EVAP 77-1

Technical Support Report for Regulatory Action

# Modification of Evaporative Emission Enclosures to Comply with Temperature Limitations of the 1978 Federal Testing Procedure

by

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January, 1977

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Standards Development and Support Branch
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Office of Mobile Source Air Pollution Control
U.S. Enviromental Protection Agency

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## Introduction

The 1978 Federal Emission Regulations require the use of a vehicle enclosure (also called a Sealed Housing for Evaporative Determination, SHED) for the determination of evaporative emissions. Because of probable effects of ambient temperature on evaporative emission levels, and to be consistent with the other parts of the emission test procedure, an allowable air temperature range inside the enclosure has been specified. This range is from 68°F (20°C) to 86°F (30°C). In order to avoid the possibility of any hydrocarbon condensation the regulations also require that all enclosure interior surfaces shall not be less than 68°F.

When a test vehicle is put inside the enclosure for hot-soak testing, the enclosure air temperature rises. The peak temperature which is reached is dependent on many factors, including initial enclosure temperature and physical size. The maximum enclosure ambient temperature will exceed 86°F for many production vehicles if no special cooling is done. In some instances this peak temperature can be as high as 100°F. The purpose of this test program was to develop a cooling system which would meet the federal evaporative emission test temperature requirements.

## Procedure

Two enclosures were included in this program. One was typical light duty vehicle size (1525 $ft^3$) and the other was considerably larger (4796 $ft^3$).

Two types of cooling systems were designed and installed for the smaller enclosure. These were an external cooling system and an internal cooling system, both of which could be used to cool the enclosure prior to the test as well as during the test. The larger enclosure was equipped with one type of cooling system. This was an air-conditioner which could only be used for cooling the enclosure prior to the test.

After installation of the systems, vehicle tests were conducted. These vehicles were provided by General Motors, Ford and Chrysler. They were considered, by their respective manufacturers, to be the vehicles that give the highest hot-soak enclosure temperatures.

## System Descriptions - 1525 $ft^3$ Enclosure

The dimensions of this enclosure are approximately 20' in length, 9.5' in width and 8' in height. One of the end walls is one-quarter inch thick masonite and the other is one-quarter inch thick glass. The lower 3' of the side walls is one-quarter inch thick masonite and the upper 5' is one-quarter inch thick glass. The ceiling is made of mylar. As previously mentioned, two general types of cooling systems were evaluated for this enclosure. These were an external system and an internal system.

A schematic of the external cooling system is shown in Figure 1. It consisted of a 36,000 BTU/hr capacity air-conditioning unit which blew approximately 1000 CFM of cooled air over the enclosure's two side walls and ceiling. The air was contained by a barrier of one inch thick styrofoam insulating panels. The insulation minimized heat transfer from the outside room air into the cool air plenum.

The internal cooling system consisted of two major components. These were a water to air heat exchanger and an air blower. The blower moved enclosure inside air over the heat exchanger coils at a flow rate of 1000 CFM (maximum allowed by the regulations). Temperature of the cooling water to the coil was maintained at 68°F. Four different configurations of the internal system were evaluated. A schematic of the baseline configuration is given in Figure 2. In this configuration, all the air leaving the coil was directed toward the back wall of the enclosure. The inlet air to the blower was taken from the front of the enclosure near floor level.

The second configuration of the internal cooling system which was tested is shown in Figure 3. This is called the modified inlet system because of the change in location of the inlet air duct. In this configuration the air inlets for the blower were along the two sides of the vehicle near floor level. The coil outlet duct was unchanged from the baseline configuration.

Figure 4 is a schematic of a third configuration of the internal cooling system. It is called the modified outlet configuration. In this arrangement, air deflectors were positioned in the outlet air stream. These devices deflected about one-third of the cool air toward each side of the enclosure. The remaining one-third was directed toward the back of the enclosure as in the baseline configuration. The inlet duct is unchanged from the baseline arrangement.

The final configuration of the internal cooling system which was tested is called the modified outlet and inlet configuration. It incorporates both the modified air inlet and the modified air outlet. This configuration is shown in Figure 5.

## System Description - 4796 $ft^3$ Enclosure

One cooling system was installed and tested for the larger enclosure. This system consisted of an air conditioner with 60,000 BTU/hour capacity. This unit was used to cool the air inside the enclosure and the enclosure walls to approximately 69°F prior to the hot-soak evaporative test. This particular unit could not be used during the test because the exit air temperature was below the 68°F minimum allowed by the regulations.

## Test Results and Discussion - 1525 $ft^3$ Enclosure

As previously mentioned, three production vehicles were obtained for evaluating the various enclosure cooling systems. A description of these vehicles follows:

| Manufacturer | Make | Model | Year | Engine | Catalysts |
|---|---|---|---|---|---|
| Chrysler | Plymouth | Fury | 1976 | 440 | 2 Monoliths |
| Ford | Lincoln | Mark IV | 1974 | 460 | 2 Monoliths |
| General Motors | Chevrolet | Caprice | 1975 | 454 | 1 Bead |

Initial testing showed that hot soak heat loss from the Chevrolet and the Lincoln was very similar. Cooling system evaluation tests were then conducted using only the Lincoln and the Plymouth.

The main objective of the test program was to identify enclosure cooling system(s) that would limit the maximum ambient temperature to less than 86°F. Figure 6 is a graph which shows the peak enclosure ambient temperatures for the various cooling systems, and compares them to the case in which no cooling system was used during the one hour test. For the tests in which cooling was used, the enclosure air and walls were precooled (to approximately 69°F) before the vehicle entered.

As shown in Figure 6, the Chrysler vehicle gave consistently higher temperatures than the Ford. Although the external cooling system did reduce the peak temperature, it was not sufficient to meet the test requirement of 86°F maximum. This finding is consistent with test results obtained at the Chrysler Proving Ground, where a similar cooling system has been tested.

The baseline and modified inlet configurations of the internal cooling system gave similar results. Although these two configurations gave lower enclosure ambient temperatures than the external cooling system, they were still not adequate for the Chrysler vehicle.

As Figure 6 shows, the modified outlet configuration resulted in substantially lower peak enclosure ambient temperatures than the baseline and modified inlet arrangements. The temperatures for the modified outlet configuration were 79.5°F and 84°F for the Ford and Chrysler, respectively. Tests conducted with the modified outlet and inlet configuration showed that this system also limited the peak temperatures to less than 86°F; however, it was somewhat less effective than the modified outlet configuration.

An understanding of why various internal cooling configurations result in different peak enclosure temperatures can be developed by examining the rate of heat removal by the heat exchanger during the hot soak test. The amount of heat removed by the coil can be directly calculated from the flow rate and change in temperature of the air as it passes over the coil. These calculations have been made and are presented in Figure 7. These values are the rate of heat transfer at the time the enclosure ambient temperature reached its maximum value. For the modified outlet configuration, the heat transfer rate was greater than the baseline configuration by 26% and 28% for the Ford and Chrysler vehicles, respectively. The heat transfer rate for the modified outlet and inlet configuration was somewhat less than the modified outlet configuration for both vehicles.

As previously mentioned, the peak temperatures shown in Figure 6 were obtained by precooling the enclosure inside air and the enclosure walls prior to the hot soak test. To determine the effect of precooling on the peak temperature, some internal cooling system tests were conducted without enclosure precooling. The results of these are shown in Figure 8. This figure indicates that enclosure precooling had a greater effect with the baseline configuration than with the modified outlet and the modified outlet and inlet configurations. For the four sets of tests conducted with the modified configurations, the peak temperature reached with precooling ranged from 0.5 to 1.5°F lower than the peak temperature reached without precooling.

As shown in Figures 4 and 5, for the modified outlet configuration, the majority of air leaving the cooling coil was directed toward the side walls of the enclosure. Since the thermocouples which measure the enclosure ambient temperature were located near the side walls, the question arose as to whether or not the lower temperatures obtained by this configuration might be a result of cool air impacting directly on the thermocouples. To investigate this, shields were placed around the two thermocouples. These shields were hollow cylindrical sections 1.5 inches in diameter and 5 inches long. They were mounted in a horizontal plane such that the thermocouples were located at the midpoint of the cylinder interiors. Tests of the modified outlet configuration and the modified outlet and inlet configuration were conducted using these thermocouple shields. The test results are given in Figure 9. As shown, shielding of the thermocouples from any direct air impact did not change the measured peak enclosure temperature by more than 0.5°F for the modified outlet system. A difference of 1.5°F was observed for the modified outlet and inlet system.

It would be expected that the air flow patterns in the enclosure would be different for the different configurations of the internal cooling system. These differences in air flow might also be expected to affect any natural vehicle underhood air movement. This might in turn affect underhood air temperature and hot-soak emissions levels. To investigate the possibility that the internal cooling system might cause atypical underhood cooling, underhood air temperature was recorded during most of the vehicle testing. The location of these temperature measurements was about three inches from the side of the carburetor body. These temperature data are presented in Fig. 10 for the two vehicles tested. As shown, underhood air temperature was also measured while the vehicles soaked in the 78°F soak area after an FTP dynamometer procedure.

Figure 10 indicates that the underhood air temperature of the Ford vehicle was more repeatable and less sensitive to changes in the surroundings than the Chrysler. There was no difference between the Ford's peak temperature in the 78°F soak area and in the uncooled enclosure where the ambient temperature was in the 90's. However, the Chrysler did experience higher underhood temperature in the uncooled enclosure than in the soak area. Both Ford and Chrysler enclosure tests without cooling showed that operation of the 1000 CFM blower does not result in lower underhood temperatures than the use of one small air mixing fan. For both vehicles, use of the modified outlet configuration resulted in underhood air temperatures which were typical of those measured in the 78° soak area. It also appeared that underhood air temperatures with the modified outlet and inlet cooling configuration were higher than those with the modified outlet configuration. Without enclosure precooling, this difference averaged 12°F for the Chrysler and 6°F for the Ford.

To directly investigate any effect of enclosure cooling on hot-soak emissions, a series of evaporative emission tests were conducted on the Ford test vehicle. This vehicle was preconditioned with one FTP driving cycle (LA-4, 10 min. soak, 505 sec). The vehicle then soaked for between 14 and 24 hrs. The diurnal test was done in the enclosure and emissions were measured. Exhaust emissions were not measured during the dynamometer driving cycle. The hot soak test was conducted according to the 1978 evaporative emission regulations. The dynamometer operation (FTP driving cycle) before the hot soak test served as preconditioning for the following day of testing.

Figure 11 shows the emission results of the hot-soak evaporative tests. As shown, the highest emission levels were obtained when the enclosure was not cooled during the test and only one small air mixing fan was used. Under these conditions, the average level was 18.4 g. When the enclosure was cooled with the modified outlet configuration (without precooling) the average hot soak emission level fell to 16.7 g; a drop of 9%. Due to the low variability in these two groups of data (pooled standard deviation = 3%) this difference is signficant at a confidence level of 99%. This 9% drop in emission level appears to have resulted from both cooling the air inside the enclosure and from the increased air circulation in the enclosure. This is indicated by the results of tests conducted with the 1000 CFM blower in operation but without cooling (shown in Fig. 11). For those tests it appears the emission level was between that with the small mixing fan only and that with the modified outlet cooling configuration in operation.

Another observation from Fig. 11 is that enclosure precooling appeared to decrease emissions. This trend was indicated in tests with both the modified outlet configuration and the modified outlet and inlet configuration. This relationship is consistent with the temperature data in Fig. 10, which showed that underhood air temperature was lower when the enclosure was precooled.

## Test Results and Discussion - 4796 $ft^3$ Enclosure

As previously described, the large evaporative enclosure was equipped with an air cooling system which was capable of cooling the inside air and enclosure walls to approximately 69°F. Tests were conducted on three vehicles to evaluate this cooling system. Two of these vehicles were the same Chrsyler and Ford products used for the smaller enclosure experiments. The third was a 1977 Cadillac Seville (350 CID fuel injected engine).

The enclosure ambient temperature test results are given in Figure 12. As shown, this system was capable of limiting the peak ambient temperature to less than 86°F on the Ford and the Cadillac, but not on the Chrysler (89°F maximum). Test results on the Cadillac indicated that precooling of this enclosure decrease the peak ambient temperature by about 3°F. This is a greater effect than observed on the smaller enclosure; however, this is expected due to the much larger wall surface area.

## Summary and Conclusions

1. Evaporative enclosure cooling systems can be designed which comply with the 1978 federal emissions regulations.

2. Internal cooling systems appear preferable to external cooling systems due to their relative effectiveness and simplicity.

3. Physical configuration (location) of internal cooling system components has a substantial effect on the measured enclosure ambient temperature and the quantity of heat removed.

4. For the most effective configuration of the internal cooling system tested, it was found that:

   (a) The maximum increase in enclosure ambient temperature, above the surrounding ambient temperature, was 6°F.

   (b) Cooling the SHED walls and inside air from 78°F to 69°F prior to the test reduced the peak ambient enclosure temperature only about 1°F.

5. It has been demonstrated on one vehicle (which had a hot soak emission level of about 17 g) that internal enclosure cooling can result in lower hot soak emission levels than no enclosure cooling. The effect of cooling on hot soak emissions is expected to be highly vehicle dependent.

Recommendations

1. Internal cooling systems of the "modified outlet" configuration tested in this study should be installed in the EPA certification enclosures.

2. Due to some dimension changes in the new EPA enclosures and some expected changes in the arrangement of the cooling system, a limited amount of testing should be done with one of these units before they are used for certification tests.

3. To achieve optimum evaporative emission correlation between laboratories, enclosure cooling systems should be as similar as possible.

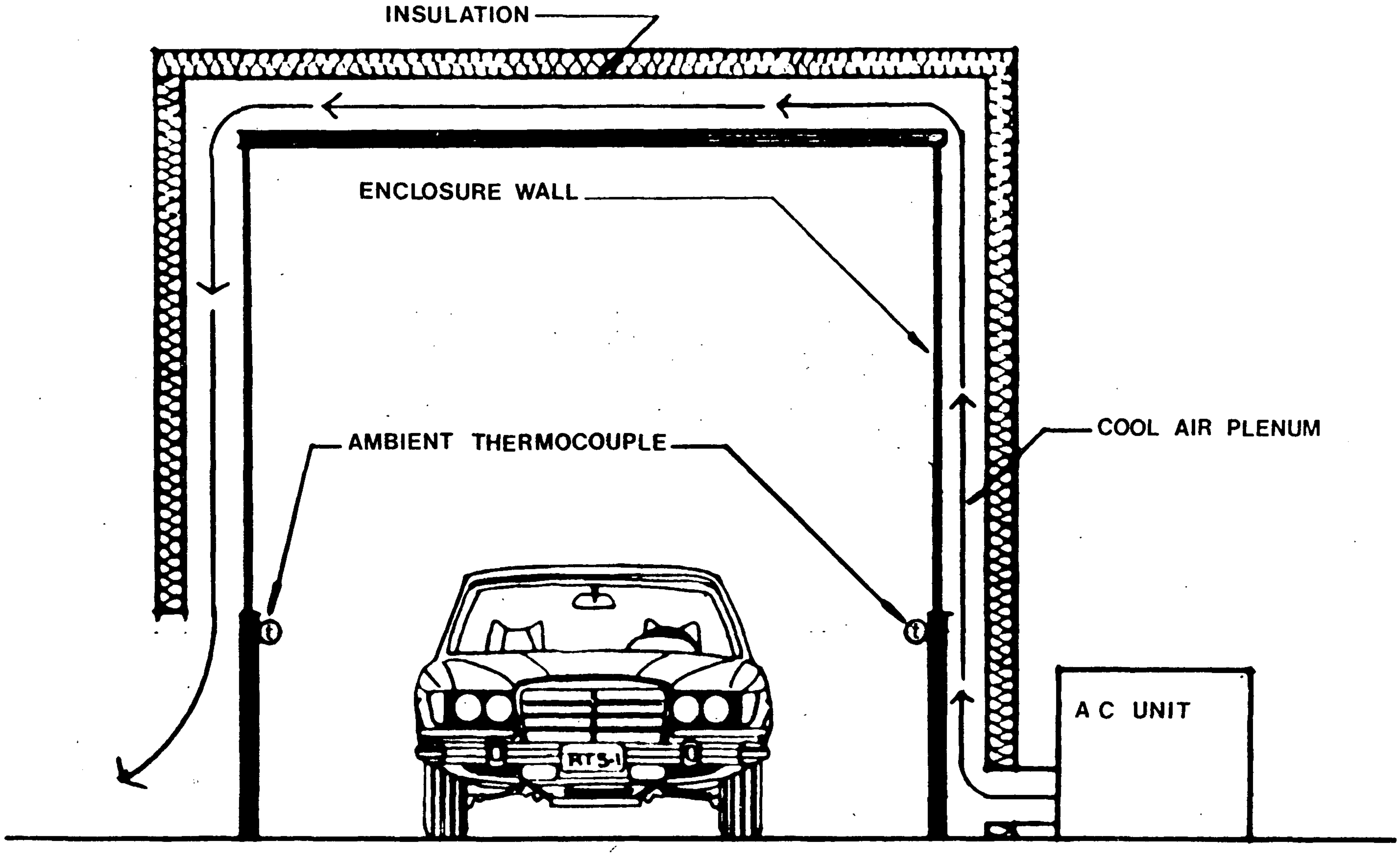


FIGURE 1 **EXTERNAL ENCLOSURE COOLING SYSTEM**

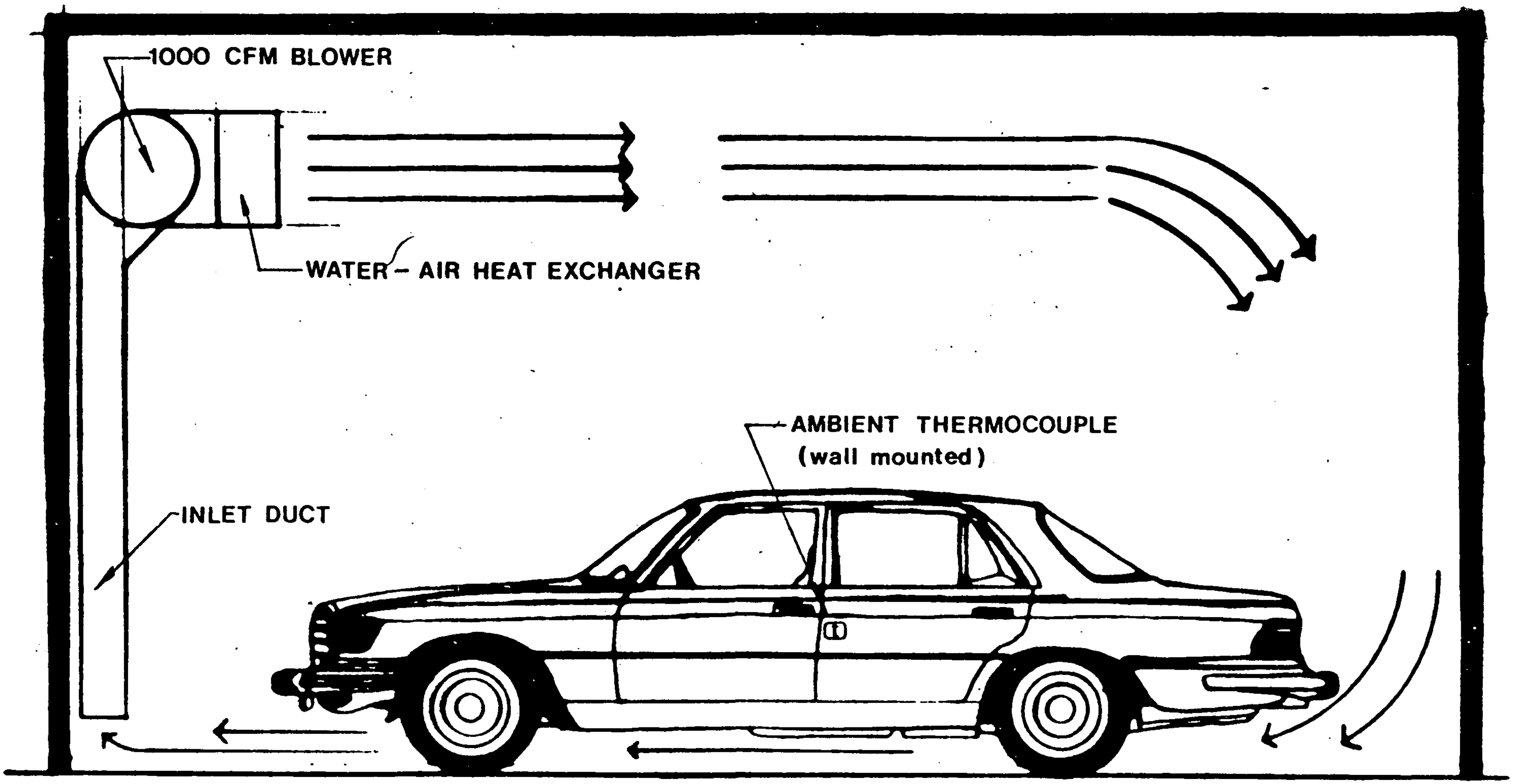


FIGURE 2 **INTERNAL ENCLOSURE COOLING SYSTEM** – Baseline

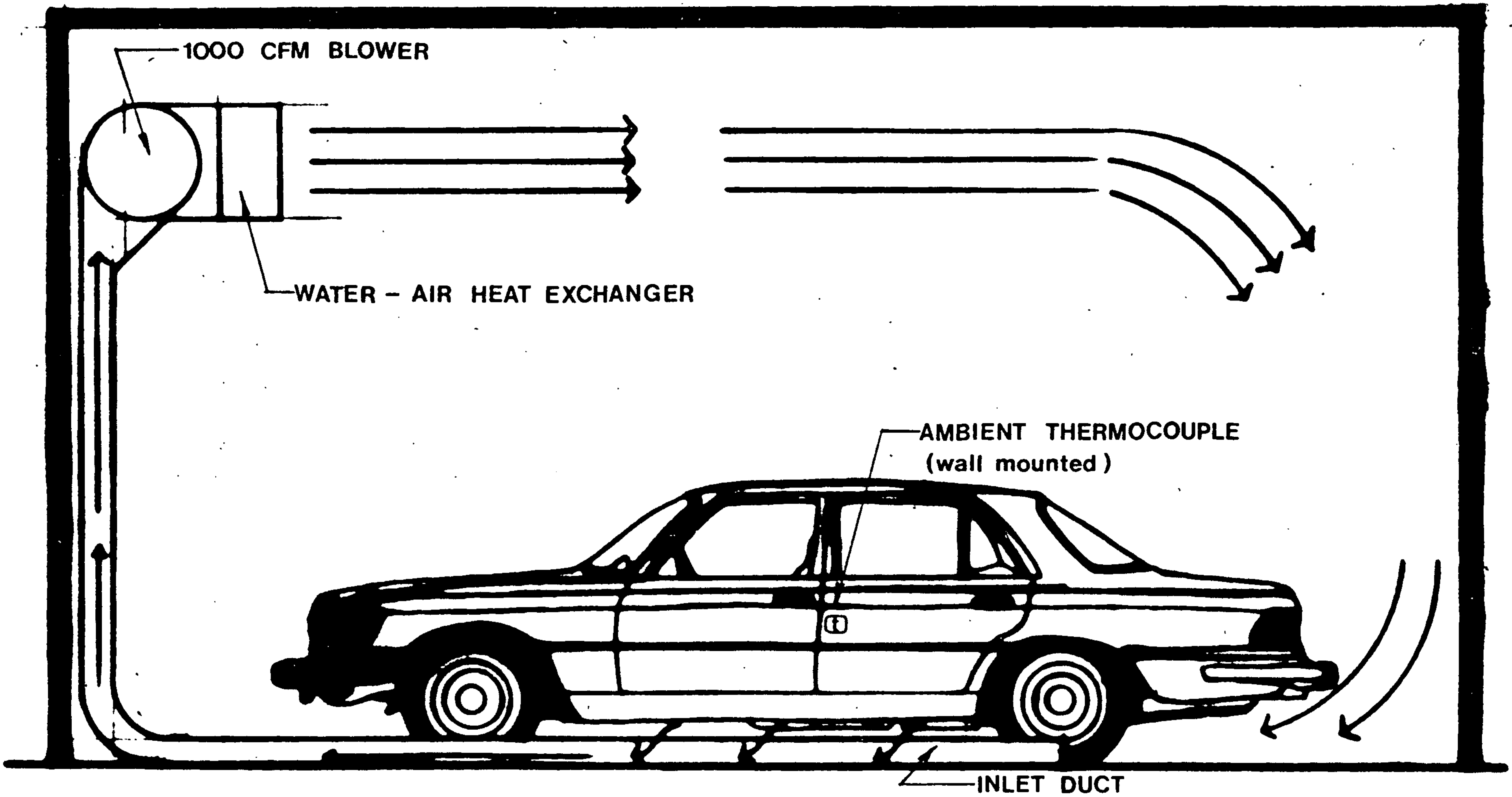


FIGURE 3 **INTERNAL ENCLOSURE COOLING SYSTEM** - Modified Inlet

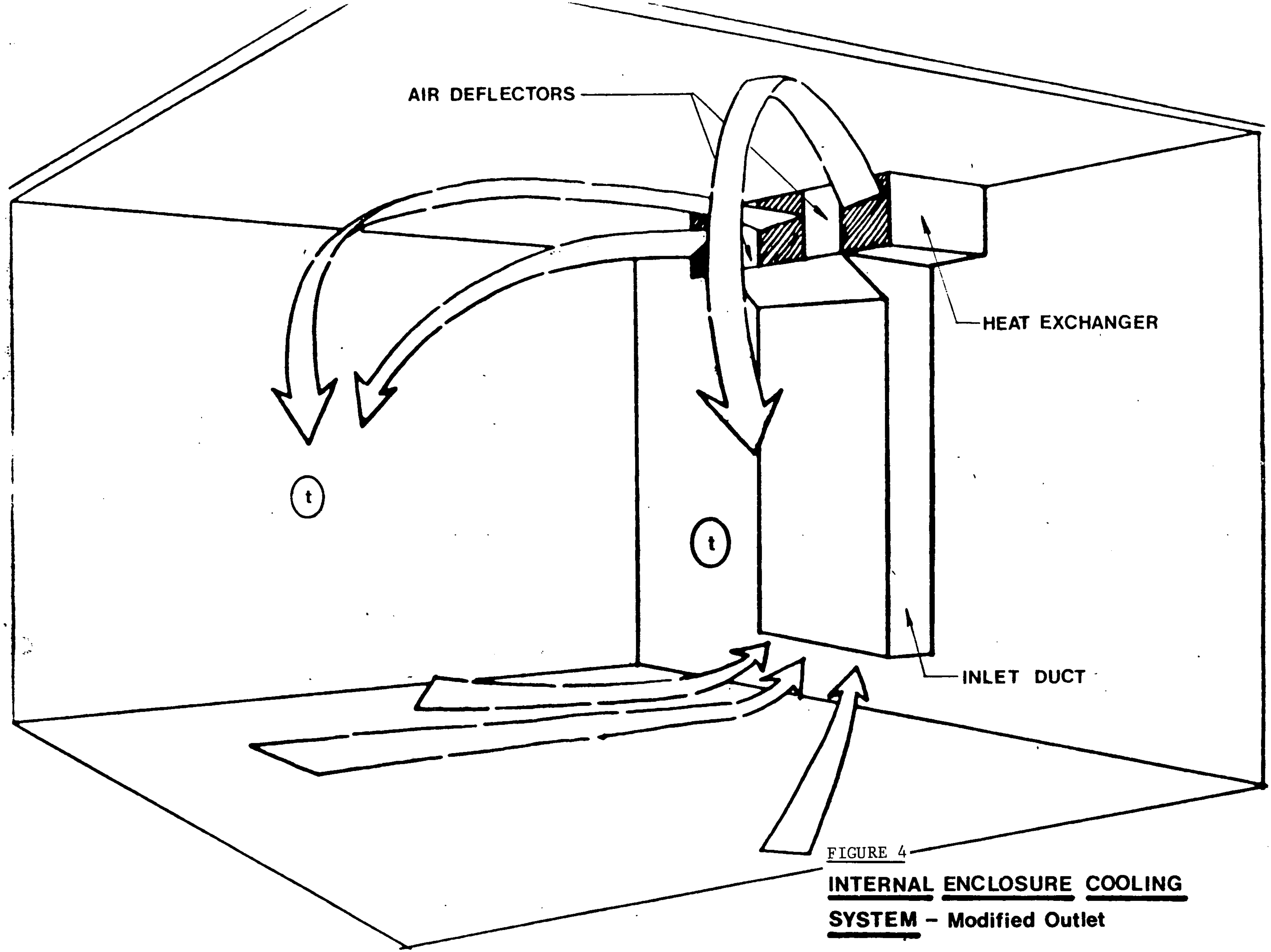


FIGURE 4

**INTERNAL ENCLOSURE COOLING SYSTEM - Modified Outlet**

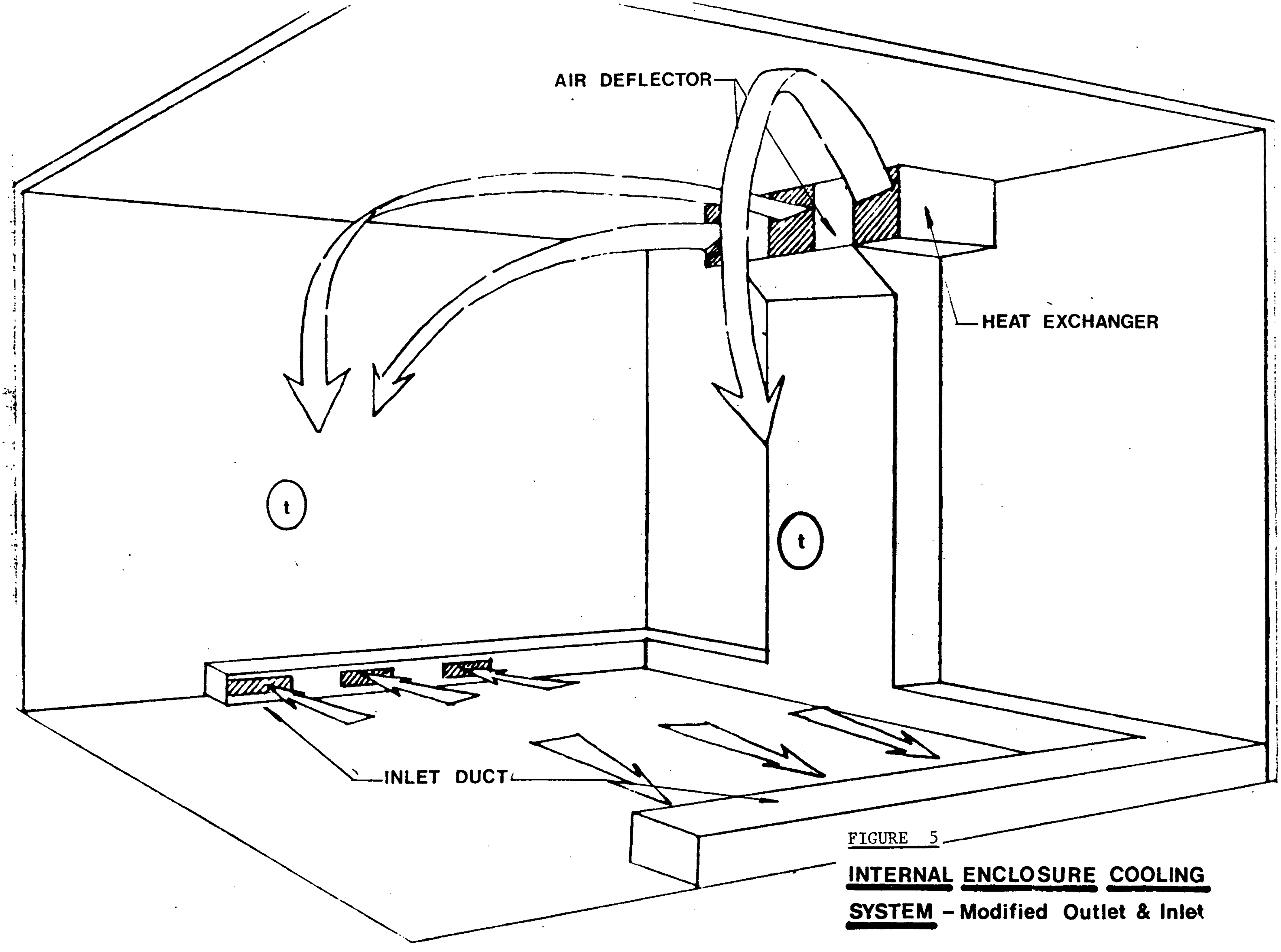


FIGURE 5

**INTERNAL ENCLOSURE COOLING SYSTEM** – Modified Outlet & Inlet

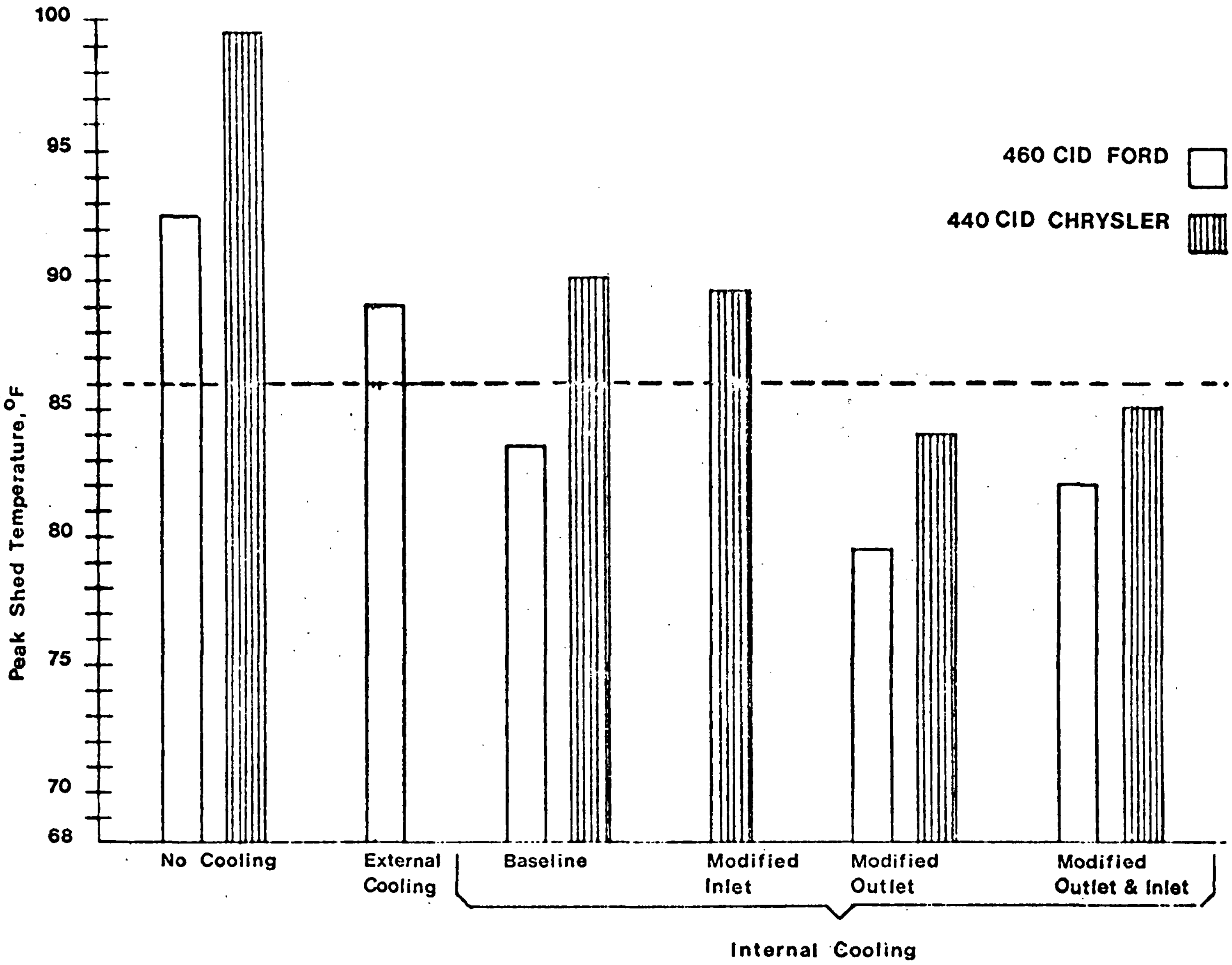


FIGURE 6 **EFFECT OF ENCLOSURE COOLING ON PEAK AMBIENT SHED TEMPERATURE**

FIGURE 7

HEAT REMOVAL RATE BY THE INTERNAL COOLING SYSTEM
AT THE TIME PEAK ENCLOSURE TEMPERATURE WAS
REACHED (PRE-COOLED ENCLOSURE)

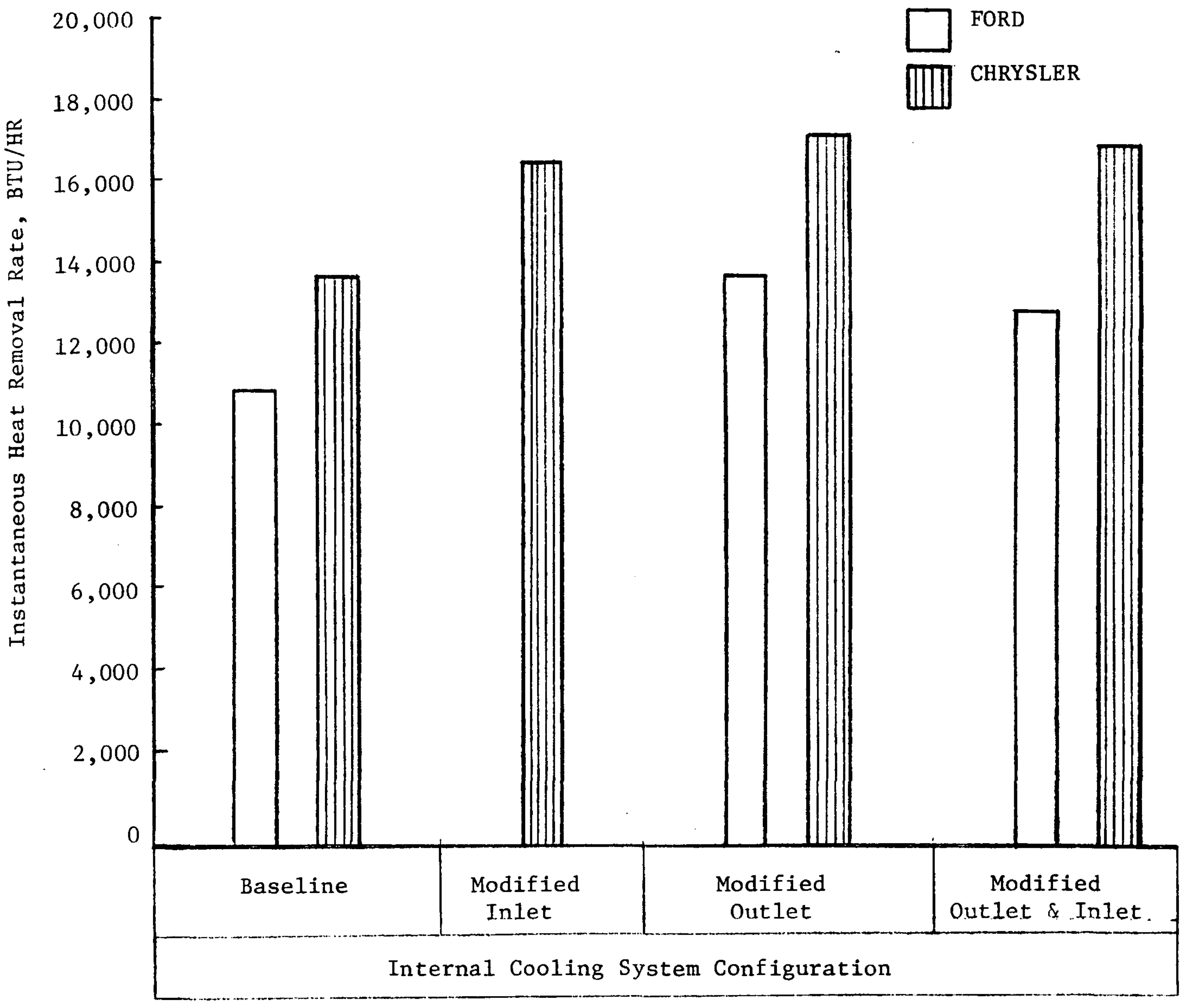

FIGURE 8

EFFECT OF ENCLOSURE AIR AND WALL PRE-COOLING ON PEAK ENCLOSURE AMBIENT TEMPERATURE

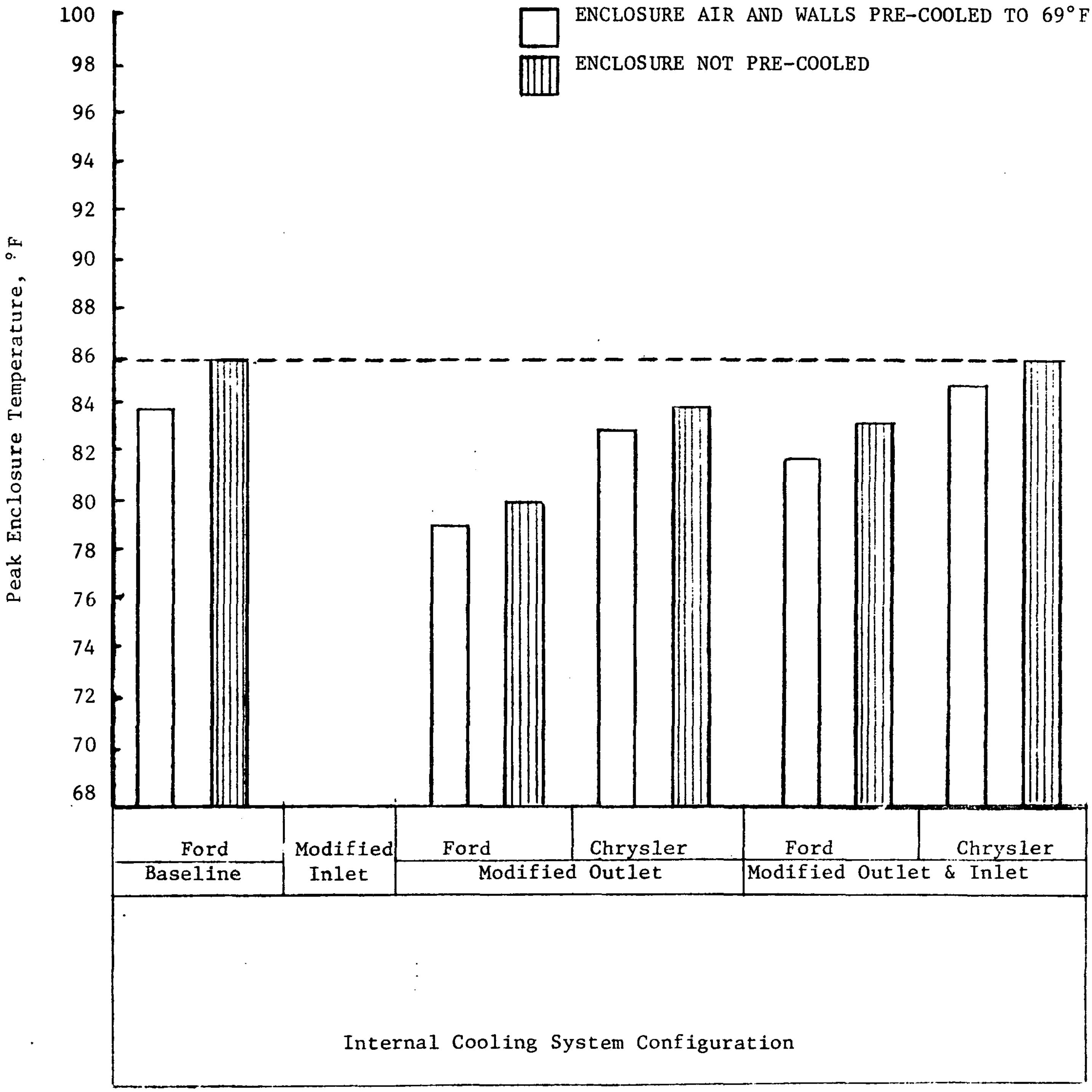

FIGURE 9

EFFECT OF THERMOCOUPLE SHIELDING
ON PEAK ENCLOSURE AMBIENT TEMPERATURE

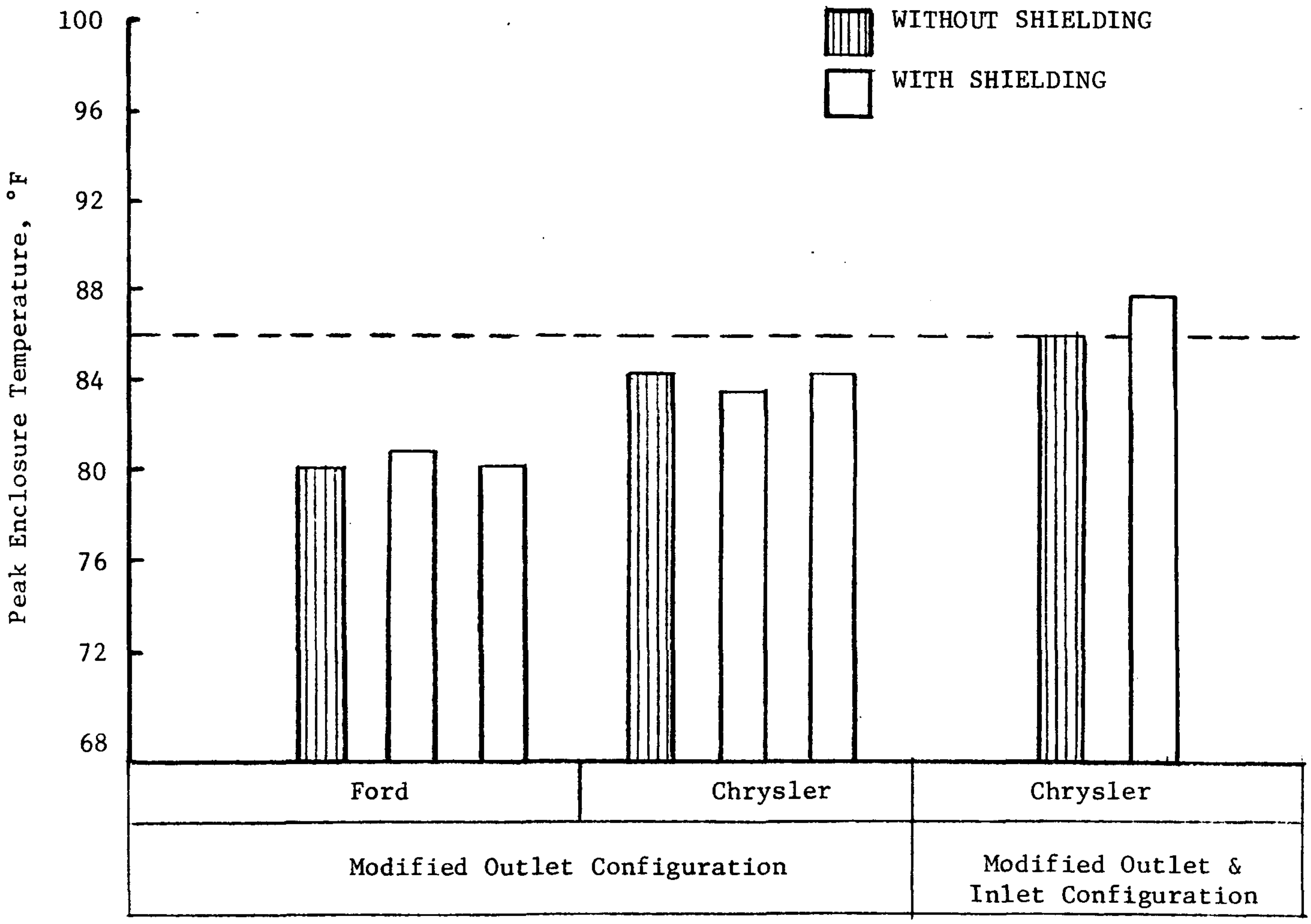

FIGURE 10

EFFECT OF ENCLOSURE
INTERNAL COOLING SYSTEM CONFIGURATION ON
PEAK VEHICLE UNDERHOOD AIR TEMPERATURE

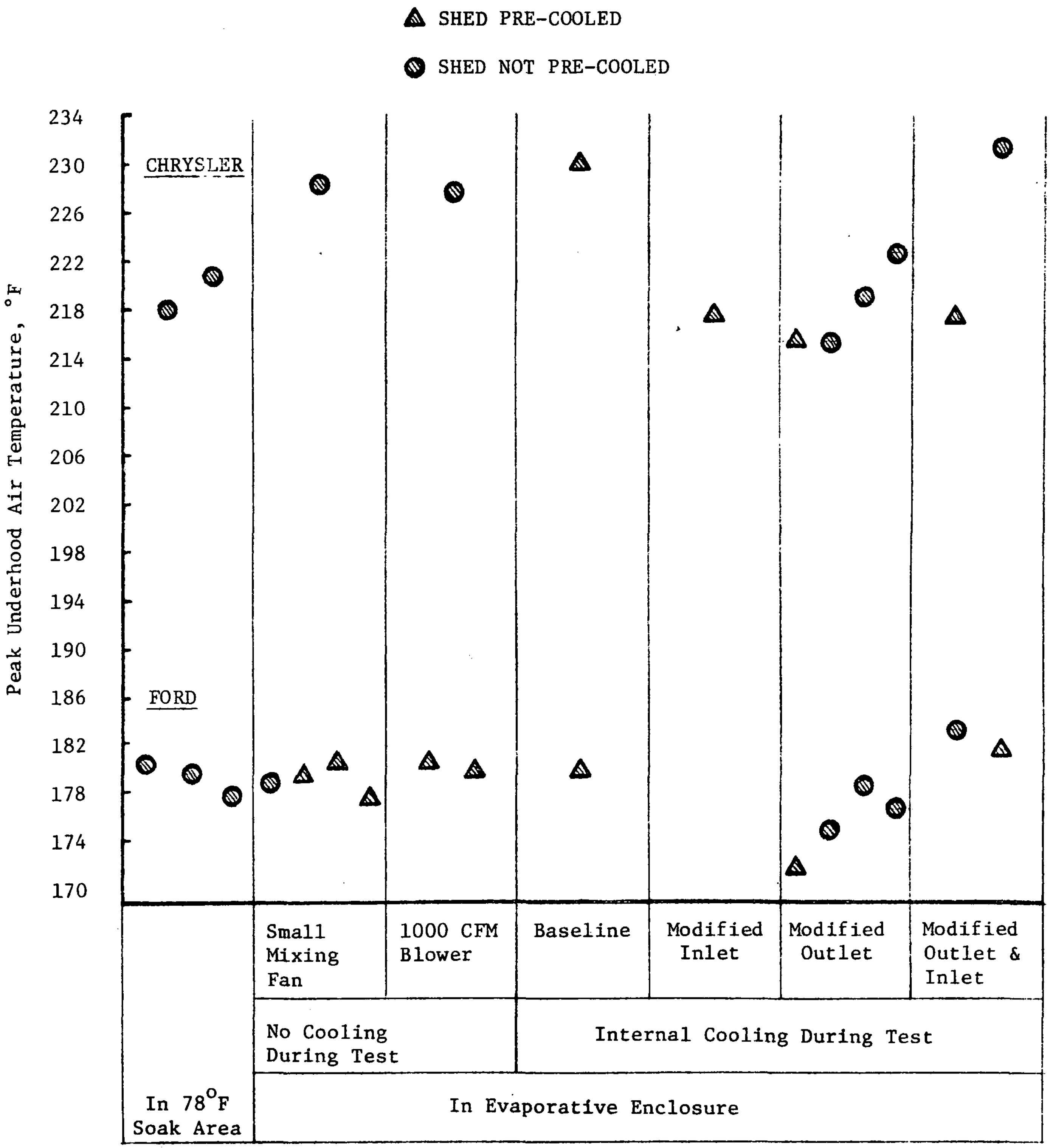

FIGURE 11

RELATIONSHIP BETWEEN ENCLOSURE COOLING SYSTEM CONFIGURATION AND HOT SOAK EVAPORATIVE EMISSIONS ON THE FORD TEST VEHICLE

▲ ENCLOSURE PRE-COOLED

● ENCLOSURE NOT PRE-COOLED

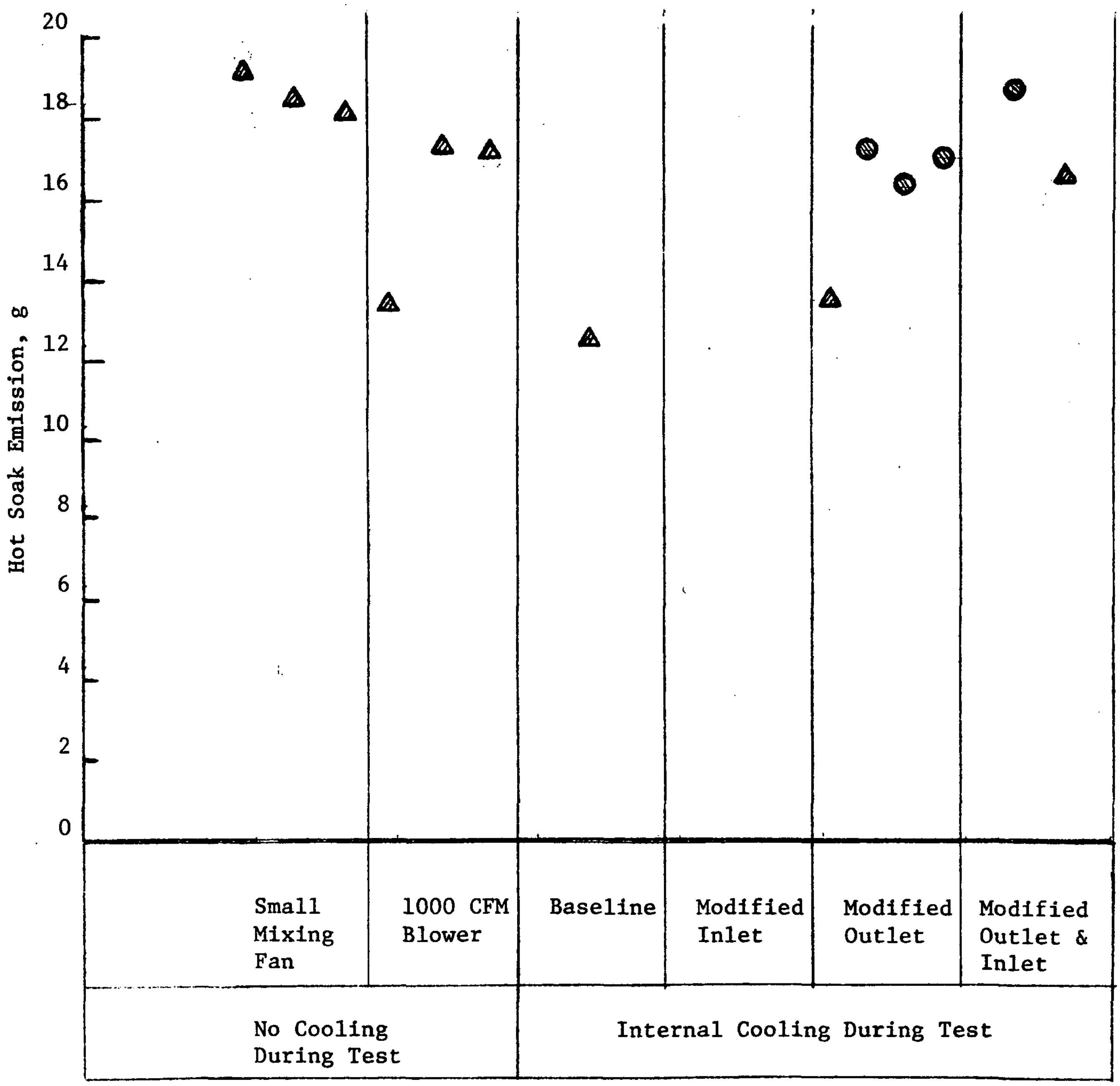

FIGURE 12

EFFECT OF PRE-COOLING ON PEAK
AMBIENT TEMPERATURE IN LARGE ENCLOSURE