			1.01				1.01				
75											
80			0.99				0.99				
85											
90			0.98								
95							0.98				
100			0.97								
105											
110							0.97				
115										0.97	
120			0.96								
125											
130							0.96				
135			0.95								
140										0.96	
145			0.94								
150							0.95				
155											
160			0.93		0.94						
165											
170		0.92						0.95		0.96	
175											
180	0.91		0.92	0.93	0.94						

FIGURE 3-5

CORRECTION FACTORS FOR SECONDARY PRESSURE

The Correction Factors given below are used to correct the flowmeter reading for SECONDARY PRESSURE other than that used for flowmeter calibration.

Secondary Pressure psig	Correction Factor	Secondary Pressure psig	Correction Factor
1/4	.778	7 3/4	.953
1/2	.784	8.	.959
3/4	.791	8 1/4	.964
1.	.797	8 1/2	.969
1 1/4	.804	8 3/4	.974
1 1/2	.810	9.	.980
1 3/4	.816	9 1/4	.985
2.	.822	9 1/2	.990
2 1/4	.828	9 3/4	.995
2 1/2	.834	10.	1.0
2 3/4	.841	10 1/4	1.005
3.	.847	10 1/2	1.010
3 1/4	.852	10 3/4	1.015
3 1/2	.858	11.	1.020
3 3/4	.864	11 1/4	1.025
4.	.870	11 1/2	1.030
4 1/4	.876	11 3/4	1.035
4 1/2	.882	12.	1.040
4 3/4	.887	12 1/4	1.045
5.	.893	12 1/2	1.049
5 1/4	.899	12 3/4	1.054
5 1/2	.904	13.	1.059
5 3/4	.910	13 1/4	1.064
6.	.915	13 1/2	1.069
6 1/4	.921	13 3/4	1.073
6 1/2	.926	14.	1.078
6 3/4	.932	14 1/4	1.083
7.	.937	14 1/2	1.087
7 1/4	.943	14 3/4	1.092
7 1/2	.948	15.	1.097

FIGURE 3-6

4.0 RESULTS

4.1 SEGMENT 1 TESTS - COMPARISON OF TEST EQUIPMENTS

The detailed results of the comparison tests of the Prototype Air Leakage Test Set have previously not been published¹¹, and are therefore summarized here. Table 4-1 shows the principal characteristics of the Prototype Air Leakage Test Set and the three existing sets used for comparison. The three units used for comparison were not initially equipped with instrumentation to measure the pressure at the flow meter; assumptions having been made by the users that the pressure at the flow meter is predictable from the equipment design.

One assumption made is that if the input pressure at the regulator is set equal to the pressure at which the flow meter has been calibrated, the readings obtained at the flow meter are correct. This does not account for the pressure drop in the flow control valve, which is dependent on flow rate. This is true even if the flow control valve is located downstream of the flow meter since the flow control valves generally used are not of the pressure regulating kind.

An alternate assumption made was that the pressure at the flow meter is atmospheric, since the test body is pressurized to only a few inches W.C. This assumption ignores the pressure drop in the piping and air delivery connection to the test body -- all downstream of the flow meter.

Since the pressure at the flow meter is a function of the length and size of the tubing used to connect the flow meter to the test van, as well as the flow at a given overpressure, the error introduced by failure to correct for the pressure is a variable, and subject to deliberate or inadvertent manipulation.

Assuming a true flow of 675 SCFH at 1/2 inch overpressure, through tubing of the same length and diameter as on the Prototype Test Set, the uncorrected readings of the various equipments would be:

TABLE 4-I

PRINCIPAL CHARACTERISTICS OF AIR LEAKAGE TEST SETS

	Prototype Test Set	Test Set A.	Test Set B	Test Set C
Flow Meter Calibrated for	Air	Air	Air	Nitrogen
Flow Meter Calibration Temperature	70 ⁰ F	70 ⁰ F	70 ⁰ F	70 ⁰ F
Flow Meter Calibration Pressure	24.7 psia	54.7 psia	14.7 psia	34.7 psia
Provision for Flow Meter Pressure Correction	Yes	No	No	No
Provision for Flow Meter Temperature Correction	Yes	No	No	No
Regulated Line Pressure of Air Supply during Test	Variable	54.7 psia	64.7 psia	59.7 psia

Equipment	Flow Meter Reading		Percent Error
	Uncorrected SCFH	Corrected SCFH	
Prototype Test Set	755	675	--
Test Set A	1055	--	56.3
Test Set B	639	--	-5.33
Test Set C	739	--	9.5

675 SCFH represents the basic allowance for trailers of length L, where $40 \text{ ft} \leq L < 45 \text{ ft}$ per TTMA Recommended Practice #38-73.

When the flow meter readings of all three existing sets were corrected by independent measurement of the pressure at the flow meter, they agreed with the corrected Prototype Test Set readings to within 3 percent. In the absence of specific information as to corrections made to previously reported data and with the knowledge that test sets currently in use do not have the instrumentation to make the needed corrections accurately, previously published data can neither be compared to each other nor to data obtained with the Prototype Test Set.

The correction factors for the temperature and humidity in the line during Segment 1 tests were either 0.99 or 1.00. Figure 3-5 shows that for normal shop environments of $70^{\circ} - 80^{\circ} \text{ F}$ (21.1 to 26.7°C) this factor will always be small compared to the correction factor due to pressure. However, in warm and humid climates this factor may become significantly different from unity, especially when portable air compressors are used, since they tend to increase supply air relative humidity.

4.2 SEGMENT 2 TESTS - AIR LEAKAGE OF IN-SERVICE EQUIPMENT.

Table 4-II is a summary tabulation of the vehicles tested during Segment 2, classified by length of the refrigerated compartment, types of doors in the compartment, type of refrigeration unit and age of equipment.

VEHICLE TYPE	REFRIGERATED COMPARTMENT LENGTH			
	16 ft (4.9m) or less	16 to 25 ft (4.9 to 7.6m)	26 to 39 ft (7.9 to 11.9m)	40 ft (12.2m) or longer
Trailer/Container with mechanical refrigeration, double hinged doors, less than 18 months old.	-	-	-	21
Trailer/Container with mechanical refrigeration, double hinged doors, more than 18 months old.	-	-	11	11
Trailer/Container with mechanical refrigeration, double hinged doors and side door(s), more than 18 months old	-	2	1	9
Trailer/Container with mechanical refrigeration, overhead rear door and side doors(s), more than 18 months old.	-	1	2	8
Truck Body with eutectic plate system, rear and side doors, less than 18 months old.	-	1	-	-
Truck Body with eutectic plate system, rear and side doors, more than 18 months old.	-	4	-	-
Truck Body with eutectic plate system, side doors only, more than 18 months old.	-	4	-	-
Truck Body with eutectic plate system, front door in driver compartment, rear doors on body, more than 18 months old.	17	-	-	-

TABLE 4-11
CLASSIFICATION OF VEHICLES TESTED DURING CORRELATION TESTS

4.2.1 Group 1

Twenty trailers of identical design were chosen from a population of 100 units, produced during the first quarter of calendar year 1978. Trailer characteristics are as follows:

Length: 40'0"

Height: 13'6"

Insulation:

Sides 3 inch urethane w/PVC furring

Front 3 inch urethane w/PVC furring

Floor 3 inch urethane w/wood furring

Rear 3 inch urethane w/PVC furring

Roof 4.5 inch urethane w/PVC furring

Inside Height: 97½ inches

Doors: Hinged double doors at rear, flat outer seals.

These tests were conducted over a period of three days. Ambient temperatures ranged from a low of 73° F (22.8°C) to a high of 100° F (37.8°C).

For the reduced interior temperature tests, three of the trailers were tested with interior temperatures near 0° F (-17.8°C) (low temperature) and 17 with interior temperatures between 36° F and 55° F (2.2° and 12.8°C) (medium temperature).

Medium Temperature Test Data

During the medium temperature difference tests, the difference between outside and inside temperature ranged from 31° to 60° F. For each ambient and medium temperature test, the three data points were corrected by means of the tables shown in Figures 3-5 and 3-6, and the resulting values plotted on logarithmic graph paper. In all cases a straight line resulted and each line was extrapolated to obtain the value of b . This is the air leakage at $p = 1$ W.C. since

$$Q = bp^n$$

and $p^n = 1$ for all values of n , when $p = 1$.

Values for the slope of the line, n , were obtained by direct measurement of the graph.

The results of the 17 medium temperature tests are shown in Table 4-III. No correlation was found between air leakage rate and the ambient temperature at which the test is performed, nor was any correlation found between air leakage rate and inside temperature. Further, no correlation could be established between air leakage rate and temperature difference.

No correlation could be established between air leakage values and the slope of the line n , for either ambient or low temperature tests. The change in air leakage rate between the two tests also shows no correlation with any of the parameters.

The range of the air leakage values is very large. At ambient condition, the median value is 2013 SCFH, with a low of 1500 SCFH and a high of 3700 SCFH. Further, the slope of the lines, n , has a median value of 0.68, with a low of 0.5 and a high of 0.88. These values of n found experimentally contradict the assumption used by the various standardization groups, that $n = 0.65$.

The lack of correlation suggests that "with proper construction leakage is not a consequence of lack of care but is inherent in the mode of construction" may not be true. Consider the changes in b and n that would be expected between the ambient and medium temperature tests, keeping in mind that the slope of the line n should increase as the character of the openings changes from "orifice" to "crack" type.

If there is a multitude of orifice type openings at ambient conditions, and the interior temperature is reduced, these openings should become smaller, with a tendency to behave more nearly as cracks. However, the total leakage should not increase at a pressure of 1 inch W.C. An increase in overall air leakage

TABLE 4-III
RESULTS OF MEDIUM TEMPERATURE TESTS - GROUP 1

VEHICLE #	YEAR OF MANUFACTURE	AMBIENT TEST			REDUCED INTERNAL TEMPERATURE TEST				COEFFICIENT CHANGE AMBIENT TO REDUCED TEMP	
		Temp ^o F	b	n	Ambient Temp ^o F	Internal Temp ^o F	b	n	α	ϕ
1	1978	84	2000	.50	81	44	4000	.62	+	+
2	1978	86	3700	.64	81	40	5200	.62	+	+
3	1978	76	1775	.64	88	50	2200	.73	-	+
4	1978	84	1575	.51	84	42	2200	.62	-	+
5	1978	86	2150	.70	83	42	2250	.72	+	-
6	1978	76	1750	.69	79	36	2000	.61	+	-
7	1978	84	1575	.88	90	40	4300	.99	-	+
8	1978	80	1850	.79	80	39	2600	.73	+	+
9	1978	81	1800	.84	97	37	1325	.78	+	-
10	1978	86	1500	.58	83	36	1875	.52	+	-
11	1978	81	2025	.68	91	40	4200	.96	-	+
12	1978	86	2400	.72	82	38	2750	.73	+	+
13	1978	75	2300	.67	81	38	3400	.75	+	+
14	1978	88	2400	.88	80	42	1250	.61	+	-
15	1978	75	2200	.68	81	40	3400	.63	+	+
16	1978	85	2200	.76	86	55	2050	.74	+	-
17	1978	89	3000	.62	89	40	5600	.60	+	+

TABLE 4-IV
RESULTS OF LOW TEMPERATURE TESTS - GROUP 1

VEHICLE #	YEAR OF MANUFACTURE	AMBIENT TEST			REDUCED INTERNAL TEMPERATURE TEST				COEFFICIENT CHANGE AMBIENT TO REDUCED TEMP	
		Temp ^o F	b	n	Ambient Temp ^o F	Internal Temp ^o F	b	n	α	ϕ
18	1978	87	2000	.70	73	8	3000	.86	-	+
19	1978	89	3000	.62	73	6	7500	.84	-	+
20	1978	82	1300	.71	100	8	2075	.55	+	-

rate at reduced temperature thus implies a change in the total openings through which air flows, although there may be an accompanying change in the character of the openings.

For example, consider a lap joint, in which the sheet materials are held together with rivets or other mechanical fasteners of the same material. Under normal conditions, such a joint does not loosen, since the contraction in thickness of the sheets is matched by the fastener contraction, and the contraction of the sheets will not normally destroy the lap.

A butt joint would, however, tend to pull apart at the seam and produce an additional opening. One area where this is especially critical is in the interior metal floor, which is normally laid over a plywood sheet supported by wooden stringers that are in turn supported by the van floor structure. For a 40° F (22.2°C) temperature difference, the interior floor can shrink up to 0.3 inches (7.6 mm) for a 40 foot (12.2 m) length compared to the outer van structure, and at some point in the structure additional openings must occur.

In order to make a qualitative estimate in the change in character of the openings, coefficients α and ϕ were calculated for each test, on the assumption that there are only true cracks and true holes, and thus

$$Q = bp^n = \alpha p^{.5} + \phi p$$

Four possible cases exist when reduced temperature coefficients are compared to the coefficients at ambient temperatures:

Case A: α increases, ϕ increases

Case B: α increases, ϕ decreases

Case C: α decreases, ϕ increases

Case D: α decreases, ϕ decreases

If, of a large group of vans tested, all vans fall into one category, one may conclude that the design of the unit causes a consistent change, and, with knowledge of the construction, one can search for the areas that contribute to

air leakage and thus eliminate them.

Table 4-III shows the change in coefficients α and β when comparing the reduced internal temperature data to the ambient data. If, as in this case, there is no consistency in this change, it is indicative of either a design problem (i.e., the design does not allow consistent assembly) or it is a lack of quality control. The large variation in air leakage for the vans in this group, all of recent construction and identical design, and the unpredictability of the low temperature leakage, suggests a quality control problem.

Visual Observations

In an attempt to locate the leaks, several of the vans were tested with commercially available smoke bombs. Although copious quantities of white smoke are generated, smoke does not generally appear on the outside unless the vehicle is also pressurized.

1. Some leakage occurred at door gaskets, but usually in isolated sections.
2. Some leakage occurred around floor drains, and where the vertical walls join the floor, especially at the rear of the vehicle.
3. Some leakage occurred at the upper rails, where the roof sheet joins the side walls.
4. No leakage through the refrigeration units (except at the defrost drains) was observed. There was also no smoke found at the refrigeration unit/trailer sealing gasket.

It was found that the smoke tests did not give a reliable estimate of the magnitude of the air leakage, nor did they necessarily indicate the precise leakage paths. If there are any insulation voids, the smoke can travel a considerable distance within the structure, and exit at a location different from the entrance. For this series of trailers, an independent test was performed in which one trailer was cooled to, and maintained at 0° F (-17.8°C) for about 24 hours. Moisture condensation, indicative of insulation voids, appeared on some exterior surfaces.

Low Temperature Test Data

Three of the Group 1 trailers were tested with $T \approx 0^{\circ} \text{F}$ (-17.8°C). The results are shown in Table 4-IV.

In all cases there was evidence of ice formation at certain door seal areas, with the thickness of ice approaching one inch (25 mm). Although this tends to seal the openings, it must be remembered that ice buildup takes place only with increased energy consumption. The thermal conductivity of ice is roughly 90 times that of urethane foam, so that frost formations less than 0.03 inches (0.8 mm) represent conductive losses greater than that of a structure with 3 inches (76 mm) of foam.

Despite the sealing effect of frost formations, air leakage increased between 150 to 250 percent over the ambient condition. The change in α and ϕ , together with the large variation in air leakage confirms a lack of quality control.

Visual Observations

As in the medium temperature tests, smoke bomb tests showed a general lack of air tightness. Leakage at the wall/floor joint appears to be a major source of the problem. In addition, leakage was observed at the penetration of the floor drain through the insulation, which implies the presence of foam voids.

Effect of Open Drains on Air Leakage

During tests of this series of trailers, all of one design, it was observed that some of the boots covering the drain fittings had become damaged. The boots consist of a rubber tube, about 1 inch (25 mm) in diameter, in which one end is pinched flat during the molding process. This pinched end expands when internal pressure is exerted above atmospheric (by water used for cleaning the interior) and permits the liquid to drain. Although overpressure tests were performed with the drains sealed with sealing compound, one trailer was re-tested without sealing the drains to determine the effect of missing drain boots.

With one drain not sealed but with the drain boot in place, air leakage was

found to have increased approximately 4.5 percent. With two unsealed drains, boots in place, air leakage increased approximately 20.6 percent.

With one drain not sealed, and the drain boot maintained in an open condition to simulate a missing boot, air leakage increased by approximately 28 percent. All of these tests were performed at an inside temperature of 40° F (4.4°C) in an ambient of 90° F (32.2°C). These values are consistent with those found by other investigators¹².

4.2.2 Group 2

The equipment in this group consisted of both trailers and containers, of various ages and different manufacturers. All had mechanical refrigeration units, hinged double rear doors, and from 3 to 4 inches (76 to 101 mm) of urethane insulation. Some units had additional vent doors or side doors, or both.

Medium Temperature Test Data -- Containers

Eleven containers were first tested at ambient conditions. Four of these were then tested at medium and five at low inside temperatures. The remaining two units are not included in the summary as a result of obvious physical damage found during the ambient tests.

The very high leakage of one unit, and the slope $n = 0.51$ indicated a single large leakage source. Further investigation showed that a bolt -- intended to hold the refrigeration unit to the container -- was missing. Since the repair could not be immediately effected, a lower temperature test was made, but it did not yield consistent results.

A second unit had damaged interior sidewalls. Both the left and right walls had two penetrations each into and through the insulation; one area was approximately 2 inches (51 mm) in diameter and entirely through the insulation. Readings for both ambient and reduced temperature tests were erratic, as evidenced by the slope of the lines being less than 0.5.

The results of the four medium temperature tests are shown in Table 4-V.

TABLE 4- V
RESULTS OF MEDIUM TEMPERATURE TESTS-GROUP 2 -Containers

VEHICLE #	YEAR OF MANUFACTURE	AMBIENT TEST			REDUCED INTERNAL TEMPERATURE TEST				COEFFICIENT CHANGE AMBIENT TO REDUCED TEMP	
		Temp ^o F	b	n	Ambient Temp ^o F	Internal Temp ^o F	b	n	α	ϕ
21	1971	84	2250	.59	70	32	2650	.71	-	+
22	1969	80	3000	.54	70	32	3150	.69		+
23	1969	75	1800	.93	74	32	5800	.52	+	-
24	1969	81	1550	.6	59	38	1780	.61	+	+

TABLE 4-VI
RESULTS OF LOW TEMPERATURE TESTS - GROUP 2 - Containers

VEHICLE #	YEAR OF MANUFACTURE	AMBIENT TEST			REDUCED INTERNAL TEMPERATURE TEST				COEFFICIENT CHANGE AMBIENT TO REDUCED TEMP	
		Temp ^o F	b	n	Ambient Temp ^o F	Internal Temp ^o F	b	n	α	ϕ
25	1976	79	460	.65	84	26	480	.87	+	-
26	1976	72	860	.61	80	30	950	.66	-	+
27	1976	74	930	.88	77	16	760	.55	+	-
28	1969	80	3350	.52	80	20	3250	.55	+	-
29	1969	80	2025	.61	70	28	1910	.53	+	-

The containers are all from one manufacturer and although these containers are 7 to 9 year old, their leakage rates appear to be as good as the newer trailers of Group 1. They show as great a variation from unit to unit as in the prior group, and no correlation was found among any of the parameters examined.

Visual Observations

Smoke bomb tests and visual examination showed considerable leakage at the door seals and at the seal between the refrigeration unit and the van. This is to be expected in older equipment due to aging of the seals and corrosion of the sealing surfaces.

Low Temperature Data -- Containers

The five low temperature tests were performed on equipment from one manufacturer. Equipment age varied from 2 to 9 years old. The results are shown in Table 4-VI. A significant difference, both in ambient and low temperature tests, was found between the two age groups. It is known that the manufacturer changed both design and manufacturing techniques in the intervening years. The two year old equipment shows leakage values approximately $\frac{1}{4}$ to $\frac{1}{2}$ as large as the older equipment. The leakage at low temperatures, which is not significantly different from the ambient values, shows that units can be built that are relatively airtight under service conditions.

Visual Observations

The units in this group have doors equipped with both inner and outer seals, which may account for their better performance as compared to Group 1.

Medium Temperature Test Data -- Trailers

Of the 11 trailers tested, 3 were found to leak so extensively that internal pressure could not be maintained at flow levels in excess of 1700 SCFH. These units were examined visually and by means of feel and sound (i.e., listening for escaping air by means of a short piece of plastic hose, one end of which is held to the ear as the other end is moved along the seals). In two cases the seal

between the refrigeration unit and body was found to be defective as a result of this examination. In the third case, a 3/4 inch diameter hidden hole in the front wall was the proximate cause.

Of the 8 remaining units, 6 were tested at ambient and medium temperature and the remaining 2 at low temperature. Equipment age varied from 2 to 13 years. Results are tabulated in Tables 4-VII and 4-VIII.

The newest equipment, from the same manufacturer as the best samples of containers, was consistently superior to that of the older equipment, showing little change between the ambient and reduced temperature tests. The only specific sources of leakage which could be identified by visual examination were door seals.

The older equipment was in very poor condition. Several doors were severely rotted, seals were broken or missing, and interior linings had been badly damaged. Subsequent tests confirmed these defects by the high air leakage readings. Trailers 30, 34 and 35 were equipped with vent doors, and trailers 34 and 35 had side doors. The effect of the vent doors, all of which exhibited leakage at the gaskets, is shown in Table 4-VII.

Low Temperature Test Data -- Trailers

Two low temperature test performed on 2 year old equipment and summarized in Table 4-VIII again show the ability to design and construct high quality equipment.

Effect of Drains on Air Leakage

To test the effect of open drains on air leakage rate, one of the containers in this group (Vehicle 26) was tested at ambient temperature with all drains sealed, and subsequently with both drains open. Figure 4-1 shows the results. Each drain is approximately 1 inch (25 mm) in diameter. Although the air leakage rate increases appreciably as drains are opened, it should be noted that the effect of these large "orifice" type openings on n is relatively small. The effect of two open drains is a 60 percent increase in air leakage at a pressure of

TABLE 4-VII
RESULTS OF MEDIUM TEMPERATURE TESTS -GROUP 2 -Trailers

VEHICLE #	YEAR OF MANUFACTURE	AMBIENT TEST			REDUCED INTERNAL TEMPERATURE TEST				COEFFICIENT CHANGE AMBIENT TO REDUCED TEMP	
		Temp ^o F	b	n	Ambient Temp ^o F	Internal Temp ^o F	b	n	α	ϕ
30	1976	.79	1190	.67	70	40	1250	.68	+	-
31	1976	85	880	.92	78	36	1075	.65	+	-
32	1968	83	2850	.5	61	38	4900	.91	-	+
33	1968	82	15050	.91	74	38	5650	.55	+	-
34	1965	74	6800	.62	77	44	7600	.61	+	+
35	1965	71	2590	.63	61	34	2490	.63	-	+

TABLE 4-VIII
RESULTS OF LOW TEMPERATURE TESTS -GROUP 2- Trailers

VEHICLE	YEAR OF MANUFACTURE	AMBIENT TEST			REDUCED INTERNAL TEMPERATURE TEST				COEFFICIENT CHANGE AMBIENT TO REDUCED TEMP	
		Temp ^o F	b	n	Ambient Temp ^o F	Internal Temp ^o F	b	n	α	ϕ
36	1976	80	990	.71	70	6	900	.82	-	+
37	1976	86	510	.53	78	0	730	.77	-	+

FIGURE 4-1

AIR LEAKAGE WITH OPEN AND CLOSED DRAINS

- -all drains closed
- x— -one drain open
- -two drains open

0.1 inch W.C. (25 Pa) and 54 percent at 1 inch W.C. (249 Pa); it may, therefore, be assumed to be a constant.

4.2.3 Group 3

This group consists of trailers used in a typical supermarket distribution system hauling both perishables (meats, vegetables) and frozen commodities. A total of 14 trailers, principally 40 feet (12.2 m) in length, were examined.

The use of this equipment is quite different from that of the trailers and containers of Groups 1 and 2. A typical supermarket distribution requirement is for mixed products, with several stops for any one vehicle. Routes are generally short -- less than 48 hours from loading to discharge. The unloading may be at a truck door, (rear doors), alongside a street curb (one or more side doors), or even to street level through the rear doors by means of an elevator built into the trailer floor (full width by 10 feet in length). See Figure 4-2.

Rear doors are either conventionally hinged or of the roll-up type. Vent doors may or may not be fitted. Floor drains are generally provided, although none of the units examined was equipped with boots over the drains.

Of the 14 trailers tested, 7 were found to be incapable of holding pressure at flow rates of up to 1700 SCFH. No units with roll-up doors were found that could hold any pressure, and observation during smoke bomb tests revealed air leakage between the door and its guide frame, between hinged door panels, and between the lower door panel and the bottom header. Where the door is poorly fitted, the top panel does not move into a completely vertical position, and this also causes leakage. The units tested which did not hold pressure or were otherwise eliminated, and the principal reasons are as follows:

Overhead Doors, with and without damage to trailer	4
Double rear and side door(s), damage discovered as a result of air test	3
Units required for transportation and unavailable for low temperature test.	1

FIGURE 4-2
GAP IN FLOOR AT JUNCTION OF TRAILER FLOOR AND
INTERIOR ELEVATOR.

Three units, all from one manufacturer, and built in recent years were tested at ambient and medium temperatures as shown in Table 4-IX. The air leakage values are extremely high and as a result, even with very high flow rates, the manometer readings were very low (0.01 to 0.05 inch W.C.)(2.5 Pa). Since at low pressure readings even small errors in the manometer readings may seriously affect the value of n , these tests were not used to draw conclusions about the types of openings in the bodies.

As a result of the apparent decrease in air leakage at reduced internal temperature for units 39 and 40 observed during testing, a careful visual examination of these trailers was made. Damage to the inner liner of both trailers was observed, with insulation missing in both cases. (Figure 4-3). The missing area was recorded at approximately 9 square inches (58 cm^2) and 324 square inches (2090 cm^2) respectively.

Trailer 39 was tested at an inside temperature of 35° F (1.7° C) and air at 59° F (15° C) and 48% R.H. Trailer 40 was tested at an inside temperature of 32° F (0° C) and air at 66° F (18.9° C) and 52% R.H. Reference to Figure 3-4 shows that in the latter case, frost was able to form over the exposed insulation and to provide a seal against air leakage.

Low Temperature Test Data

The three units tested at low temperature are shown in Table 4-X. These units were equipped with side doors and a two-step ladder below the door. This structure is such that its use would eventually distort the door frame at the lower left-hand edge and cause leakage. This was observed to have occurred. (Figure 4-4).

If frost forms in a low temperature test, this is indeed representative of actual use condition, i.e., operating personnel are aware of frost formations with 0° F (-18.8° C) loads in humid ambients. This effect is cited as "reducing the air leakage". That there is an energy waste, to keep the frost in place, is not generally recognized.

TABLE 4-IX.

RESULTS OF MEDIUM TEMPERATURE TESTS - GROUP 3

VEHICLE #	YEAR OF MANUFACTURE	AMBIENT TEST			REDUCED INTERNAL TEMPERATURE TEST				COEFFICIENT CHANGE AMBIENT TO REDUCED TEMP	
		Temp ^o F	b	n	Ambient Temp ^o F	Internal Temp ^o F	b	n	α	ϕ
38	1977	55	6000	.68	55	32	9000	.56	+	-
39	1977	58	5800	.67	58	35	5800	.51	-	+
40	1976	67	8400	.57	67	32	6200	.55	-	+

TABLE 4-X

RESULTS OF LOW TEMPERATURE TESTS - GROUP 3

VEHICLE #	YEAR OF MANUFACTURE	AMBIENT TEST			REDUCED INTERNAL TEMPERATURE TEST				COEFFICIENT CHANGE AMBIENT TO REDUCED TEMP	
		Temp ^o F	b	n	Ambient Temp ^o F	Internal Temp ^o F	b	n	α	ϕ
41	1974	64	4350	.59	79	30	3600	.5		-
42	1978	80	1850	.72	69	26	1625	.66	-	-
43	1976	62	3850	.75	62	24	3950	.67	+	-

FIGURE 4-3
TYPICAL DAMAGE TO INSULATION AND DOOR.

FIGURE 4-4
DISTORTION OF DOOR FRAME DUE TO LADDER

The results of the low temperature tests, compared with the medium temperature test results, indicate that testing below 35⁰ F (1.7⁰C) is not recommended, as frost formation affects the results obtained.

Visual Observations

Where vent doors exist, steps are generally provided at the front of the trailer; these steps also provide access to the refrigeration unit. The steps are made of bar stock riveted to the front skin. The rivets are invariably a source of smoke when the unit is smoke bomb tested. This also implies voids in the insulation behind the rivets. Several areas where damaged door seals had been removed without replacement were noted. Even where door seals had been replaced a new section was butted against the existing portion, thus providing a direct leakage path.

4.2.4 Group 4

The vehicles in this group are representative of dairy operations, and comprise several different body styles from small ice cream trucks to 40 foot (12.2 m) trailers.

Trailers

The six van trailers tested are all provided with overhead roll-up doors, and in five out of the six it was impossible to hold any pressure at flow of 1200 SCFH. In the sixth unit a pressure of .015 inch W.C. was attained at 1200 SCFH, but testing was stopped when spilled milk leaked out under the rear door. The extent to which the liquid sealed the gap could not be determined.

Milk Delivery Trucks 16 feet or less

These units are principally of the eutectic plate-type. A small compressor, mounted under the vehicle and driven by a 110 volt 60 Hz electric motor, cools a eutectic plate system in the refrigerated space. Figure 4-5. The loaded vehicles are parked overnight and connected to a utility outlet. In the morning the driver disconnects the power line and begins his route. He returns between

FIGURE 4-5
MOUNTING OF REFRIGERATION UNIT ON
MILK DELIVERY TRUCK.

FIGURE 4-6
SLIDING DOORS IN DRIVER'S COMPARTMENT

2:00 PM and 4:00 PM and the truck is reloaded with fresh product and again parked overnight. This practice eases the loading congestion, since the trucks do not all return at the same time, and gives the dairy additional product storage space.

The eutectic plates maintain the desired temperature during delivery. Defrosting of the plates is performed about every six weeks (more frequently in the summer months). In this way energy is conserved in the system and moisture penetration into the insulation is also minimized. The older compressor units operate whenever the power line is connected while the newer units operate under thermostatic control.

The milk delivery vehicles are equipped with front and rear doors, almost exclusively of double side-sliding type (Figure 4-6). The rear doors are either sliding type or hinged (Figure 4-7). The front doors open to the driver's compartment.

Attempts to pressurize the bodies failed due to the poor condition of the doors and door seals (Figure 4-8). Therefore an alternate procedure was adopted. A man entered the cargo space to observe the presence of light, and measured the length and depth of the open areas. Table 4-XI shows the results of this investigation.

Milk Delivery Truck -- 16 to 25 ft length

Six vans of this type were tested. Three of the vans were equipped with eutectic plate refrigeration units and three vans with over the cab mechanical refrigeration units. Only one of the three units equipped with eutectic plates was able to hold pressure. Since eutectic plate units are not regularly defrosted, only a medium temperature test was possible. Tested at $T_e = 64^{\circ} \text{F}$ (17.7°C) and $T_i = 42^{\circ} \text{F}$ (5.6°C), the air leakage value at $p = 0.05$ is 480 SCFH.

The units with mechanical systems showed visual damage severe enough to preclude a pressure test in two of these cases. On the third unit, no pressure could be maintained at a flow rate of 1200 SCFH ($34 \text{ m}^3/\text{h}$).

FIGURE 4-7
REAR DOOR OF MILK DELIVERY VEHICLE.

FIGURE 4-8
TYPICAL DOOR AND DOOR SEAL DAMAGE.

TABLE 4-XI
INSPECTION RESULTS-MILK VANS

VEHICLE #	FRONT DOOR		REAR DOOR	
	VERTICAL SEAL	HORIZONTAL SEAL	VERTICAL SEAL	HORIZONTAL SEAL
44	3 @ 1/4 x 56"	2 @ 1/4 x 31"	3 @ 1/4 x 54"	2 @ 1/4 x 28"
45	1 @ 1/8 x 56"		Large Gap in Corner	
46	1 @ 1/8 x 56"	1 @ 1/8 x 28"	1 @ 1/8 x 18"	1 @ 1/8 x 28"
47	1 @ 3/16 x 18"	1 @ 3/16 x 3"	1 @ 3/16 x 24"	1 @ 3/16 x 3"
	1 @ 3/16 x 48"	No Light Visible	No Light Visible	No Light Visible
48	1 @ 1/8 x 56"	No Light Visible	No Light Visible	No Light Visible
	1 @ 1/8 x 9"	No Light Visible	No Light Visible	No Light Visible
49	1 @ 1/8 x 56"	No Light Visible	No Light Visible	No Light Visible
	1 @ 1/8 x 56"	No Light Visible	No Light Visible	No Light Visible
50	1 @ 1/8 x 56"	1 @ 1/8 x 4"	1 @ 3/16 x 54"	No Light Visible
	1 @ 1/8 x 4"	No Light Visible	No Light Visible	No Light Visible
51	1 @ 1/16 x 56"	No Light Visible	No Light Visible	1 @ 3/16 x 9"
	No Light Visible	No Light Visible	No Light Visible	1 @ 3/16 x 4"
52	1 @ 1/8 x 56"	No Light Visible	No Light Visible	1 @ 1/8 x 9"
	1 @ 3/16 x 56"	No Light Visible	No Light Visible	No Light Visible
53	1 @ 1/8 x 42"	Large Gap in Corner	No Light Visible	No Light Visible
54	1 @ 1/4 x 28"	No Light Visible	No Light Visible	No Light Visible
55	No Light Visible	No Light Visible	1 @ 1" x 20"	No Light Visible
56	1 @ 3/8 x 56"	No Light Visible	No Light Visible	No Light Visible
57	1 @ 3/32 x 56"	No Light Visible	1 @ 1/16 x 54"	No Light Visible
58	Door Not Supported at Bottom -- Swings Open		No Light Visible	No Light Visible
59	1 @ 1/8 x 56"	1 @ 1/8 x 31"	No Light Visible	No Light Visible
	1 @ 1/8 x 56"	No Light Visible	No Light Visible	No Light Visible
60	1 @ 1/8 x 12"	No Light Visible	No Light Visible	No Light Visible
	1 @ 1/8 x 3"	1 @ 1/8 x 3"	No Light Visible	No Light Visible
	1 @ 1/8 x 3"	1 @ 1/8 x 3"	No Light Visible	No Light Visible

Ice Cream Trucks

Six ice cream trucks, each less than 16 feet (4.9 m) in length, were tested. These units are heavily insulated, 4 inches or more (101 mm) of insulation, and are equipped with eutectic plate systems.

The doors of these units are small, about 24 x 24 inches (610 x 610 mm), and are extremely well fitted. The door latches provide for adjustment of the gasket compression. Ice cream is carried at -20°F (-28.9°C) to preserve its quality, so that even in moderate ambient conditions of 68°F (20°C), the refrigeration load is severe.

Despite a high level of maintenance, each of the six side doors showed ice formation along the bottom edge, and equivalent openings may be presumed to exist along other edges to permit entry of air. The units are loaded with product, and thus it was not possible to confirm ice formation on the inside of the door seals where air would enter. Further, the loaded vans could not be leak tested with warm air because of potential product damage. Although there was a tight fit between doors and door frames which would have made installation of the air supply and manometer tubing difficult, this problem could have been resolved in an empty vehicle.

The ice formation was measured at about 1/4 inch (6.4 mm) thick maximum.

4.3 INCREASED COOLING LOAD DUE TO AIR LEAKAGE

The cooling load is composed of three parts:

1. Heat transmission through the walls, roof and floor of the van.
2. Heat generated by the cargo. (Respiring cargo, as opposed to frozen commodities, all exhibit a heat of respiration, which is itself a function of temperature.)
3. Heat load due to air leakage.

The greater the values of 1 and 2 above, the less the influence of air leakage on the total load.

The heat transmission through an insulated body is conventionally stated in terms of overall heat transmission coefficient (U_A). The total heat load is then the U_A value multiplied by the temperature difference between the inside of the van and ambient.

When the ambient temperature is at or below the maximum allowable product temperature, no cooling is required, and air leakage has no adverse results. At the other extreme, if frozen cargo is carried in an ambient of 100°F (37.8°C) and 50% RH, 100 SCFH equivalent volumetric flow represents an energy loss of 358 Btu/hr (105w).

In addition to the ambient temperature, which is a function of season and route, the temperature of the product, i.e., T_i , establishes the energy wasted, since the entering air must be cooled to the level of T_i .

Respiring cargo decays, and gives off CO_2 , moisture and heat of respiration. For example, oranges are normally carried at between 38° and 42°F (3.3° and 5.6°C), and produce a heat respiration of about 1600 Btu/ton-day (.0216 w/kg-h). A typical 48,000 pound (21725 kg) cargo of oranges, therefore, would exhibit a respiration heat load of 1600 Btu/hr (469w).

The TTMA study¹³ confirmed the findings of the U.S.D.A. study¹⁴ and showed that when an air leakage test is performed at $T_e = 100^{\circ}\text{F}$ (37.8°C) and $T_i = 0^{\circ}\text{F}$ (-17.8°C), the results of such test at 0.05 inches W.C. (13 Pa) overpressure are representative of the increased heat load at these operational conditions. For purposes of a testing standard, a pressure of 0.5 inch W.C. (125 Pa) was chosen arbitrarily, as it is easier to maintain this level of pressure, and the relationship $Q = bp^n$, with $n = .65$ was assumed to relate the quantity of air leakage at 0.05 (13 Pa) and 0.5 inches W.C. (125 Pa).

The current test program was conducted with three different pressures for each test and this results in a calculated value of n for each vehicle, from which the operational air leakage at 0.05 inches W.C. (13 Pa) can be calculated

directly. Thus no value of n needs to be assumed. If the test is performed at expected operating conditions, it is then possible to make estimates of the energy loss at these conditions.

4.3.1 Estimated Losses, Group 1

Cargo Temperature $T_i = 0^\circ \text{F} (-17.8^\circ \text{C})$

The trailers of Group 1 at a mean wall temperature of 50°F , are calculated to have a U_A value of about $85 \text{ Btu/hr}^\circ \text{F}$ ($44.8 \text{ w/}^\circ \text{C}$). When increased to account for the operation of the cooling fans and road speed (approximately 14%), the U_A value is 96.9 Btu/hr ($51.1 \text{ w/}^\circ \text{C}$). Since the higher U_A value results in a conservative estimate of the air leakage effect, a $U_A = 100 \text{ Btu/hr}^\circ \text{F}$ ($52.8 \text{ w/}^\circ \text{C}$) will be assumed.

One of the three trailers of Group 1 (#20) was tested at close to $T_e = 100^\circ \text{F}$ (37.8°C) and $T_i = 0^\circ \text{F} (-17.8^\circ \text{C})$. The air leakage rate at this condition, calculated at $p = 0.05$, and b and n from Table 4-III, is 400 SCFH ($11.33 \text{ m}^3/\text{h}$). Using the method of Appendix B, each cubic foot per hour of air leakage results in a heat loss of 3.58 Btu/hr (1.05 w).

Therefore,

$$\begin{aligned} \text{Heat transmission Loss} &= U_a \Delta t \\ &= 100(100-0) = 10,000 \text{ Btu/hr} \\ \text{Heat of respiration} &0 \\ \text{Air Leakage } 400 \times 3.58 &= 1432 \text{ Btu/hr} \\ \text{Increased Heat Load due to Air Leakage} &= 14.3 \text{ percent} \end{aligned}$$

Trailers 18 and 19 were tested in an ambient of 73°F (22.8°C) and have operational level air leakage quantities of 228 and 605 CFH (6.46 & $17.13 \text{ m}^3/\text{h}$) respectively.

Using the method of Appendix B at 73°F (22.8°C) and 50% RH outside conditions, the effect of one cubic foot per hour of air leakage is approximately 2 Btu/hr ($.58 \text{ w}$); at 100% and 0% RH, the values are 2.752 and 1.302 Btu/hr-CFH

(28.5 & 13.5 w/m³h) respectively. Thus, the effect of air leakage can range from a low of 297 (87 w) to a high of 1665 Btu/hr (488 w). Since the heat transmission load is reduced to 100 (73-0) = 7300 Btu/hr (2140 w), the effect of the air leakage is an increase in load of 4 to 22.8 percent. At an average of 50% RH the air leakage influence of the two trailers is 6.25 and 16.6 percent respectively.

Table 4-III shows that several trailers were tested with interior temperature at about 40° F (4.4°C) in ambients near 80° F (26.7°C). For these trailers (Numbers 2, 8, 12, 13, 14, 15), solving the equation $Q = bp^n$ for values of $p = 0.05$, results in air leakage values of 812, 292, 309, 360, 201 and 515 CFH (23, 8.27, 8.75, 10.2, 5.7 and 14.6 m³/h) respectively.

Using the method elaborated above for the lowest and highest air leakage values, and assuming a heat of respiration of a load of oranges, the results are:

Air Leakage, CFH	<u>201</u>	<u>812</u>
Heat transmission (100 (80-40))	4000 Btu/hr	4000 Btu/hr
Heat of Respiration	1600	1600
Air Leakage Effect @ 80° F & 50% RH	237	955
Increased Load due to Air Leakage	4.23%	17%

If all six trailers had been used, the average increase of refrigeration load due to air leakage would have been 8.72 percent.

4.3.2 Estimated Losses -- Group 2

The older equipment covered in Tables 4-V through 4-VIII inclusive give results comparable to those of Group 1, as can be observed by comparison of the values of b and n .

Two exceptions are noted. Vehicle 33 is so poor in performance that the energy loss due to air leakage at $T_e = 74° F$ (23.3°C) and 50% RH with $T_i = 38° F$ (3.3°C) approaches 25 percent. At a lower inside temperature and higher ambient temperature, the effect increases to over 30 percent.

The second exception comprises vehicles 36 and 37, which have previously

been identified as showing superior air leakage performance. At ambient temperatures of 80°F (26.7°C) and 50% RH with frozen cargo, the increased refrigeration load is only 2.18 and 2.33 percent, respectively.

The effect of two open drains, or drains with damaged boots, measured to be approximately a 60 percent increase in air leakage, would tend to increase the energy loss substantially.

4.3.3 Estimated Losses - Group 3

Many vehicles of this group were eliminated due to air leakage so substantial that test pressure could not be attained. The following estimates, therefore, cannot be applied as average values, but represent the best conditions, with more than half the fleet in worse condition.

Trailer 39 is relatively new, yet in ambient conditions of only 58°F (14.4°C) and 50% RH, with cargo temperatures of 35°F (1.7°C) -- at this condition there is no latent heat removed from the air -- the effect of air leakage is 11 percent. Trailer 40, used at $T_e = 67^{\circ}\text{F}$ (19.4°C), 50% RH and $T_i = 32^{\circ}\text{F}$ (0°C), would be affected approximately 20 percent.

The above figures are based on data taken with all drains closed. With four drains open, as actually used, a direct path is present for cooler, and therefore, heavier air to escape. Based on the test data, a 30% increase in air leakage is to be expected as a minimum, so that typical values for the best equipment in service are closer to 14.6% and 26% respectively.

4.3.4 Group 4

The estimated additional energy consumption due to air leakage of the 40 ft. (12.2 m) vans when used to carry milk products at 40°F (4.4°C) in ambients of 80°F (26.7°C) is a minimum of 25 percent based on the tests during which no over-pressure could be maintained.

The effect of air leakage on refrigeration load of the milk vans, all of which were unable to support any air pressure, can be estimated based on the

method of F. L. Levy¹⁵. The effect of air leakage is calculated based on the assumption that in a vertical slit, air flows in at the top and out at the bottom, and that the internal and external air pressure is equal at some point intermediate to the ends of the slit. Using an ambient temperature of 80° F (26.7°C) and 50% RH, and an interior temperature of 40° F (4.4°C), the effect of a seal opening of 1/8 inch (3.2 mm) all around a double-hinged door, 54 inches (1.372 m) x 28 inches (.71 m), as in Vehicle #44, results in a heat gain of 854 Btu/hr (250 w). For a U_A value of 60 Btu/hr, the effect of the opening is 35.5 percent for the rear door only. Based on the defects identified for the fleet, a year round average of 25 percent energy loss appears to be a conservative estimate.

Of the six milk delivery trucks only one was able to attain test pressure. Based on the size of the refrigerated body, a U_A value of 48 Btu/hr°F (25.3 w/°C) is calculated, and for $T_e = 80^\circ \text{ F}$ (26.7°C) and 50% RH, and $T_i = 40^\circ \text{ F}$ (4.4°C), the heat transmission loss is 1920 Btu/hr (563 w). The effect of 480 CFH air leakage at this condition is 566 Btu/hr (165.8 w), a refrigeration load increase of 29.5 percent.

4.3.5 Air Leakage into Heated Vans

In cold climates, some van heating may be required to maintain temperature. Cold air leaks into the interior, and must be heated to prevent product damage. The energy loss can be calculated using the method of Appendix B, keeping in mind that there is no condensation of moisture in this case, but that heat must nevertheless be added to the water vapor to raise its temperature. Van bodies can be air leakage tested under such conditions, but this was not possible in this study since low ambient temperatures were not available. The TTMA data¹⁶ suggests that the air leakage with an interior temperature of 100° F (37.8°C) and an exterior temperature of 0° F (-17.8°C) is not substantially different from the leakage at ambient conditions.

Consider, as an example, a load of oranges in an ambient temperature of 0°F (-17.8°C). (See Paragraph 4.3.1).

Heat loss through van	$100(0-40)$	= 4000 Btu/hr
Heat of respiration		= <u>-1600</u>
Heating load		= 2400 Btu/hr
Effect of 1 cubic foot of air per hour		= $0.83 \text{ Btu/ft}^3\text{-hr}$
(per Appendix B)		
Air Leakage		= 278 SCFH
Additional Heating load due to Air Leakage		= 230 Btu/hr
		or 9.6 percent

This is comparable to the losses calculated for warm air leaking into a refrigerated trailer. Although there is less energy loss per cubic foot of air, since cold air contains less moisture that must be heated, the total load is also reduced because the heat of respiration is of benefit to maintain correct temperature. For frozen cargo, the inward leakage of cold air (0°F and below) is obviously beneficial.

4.3.6 Summary

Determination of the total energy loss due to air leakage requires a detailed knowledge of the commodity characteristics, carrying temperature and ambient temperatures along the routes used, as well as an estimate of the number of vehicles of each class in use. Based on a variety of vehicles tested and on typical operating conditions, a minimum value for the energy loss due to air leakage of 25 percent appears to be a conservative estimate. Under extreme conditions, such as operation with open drains (which is a frequent occurrence), increased refrigeration loads as high as 60 percent have been observed.

4.4 INCREASED FUEL CONSUMPTION DUE TO AIR LEAKAGE.

Trailers

In the twelve year period from 1964 to 1975, 153,141 Insulated Vans and

Trailers were manufactured in the United States¹⁷ The refrigeration units are predominantly powered by diesel engines, either direct drive or through an electric generator/motor system. A small portion of the units are electrically powered all or part of the time and the energy used may come from sources other than diesel fuel. Since data are lacking on the exact composition of the United States refrigerated fleet, the energy cost is calculated on the basis of all diesel operation.

The overall heat transfer rate of a typical 40 foot van is 100 Btu per hour-degree F (52.6 w/⁰C). At 0⁰ F (-17.8⁰C) inside and 100⁰ F (37.8⁰C) outside conditions the heat transfer rate is thus 10,000 Btu/hr (2931 w); using an average air leakage effect of 25 percent, an additional heat load due to air leakage of 2500 Btu/hr (733 w) is created. At other conditions the additional load is less, possible zero, so that 1250 Btu/hr is a conservative assumption. Typical cooling capacity curves and power consumption estimates of transport refrigeration equipment¹⁸ show that at these temperature limits, 1250 Btu per hour (366 w) of cooling capacity requires 0.78 pounds of fuel per hour (0.35 Kg/h), equal to 0.104 gallons (0.4 l) of diesel fuel.

For a van in which the refrigeration unit is operated only 50 percent of the time (4380 hours per year), and the number of insulated vans built between 1964 and 1975, the resulting energy waste is:

$$0.104 \times 4380 \times 153,141 = 69,758,788 \text{ gallons per year } (264 \times 10^6 \text{ l/yr.})$$

At a current fuel cost of 60 cents per gallon for #2 diesel fuel, this amounts to \$41,855,272 per year. On a vehicle basis, this is 455 gallons per truck per year (1724 liters per truck per year) or \$273.31 per truck per year.

4.5 LIMITATION ON REDUCING FUEL CONSUMPTION.

The majority of transport refrigeration units utilize a direct diesel engine drive system. The capacity of these units is substantially greater than the cooling requirement calculated to maintain the cargo at the required

temperature. This is to provide the capacity for the not uncommon requirement to "pull down" cargo loaded at ambient temperature to the carrying temperature. For example, grapefruit may be loaded at a temperature of 80°F (26.7°C). To achieve the desired temperature of 55°F (12.8°C) the refrigeration unit must reduce the temperature of the product and, in addition, must overcome the heat gain of the trailer, and the heat of respiration of the cargo. Therefore, once the cargo has reached the desired temperature, the unit is not required to operate continuously for the entire journey, since the refrigeration load is well below the unit capacity.

Even during periods that the refrigeration unit is not required to cool the cargo, it is desirable to operate the air circulation fans to maintain air flow in the refrigerated van. This continuous air circulation prevents "hot spots" from forming in the cargo. The fans are usually belt-driven from the diesel engine output shaft, since no external power is otherwise available. The manufacturers have met the need to provide continuous air circulation by designing the refrigeration plants to operate continuously, but alternating between cooling and heating modes in order to maintain the required temperature. Switching from high speed to low speed operation during the alternating cycle reduces the fuel consumption from approximately 1 gallon/hr (3.78 l/h) to 0.7 gallon/hr (2.65 l/h).

This typical mode of operation severely limits the reduction in energy consumption achievable by elimination of air leakage, as detailed in the following calculation. Assume a trailer with a heat transmission of $100\text{ Btu/hr}^{\circ}\text{F}$ ($52.8\text{ w}^{\circ}\text{C}$), an exterior temperature of 80°F (26.7°C) and an interior temperature of 40°F (4.4°C). Further, assume a cargo of 48,000 pounds (21725 Kg) of oranges with a heat respiration of 1600 Btu/ton-day ($.0216\text{ w/Kg-h}$). Under the assumed temperature conditions a typical transport refrigeration system will have a cooling capacity of 22,000 Btu/hr (6448 w). A heating capacity of 15,000 Btu/hr (4397 w) will be assumed as a typical value.

The required cooling capacity, without air leakage is:

Heat transmission, $U_A \Delta t = 100 \times (80-40)$	4000 Btu/hr
Heat of respiration	<u>1600</u>
	5600 Btu/hr

$$\begin{aligned}\text{Required running time} &= \frac{\text{Cooling Load}}{\text{Cooling Capacity}} \times 100 = \\ &= \frac{5,600}{22,000} \times 100 = 25.5 \text{ percent}\end{aligned}$$

$$\text{Required fuel consumption @ 0.7 gal/hr} = 0.178 \frac{\text{gallons}}{\text{hr}}$$

But the unit runs the entire time, the additional running time accounted for by additional cooling and alternate heating to produce zero net heat input. Mathematically:

$$\begin{aligned}22,000 (1 - 0.255 - x) &= 15,000 (x) \\ x &= 0.443\end{aligned}$$

or 44.3 percent of the time is spent in the heat mode and 55.7 percent in the cooling mode. The fuel consumption is 0.7 gal/hr, regardless of operating mode.

If air leakage is present, its effect is to increase the cooling load, and this affects the portion of time the unit is in cooling or heating, but not the total running time or fuel consumption. For example, assume a 25 percent increase in cooling load due to air leakage, from 5600 to 7000 Btu/hr.

The heating time is now

$$\begin{aligned}22,000 (1 - 0.318 - x') &= 15,000 (x') \\ x' &= 0.405 \text{ or } 40.5 \text{ percent,}\end{aligned}$$

with the remainder of the time, 59.5 percent, spent in cooling.

Although air leakage causes a 25 percent increase in the required cooling load, the mode of operation produces a fuel waste of almost 75 percent.

This method of control, therefore, represents a limitation on the savings that can be achieved by elimination of air leakage.

With regard to eutectic plate units in which the electric motor operates when the power is connected regardless of cooling load, the same reasoning applies. Where units are provided with thermostatic control so that the refrigeration plant only operates when needed, the savings possible by reducing air leakage can be realized.

5.0 CONCLUSIONS

The following observations and conclusions, listed in the order of importance, are based upon analysis of the results obtained from this project.

5.1 The results obtained provide support for the conclusion that air leakage in refrigerated vans, even in new equipment, represents an average increase in refrigeration load of twenty-five percent.

5.2 Depending on operating mode, lack of care exercised by equipment operators in sealing openings such as drains and the lack of maintenance of door seals, an increase in cooling load due to air leakage as high as 60 percent has been observed.

5.3 Overpressure test data with the interior of the van at ambient temperature does not adequately predict the behavior at reduced temperature conditions experienced during use. The air leakage values obtained at reduced temperature conditions may be greater or less than those obtained at ambient temperature, due to structural changes caused by differential thermal contraction of the interior shell relative to the exterior shell.

5.4 The control systems of current transport refrigeration units limit the energy savings that can be achieved by reducing air leakage, and are inherently responsible for an energy waste of upward of 40 percent. The combined effects of air leakage and operating control mode represents a total energy loss of 55 to 75 percent.

5.5 The air leakage values obtained with instrumentation built and used in accordance with the TTMA Recommended Practice #38-73 are not necessarily correct. The reference level for pressure and temperature of the flow meter, as well as the length and diameter of the hose to the test body must be specified, or alternatively, the test set must be provided with a pressure gage to correct the flow meter reading for actual pressure.

5.6 Testing for air leakage should be performed at several overpressures to establish the exponent n in the equation $Q = bp^n$. The value of the exponent is an aid in determining the overall characteristic of the air leakage, and the assumption made by various standardization bodies that $n = 0.65$ is not supported by the evidence obtained in this study.

5.7 Visual inspection of vans prior to air leakage testing should always be performed to identify major damage such as torn interior linings, and distorted or corroded doors or door frames. However, visual inspection alone is not sufficient to establish the magnitude of air leakage.

5.8 Smoke bomb tests, while being a simple method for establishing the parts of a body through which air leaks, do not establish the amount of air leakage and may be misleading, since insulation voids may allow the smoke to exit the exterior skin at a substantial distance from the interior leak point.

5.9 Smoke bomb tests should be conducted only on pressurized vans in order to reveal all openings.

5.10 The test standards of TTMA, ISO, and ANSI are based on the assumption that the air leakage rate can be described by the equation $Q = bp^{0.65}$, and the acceptance values for different lengths of vehicles have been adjusted using this equation to account for the different test pressures used by the standards. In view of the fact that the units examined in this study did not exhibit a uniform exponent n , and that this exponent varies substantially, it is possible that a given unit will pass a test in accordance with one standard and fail under a second standard.

5.11 Periodic maintenance checks for air leakage should be performed to evaluate the condition of the vehicle. For this purpose a simplified test set can be used, as specified in Appendix C.

5.12 The temperature and humidity of shop air supplies typically encountered do not influence the flow meter reading to any great extent. Temperature and

humidity correction may be neglected for production and maintenance testing.

5.13 Double, lip-type seals perform better than single flat seals. Seals should be continuous with molded corners, as butt jointed strips are conducive to leakage. Seals should be sufficiently deep and flexible to allow for normal warpage of door panels and frames.

5.14 Roll-up doors are a serious source of air leakage that overrides the effect of all other sources in a refrigerated van so equipped.

5.15 The gaskets between the refrigeration unit and vehicle are subject to leakage due to overcompression, aging and poor installation.

5.16 It has been demonstrated that units with low air leakage can be consistently manufactured.

5.17 The air leakage values obtained during tests at reduced interior temperatures are a function of the interior temperature and the moisture in the air used for testing. Frost formations at openings in the body tend to reduce the amount of air leakage and testing at temperatures below 35° F requires special care.

6.0 RECOMMENDATIONS

6.1 It is recommended that manufacturers of refrigerated vehicles test each production unit at ambient conditions. This simple quality check will confirm whether or not the production process is in control. Consider vehicles 1 through 17 (Table 4-III), for which the values of b and n have been plotted on a time ordered basis as established by vehicle serial numbers (See Figure 6-1). If a quality audit system had been in existence during manufacture, the lack of control would have been easily identified. Also shown are the ISO acceptance values for air leakage for this size trailer. The variation in the production process is readily apparent.

It is not within the scope of this study to identify the reasons for the lack of control in this series of trailers, and it may well be that to achieve consistent production, design changes need to be made. However, the determination of air leakage by means of a simple and quick test procedure at the end of production would be in the interest of the purchaser since he pays the fuel bill for the life of the vehicle.

6.2 It is recommended that the manufacturers of refrigerated vans perform air leakage tests at both ambient conditions and at typical operating conditions for design improvement purposes. When a manufacturing process has been shown to be in control, as evidenced by consistent results in ambient temperature tests, reduced temperature tests can help to identify the changes which take place in the structure and which increase the air leakage. To this end the calculation of α and $\emptyset$ factors, i.e., the coefficients of the two parts of the air leakage equation can identify the types of additional openings created by reduced internal temperature.

6.3 It is recommended that air leakage overpressure tests be performed with

standardized test equipment so that results will be reproducible and comparable among different manufacturers of vans.

A specification for a test set, with an accuracy of ± 5 percent, is included in Appendix C. With the input air known to be within the typically narrow temperature range found in most shops and manufacturing plants, such instrumentation need not be provided with means to measure air temperature and humidity. The maximum error when testing with air in the range of 55 - 100° F (12.8° to 37.8°C) and with relative humidity between 0 and 100%, does not exceed 2 percent.

6.4 It is recommended that the transport refrigeration industry consider methods of achieving adequate air circulation in the vans by means other than constant operation of the diesel engine. The key areas to be considered are operation during loading, while parked, and during transit.

Assuming 4380 hours per year of operation, a reduction in overall fuel usage of 0.3 gallons per hour, a refrigeration unit life of ten years, and diesel fuel cost of \$0.60 per gallon (increasing at 8 percent per year), the present worth of the fuel savings at a 10 percent rate of return is in excess of \$ 6600.00

6.5 It is recommended that the industry also consider retro-fitting capability as the potential savings are substantial enough to warrant such action on recently acquired equipment.

6.6 The immediate use of air leakage test equipment as a maintenance tool is not recommended at this time, unless air tightness is required for cargo atmosphere or temperature control. This is because little or no fuel savings will be realized by the majority of operators unless the operating mode of the refrigeration units is changed.

Nevertheless, operators should specify and monitor air leakage in their procurement specifications to assure quality production, and to take advantage of retrofit capability as alternate modes of control become available.

6.7 It is recommended that operators of equipment in which the diesel engine

or other power source does not operate continuously evaluate their operations to determine the impact of air leakage on fuel consumption. If trade routes and commodities show that a saving can be made, air leakage checks, and simple periodic maintenance on seals, gasket and other surfaces should be performed.

7.0 REDUCTION OF AIR LEAKAGE IN REFRIGERATED VANS

7.1 DESIGN

The examination of the vehicles tested in this study has identified several areas that consistently impair air tightness. Design changes should be considered to improve performance, and the most significant of these areas are detailed on the following pages.

7.1.1 Floor Drains

Open floor drains represent a significant source of air leakage. There is a direct loss through the drain caused by missing or damaged "boots" and also around the drain where it penetrates the insulated floor space.

In most cases such drains are not really needed since relatively little cargo is carried with "top ice". For most operators the drains only serve to simplify the removal of cleaning water. Thus it may be reasonable to delete at least the front drain holes, and modify the trailer parking area at the cleaning station to have a slight pitch so that water drains to the rear of a trailer. The front rubber boots are particularly subject to damage when a tractor couples to a semitrailer.

Where drains cannot be eliminated, a spring cap device, as shown in Figure 7-1, would be adequate for periodic cleaning of the trailer. This is preferred over a cap on the inside of the trailer, as is sometimes provided, since the latter can be damaged during loading of cargo.

Alternately, floor drains can be provided with plastic caps available from several manufacturers. These are inexpensive, can be pushed out with a stick during cleaning, and are easily replaced.

7.1.2 Refrigeration Unit Seal

Figure 7-2 shows a typical installation of a sealing gasket between the van body and refrigeration unit. Air leakage can occur as a result of improper

FIGURE 7-1
FLOOR DRAINS - ALTERNATE CONCEPTS

FIGURE 7-2
SILL GASKET - ALTERNATE CONCEPT

installation, corrosion and aging of the gasket material. It has already been mentioned that openings in the front wall are especially detrimental due to high static pressure at typical road speeds.

The dimension of the opening for the refrigeration unit must be carefully matched to the refrigeration unit, and must include a tolerance on the flatness of the surfaces. If the opening is oversize, the inner gasket bulb will not seal and air can leak past the mounting bolt, (Figure 7-2a). Some refrigeration units are designed to be mounted with spacers between the refrigeration unit and the van body to prevent crushing of the gasket; on older units these spacers are loose pieces. If forgotten during installation, the seal gasket may distort and extrude due to overcompression.

Depending on how the mounting bolts are attached to the front wall of the van, air leakage may also take place along the bolt since the gasket is pierced to fit around the bolt. Finally, most gaskets do not have sufficient compliance to allow for any significant warpage of the van body front wall in service.

A new seal design, along the concept shown in Figure 7-2b could be developed to overcome these difficulties. Because of projections on the evaporator section, sealing gaskets designed to be mounted to the van are likely to be torn when a unit is installed or removed for service. However, the gasket most commonly used can be modified to provide a positive seal at the side of the opening in addition to the face. Commercially available sealing washers, used over the bolt heads, can act as both a seal and spacer plate to eliminate leakage at these points.

7.1.3 Roll-Up Door Seals

The sealing of roll-up doors is usually accomplished by means of a rubber gasket along the vertical door framing members, such as shown in Figure 7-3a. This seal is subject to wear as the door moves up and down and is sensitive to damage during loading. Further, it is difficult to make a seal that is sufficiently compliant to produce low frictional loads during opening and closing of

FIGURE 7-3
ROLL UP DOOR GASKETS - ALTERNATE CONCEPT

the door while allowing for adequate takeup of wear during use.

A new seal concept, proposed by Schlegel Corporation, and using their Polyflex^(R) and patented Finseal^(R) material (U.S. Patent #3,175,256) is reproduced in Figure 7-3b with their permission. It is capable of being retrofitted and requires no fastening means to the existing door frame. The sealing surface consists of a multitude of fine bristle like fibers which can deflect for panel irregularities and which encase a central fin member which provides an additional seal.

Due to the characteristics of the materials used, the friction on the door is claimed to be sufficiently low that it will not hamper operations. To make the seal continuous at the top of the door, a new framing member must be added; this can be accomplished by means of screws or rivets, and is essentially a small angle with ends curved to meet the existing vertical flanges. A bulb type seal is proposed to be added to the bottom of the door.

Seals encompassing similar construction have been used as air seals in the past with considerable success in confining air streams to specific paths. However, any seal attached to the door frame is subject to damage during loading and unloading, and attaching a seal to the door would appear to be a safer procedure. Life cycle testing is needed before the new design can be recommended as a specific improvement.

7.1.4 Intersection of Aluminum Interior Floor With Shell

During cooling the interior van shell contracts relative to the exterior. If the exterior shell is aluminum, and the floor is also made of aluminum, a temperature difference of 100⁰ F (55.5⁰C) will cause the interior floor to shrink approximately 0.638 inches (16.2 mm) for a 40 foot (12.2 m) van.

The effect of this contraction of the interior is to cause openings within the insulated cavity between the outer and the inner shell. Figure 7-4a illustrates this. Where the opening occurs is dependent on the detail design, but in

(a)

(b)

FIGURE 7-4
ALUMINUM FLOOR INTERSECTION WITH SHELL

most cases observed the rear of the floor is well anchored to the rear sill and the shrinkage is taken up all at the front wall. The same relative motion occurs along the entire sidewall, although the movement of the floor is progressively less as the distance from the rear sill decreases. There is also a contraction in the transverse direction, approximately 1/8 inch for an eight foot wide body.

The distortion in the insulation that takes place to accommodate the dimensional change may be merely a separation of the insulation from the sidewall or actual tearing within the foam material. The wooden sill members, to which the aluminum floor is attached, must also move, and cause a shearing action on the surface of the insulation. Alternate designs to accommodate this expansion must also prevent water used for cleaning the vans from entering the insulation.

Improvements that have been suggested do not provide a complete solution. Figure 7-4b shows two such concepts. Alternate #1 limits the effect of the distortion to the lower portion of the front wall but does not prevent the tearing of the insulation in the floor; alternate #2 eliminates front wall distortion entirely but does not limit the shearing action of the aluminum floor with the plywood subfloor.

Conceptually, the plywood subfloor can be attached to the wooden sill members separately, and the aluminum floor laid over the plywood subfloor with fasteners that permit movement. Whether and how such movement would actually take place, especially when cargo is in place is not known. Over a period of use, during which the aluminum floor materials will deform, any possibility of relative motion between the aluminum floor and the wood subfloor would probably be eliminated.

When foam insulation is installed, there is a tendency for the foam to adhere to the confining surfaces. It would seem prudent as a minimum to place a plastic sheet (Mylar or similar material) against the outside skin prior to foaming, so that the entire foam mass can slide over the outer skin as it contracts. This

would also form an acceptable vapor barrier.

Ultimately, any design improvement must be made by each manufacturer to suit his particular production process. As evidenced by the tests performed in this study, most vans show increased air leakage at reduced temperatures, and it is in this area especially that manufacturers should undertake low temperature tests to evaluate alternate methods of improving the structure.

7.1.5 Door Seals

Door seals used by American manufacturers are of many different types. Typical designs are shown in Figure 7-5.

Flat seals, such as shown in Figure 7-5b are not as effective as lip type seals especially where corners are merely butted joints. The compliance of the materials is generally insufficient to overcome the distortion of the doors that takes place with use, and any foreign matter trapped between the door and the door frame prevents a tight seal. Multiple lip type seals, such as shown in Figure 7-5c have consistently shown superior performance, especially where additional care has been taken to provide molded corners contiguous with the straight runs. The effectiveness of such existing seals shows that this is an area that requires little in the way of development to be implemented.

7.2 MAINTENANCE

Once a vehicle has been put into service there is little that can be done to reduce air leakage, but the quality level provided in the original structure can be maintained relatively simply and inexpensively.

7.2.1 Floor Drains

Plastic caps should be installed in those floor drains not provided with boots, or where boots have been damaged (approximately \$0.12 each). After cleaning a trailer, the caps may also be cleaned, or new caps installed without use of tools. Where drains are of different diameters, molded caps can be procured in different colors for the different sizes.

FIGURE 7-5
DOOR SEALS - ALTERNATE DESIGNS

7.2.2 Interior Linings

Interior linings and insulation are damaged by improper cargo loading procedures. When this occurs, immediate repair should be effected, since exposed insulation causes increased air exchange and moisture penetration into the insulation.

Damaged foam insulation may be repaired by use of urethane filler which is commercially available in various forms, from small aerosol cans to kits in which two components must be mixed together. After foaming, the material can be sanded or planed to a smooth finish, and fiberglass patches used to repair the interior lining. For very large areas, block foam can be used in lieu of foaming in place if adequate care is taken to seal the adjoining surfaces. In any case, this type of damage should be repaired as soon as it occurs to prevent further deterioration and also for sanitary reasons.

7.2.3 Door Seals

Simple visual examination of door seals will reveal most damage. If the door itself has been damaged, repair of the seals alone is generally of little value. Doors should be in good condition (i.e., no corrosion, holes, warpage) before seals are replaced.

When strip-type seals are deficient, the entire length should be replaced, rather than only the damaged area, since the older material is probably at or beyond its useful life. This procedure also avoids splices which are difficult to make airtight. Where such splices are necessary, the joint should be angled at 45° and sealing compound applied. The material used and means of attachment should be per manufacturer's instructions to insure proper fit.

7.2.4 Refrigeration Unit Seals

Whenever a refrigeration unit is removed for maintenance, the seal should be replaced following the manufacturer's recommended procedure. The front wall of the vehicle should be examined for corrosion, punctures and trueness of the

mounting surface. If the opening is oversize, a bead of sealing compound should be applied to seal mismatching areas of refrigeration unit and gasket.

7.2.5 Smoke Bomb Test

A pressurized smoke bomb test should be performed at least once each year, and any leakage paths identified should be investigated. Although in many cases there is little corrective action that can be taken, such tests do identify hidden damage that may have been missed on visual inspection and which can be repaired with sealing compounds.

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GLOSSARY OF TERMS

Air Leakage

Air leakage is the phenomenon under study, wherein air from inside a van body escapes to the outside of the container, and is replaced by air from the outside.

Ambient (Ambient Temperature)

The temperature of a substance surrounding a body. Thus the ambient temperature of a container holding a refrigerated cargo would be the temperature of the air to which it is exposed on its outside surface.

CFH

Cubic feet per hour.

Container

An article of transport equipment (i) fully or partially enclosed to constitute a compartment intended for containing goods; (ii) of a permanent character and accordingly strong enough to be suitable for repeated use; (iii) specifically designed to facilitate the carriage of goods, by one or more modes of transport, without intermediate reloading; (iv) designed for ready handling, particularly when being transferred from one mode of transport to another.

Cooling Load

Power required to maintain the interior of a van at a temperature different from that of the surrounding air. It may be defined in various ways, i.e., Btu/hour, or in size of cooling equipment, i.e., 5 ton refrigerated unit.

Enthalpy

A measure of the energy content of a system per unit mass.

Heat Load (see Cooling Load)

Heat Transmission

Heat transmission of refrigerated vans is the total heat which is transmitted through the walls, floor, and roof of the van by conduction, radiation and convection.

In-Service Use

Conditions prevailing during the actual use of the vans in carrying out the service of carriage of product, and the temperatures necessary to maintain the good condition of those products.

Rating Standards

Rating standards are defined and accepted conditions by which vans and trailer structures are tested and compared.

Refrigerated Vans (see Vehicle, Refrigerated)

SCFH

Standard cubic feet per hour -- a measure of volume at standard conditions of temperature and pressure, usually 14.7 psia and 78° F for air.

Smoke Bomb

A smoke bomb is a device which, when triggered, emits volumes of smoke and allows observance of air motion patterns, such as convection currents, and leakage routes from inside a body to the outside air.

T_e

The ambient temperature in which a refrigerated van is located.

T_i

The temperature of the interior of a refrigerated van.

True Crack

An opening characterized by a large depth to width ratio, in which the air flow velocity is directly proportional to the imposed pressure difference.

True Hole

A thin plate orifice through which air flow is proportional to the square root of the imposed pressure difference in accordance with Bernoulli's Theorem.

U_A

The value of the total rate of heat transfer per hour per degree for a specific body is denoted by the symbol " U_A ". It is related to the value " k " by the equation $U = kS$, where S is the surface area.

Vehicle, Refrigerated

Thermal body served by a refrigerated appliance. It may be a container, semi-trailer or straight truck.

W.C.

Water column -- a measure of pressure used as a standard.

One inch of W.C. = 249.1 Pa.

AIR LEAKAGE TEST DATA SHEET

Date _____

TRAILER
OR VAN

Make _____ Year _____ Size _____ Model # _____ Serial # _____ Registration # _____

Owner _____ Address _____

INSULATION
THICKNESS
AND TYPE

Walls _____ Floor _____ Roof _____ Doors _____ REFRIGERATION
UNIT Make & Model # _____

DOOR LOCATIONS
INDICATE BY

DOOR VENTS
IF ANY

Front _____ Rear _____

OBSERVATIONS AND CORRECTED RESULTS

$CORRECTED\ AIR\ FLOW = FLOW\ METER\ READING \times Correction\ Factor\ 1 \times Correction\ Factor\ 2$

TEST	AMBIENT TEMP OF	REGULATED LINE		MANO- METER "H ₂ O	TEST BODY TEMP OF	SECOND. PRESS psig.	FLOW METER SCFH	CORRECTION FACTOR		CORRECTED AIR FLOW SCFH	CORRECTION FACTOR 3	ACTUAL AIR LEAKGE CFH
		TEMP OF	HUM. %					1	2			
1												
2												
3												
4												
5												
6												
7												
8												
9												

CORRECTION FACTOR 1 - Corrects Air Flow Meter reading for the Regulated Line Temperature and Humidity - USE TABLE I.
 CORRECTION FACTOR 2 - Corrects Flow Meter reading for Secondary Pressure - USE TABLE II
 CORRECTION FACTOR 3 - Corrects measurement for test body temperatures other than 70°F - USE TABLE III

OPERATING INSTRUCTIONS
(See Manual, Section 4.0)

SET UP OF EQUIPMENT AND PRE-OPERATION CHECK

1. Position the test set so that it is located within 15 feet of the vehicle to be tested. Open the rear and front doors of the test set and swing the doors against the sides of the unit. Remove the dust caps from the air inlet and outlet.
2. Visually inspect the unit for damage. Any broken glass, hoses or pipe must be replaced before use.
3. Turn the PRESSURE REGULATOR counterclockwise until the handle is completely removed.
4. Inspect the AIR FILTER ASSEMBLY through the rear door; if more than six months have elapsed since FILTER TUBE replacement, replace the FILTER TUBE. Make certain that the DRAIN TUBE is connected to the FLOAT DRAIN.
5. Connect the shop air supply to the test set.
6. Level the test set using the BUBBLE LEVEL located at the base of the cabinet and the LEVELING SCREWS provided under the base of the unit.
7. Open the FLOW CONTROL VALVE fully.
8. Insert handle in the PRESSURE REGULATOR and slowly turn the handle clockwise until air can be heard flowing from the test set outlet. The PRIMARY PRESSURE GAGE will begin to show a positive pressure, and the float in the FLOW METER will begin to rise.
9. As soon as air flow is noted, stop turning the handle. Allow the air to flow for at least one minute, or until the REGULATED LINE TEMPERATURE and RELATIVE HUMIDITY readings stabilize.

If the temperature reading is less than 32°F or greater than 180°F, do not proceed. Refer to Section 7.0 of manual.

10. Turn the handle of the PRESSURE REGULATOR counterclockwise until all air flow ceases.

CONNECTION OF TEST SET TO VEHICLE UNDER TEST

1. Attach the Test Set DELIVERY CONNECTION to the vehicle under test by inserting tube through drain hole or past seal. Seal opening with duct sealing compound.
2. Install the MANOMETER TUBE and the INSIDE THERMOMETER BULB in the test vehicle. Make certain that the MANOMETER TUBE is at least 3 feet from the air outlet in the vehicle, and that the THERMOMETER is approximately in the center of the free volume of the vehicle.
3. Open the two valves at the top of the MANOMETER by turning them counterclockwise one and one half turns. Connect the MANOMETER TUBE to the valve on the left side.
4. Check the MANOMETER to make sure it is level. If not, see Section 6.0 of the manual.
5. Turn the oil level adjustment knob to set the meniscus of the oil level at zero. Align the oil meniscus and its reflected image to eliminate parallax error.

CONDUCTING TEST MEASUREMENT

1. Slowly turn the PRESSURE REGULATOR handle in a clockwise direction. Observe the MANOMETER and FLOW METER.

THE PRESSURE RISE AND THE FLOW METER READING VARY WITH THE DEGREE OF AIR LEAKAGE OF THE TRAILER. TURN THE HANDLE SLOWLY TO PREVENT EXCESSIVE PRESSURE IN THE VEHICLE. UNDER NO CONDITIONS SHOULD THE PRESSURE IN THE VEHICLE EXCEED 2 INCHES OF WATER OR DAMAGE MAY RESULT.

2. When the MANOMETER reads approximately 1.0 inch of water, stop increasing the pressure at the REGULATOR.
3. Without further adjustment, allow the air flow to continue for at least one minute.
4. After at least one minute, when the readings have stabilized, observe and record the following instrument readings on the data sheet.
 - a - Flow Meter Reading
 - b - Secondary Pressure Gage Reading
 - c - Regulated Line Temperature
 - d - Regulated Line Humidity
 - e - Manometer Reading
 - f - Test Body Temperature
 - g - Ambient Temperature

TROUBLE SHOOTING CHART

SYMPTOMS

CAUSE

REMEDY

A. No air flow when regulator is turned clockwise.

1. Flow control valve closed.
2. Air supply inadequate
3. Excessive pressure (pressure relief open).
4. Regulator stuck closed.

1. Open flow control valve.
2. Open air supply hose at source. Check line pressure.
3. Check air pressure at source
4. Service regulator.

B. Manometer reading zero with air flow present.

1. Manometer valves closed.
2. Supply connection loose.

1. Open valves.
2. Check and tighten.

C. Erratic flow meter reading.

1. Hoses kinked.

1. Straighten hoses.

5. Repeat the test at additional test points as required in Section 3.0 of the manual.

STORING EQUIPMENT AT END OF TEST

1. To stop all air flow at the end of the test, turn the PRESSURE REGULATOR handle counter-clockwise until all air flow ceases with the FLOW CONTROL VALVE fully open.
2. Disassembly of the test set for storage:
 - a) Disconnect the air supply hose.
 - b) Remove all flexible hoses, tubing and the temperature probe, and store them in the rear compartment.
 - c) Cover the inlet and outlet connections with dustcaps.
 - d) Close the MANOMETER valves completely by turning these clockwise until handtight.
 - e) Retract the leveling feet.

WARNING

WHEN SHIPPING TEST SET BY COMMERCIAL CARRIER REMOVE FLOW METER FLOAT AS PER MANUFACTURER'S INSTRUCTIONS. SEE APPENDIX A OF MANUAL.

APPENDIX B

CALCULATION OF THE ENERGY EQUIVALENT OF AIR LEAKAGE

The energy required to cool (or heat) air from one condition to a second condition is:

$$1) \text{ Cooling Load} = Q_T = Q_L + Q_S$$

$$\begin{aligned} \text{where } Q_L &= \text{latent heat} \\ Q_S &= \text{sensible heat} \end{aligned}$$

$$2) Q_S = Wa(h_1 - h_2)$$

$$\begin{aligned} \text{where } Wa &= \text{weight of dry air, exterior temperature} \\ h_1 &= \text{enthalpy of dry air @ exterior temperature} \\ h_2 &= \text{enthalpy of dry air @ inside temperature} \end{aligned}$$

$$3) Q_L = (M_1 - M_2)Wa(h_3 - h_4) + M_2(h_3 - h_5)$$

$$\begin{aligned} \text{where } M_1 &= \text{moisture in air, pounds of water per pound of dry air, exterior condition} \\ M_2 &= \text{moisture in air, pounds of water per pound of dry air, interior condition} \\ h_3 &= \text{enthalpy of water vapor, exterior condition} \\ h_4 &= \text{enthalpy of liquid water, interior condition} \\ h_5 &= \text{enthalpy of water vapor, interior condition} \end{aligned}$$

If the interior temperature is below 32° F, h_4 must be taken as the enthalpy of ice and for 0° F, $M_2 = 0$ and $h_4 = 0$ so that equation 3 reduces to $M_1(Wa)(h_3)$

Example: Exterior air @ 80° F and 50% RH

Interior air @ 40° F saturated.

From Reference 1: $h_1 = 129.06 \text{ Btu/\#}$
 $h_2 = 119.48 \text{ Btu/\#}$

From Reference 2: $h_3 = 1096.6 \text{ Btu/\#}$
 $h_4 = 8.05 \text{ Btu/\#}$
 $h_5 = 1079.3 \text{ Btu/\#}$

From Reference 3: $W_a = 0.0736 \text{ lbs/ft}^3$

From Figure 3: $M_1 = 0.011 \text{ pounds moisture/pound dry air}$
 $M_2 = 0.0052 \text{ pounds moisture/pound of dry air.}$

Per cubic foot of outside air:

$$Q_L = (.0736)(129.06 - 119.48)$$
$$= 0.705 \text{ Btu/hr - CFH}$$

$$Q_S = (.011 - .0052)(.0736)(1096.6 - 8.05) + .0052(.0736)$$
$$(1096.6 - 1079.3)$$
$$= 0.465 + 0.007 = 0.472 \text{ Btu/hr - CFH}$$

$$Q_T = 0.705 + 0.472 = 1.177 \text{ Btu/hr - CFH.}$$

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APPENDIX C

SPECIFICATION FOR AIR LEAKAGE TEST SET

1.0 SCOPE

1.1 PURPOSE - This document establishes the requirements for a portable test set to be used for static overpressure measurement of air leakage in insulated and refrigerated truck bodies. The test set described herein is to be constructed as an independent system, requiring only a pressurized air supply normally found in maintenance garages and manufacturing plants.

This specification also covers the requirements for calibration, operation and maintenance instructions to be furnished with the equipment.

1.2 SELECTION CRITERIA - Components of the system shall be selected so that the test set may be easily used by persons possessing a high school diploma plus a minimum of two years' experience as a mechanic or technician, or equivalent experience.

Insofar as practicable, selection of components shall be made from commercially available sources in the following order:

1.2.1 Components that require no periodic calibration prior to use.

1.2.2 Components with replaceable elements and provided with visual indication that replacement is required.

1.2.3 Components with replaceable elements requiring monitoring prior to or during use.

1.2.4 Components that require calibration prior to use.

1.2.5 Components that require calibration during use.

1.3 PRESSURE RATING - The instrumentation shall be capable of performing the overpressure test as described in Section 5.0, Intended Use, at air pressures of 100 ± 50 psi gage (689 ± 345 kPa) and a flow capacity of 1800 ft³/h (51 m³/h) maximum, expressed in standard atmospheric conditions.

2.0 APPLICABLE DOCUMENTS

2.1 Specifications - None

2.2 Standards - None

2.3 Publications - None

2.4 References - None.

3.0 REQUIREMENTS

3.1 DEFINITIONS

3.1.1 Ambient Air Temperature - The temperature of a substance surrounding a body. Thus the ambient temperature of a vehicle holding a refrigerated cargo would be the temperature of the air to which it is exposed on its outside surface.

3.1.2 SCFH - See Standard Cubic Feet per Hour.

3.1.3 Overpressure Test - An air leakage test wherein air from inside a van body escapes to the outside of the container, and is replaced by air from the outside by mechanical means. It is conducted at a fixed internal pressure level.

3.1.4 Standard Cubic Feet per Hour - (SCFH) - a volume unit taken when a gas is at a standard or base condition, generally at 14.7 psia and 70° F.

3.1.5 W.C. - Water Column - a measure of pressure used as a standard. (1 inch W.C. = 0.03613 psi = 249.1 Pa)

3.2 MATERIALS OF CONSTRUCTION

3.2.1 Unless required for proper operation, all components, instruments, metallic tubing and piping, valves and fittings, and all hardware are to be constructed of corrosion resisting materials or are to be protected against corrosion.

3.2.2 All hose, flexible tubing, gaskets and valve seats are to be made of materials that are water and oil resistant. All materials used in the system are to be fully compatible with each other.

3.2.3 All components used on the inlet side of the test set up to and including the pressure regulator shall have a pressure rating of at least 150 psi (1034 kPa)

3.2.4 All components downstream of the pressure regulator shall have a minimum operating pressure rating of 50 psig (345 kPa).

3.2.5 All components shall have a minimum burst pressure rating of at least 2½ times the operating pressure rating.

3.2.6 All piping and tubing shall not be smaller than the port size of the flowmeter.

3.3 PERFORMANCE REQUIREMENTS

3.3.1 Design Test Limits

3.3.1.1 The test set is to be designed for use in truck maintenance facilities or in vehicle manufacturing plants. Although such facilities

are normally maintained at temperatures between 50° F (10° C) and 90° F (32° C), the test set shall be designed to be used in ambient air temperatures between 0° F (-18° C) and 120° F (50° C). The air used for testing is to be free of moisture if the supply air temperature is below 35° F (2° C) to prevent formation of frost or ice in the instrumentation.

3.3.2 System Description

Figure 1 is a schematic of the components of the test system. The function of the individual components is as follows:

3.3.2.1 Air Supply Connection - This provides a means of connecting the test set to a source of pressurized air.

3.3.2.2 Primary Pressure Relief Valve - This valve provides a means of preventing pressures in excess of 150 psi gage (1034 kPa) from being inadvertently applied to the test set.

3.3.2.3 Air Filter - The air filter provides a means of removing entrained dust, water, and oil from the air supply, and to drain liquid contaminants from the system.

3.3.2.4 Pressure Regulator - The pressure regulator reduces the supply air pressure to the level required by the system design.

3.3.2.5 Regulated Line Pressure Relief Valve - The regulated line pressure relief valve provides a means of preventing pressures in excess of the set pressure from entering the regulated line.

3.3.2.6 Flowmeter - The flowmeter provides a means of measuring the quantity of air being supplied to the body under test. It shall read in SCFH so that readings may be compared to existing standards.

3.3.2.7 Secondary Pressure Gage - The secondary pressure gage provides a means of accurately measuring the line pressure downstream of the flowmeter to enable correction factors to be applied to the flowmeter readings.

3.3.2.8 Delivery Connection - The delivery connection provides a means of connecting the test set to the truck body under test.

3.3.2.9 Ambient Air Thermometer - The thermometer provides a means of measuring the ambient air temperature during the test.

3.3.2.10 Manometer - The manometer provides a means of measuring over-pressure in the vehicle body under test.

3.3.2.11 Test Body Thermometer - The test body thermometer provides a means of measuring the temperature in the body under test when the vehicle is not equipped with such a thermometer.

3.3.2.12 Enclosure - The enclosure provides a means of housing all of the system components for portability and protection during transport and use. It also provides means for leveling the instrument package.

3.3.2.13 Panel - The panel shall mount all components included in this specification and shall be removable from Enclosure if the user desires to use the panel only in a permanent installation.

3.4 DESIGN AND CONSTRUCTION REQUIREMENTS

3.4.1 Air Supply Connection

3.4.1.1 The air supply connection shall be located within the enclosure and shall be easily accessible. It shall be a male sleeve-type quick connect fitting, specified by the end user to mate with his shop air supply system.

3.4.1.2 The supply connection shall be clearly marked to indicate the maximum safe operating pressure.

3.4.1.3 The supply connection shall be so located that the operator, in normal operating position, is not endangered in case of supply connection failure.

3.4.1.4 A durable and easily removable dust cap shall be provided to prevent contamination of the system when not in use.

3.4.2 Primary Pressure Relief Valve

3.4.2.1 The primary pressure relief valve shall be located immediately after the supply fitting and before any other component.

3.4.2.2 The primary pressure relief valve shall be tamper proof, or shall be so mounted that it is not accessible to the operator.

3.4.2.3 The exhaust port of the relief valve shall be provided with a deflector cap or suitable device to divert high pressure blasts away from the operator when in a normal work position.

3.4.2.4 The relief valve shall be set at a cracking pressure of 150 psi (1034 kPa) gage $\pm 5\%$.

3.4.2.5 The pressure relief valve seal shall provide line contact with a poppet seat, and shall reseal to a dead tight condition at a pressure not less than 70 percent of cracking pressure.

3.4.2.6 The valve seat shall be made of Buna N rubber.

3.4.3 Air Filter

3.4.3.1 The air filter shall remove liquid (water and oil) entrained in the air supply and allow it to collect for removal. The filter shall have a retention efficiency greater than 95 percent for 0.6 micron particle size.

3.4.3.2 The air filter shall be capable of operating with dry air supplied at a temperature between 0° F (-18° C) and 35° F (2° C); and with moist air

from 35⁰ F (2⁰C) to 180⁰ F (82⁰C). It shall be capable of processing air supplied at a pressure of 150 psi (1034 kPa) gage at a rate of 1800 SCFH (51 m³/h).

3.4.3.3 The maximum pressure drop through the filter at a flow of 1800 SCFH (51 m³/h) shall not exceed 10 psig (69 kPa).

3.4.3.4 The air filter shall be a rigid housing enclosing a borosilicate glass microfiber core. The air flow shall be from "inside to outside" through the filter core.

3.4.3.5 The filter housing shall have a metal filter bowl. The housing shall accommodate a single, self-supporting and self-gasketing core. The bowl shall seal after each change of core by means of a gasket and screw retainer.

3.4.3.6 The housing shall have a collection area at its bottom for the collection of coalesced liquid and shall have an automatic drain for the removal of collected liquid before the level of liquid reaches the bottom of the filter core. The drain shall be so positioned, or provided with suitable tubing, to assure that liquids are drained free of the enclosure.

3.4.3.7 A decal shall be applied to the filter to detail operation and instructions for filter replacement.

3.4.4 Pressure Regulator

3.4.4.1 The pressure reducing regulator shall be a spring loaded type with air inlet pressure rating not less than 150 psi (1034 kPa) gage, and shall be capable of throttling the supply air to a regulated line pressure between zero and 50 $\pm$ 2 psi (345 $\pm$ 14 kPa) gage.

3.4.4.2 The pressure regulator shall have a manual control of outlet pressure.

3.4.5 Regulated Line Pressure Relief Valve

3.4.5.1 The regulated line pressure relief valve shall maintain the regulated set pressure and shall be integral with the regulator.

3.4.5.2 The valve shall be sized to accommodate maximum flow and shall reseal to a dead tight condition at a pressure no less than 70 percent of cracking pressure.

3.4.5.3 The exhaust port from the pressure relief valve shall be provided with a deflector cap, or other suitable means, to divert high pressure blasts away from the operator when in normal working position.

3.4.6 Flowmeter

3.4.6.1 The flowmeter shall be of the variable-area type suitable for air service.

3.4.6.2 The flowmeter shall be capable of measuring the rate of flow of the air within a range of 180 to 1800 SCFH (5.1 to 51 m³/h). It shall be calibrated for an outlet pressure of 0 psi (0 Pa) gage and a temperature of 70° F (21° C).

3.4.6.3 The air flowmeter shall be accurate to ±5% of the flow reading, dry air basis.

3.4.6.4 The air flowmeter shall be capable of operating within a pressure range of 0 to 25 psi maximum (0 to 172 kPa) gage outlet pressure.

3.4.6.5 The flowmeter shall be provided with a float appropriately guided within the tube. There shall be no float bounce or chatter during operation of the meter.

3.4.6.6 The air flowmeter shall have its scale markings in SCFH.

3.4.7 Secondary Pressure Gage

3.4.7.1 The secondary pressure gage shall indicate pressure of the air downstream of the flowmeter within a range of 0 to 25 psi (0 to 172 kPa) gage.

3.4.7.2 The secondary pressure gage shall be free from fluctuations and pulsations in operation. It shall be resistant to overpressure to a maximum of 50 psi (345 kPa).

3.4.7.3 The secondary pressure gage shall have a zero adjustment screw to adjust the dial pointer. The adjustment screw shall be accessible from the face side of the dial.

3.4.7.4 The secondary pressure gage shall be accurate to ±3% of full scale.

3.4.8 Delivery Connection

3.4.8.1 The delivery connection shall consist of flexible plastic tubing and shall be at least 25 feet (9.6 m) in length.

3.4.8.2 The delivery tubing shall be no less than 1/2 inch (13 mm) in diameter.

3.4.8.3 A durable and easily removable dust cap shall be provided to prevent contamination of the system when not in use.

3.4.9 Ambient Air Thermometer

3.4.9.1 The thermometer shall be a dial type having a minimum range of 0° F to 120° F (-18° C to 49° C).

3.4.9.2 The thermometer shall be mounted so that its sensing element is exposed to ambient air.

3.4.9.3 The thermometer shall be accurate to $\pm 3\%$ of full scale reading.

3.4.10 Manometer

3.4.10.1 The manometer shall have the capability of measuring the air pressure inside the container within a range of $-.20/0/2.0$ inches water column.

3.4.10.2 The manometer shall have provisions for leveling of the instrument by use of a built-in spirit level.

3.4.10.3 The manometer shall be capable of zeroing the gage by means of built in bubble levels and adjustment screws.

3.4.10.4 The manometer fluid shall be non-toxic in nature and have color for easy visibility. The manometer shall have provision for easy fluid replacement.

3.4.10.5 The manometer accuracy shall be no less than $\pm 1\%$ of the full scale reading.

3.4.10.6 The manometer shall be supplied with at least 25 feet of $1/4$ inch diameter (6.35 mm) of tubing to connect it to the body under test.

3.4.11 Test Body Thermometer

3.4.11.1 The thermometer shall have a minimum range of -20° F to 120° F.

3.4.11.2 The thermometer shall be graduated in increments no greater than 2° F.

3.4.11.3 The thermometer shall have a remote sensor at least 25 feet (7.6 m) long so that the sensor can be located within the body under test.

3.4.11.4 The thermometer shall be accurate to at least $\pm 2\%$ of full scale reading.

3.4.12 Enclosure

3.4.12.1 The enclosure shall house a removable panel to which all components comprising the test system are mounted.

3.4.12.2 The enclosure shall be portable, capable of being fastened shut and accommodate a lock. The total weight of the enclosure and instruments shall not exceed 120 pounds (54.5 Kg).

3.4.12.3 The enclosure shall be provided with handles.

3.4.12.4 Where required, the enclosure shall have devices that will allow leveling of the instruments housed within the cases from at least 5° out of level attitude. The devices shall have the capability of maintaining the level position during the "hands-on" activity of a test performance.

3.5 MARKINGS

3.5.1 All components not marked by the manufacturer shall be marked to indicate function in black letters at least 1/4 inch (6.35 mm) high on a contrasting background.

3.5.2 All scale markings used on instruments shall be in English units. Dual markings (English and metric) shall not be used.

3.5.3 An abbreviated, but complete set of operating instructions, in step by step format, shall be included in each test set and shall be protected by a plastic sheet or be plasticized, to prevent accidental removal or obliteration.

3.5.4 Decals shall be applied to individual components indicating direction of rotation for opening and closing valves, frequency of calibration, etc.

3.6 MANUALS

3.6.1 A complete, durable instruction manual for the use, calibration, operation and maintenance of the test set shall be furnished.

3.6.2 Provision shall be made in the enclosure to store the manual, and a copy of the manual shall be so provided.

3.6.3 The instruction manual shall include instructions for calibration and recommended time intervals for such calibration.

3.6.4 All correction factors required shall be given in tabular or graphic form within the manual. No additional reference material shall be required.

4.0 QUALITY ASSURANCE

4.1 All components of the system shall be inspected prior to assembly to assure compliance with this specification.

5.0 NOTES

5.1 INTENDED USE - The test set is to be used to conduct overpressure tests on truck and container bodies to investigate the relationships between air leakage rates at varying internal test body temperatures and pressures. The general procedure to be followed is:

5.1.1 The test set is used in a garage or factory location close to an available air supply. It is leveled to insure instrument accuracy.

5.1.2 Prior to use, all protective caps are removed and the pressure regulator position is adjusted to zero regulated pressure.

5.1.3 The air supply is connected to the input connection.

5.1.4 With the delivery connection disconnected from the test vehicle, the regulator handle is slowly turned until air is discharged from the delivery connection. The regulated pressure is increased until the flow meter reads full scale. After this check the handle is turned to close the regulator until all flow ceases.

5.1.5 The test vehicle is now prepared by installation of the delivery connection. The delivery hose is fed to the vehicle through an existing opening, such as a floor drain, or through one of the door seals. The delivery opening is then sealed by a nonhardening modeling compound such as duct seal.

5.1.6 The manometer is connected to the test vehicle in a similar manner. It is leveled and zero adjustments are made.

5.1.7 The test body thermometer is installed in the vehicle at approximately the center of the free volume of the body.

FIGURE C-1
TEST SYSTEM SCHEMATIC