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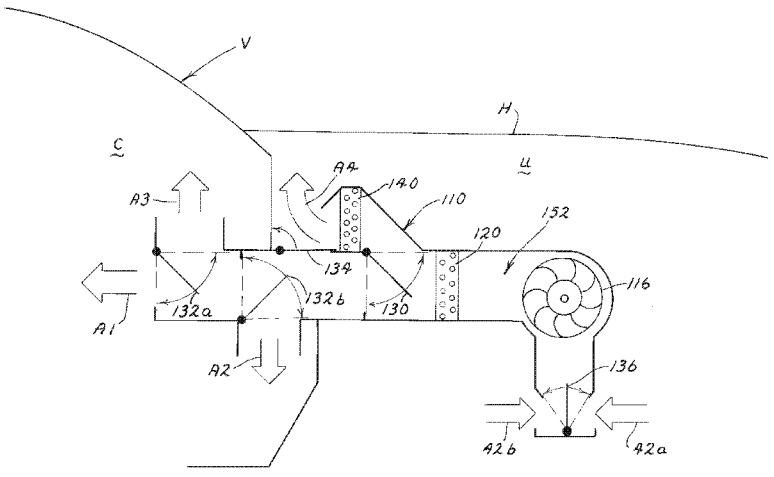


FIG. 3

(57) **Abstract**: A dual use of a heater core that enables heating the cabin, cooling the engine or both on demand regardless of the passenger's cabin heating and cooling requirements. This use of the heater core is enabled by a HVAC airbox system with a cooling door that can be selectively positioned such that at least some of the air moving through the heater core is directed outside of the HVAC system and outside of the passenger cabin to the underhood area of a vehicle, thereby providing supplemental engine cooling on demand regardless of the passenger's cabin heating and cooling requirements. The cooling door can be positioned automatically dependent on any parameter, or combination of parameters, of the engine such as engine coolant temperature or engine oil temperature. The blower speed and the position of the cooling door are adjusted depending on the whether and how much supplemental engine cooling is required.

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# HVAC Airbox Systems and Methods

## BACKGROUND

1. Field of the Invention

**[0001]** The present invention relates generally to heating, ventilation and air conditioning ("HVAC") airbox systems and methods of cooling an engine. Particularly, the present invention relates to HVAC airbox systems and cooling methods for an engine, which is part of a vehicle having a passenger cabin and an underhood area. Even more particularly, preferred HVAC airbox systems have a dual use of a heater core that enables heating the passenger cabin, cooling the engine or both on demand regardless of the passenger's cabin heating and cooling requirements.

2. Description of the Related Art

**[0002]** Combustion engines must be cooled to prevent overheating, which can cause damage to the engine. In a typical engine cooling system, a radiator or cooling pack is primarily used for cooling the engine, whereas a heater core draws heat from the engine and is used to heat the cabin. When the cabin is being heated, the heater core draws heat from the engine and contributes to engine cooling. However, when the cabin heat is not turned on, there is no airflow across the heater core and, therefore, the heater core does not draw heat from the engine.

**[0003]** The present invention addresses problems and limitations associated with the related art.

## SUMMARY OF THE INVENTION

**[0004]** The present invention uses a heater core of a vehicle in not only heating the passenger cabin but also for engine cooling. In preferred heating, ventilation and air conditioning ("HVAC") airbox systems, the airbox is configured to enable airflow across the heater core by implementing a cooling door such that at least some of the air from exiting the heater core is directed both outside the HVAC airbox system and outside of the passenger cabin. This contributes to engine

cooling on demand, even when passenger cabin heating is turned off. Such a configuration enables the heater core to supplement the radiator in engine cooling, which means that the radiator or cooling pack can be smaller and/or require less airflow through the front grill, which can directly improve the fuel economy of the vehicle.

**[0005]** Preferred HVAC airbox systems are configured for a combustion engine, which is part of a vehicle having a radiator having a coolant capable of absorbing heat from the engine, a passenger cabin and an underhood area. The HVAC airbox system includes a heater core connected to the engine using coolant passages such that heat absorbed by the coolant can be transferred to the heater core. The HVAC airbox system further includes at least one blower capable of directing air through the heater core and a cooling door that can selectively be positioned such that at least some of the air moving through the heater core is directed outside the HVAC airbox system to the underhood area of the vehicle.

**[0006]** The invention also includes methods of cooling an engine. Preferred methods of the invention generally include at least partially opening or closing the cooling door such that at least some of the air from exiting the heater core is directed outside of the HVAC airbox system to the underhood area. Whether the cooling door is opened or closed can depend on a variety of factors including coolant temperature or whether the passenger cabin heat is on, for example. In preferred methods, the HVAC airbox system is configured to have high and low threshold temperatures for the engine coolant. Preferably, the cooling door opens such that air is directed to the outside of the HVAC system to the underhood area when the coolant temperature reaches the high threshold temperature and the cooling door closes when the coolant temperature reaches the low threshold temperature such that air is no longer directed to the underhood area outside of the HVAC airbox system. During such operation, the heater core provides supplemental cooling of the engine.

**[0007]** The present invention also includes the following inventive aspects:
Aspect 1: A heating, ventilation and air conditioning ("HVAC") airbox system, which is part of a vehicle having an engine capable of generating heat, a radiator having a coolant, the coolant capable of absorbing heat from the engine, the vehicle

further having a passenger cabin and an underhood area, the HVAC airbox system comprising:

an air conditioner ("AC") evaporator;

a heater core fluidly connected to the engine such that heat absorbed by the coolant can be transferred to the heater core;

at least one blower capable of directing air through the heater core; and

a cooling door, which is optionally pivotable; wherein the cooling door can selectively be positioned such that at least some of the air moving through the heater core is directed both outside of the HVAC system and outside of the passenger cabin.

Aspect 2: The HVAC airbox system according to aspect 1, wherein the cooling door enables hot air from heater core to be released to the underhood area.

Aspect 3: The HVAC airbox system according to aspect 1 or 2, wherein the cooling door has at least three positions, wherein, in the first position, air exiting the heater core is directed to the passenger cabin; in the second position, air exiting the heater core is directed outside of the HVAC system and outside of the passenger cabin; and, in the third position, air exiting the heater core is directed to both the passenger cabin and the underhood area.

Aspect 4: The HVAC airbox system according to any one of aspects 1 to 3, wherein the system includes at least two blowers, wherein one blower directs air to the heater core and the second blower directs air to the AC evaporator.

Aspect 5: The HVAC airbox system according to any one of aspects 1 to 4, wherein substantially all of the air exiting the heater core is directed to the underhood area.

Aspect 6: The HVAC airbox system according to any one of aspects 1 to 5, further comprising a duct proximate the heater core such that the air passing

through the heater core can be directed to the underhood area and to the bottom of the vehicle via the duct.

Aspect 7: A method of cooling an engine that is part of a vehicle having a passenger cabin and an underhood area in which the engine is located; the method comprising the steps of:

providing an engine capable of generating heat; a heating, ventilation and air conditioning ("HVAC") airbox system including a radiator having a coolant, the coolant capable of absorbing heat from the engine, an air conditioner ("AC") evaporator, a heater core fluidly connected to the engine such that heat absorbed by the coolant can be transferred to the heater core and at least one blower capable of directing air through the heater core; and

actuating a cooling door such that at least some of the air from exiting the heater core is directed to the underhood area.

Aspect 8: The method according to aspect 7, wherein the cooling door is adjustable such that the cooling door can direct the air exiting to the heater core to the passenger cabin, the underhood area, or both the passenger cabin and the underhood area.

Aspect 9: The method according to aspect 7 or 8, wherein air is directed from the blower, through the AC evaporator and then to the heater core.

Aspect 10: The method according to any one of aspects 7 to 9, further providing a duct proximate the heater core such that the air passing through the heater core is directed to the bottom of the vehicle via the duct.

Aspect 11: The method according to any one of aspects 7 to 10, further defining a high threshold temperature; wherein the cooling door opens such that air is directed to the underhood area when the coolant temperature reaches the high threshold temperature.

Aspect 12: The method according to aspect 11, further defining a low threshold temperature; wherein the cooling door closes such that air is not directed to the underhood area when the coolant temperature reaches the low threshold temperature.

Aspect 13: The method according to aspect 12, wherein the difference between the high threshold temperature and the low threshold temperature is about 2 to about 15 degrees Fahrenheit, further optionally comprising the step of providing supplemental engine cooling on demand using the heater core regardless of the passenger cabin heating and cooling requirements.

Aspect 14: The method according to any one of aspects 7 to 13, wherein at least some of the air exiting the heater core is directed to the passenger cabin.

Aspect 15: The method according to any one of aspects 7 to 13, wherein substantially all of the air exiting the heater core is directed outside of the passenger cabin and outside of the HVAC system.

Aspect 16: A heating, ventilation and air conditioning ("HVAC") airbox system, which is part of a vehicle having an engine capable of generating heat, a radiator having a coolant, the coolant capable of absorbing heat from the engine, the vehicle further having a passenger cabin and an underhood area, the HVAC airbox system comprising:

an air conditioning ("AC") evaporator;

a heater core fluidly connected to the engine such that heat absorbed by the coolant can be transferred to the heater core;

at least one blower capable of directing air through the heater core; and

a cooling door; wherein the cooling door can selectively be positioned such that at least some of the air moving through the heater core is directed both outside of the HVAC system and outside of the passenger cabin.

Aspect 17: The HVAC airbox system of aspect 16, wherein the cooling door has at least three positions, wherein, in the first position, air exiting the heater core is directed to the passenger cabin; in the second position, air exiting the heater core is directed to the underhood area; and, in the third position, air exiting the heater core is directed to both the passenger cabin and the underhood area.

Aspect 18: The HVAC airbox system of aspect 17, wherein the system includes at least two blowers, wherein one blower directs air to the heater core and the second blower directs air to the AC evaporator.

Aspect 19: The HVAC airbox system of aspect 16, wherein substantially all of the air exiting the heater core is directed outside of the HVAC system and outside of the passenger cabin.

Aspect 20: The HVAC airbox system of aspect 16, wherein the cooling door can pivot.

Aspect 21: The HVAC airbox system of any of one aspects 16 to 20, further comprising a duct such that the air passing through the heater core can be directed to the underhood area or to the bottom of the vehicle via the duct.

Aspect 22: A heating, ventilation and air conditioning ("HVAC") airbox system, which is part of a vehicle having an engine capable of generating heat, a radiator having a coolant, the coolant capable of absorbing heat from the engine, the vehicle further having a passenger cabin and an underhood area , the HVAC airbox system comprising:

a heater core fluidly connected to the engine such that heat absorbed by the coolant can be transferred to the heater core;

an air conditioning ("AC") evaporator;

at least one blower capable of directing air through the heater core; and

a cooling door proximate the heater core; wherein the cooling door has at least three positions, wherein, in the first position, air exiting the heater core is

directed to the passenger cabin; in the second position, air exiting the heater core is directed both outside of the HVAC airbox system and outside of the passenger cabin; and, in the third position, air exiting the heater core is directed to both the passenger cabin and outside of the passenger cabin.

Aspect 23: The HVAC airbox of aspect 22, wherein the system includes at least two blowers, wherein one blower directs air to the heater core and the second blower directs air to the AC evaporator

Aspect 24: The HVAC airbox of aspects 22 or 23, wherein substantially all of the air exiting the heater core is directed to the underhood.

Aspect 25: The HVAC airbox of any one of aspects 22 to 24, wherein the cooling door can pivot.

Aspect 26: A method of cooling an engine that is part of a vehicle having a passenger cabin and an underhood area in which the engine is located; the method comprising the steps of:

providing an engine capable of generating heat; a heating, ventilating and air conditioning ("HVAC") airbox system including a radiator having a coolant, the coolant capable of absorbing heat from the engine, an air conditioning ("AC") evaporator, a heater core fluidly connected to the engine such that heat absorbed by the coolant can be transferred to the heater core and at least one blower capable of directing air through the heater core; and

actuating a cooling door such that at least some of the air from exiting the heater core is directed to the underhood area.

Aspect 27: The method of aspect 26, wherein at least some of the air exiting the heater core is directed to the passenger cabin.

Aspect 28: The method of aspect 26 or 27, wherein the cooling door is adjustable such that the cooling door can direct the air exiting to the heater core to

only the underhood area, only the passenger cabin or both the underhood area and the passenger cabin.

Aspect 29: The method of any one of aspects 26 to 28, wherein substantially all of the air exiting the heater core is directed to the underhood area.

Aspect 30: The method of any one of aspects 26 to 29, wherein air is directed from the blower, through the AC evaporator and then to the heater core.

Aspect 31: The method of any one of aspects 26 to 30, wherein the HVAC airbox system further includes a duct such that the air passing through the heater core can be directed to the underhood area to the bottom of the vehicle via the duct.

Aspect 32: The method of any one of aspects 26 to 31, wherein the HVAC airbox system is configured to have a high threshold temperature; wherein the cooling door opens such that air is directed to the underhood area when the coolant temperature reaches the high threshold temperature.

Aspect 33: The method of aspect 32, wherein the HVAC airbox system is configured to have a low threshold temperature; wherein the cooling door closes such that air is not directed to the underhood area when the coolant temperature reaches the low threshold temperature.

Aspect 34: The method of aspect 33, wherein the difference between the high threshold temperature and the low threshold temperature is about 2 to about 15 degrees Fahrenheit.

Aspect 35: The method of aspect 33 or 34, further comprising the step of providing supplemental engine cooling on demand using the heater core regardless of the passenger cabin heating and cooling requirements.

**[0008]** These and various other advantages and features of novelty which characterize the present invention are pointed out with particularity in the claims annexed hereto and forming a part hereof. However, for a better understanding of the invention, its advantages and objects obtained by its use, reference should be made to the drawings which form a further part hereof, and to the accompanying descriptive matter, in which there is illustrated and described preferred embodiments of the present invention.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0009]** In the drawings, in which corresponding reference numerals and letters indicate corresponding parts of the various embodiments throughout the several views, and in which the various embodiments generally differ only in the manner described and/or shown, but otherwise include corresponding parts;

**[0010]** FIGURE 1 is a partial, perspective schematic view of a vehicle V having a hood H, a radiator or cooling pack 112, an engine 124 and a heating, ventilation and air conditioning ("HVAC") airbox system 110 having an air conditioning ("AC") evaporator 120, a heater core 140 and a blower (blower 116 not shown in this Figure for clarity);

**[0011]** FIGURE 2 is a schematic illustration of a known heating, ventilation and air conditioning ("HVAC") airbox system 10;

**[0012]** FIGURE 3 is a schematic illustration of a preferred HVAC airbox 110 of Fig. 1, the HVAC airbox 110 including heater core 140 and a cooling door 134; wherein the cooling door 134 is positioned to direct air A4 exiting the heater core 140 to an underhood area U of the vehicle V;

**[0013]** FIGURE 4 is a schematic illustration of the preferred HVAC airbox system 110 of Figs.1 and 3, wherein the cooling door 134 is positioned to direct air A4 exiting the heater core 140 into the passenger cabin C of the vehicle V;

**[0014]** FIGURE 5 is a schematic illustration of the preferred HVAC airbox system 110 of Figs. 1 and 3-4, wherein the cooling door 134 is positioned to direct air exiting the heater core 140 into both the underhood area U and the passenger cabin C of the vehicle V;

**[0015]** FIGURE 6 is a schematic illustration of the preferred HVAC airbox system 110 of Figs. 1 and 3-5, wherein an air conditioning evaporator 120 of the HVAC airbox system 110 is on and is directing cool, dehumidified air into the passenger cabin C, bypassing the heater core 140 to cool the passenger cabin C;

**[0016]** FIGURE 7 is a schematic illustration of a second preferred heating, ventilation and air conditioning ("HVAC") airbox system 110' including first and second blowers 116', 116", one blower 116' for directing air to through the AC evaporator 120 to the passenger cabin C and the second blower 116" dedicated to directing air to a heater core 140";

**[0017]** FIGURE 8 is a schematic illustration of an alternative known HVAC airbox system 10';

**[0018]** FIGURE 9 is a schematic illustration of a further preferred heating, ventilation and air conditioning ("HVAC") airbox system 210 including a cooling door 234 that can direct air from a heater core 240 to the underhood area U of the vehicle V, wherein air A4 directed to the underhood U is further transferred down a duct 260 to the bottom of the vehicle V;

**[0019]** FIGURE 10 is a flow chart illustrating one preferred method of operating the HVAC airbox systems 110, 110', 210;

**[0020]** FIGURE 11 is a flow chart illustrating another preferred method of operating the HVAC airbox systems of 110, 110', 210;

**[0021]** FIGURE 12 is a graph illustrating the Heater Core Performance as analyzed in Example 1; and

**[0022]** FIGURE 13 is a graph illustrating the Required Airflow at the Radiator with and without the heater core assistance as analyzed in Example 1.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

**[0023]** Known heating, ventilation and air conditioning ("HVAC") airbox systems 10, 10' are illustrated in Figs. 2 and 8. In these systems, air is directed through an airbox or passageway 52, 52' to an air conditioning ("AC") evaporator 20, 20' with a blower 16, 16'. A blend door 30, 30' can then selectively direct the air from the AC evaporator 20, 20' to either the passenger cabin (via cabin vent doors 32a, 32b, 32a', 32b') or to the heater core 40, 40' or both areas. If air is directed to the

heater core 40, 40', the air passing through the heater core will be heated and can only escape the system via passenger cabin vent doors 32a, 32b, 32a', 32b' (see air A1-A3). If heated airflow is not desired in the passenger cabin C, there is no airflow across the heater core 40, 40', and therefore it cannot remove heat from the engine. The HVAC airflow system preferably further includes a blower door 36, 36' which can selectively direct fresh air 42a or re-circulated air 42b into the system and toward blower 16, 16'.

**[0024]** Heating, ventilation and air conditioning ("HVAC") airbox systems 110, 110', 210 of the present invention, such as the ones disclosed herein, can be used for cooling an engine 124, located in the underhood area U, under the hood H of a vehicle V, which has a passenger cabin C that may be heated or cooled, as desired. Illustrative embodiments are schematically shown in Figures 1 and 3-7 and 9-11. Collectively, Figures 1 and 3-6 illustrate one preferred HVAC airbox 110, a radiator or cooling pack 112 having hoses 118a filled with coolant fluid 119 and a fan (not shown) that can direct air across the radiator 112 and a blower 116 to direct air toward an air conditioning ("AC") evaporator 120 and heater core 140. As with known systems, the engine 124 is fluidly connected with hoses 118b to the heater core 140. Hoses 118a are interconnected to hoses 118b. Air A1-A3 can be directed, via a blend door 130, to a passenger cabin of the vehicle via cabin vent doors 132a, 132b, to the heater core 140 or to both the heater core 140 and the passenger cabin C. A passageway 152 for air movement is located between the blower door 136, blower 116, AC evaporator 120, heater core 140 cabin vent doors 132a, 132b and passenger cabin C. Blower door 136 is configured to selectively allow blower 116 to intake either fresh air 42a from the outside of the vehicle V or re-circulated air 42b from inside the passenger cabin C. The HVAC airflow system 110 further includes a cooling door 134 which can be selectively positioned to direct air via a first passageway 150 either outside of the passenger cabin C and outside of the HVAC system to the underhood area U of the vehicle V or to the passenger cabin C or both. It will be understood that the air directed outside of the passenger cabin C can be directed to many areas outside of the HVAC system. The cooling door 134 preferably is pivotal and has at least three positions, wherein, in the first position, air A4 exiting the heater core 140 is directed to the passenger

cabin C; in the second position, air A4 exiting the heater core 140 is directed both outside of the passenger cabin C and outside of the HVAC system 110 to the underhood area U; and, in the third position, air A4 exiting the heater core 140 is directed to both the passenger cabin C and outside of the HVAC system 110, such as the underhood area U. Preferably, the cooling door 134 will have many positions in between fully open and fully closed to enable a precise control of air temperature entering the passenger cabin C. Therefore, preferred embodiments are capable of supplementing the cooling of the engine 124 by using the heater core 140 on demand at all operating conditions regardless of whether the cabin heating is turned on or off. A blower 16 for the heater core 140 is provided to direct airflow across the heater core 140, and this heated air A4 is vented outside of the HVAC system 110 and outside of the passenger cabin C to the underhood area U if the passenger does not desire cabin C heating. Such a configuration enables the heater core 140 to have airflow across it on demand and draw heat from the engine 124 even when the passenger cabin C heating is turned off. In preferred embodiments, the cooling door 134 is activated automatically by an engine control unit ("ECU" or powertrain control module "PCM") depending on any parameter in the engine such as coolant fluid 119 temperature or engine oil temperature, for example. The invention is not intended to be limited to any specific metric for evaluating engine temperature. It will be understood that different car OEMs might want to set different trigger or threshold points to activate the cooling door depending on what other fuel economy strategies may be employed by the particular vehicle design.

**[0025]** Referring now also to Figure 7, which schematically illustrates another preferred HVAC airbox 110'. In this embodiment, two blowers 116', 116" are employed. HVAC airbox system 110' can be used with a vehicle V having an engine 124 capable of producing heat, a radiator 112 and fan capable of directing air past the radiator 112 (see engine 124 and radiator 112 disclosed herein). HVAC airbox system 110' includes a heater core 40' fluidly connected to the engine 124 and at least one of the two blowers 116' 116" (see also, Fig. 1 and the discussion thereof). One blower 116" directs air to the heater core 140' via a first passageway 150' and the second blower 116' directs air to the AC evaporator 120'

via a second passageway 152'. Blower door 136' is configured to selectively allow blowers 116', 116" to intake either fresh air 42a from outside of the vehicle V or re-circulated air 42b from inside the passenger cabin C. Cabin vent doors 132a', 132b' are employed to direct air A4 into the passenger cabin C and cooling door 134' is configured to direct air toward the passenger cabin C, outside of the passenger cabin C and outside of the HVAC system 110' to the underhood area U of the vehicle V, for example, or to both areas as also disclosed with respect to Figs. 1 and 3-6. As before, the cooling door 134' preferably is pivotal and has at least three positions, wherein, in the first position, air A4 exiting the heater core 140' is directed to the passenger cabin C; in the second position, air A4 exiting the heater core 140' is directed outside of the passenger cabin C and outside of the HVAC system 110' to the underhood area U; and, in the third position, air A4 exiting the heater core 140' is directed to both the passenger cabin C and outside of the HVAC system 110' to the underhood area U, for example. It will be understood that the air can be directed to many areas outside of the HVAC system 110'. Preferably, the cooling door 134' will have many positions in between fully open and fully closed to enable a more precise control of air temperature entering the passenger cabin C. Such an embodiment may be preferred over the single blower embodiment if a single blower cannot sufficiently deliver enough air to the AC evaporator 120' for cooling the passenger cabin C and enough air to the heater core 140' for cooling the engine 124 at the same time. Advantages of the HVAC airbox system 110' of Fig. 7 potentially include less noise, more control of airflow and more airflow at a higher efficiency as compared to a single blower system such as that illustrated in Figs. 3-6. Disadvantages of the HVAC airbox system 110' of Fig. 7 as compared to the HVAC airbox system 110 of Figs. 3-6 include additional cost, additional space required for the second blower and more power is consumed by two blowers, which may offset some of the fuel economy gains.

**[0026]** Yet another alternate heating, ventilation and air conditioning ("HVAC") airbox system 210 is schematically illustrated in Fig. 9. In previously disclosed embodiments, there are no aspects of the HVAC airbox system that assist to dissipate the heated air once it is vented to the underhood area U. Air in the underhood area U will eventually escape the system through the bottom of the

vehicle V. In alternative embodiments as illustrated in Fig. 9, the HVAC airbox system 210 can include a duct 260 proximate an exit area 262 near the heater core 240 such that hot air A4 exiting the heater core 240 is directed through the duct 260 and to the bottom of the vehicle V, or alternate location, as desired. Such embodiments will help reduce the temperature of the underhood area U, which could lower the temperature of the engine 124. Such embodiments are also beneficial in that they are believed to increase the airflow through the front-end radiator (see, for example, radiator 112 of Fig. 1) by lowering the airflow resistance. Whether this increase in airflow and other benefits of releasing the heated air to the bottom of the vehicle is worth the additional costs is up to the preference of the vehicle manufacturer.

**[0027]** The HVAC airbox system 210 of Figure 9 includes a blower 216 that directs air past an air conditioning ("AC") evaporator 220. From there, a blend door 230 directs the air either through a heater core 240 if heating of the passenger cabin C is desired or directly to the passenger cabin C if no heating is desired. Passenger cabin vent doors 232a, 232b can selectively direct air A1-A3 to various areas of the passenger cabin C, as with previous embodiments. An airbox or passageway 252 for air movement is located between the blower door 236, blower 216, AC evaporator 220, heater core 240 cabin vent doors 232a, 232b and passenger cabin C. Blower door 236 is configured to selectively allow blower 216 to intake either fresh air 42a from outside of the vehicle V or re-circulated air 42b from inside the passenger cabin C. This invention differs from the prior art embodiment illustrated in Fig. 8 in that a cooling door 234 can direct the airflow from the heater core to the underhood when the cabin heating is not required but the supplemental engine cooling is required. This air flow through the heater core 240 can then, if required, be directed via duct 260 toward the bottom of the vehicle V when blend door 230 and cooling door 234 are selectively positioned as illustrated in Fig. 9. It will be understood that duct 260 is not required. The cooling door 234 preferably is pivotal and has at least three positions, wherein, in the first position, air A4 exiting the heater core 240 is directed to the passenger cabin C; in the second position, air A4 exiting the heater core 240 is directed outside of the passenger cabin C and outside of the HVAC system 210 to the underhood area U;

and, in the third position, air A4 exiting the heater core 240 is directed to both the passenger cabin C and outside of the HVAC system 210 to the underhood area U.

**[0028]** The cooling doors and blend/vent doors 130, 132a, 132b, 134, 132a', 132b', 134', 230, 232a, 232b, 234 of the present invention may be of the type used for other vent doors used in known vehicle HVAC airflow systems. For example, the cooling and cabin blend/vent doors 30, 32a, 32b, 34, 32a', 32b', 34' can be of the type commonly used to regulate airflow to the passenger cabin, to regulate passenger cabin/outside air intake and various blend doors to regulate a mix of air from the AC evaporator 120, 120', 220 and heater core 140, 140', 240. It will be understood that there are many ways in which air can be effectively directed and the present invention is not intended to be limited to any specific method or apparatus for directing air.

**[0029]** The recent trend in engine design is toward more powerful engines desired by consumers and better fuel economy driven by oil prices and federal Corporate Average Fuel Economy ("CAFE") requirements. This means that increasingly engines are turbocharged and use many technologies such as exhaust gas recirculation ("EGR") coolers, transmission oil coolers and the like to meet the power and fuel economy goals. Many of these fuel economy improvement technologies generate more heat under the hood and, therefore, require more air flow under the hood to adequately cool the engine. The underhood engineer typically desires to design the vehicle with as open of a front-end as possible to allow lots of airflow to come into the underhood to help meet the engine cooling requirements. The external body designer of the vehicle, on the other hand, typically desires for the vehicle design to be a sleek, aerodynamic shape with very little front-end opening to reduce the drag of the vehicle and make it look visually appealing to potential buyers. Reducing the drag also improves the fuel economy significantly. One of the most significant impacts of the present invention is that less airflow is needed from the front end of the vehicle, which will, in turn, reduce the drag of the vehicle and the fuel consumed by the vehicle. For example, at highway speeds, about 60% of the power required to cruise is used to overcome aerodynamic effects. By minimizing this drag, by reducing airflow requirements

underhood, embodiments of the present invention translate directly into improved fuel economy.

**[0030]** For example, a typical front end radiator needs to remove about 50 kW from a typical passenger car engine when running in normal city driving. The heat that needs to be removed jumps up to about 60 kW when the engine is working hard and towing a trailer. The front end radiator and grill opening are designed for the higher strain scenario. A typical heater core can remove about 10 kW of heat. This means that if the heater core is employed to remove heat to its full potential, then the radiator can be deigned to remove 50 kW (enough heat under most circumstances) and the heater core can remove the remaining 10kW of heat from the engine. The airflow required through the front-end radiator to remove 50 kW of heat rather than 60 kW of heat is almost linearly related to the amount of heat that needs removing. Therefore, about 20% less airflow through the radiator is required in this example, which will lead to fuel economy gains presuming that the vehicle manufacturer designs the front end of the vehicle accordingly to take advantage of the lower airflow requirement.

**[0031]** Preferred methods are disclosed herein and further illustrated in the flow charts of Figs. 10-11. Turning now also to Fig. 10, it is preferably determined if supplemental engine cooling is required 180 by monitoring the desired parameter of the engine 124 such as coolant fluid 119 temperature or engine 124 oil temperature, for example. If supplemental engine cooling is required and the cabin heat is on 181, the cooling door 134, 134', 234 will preferably be partially open 183 so that heated air A4 from the cooling system is vented to both the underhood area U and the passenger cabin C (see also, Fig. 5, for example). If supplemental engine cooling is required but the cabin heat is not on 181, the cooling door 134, 134', 234 will be completely open 184 so that heat from the HVAC airbox system 110, 110', 210 is vented only to the underhood area U (see also, Fig. 3, for example). If supplemental engine cooling is not required 180 and the cabin heat is on 182, the cooling door 134, 134', 234 will be closed 185 so that heated air A4 from the cooling system 110, 110', 210 is directed into the passenger cabin C. If supplemental engine cooling is not required 180 and the cabin heat is off 182, the cooling door 134, 134', 234 and the blend door 230 are closed 186.

**[0032]** Turning also now to Fig. 11, which illustrates a further preferred method of operating the HVAC airbox systems 110, 110', 210 disclosed herein. As illustrated, initially the engine cooling door 134, 134', 234 is closed and engine coolant 119 temperature is measured 191. When supplementary engine cooling is required 190 (e.g. when the radiator 112 cannot sufficiently cool the engine 124), as determined by when the coolant 119 temperature is greater than the predetermined high threshold temperature 192, the cooling door 134, 134', 234 is opened 193 and the blower 116, 116", 216 speed is increased to achieve adequate engine cooling and cabin C heating and/or requirements 194. This mode of operation continues as long as supplemental cooling is required. The cooling door and the blower speed might be adjusted by the ECU to increase the supplemental cooling provided. When the coolant temperature becomes less than a predetermined lower threshold temperature, the engine cooling door is closed 196 and the blower 116, 116', 216 speed is adjusted according to cabin C heating requirements 197. This cycle is repeated 198 as the coolant 119 temperature fluctuates. As will be appreciated, the methods disclosed in Figs. 10-11 can be performed with any metric desired, such as a specific engine oil temperature, and are not limited only to evaluating coolant temperature.

**[0033]** In one example, if the coolant 119 temperature is greater than 220 degrees F, the engine cooling door 134, 134', 234 is opened, and the cooling door 134, 134', 234 is closed when the coolant temperature falls below 220 degrees F. Then the cooling door 134, 134', 234 will reopen when the coolant 119 temperature reaches 221 degrees F and will close as soon as temperature drops to 219 degrees F. This will make the door open and close every few seconds, which is less preferred as it will increase wear and tear on the cooling door 134, 134', 234.

**[0034]** What is more preferred is that the cooling door 134, 134', 234 should be closed when coolant 119 temperature drops below 210 degrees F. (i.e., the cooling door 134, 134', 234 is open when coolant temperature goes above 220 degrees F "higher threshold coolant temperature"), but the door only closes when coolant temperature drops to a lower threshold coolant temperature (e.g. 210 degrees F). It is believed that this method will result in an engine cooling system that is more stable. In preferred embodiments, the difference between the high threshold

temperature and the low threshold temperature is about 2 to about 15 degrees Fahrenheit and the exact temperature gap between low and high threshold can vary depending the size of the engine and the design of the vehicle.

**[0035]** Preferred methods of cooling a combustion engine 124 that is part of a vehicle V having a passenger cabin C and an underhood area U in which the combustion engine 124, 124' is located include the steps of providing a combustion engine 124, 124' capable of generating heat; a radiator 112 fluidly connected to the engine 124, 124', the radiator having a coolant 119. The coolant 119 capable of absorbing heat from the engine 124. The vehicle V further including a HVAC airbox system 110, 110', 210 having a heater core 140, 140', 240 fluidly connected to the engine 124, 124' such that heat absorbed by the coolant 119 can be transferred to the heater core 140, 140', 240. The HVAC airbox system 110, 110', 210 further including at least one blower 116, 116", 216 capable of directing air through the heater core 140, 140', 240. The HVAC airbox system 110, 110', 210 further comprises an AC evaporator 120, 220, wherein air is directed from the blower 116, 216, through the AC evaporator 120, 220 and then to the heater core 140, 240. The method further includes the step of actuating a cooling door 134, 134', 234 such that at least some of the air from exiting the heater core A4 is directed outside of the HVAC system 110, 110', 210 to the underhood area U of the vehicle V. In various methods, at least some of the air A4 exiting the heater core 140, 140', 240 is directed to the passenger cabin C. In further preferred methods, the cooling door 134, 134', 234 is adjustable such that the cooling door 134, 134', 234 can direct the air exiting to the heater core 140, 140', 240 to only the underhood area U, only the passenger cabin C or both the underhood area U and the passenger cabin C. In alternate preferred methods, substantially all of the air A4 exiting the heater core 140, 140', 240 is directed outside of the HVAC system 110, 110', 210 to the underhood area U of the vehicle V. In further preferred methods, the engine cooling system 210 further includes a duct 260 proximate the heater core 240 such that the air A4 passing through the heater core 240 can be directed to the underhood area U and then to the bottom of the vehicle V via the duct 260.

**[0036]** **EXAMPLE 1**

**[0037]** For example, consider a vehicle towing a 3,000 pound trailer driving up a 6% grade on a 110 degrees F day. This scenario describes approximately less than 1% of the car consumer population's driving time, but 100% of vehicles have cooling packs designed around this contingency scenario. This over design of vehicles means that an oversized radiator or cooling pack and fan are incorporated into vehicles leading to higher drag and lower fuel economy for the everyday driver. A recent study concluded that a 10% incremental aerodynamic drag reduction gives a 1.5% improvement in vehicle fuel economy for mid-sized vehicles and 3% improvement in trucks. It is believed that the disclosed invention is a more elegant solution, which would allow for the extreme driving condition scenario mentioned above by leveraging the heater core, while downsizing the cooling pack thus increasing fuel economy and reducing costs for the OEM as well as their customers who do the driving. The disclosed embodiments preferably include an additional vent door in the HVAC airbox in conjunction with the heater core to make better use of existing vehicle components to optimize efficiency.

**[0038]** In most vehicles, the heater core is capable of removing approximately 5% - 20% of the total engine waste heat because the heater core is a heat exchanger that is already plumbed into the engine with constant ample coolant flow. The heater core could be used to supplement engine cooling, on-demand, so that the front-end cooling pack can be optimized for regular driving, which would improve fuel economy. The trouble is, when it is hot outside and the engine needs extra cooling, the driver is presumably also hot, and is unlikely to turn on the heater. This situation is where the disclosed embodiments are particularly useful. In the disclosed embodiments, the HVAC airbox is modified by adding a vent door, called the "cooling door", near the heater core. This cooling door vents hot air from the heater core back out of the passenger cabin so the passenger cabin comfort would not be affected (see also, Figure 10).

**[0039]** During extreme operating conditions and when the driver of the vehicle has the air conditioning ("AC") on, the blend door allows some air to go to the heater core while maintaining the cool airflow to the passenger cabin. Figure 3 shows positioning of the blend door and cooling door in such a scenario. This diverted airflow passes through the heater core to provide supplemental engine

cooling. The amount of airflow through the heater core will determine the amount of supplemental engine cooling that the heater core will provide. The blower will typically need to be operated at a slightly higher speed to deliver enough airflow to the passenger cabin and to the heater core. The cooling door position and the blower speed are preferably controlled automatically by the ECU depending on the engine cooling and cabin comfort requirements.

**[0040]** When passenger cabin heating is also desired in addition to supplemental engine cooling, the engine cooling door would be positioned such that some of the hot air from the heater core is sent into the passenger cabin and the remaining hot air is vented into the underhood providing both passenger cabin heating and supplemental engine cooling. When supplemental engine cooling is not desired, the engine cooling door would remain closed (see, for example, Figure 4).

**[0041]** The efficacy of this design was computationally evaluated using a commercial CAE tool (Flowmaster, version 7.9.1, developed by Mentor Graphics, Wilsonville, Oregon). A specific operating scenario is shown in Figure 12. Figure 12 shows that when 150 cubic feet per minute (CFM) of airflow at 110 degrees F was sent through the heater core, the heater core provided 5.5kW of heat removal.

**[0042]** With the heater core providing 5.5 kW of supplemental cooling to the engine, the required front end airflow for the vehicle dropped from 2430 CFM to 2200 CFM, as shown in Figure 13. This reduction in airflow corresponded to a smaller fan. Specifically, the fan was downsized from a 650 W fan to a 400W fan. This translated to a 0.4 mpg fuel economy benefit for this specific passenger car.

**[0043]** One would notice that sending 150 CFM through the heater core reduced the front-end required airflow by 230 CFM. This is a scaling effect. This scaling effect is due to higher effectiveness of the heater core as compared to the radiator or cooling pack at their corresponding operating points. The effectiveness of the heater core and the radiator or cooling pack, at their corresponding operating points are provided in Tables 1 and 2, respectively, and the operating points are marked in the respective tables with an asterisk.

**[0044] Table 1: Heater Core Effectiveness**

| Heater core airflow | Heater core heat removal | Heater Core Effectiveness |
|---|---|---|
| CFM | kW | |
| 0 | 0.00 | 92% |
| 30 | 1.10 | 92% |
| 60 | 2.19 | 92% |
| 90 | 3.29 | 92% |
| 120 | 4.39 | 92% |
| 150* | 5.50 | 92% |
| 180 | 6.27 | 87% |
| 210 | 7.34 | 87% |
| 240 | 7.96 | 83% |
| 270 | 8.96 | 83% |

**[0045] Table 2: Radiator Effectiveness**

| Radiator airflow | Radiator Heat Removal | Radiator Effectiveness |
|---|---|---|
| CFM | kW | |
| 2000 | 63.12 | 90% |
| 2100 | 65.68 | 89% |
| 2200 | 68.17 | 88% |
| 2300 | 70.59 | 87% |
| 2400 | 72.96 | 86% |
| 2430* | 73.65 | 86% |
| 2500 | 75.26 | 85% |
| 2600 | 77.51 | 84% |
| 2700 | 79.73 | 84% |
| 2800 | 81.87 | 83% |
| 2900 | 83.97 | 82% |

**[0046]** The key benefit of the disclosed embodiments is that the cooling capacity of the engine has been increased leading to an increased trailer tow capacity or a reduced size of the cooling fan. If the front-end cooling module size and architecture were fixed for, perhaps, legacy reasons, then adding this technology

would give the vehicle a higher trailer-tow rating as the engine cooling capability has been increased. In addition, this technology enhances the operation and benefits of other fuel-saving technologies such as Automatic Grill Shutters and Exhaust Gas Recirculation by enabling them to operate closer to their optimum efficiency points.

**[0047]** It is believed that the disclosed embodiments scale well for larger vehicles such as a minivan or sports utility vehicles ("SUVs") that have front and rear heater cores. Larger vehicles have front and rear heaters to supplement the engine cooling. The engine cooling door in the HVAC air box offers on-demand supplemental engine cooling; that is, airflow through the heater core is independent of the passenger heat and blower settings.

**[0048]** Although the preferred embodiments of the present invention have been described herein, the above description is merely illustrative. Further modification of the invention herein disclosed will occur to those skilled in the respective arts and all such modifications are deemed to be within the scope of the invention as defined by the appended claims.

What is claimed is:

1. A heating, ventilation and air conditioning ("HVAC") airbox system, which is part of a vehicle having an engine capable of generating heat, a radiator having a coolant, the coolant capable of absorbing heat from the engine, the vehicle further having a passenger cabin and an underhood area, the HVAC airbox system comprising:

an air conditioner ("AC") evaporator;

a heater core fluidly connected to the engine such that heat absorbed by the coolant can be transferred to the heater core;

at least one blower capable of directing air through the heater core; and

a cooling door; wherein the cooling door can selectively be positioned such that at least some of the air moving through the heater core is directed both outside of the HVAC airbox system and outside of the passenger cabin.

2. The HVAC airbox system of claim 1, wherein the cooling door has at least three positions, wherein, in the first position, air exiting the heater core is directed to the passenger cabin; in the second position, air exiting the heater core is directed both outside of the HVAC airbox system and outside of the passenger cabin; and, in the third position, air exiting the heater core is directed to both the passenger cabin and the underhood area.

3. The HVAC airbox system of claim 1, wherein the system includes at least two blowers, wherein one blower directs air to the heater core and the second blower directs air to the AC evaporator.

4. The HVAC airbox system of claim 1, wherein substantially all of the air exiting the heater core is directed to the underhood area.

5. The HVAC airbox system of claim 1, wherein the cooling door can pivot.

6. The HVAC airbox system of claim 1, further comprising a duct proximate the heater core such that the air passing through the heater core can be directed to the underhood area and to the bottom of the vehicle via the duct.

7. A heating, ventilation and air conditioning ("HVAC") airbox system, which is part of a vehicle having an engine capable of generating heat, a radiator having a coolant, the coolant capable of absorbing heat from the engine, the vehicle further having a passenger cabin and an underhood area, the HVAC airbox system comprising: a heater core fluidly connected to the engine such that heat absorbed by the coolant can be transferred to the heater core;

an air conditioner ("AC") evaporator;

at least one blower capable of directing air through the heater core; and

a cooling door proximate the heater core; wherein the cooling door has at least three positions, wherein, in the first position, air exiting the heater core is directed to the passenger cabin; in the second position, air exiting the heater core is directed both outside of the HVAC airbox system and outside of the passenger cabin; and, in the third position, air exiting the heater core is directed to both the passenger cabin and outside of the passenger cabin.

8. The HVAC airbox of claim 7, wherein the system includes at least two blowers, wherein one blower directs air to the heater core and the second blower directs air to the AC evaporator

9. The HVAC airbox of claim 7, wherein substantially all of the air exiting the heater core is directed to the underhood area.

10. The HVAC airbox of claim 7, wherein the cooling door can pivot.

11. A method of cooling an engine that is part of a vehicle having a passenger cabin and an underhood area in which the engine is located; the method comprising the steps of:

providing an engine capable of generating heat; a heating, ventilation and air conditioning ("HVAC") airbox system including a radiator having a coolant, the coolant capable of absorbing heat from the engine; an air conditioning ("AC") evaporator; a heater core fluidly connected to the engine such that heat absorbed by the coolant can be transferred to the heater core; at least one blower capable of directing air through the heater core; and

actuating a cooling door such that at least some of the air exiting the heater core is directed to the underhood area.

12. The method of claim 11, wherein at least some of the air exiting the heater core is directed to the passenger cabin.

13. The method of claim 11, , wherein the cooling door is adjustable such that the cooling door can direct the air exiting to the heater core to the passenger cabin, the underhood area, or both the passenger cabin and the underhood area.

.

14. The method of claim 11, wherein substantially all of the air exiting the heater core is directed to the underhood area.

15. The method of claim 11, wherein air is directed from the blower, through the AC evaporator and then to the heater core.

16. The method of claim 11, wherein the HVAC airbox system further includes a duct proximate the heater core such that the air passing through the heater core can be directed to the underhood area and then to the bottom of the vehicle via the duct.

17. The method of claim 11, wherein the HVAC airbox system is configured to have a high threshold temperature; wherein the cooling door opens such that air is directed to the underhood area when the coolant temperature reaches the high threshold temperature.

18. The method of claim 17, wherein the HVAC airbox system is configured to have a low threshold temperature; wherein the cooling door closes such that air is not directed to the underhood area when the coolant temperature reaches the low threshold temperature.

19. The method of claim 18, wherein the difference between the high threshold temperature and the low threshold temperature is about 2 to about 15 degrees Fahrenheit.

20. The method of claim 18, further comprising the step of providing supplemental engine cooling on demand using the heater core regardless of the passenger cabin heating and cooling requirements.

21. A heating, ventilation and air conditioning ("HVAC") airbox system, which is part of a vehicle having an engine capable of generating heat, a radiator having a coolant, the coolant capable of absorbing heat from the engine, the vehicle further having a passenger cabin and an underhood area, the HVAC airbox system comprising:

an air conditioner ("AC") evaporator;

a heater core fluidly connected to the engine such that heat absorbed by the coolant can be transferred to the heater core;

at least one blower capable of directing air through the heater core; and

a cooling door, which is optionally pivotable; wherein the cooling door can selectively be positioned such that the air moving through the heater core is directed both outside the HVAC airbox system and outside of the passenger cabin.

22. The HVAC airbox system according to claim 21, wherein the cooling door is proximate the heater core.

23. The HVAC airbox system according to claim 21 or 22, wherein the cooling door has at least three positions, wherein, in the first position, air exiting the heater

core is directed to the passenger cabin; in the second position, air exiting the heater core is directed to the underhood area; and, in the third position, air exiting the heater core is directed to both the passenger cabin and the underhood area.

24. The HVAC airbox system according to any one of claims 21 to 23, wherein the system includes at least two blowers, wherein one blower directs air to the heater core and the second blower directs air to the AC evaporator.

25. The HVAC airbox system according to any one of claims 21 to 24, wherein substantially all of the air exiting the heater core is directed to the underhood area.

26. The HVAC airbox system according to any one of claims 21 to 25, further comprising a duct proximate the heater core such that the air passing through the heater core can be directed to the underhood area and to the bottom of the vehicle via the duct.

27. A method of cooling an engine that is part of a vehicle having a passenger cabin and an underhood area in which the engine is located; the method comprising the steps of:

providing an engine capable of generating heat; a heating, ventilation and air conditioning ("HVAC") airbox system including a radiator having a coolant, the coolant capable of absorbing heat from the engine; an air conditioner ("AC") evaporator; a heater core fluidly connected to the engine such that heat absorbed by the coolant can be transferred to the heater core; at least one blower capable of directing air through the heater core; and

actuating a cooling door such that at least some of the air from exiting the heater core is directed to the underhood area.

28. The method according to claim 27, wherein the cooling door is adjustable such that the cooling door can direct the air exiting to the heater core to only the underhood area, or both the underhood area and the passenger cabin.

29. The method according to claim 27 or 28, wherein air is directed from the blower, through the AC evaporator and then to the heater core.

30. The method according to any one of claims 27 to 29, further providing a duct proximate the heater core such that the air passing through the heater core is directed to the underhood area and then to the bottom of the vehicle via the duct.

31. The method according to any one of claims 27 to 30, further defining a high threshold temperature; wherein the cooling door opens such that air is directed to the underhood area when the coolant temperature reaches the high threshold temperature.

32. The method according to claim 31, further defining a low threshold temperature; wherein the cooling door closes such that air is not directed to the underhood area when the coolant temperature reaches the low threshold temperature.

33. The method according to claim 32, wherein the difference between the high threshold temperature and the low threshold temperature is about 2 to about 15 degrees Fahrenheit, further optionally comprising the step of providing supplemental engine cooling on demand using the heater core regardless of the passenger cabin heating and cooling requirements.

34. The method according to any one of claims 27 to 33, wherein at least some of the air exiting the heater core is directed to the passenger cabin.

35. The method according to any one of claims 27 to 33, wherein substantially all of the air exiting the heater core is directed to the underhood area.

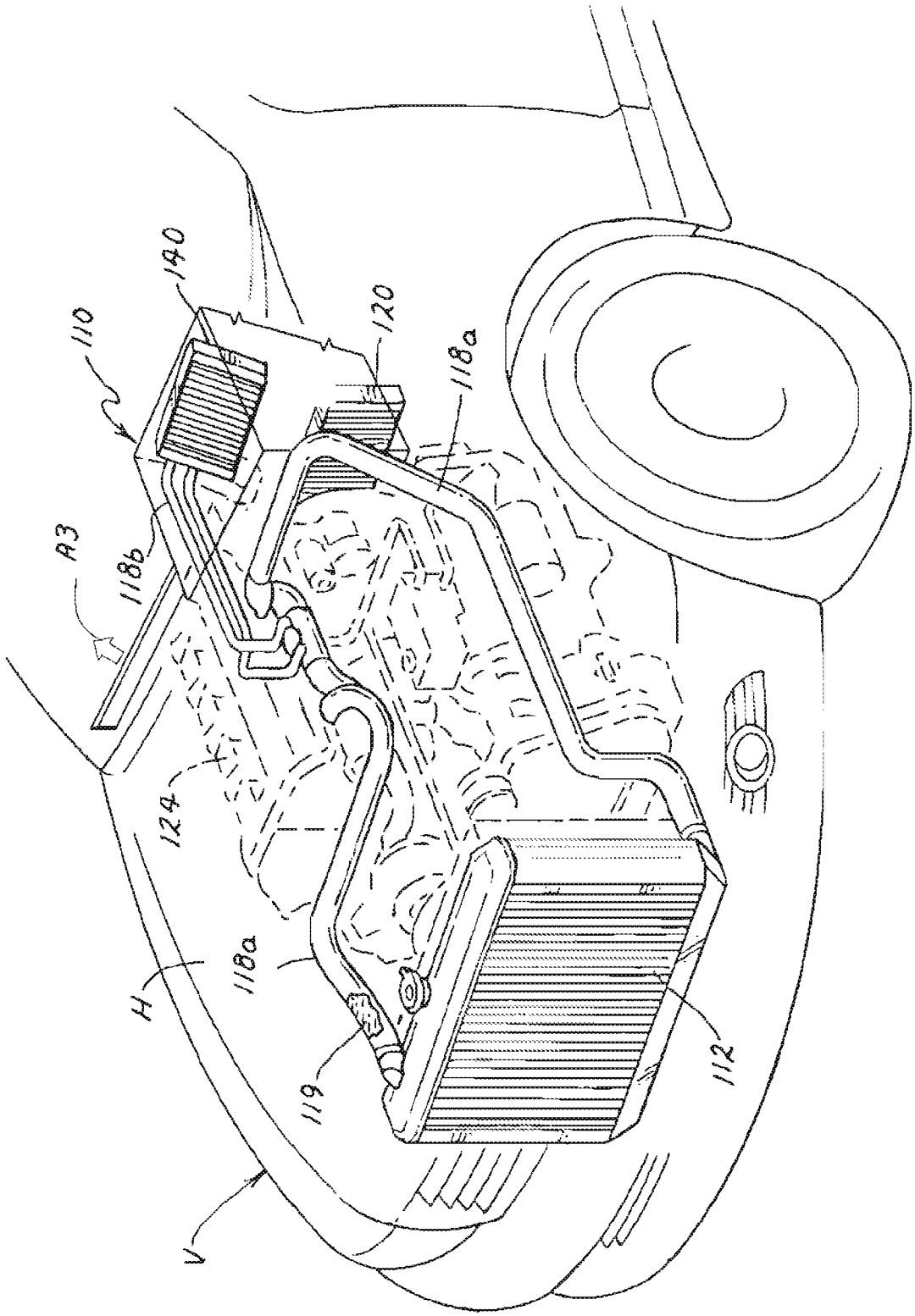



FIG. 1

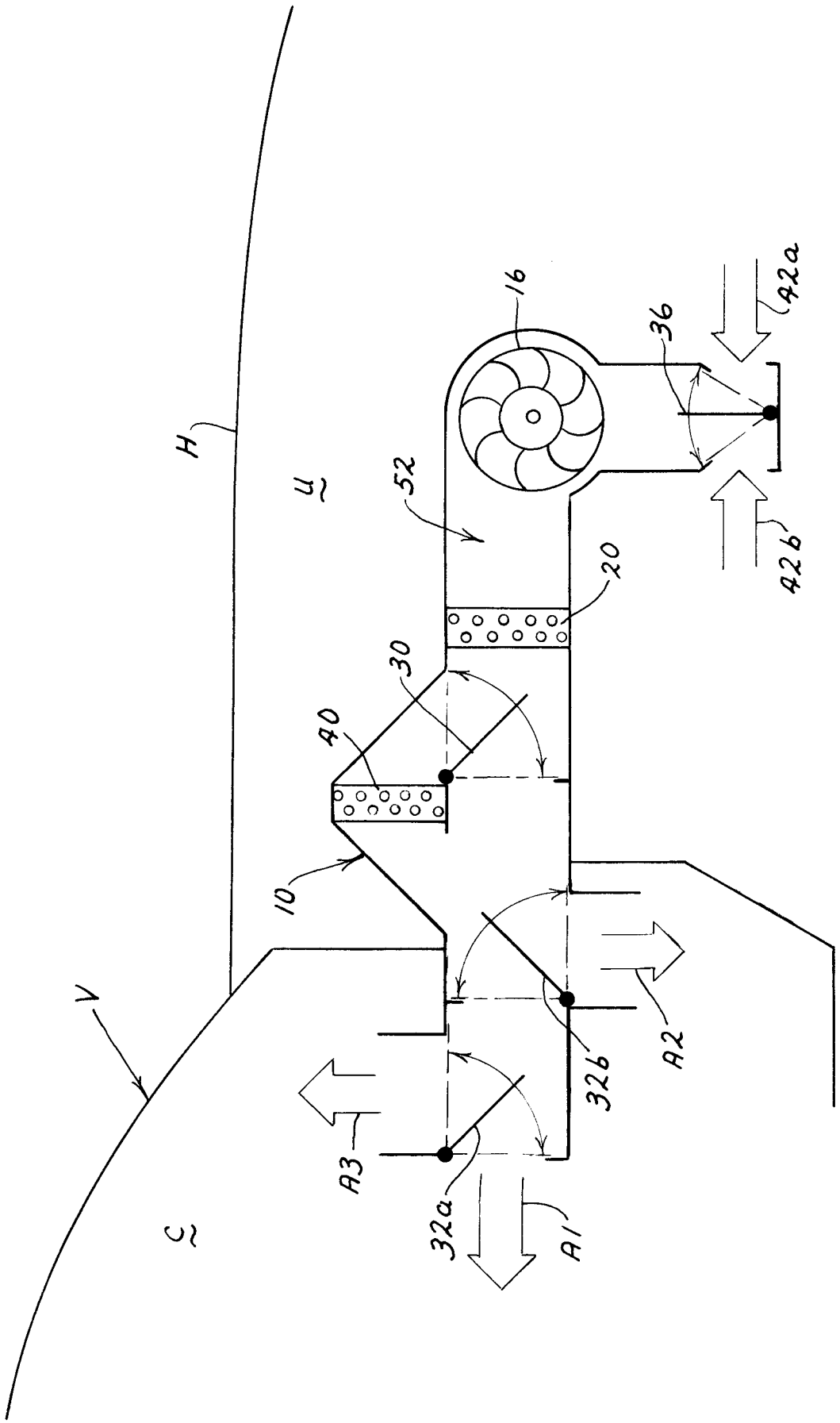



FIG. 2
PRIOR ART

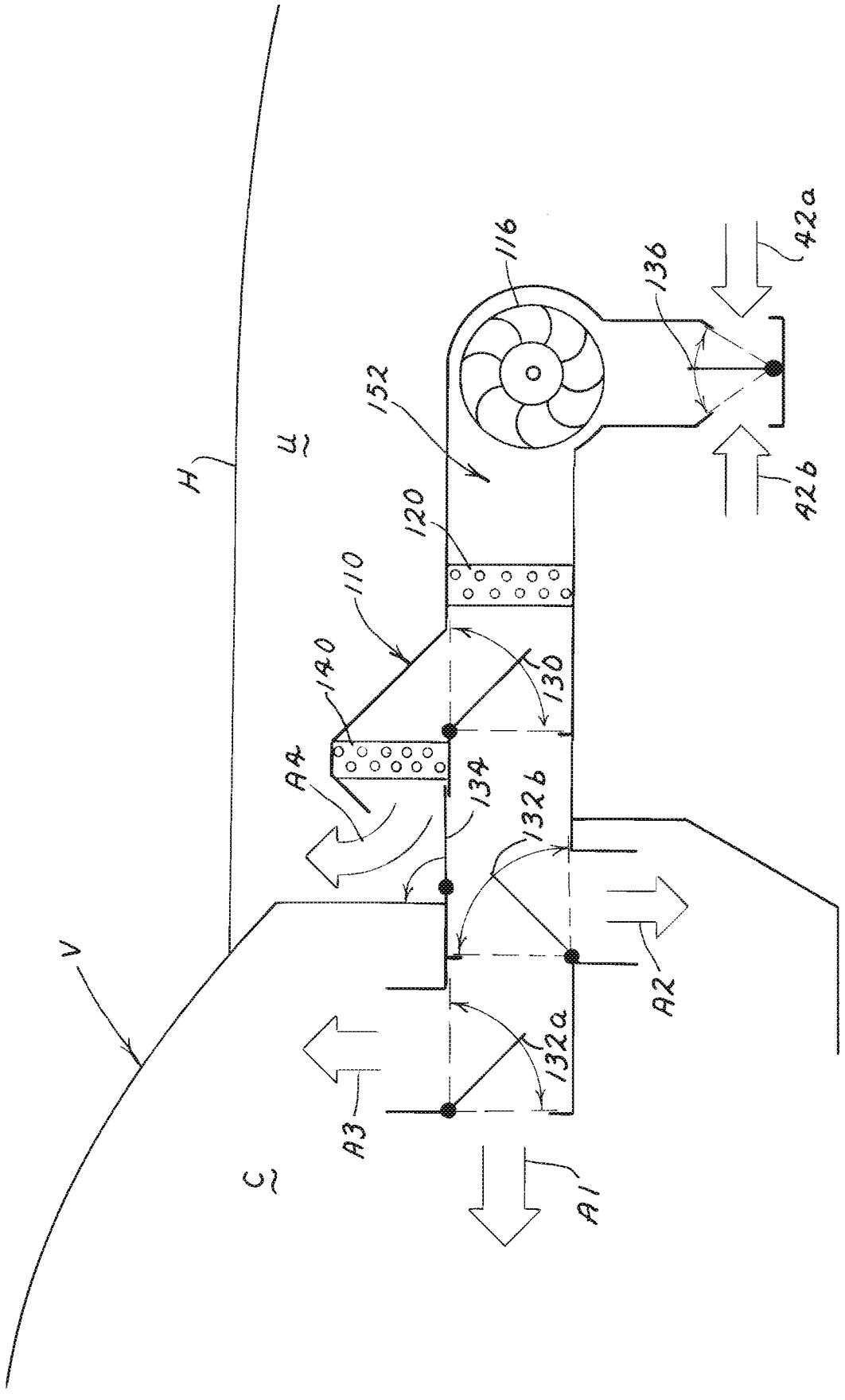
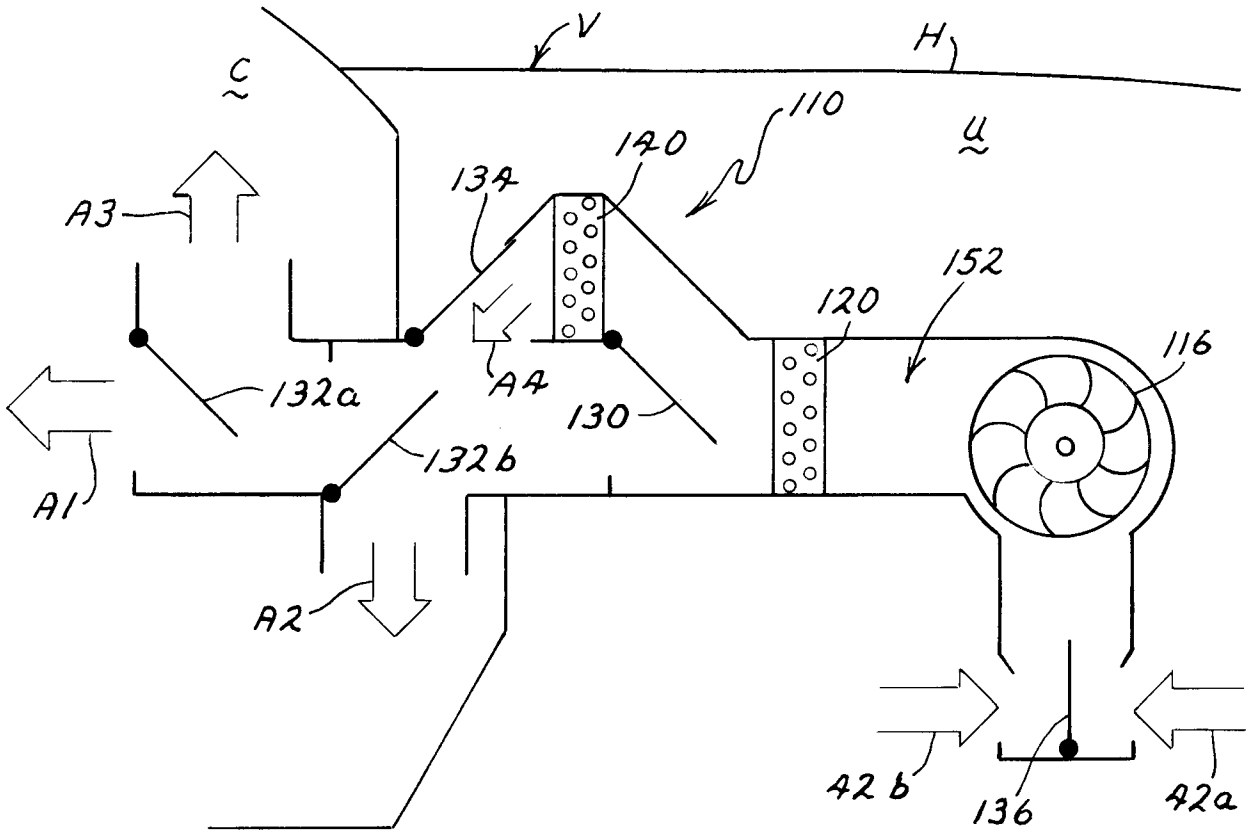

H
U
V
C
116
136
42a
42b
152
120
110
140
130
A4
134
132b
132a
A2
A3
A1

FIG. 3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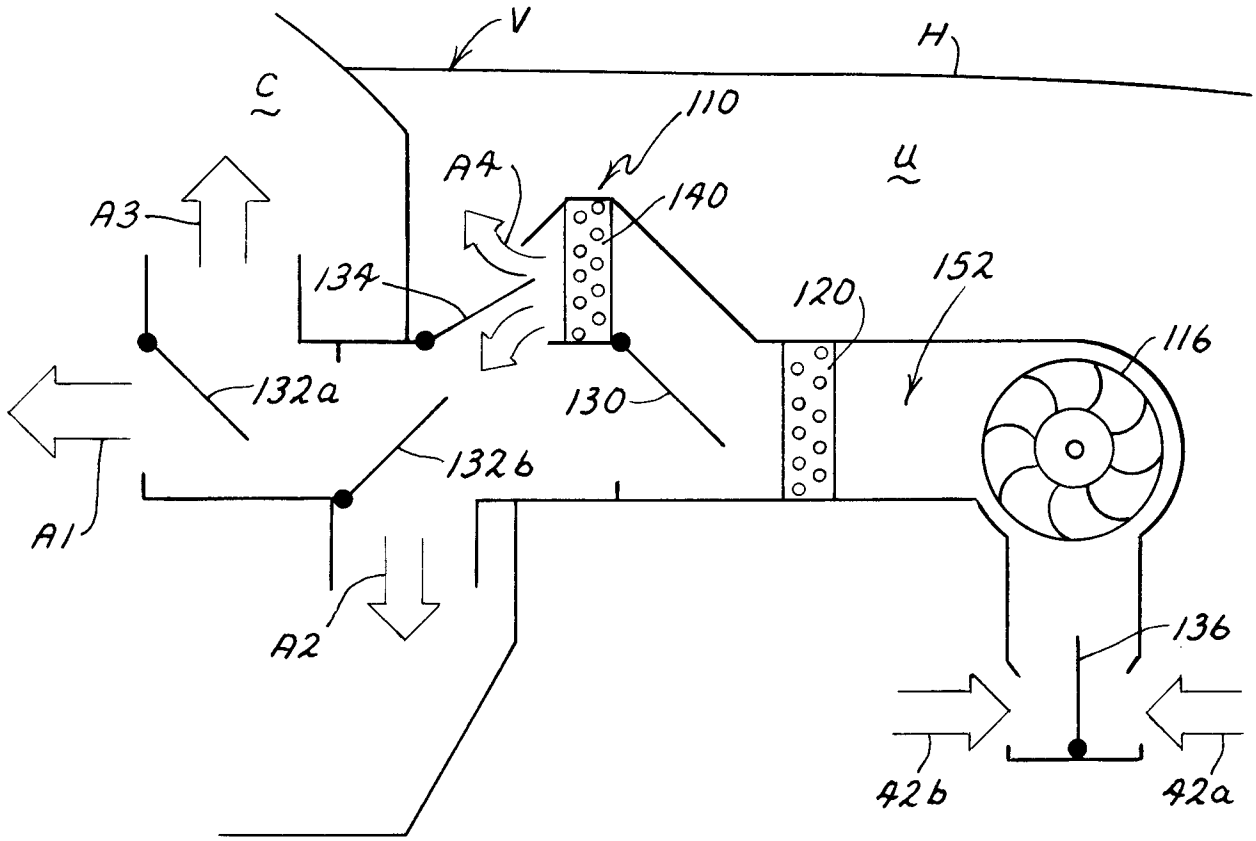
42a

FIG. 4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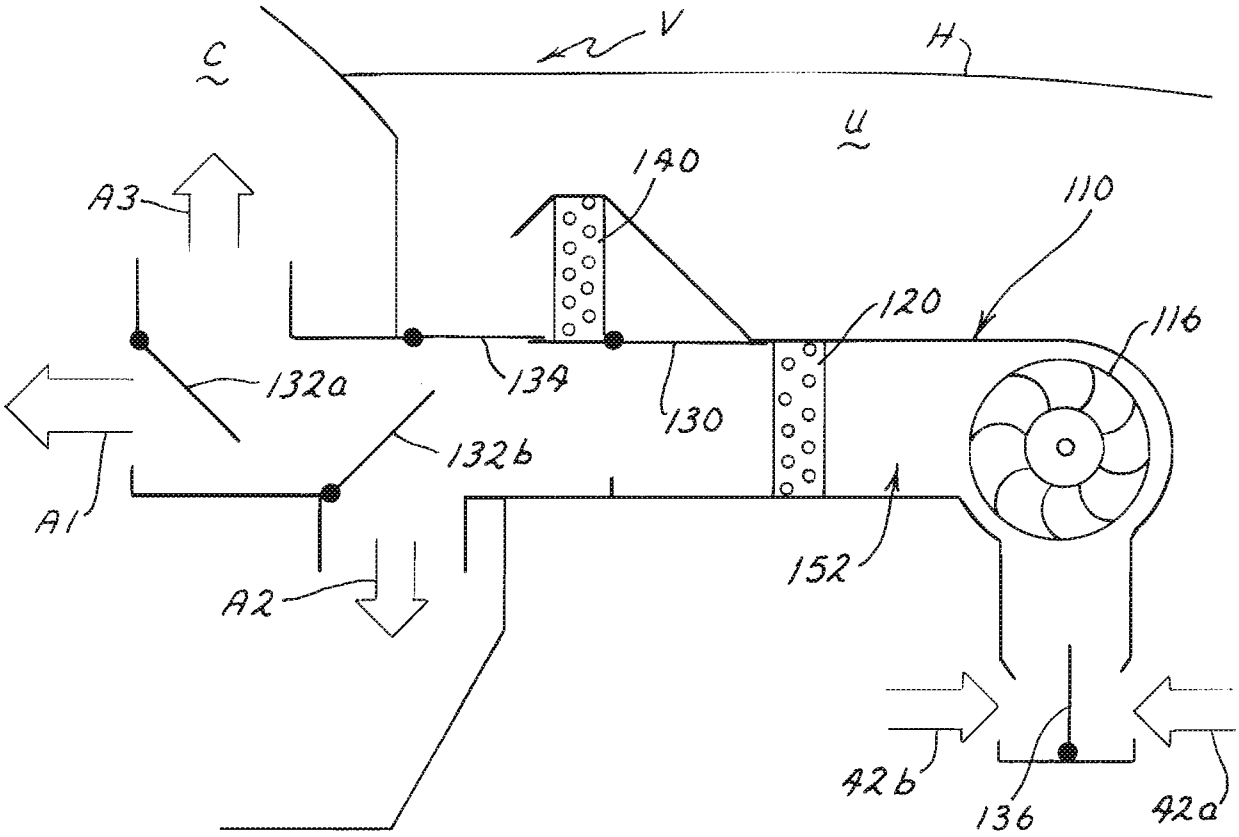
42b
42a

FIG. 5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130
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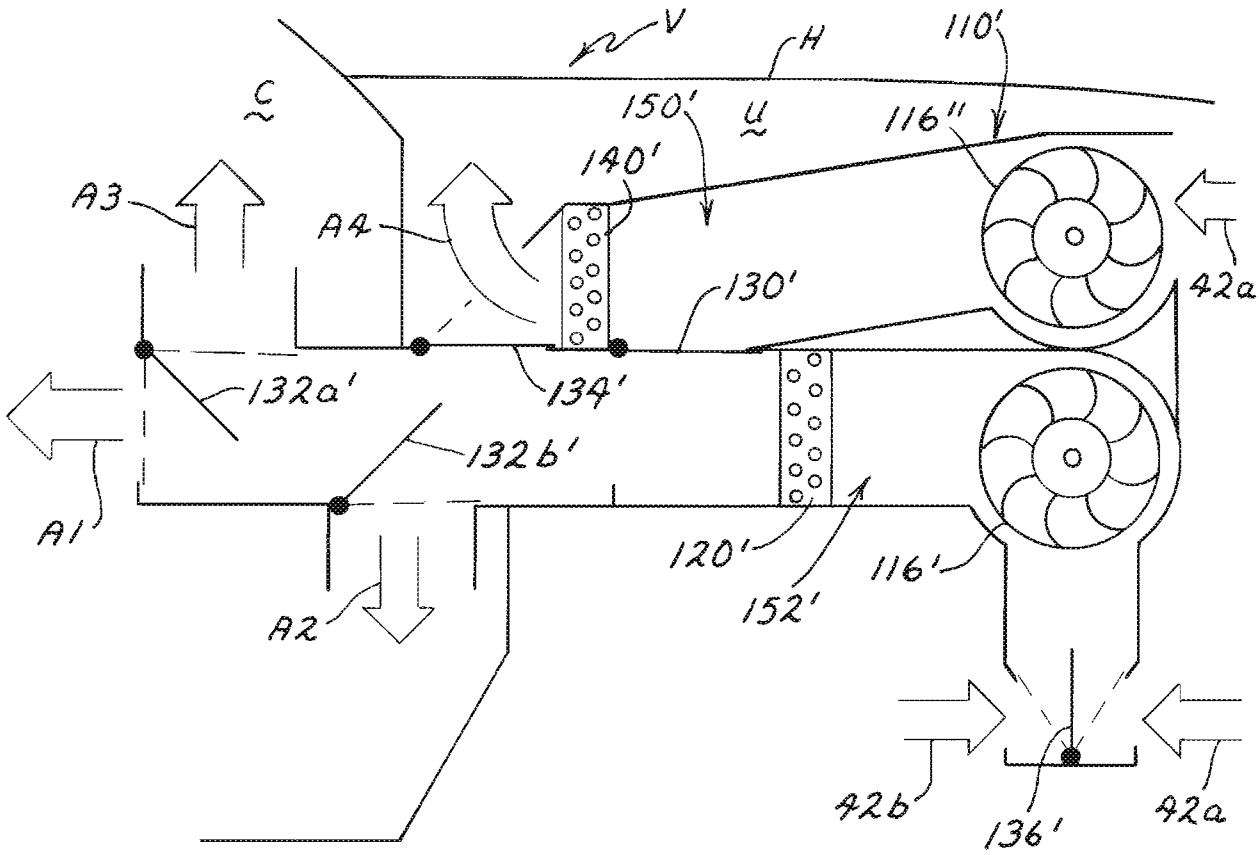
136
42a

FIG. 6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H
110'
C
150'
U
116''
140'
A3
A4
42a
130'
132a'
134'
132b'
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116'
152'
A2
42b
136'
42a

FIG. 7

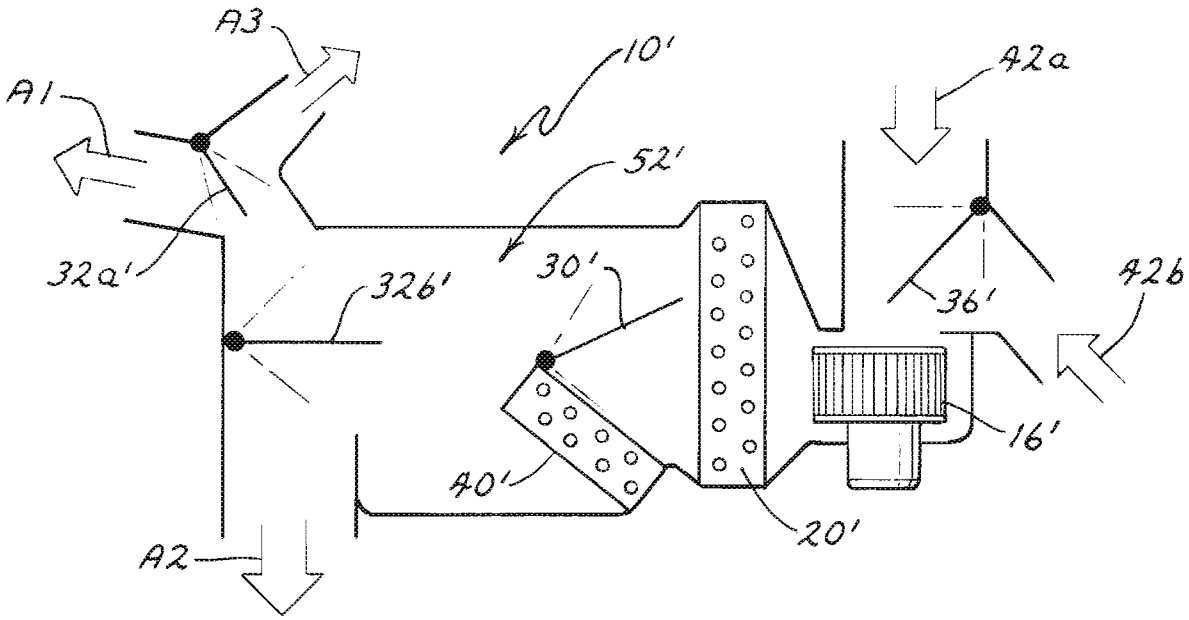


FIG. 8
PRIOR ART

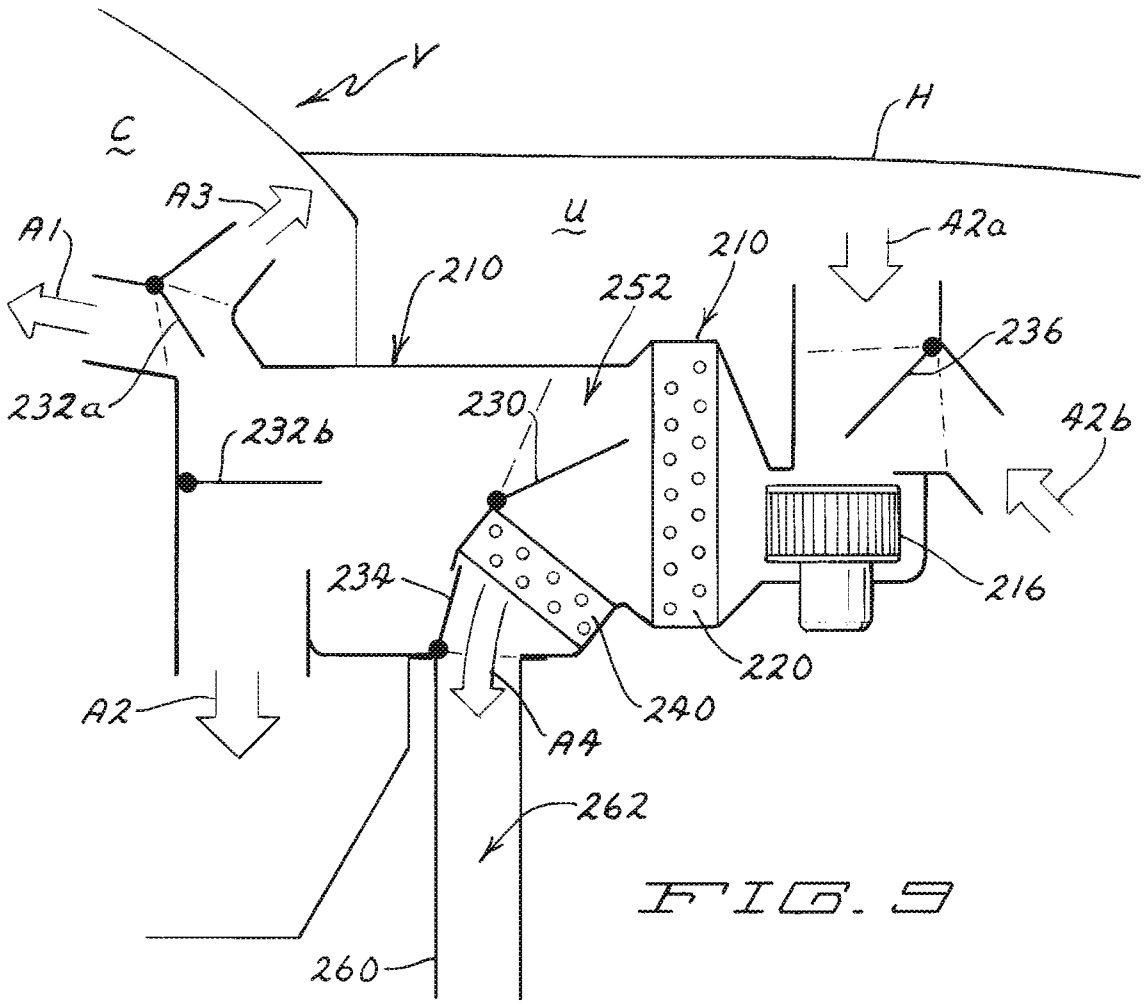


FIG. 9

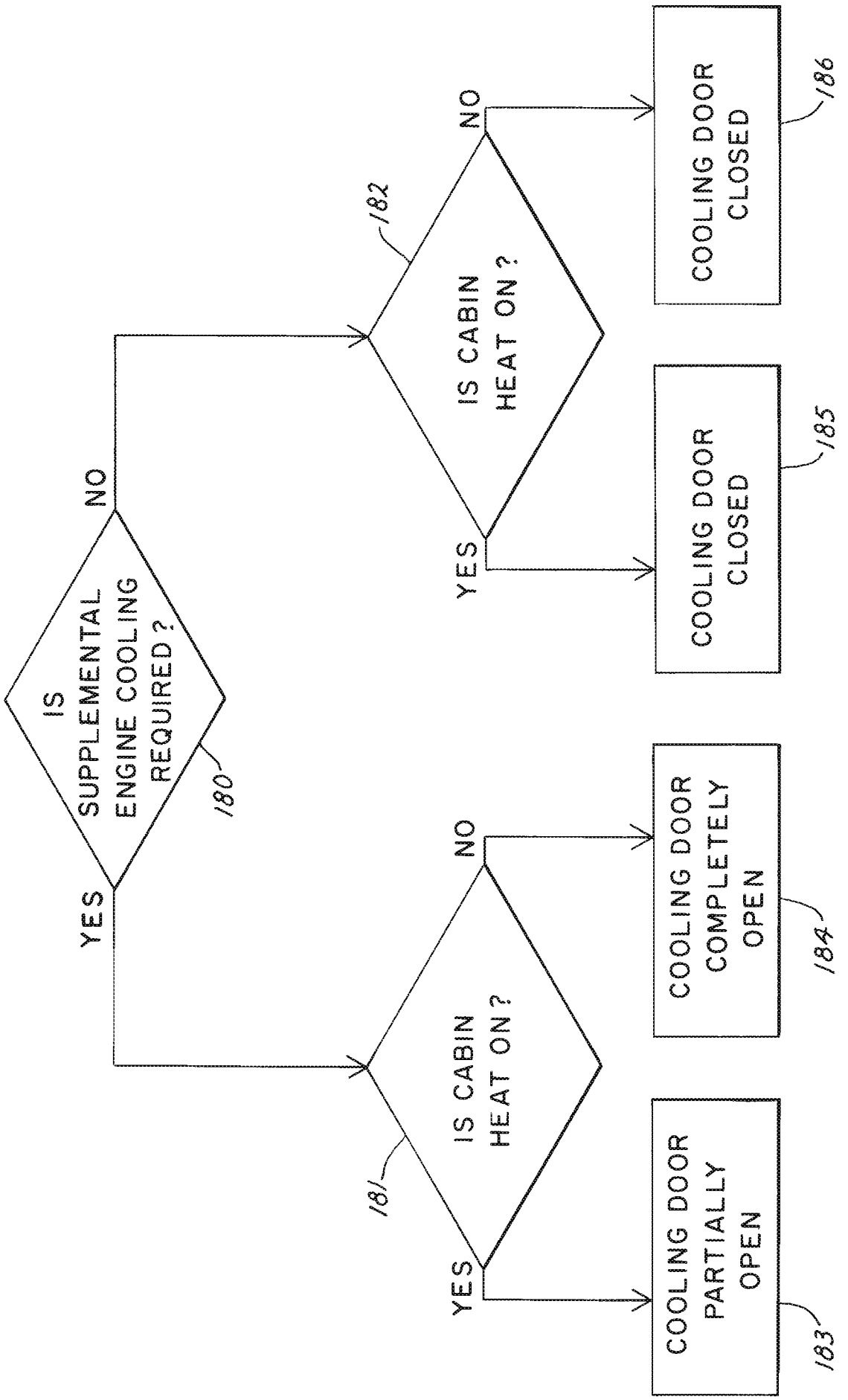
IS SUPPLEMENTAL ENGINE COOLING REQUIRED ?
180
NO
YES
IS CABIN HEAT ON ?
182
NO
YES
COOLING DOOR CLOSED
186
COOLING DOOR CLOSED
185
IS CABIN HEAT ON ?
181
NO
YES
COOLING DOOR COMPLETELY OPEN
184
COOLING DOOR PARTIALLY OPEN
183

FIG. 10

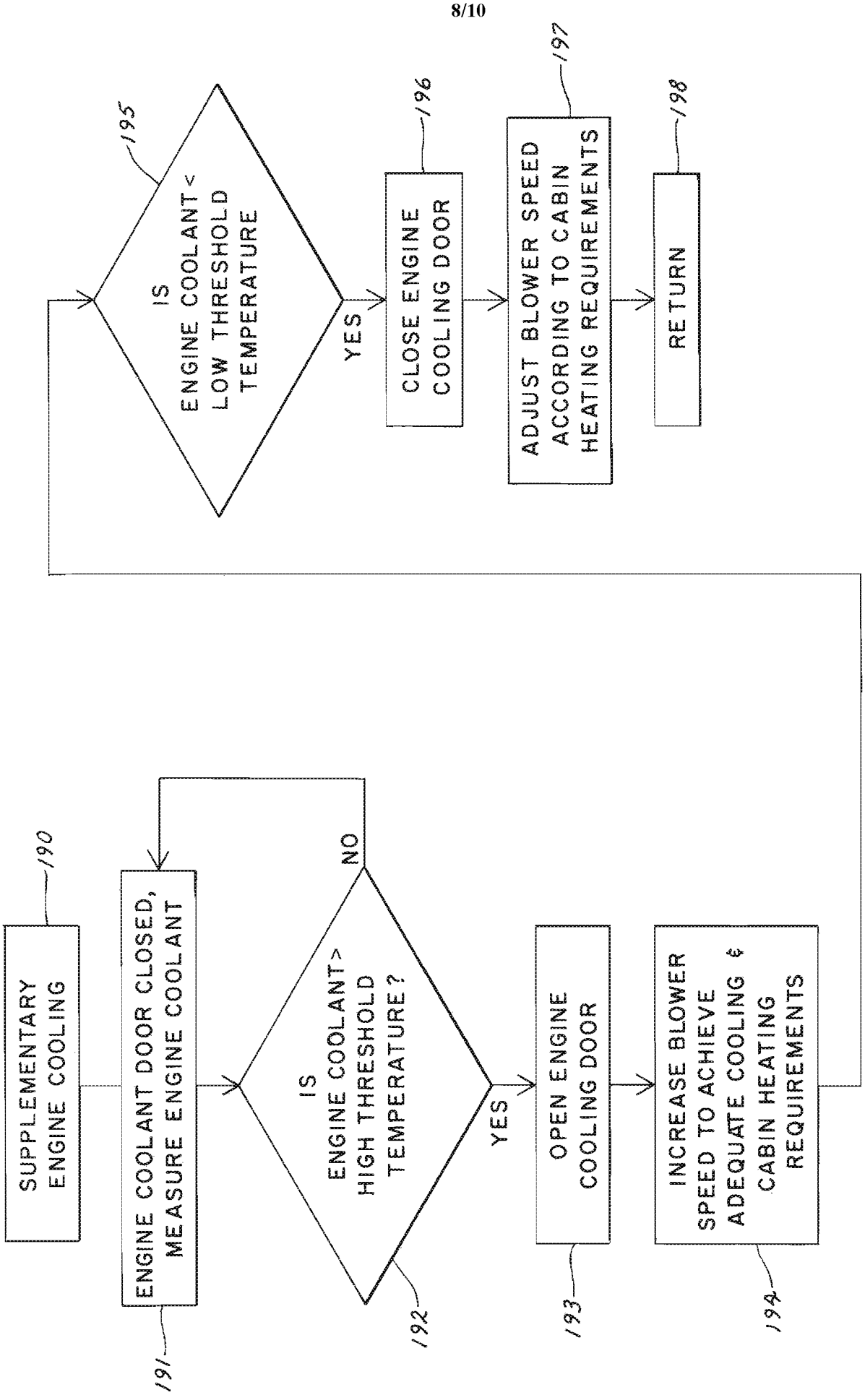
SUPPLEMENTARY ENGINE COOLING
190
ENGINE COOLANT DOOR CLOSED, MEASURE ENGINE COOLANT
191
IS ENGINE COOLANT > HIGH THRESHOLD TEMPERATURE?
192
NO
YES
OPEN ENGINE COOLING DOOR
193
INCREASE BLOWER SPEED TO ACHIEVE ADEQUATE COOLING & CABIN HEATING REQUIREMENTS
194
IS ENGINE COOLANT < LOW THRESHOLD TEMPERATURE
195
YES
CLOSE ENGINE COOLING DOOR
196
ADJUST BLOWER SPEED ACCORDING TO CABIN HEATING REQUIREMENTS
197
RETURN
198

FIG. 11

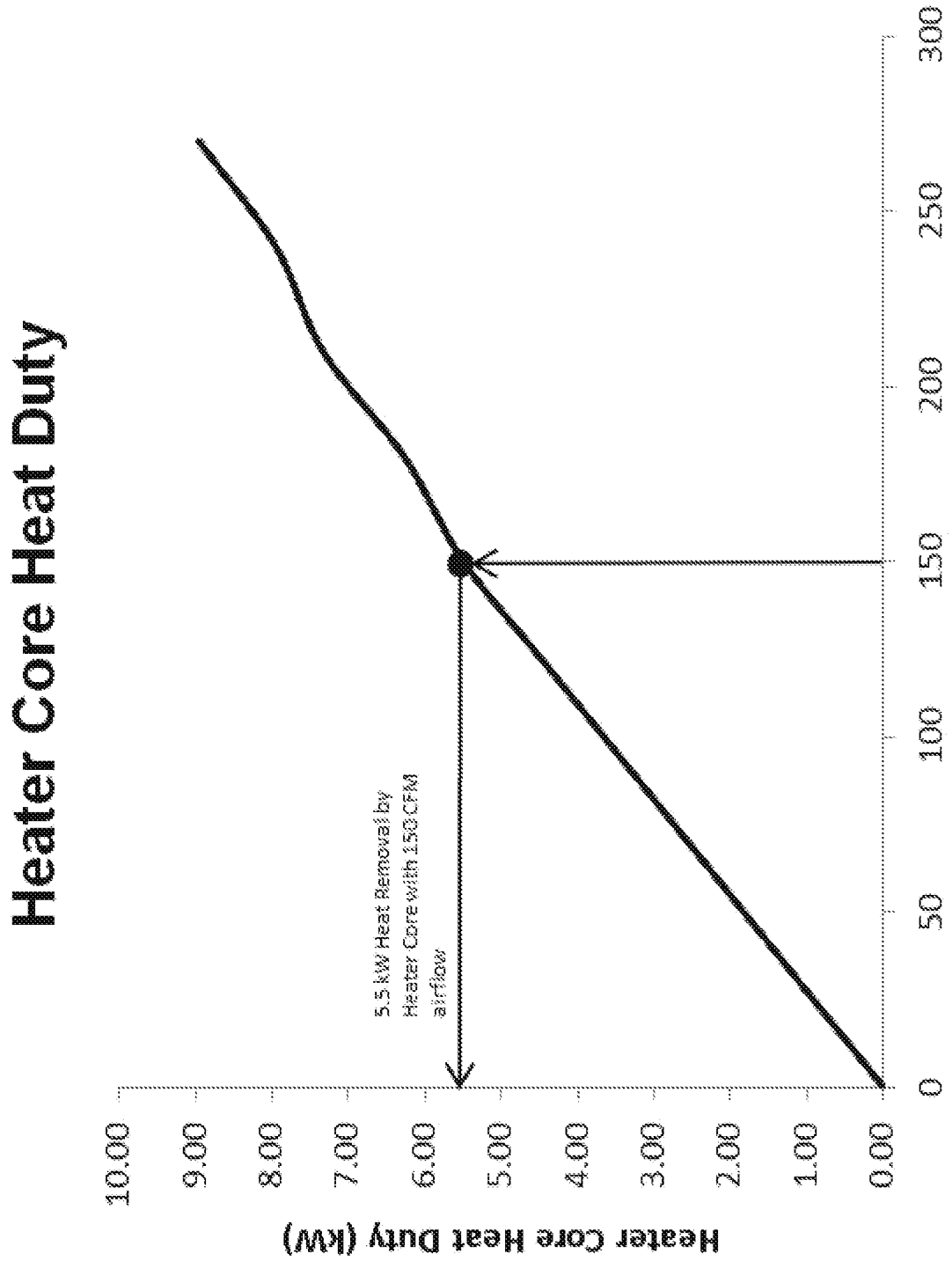
Heater Core Heat Duty
Heater Core Heat Duty (kW)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
50
100
150
200
250
300
Airflow Through Heater Core (CFM)
5.5 kW Heat Removal by
Heater Core with 150 CFM
airflow

FIG. 12

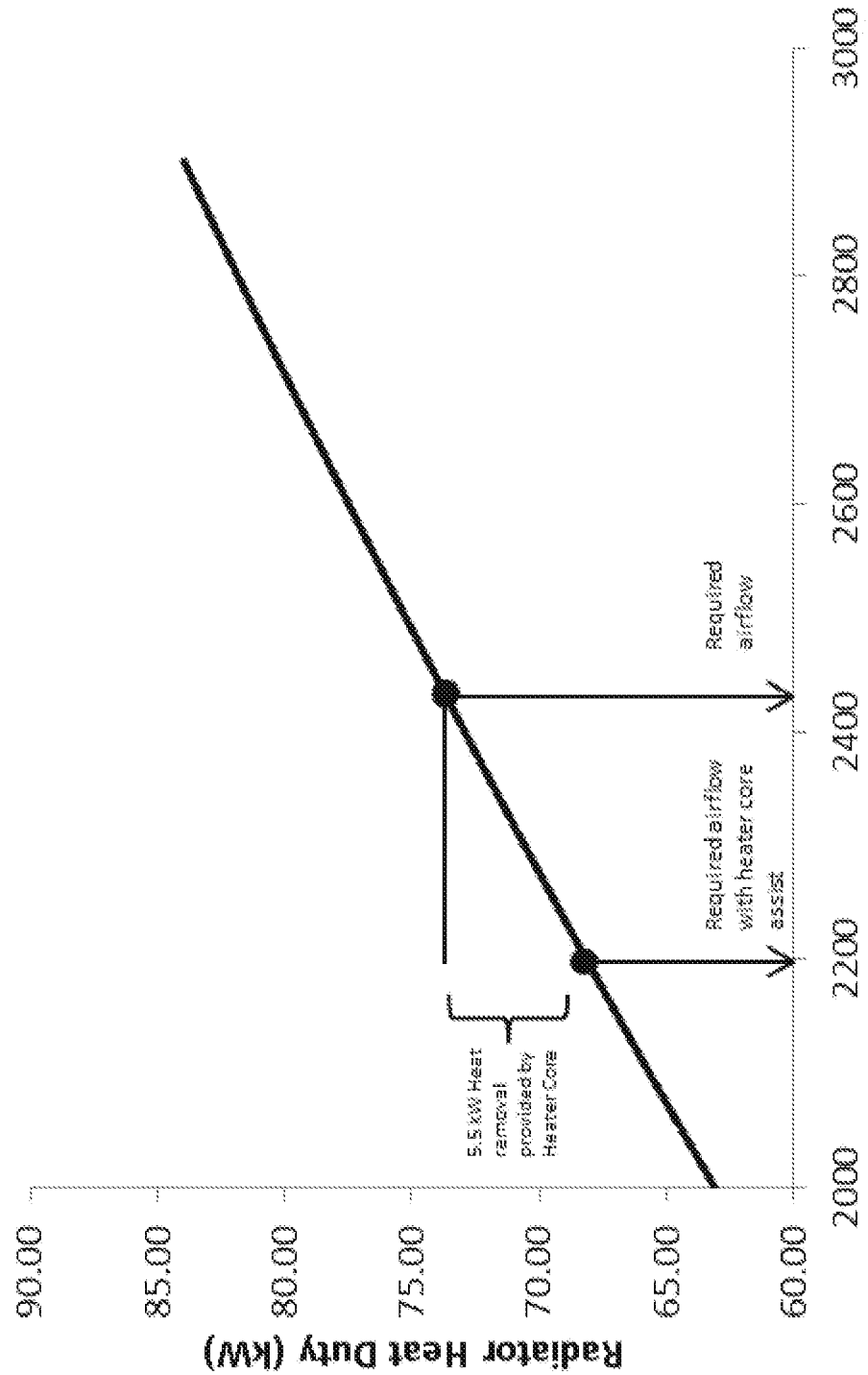
Required Airflow at Radiator
(With and Without Heater Core Assist)
Radiator Heat Duty (kW)
90.00
85.00
80.00
75.00
70.00
65.00
60.00
2000
2200
2400
2600
2800
3000
Required Airflow (CFM)
5.5 kW Heat removal provided by Heater Core
Required airflow with heater core assist
Required airflow

FIG. 13

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/015987

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B60H 1/22 (2014.01)
USPC - 165/202
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - B60H 1/22; F24F 3/147, 12/00 (2014.01)
USPC -60/456; 126/247; 165/43, 103, 202; 237/12.3R, 12.3A

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
CPC - B60H 1/00857 (2014.02)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase, Google Patents, Google

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | US 4,072,186 A (BARTON) 07 February 1978 (07.02.1978) entire document | 1-23, 27-29 |
| A | US 2009/0020280 A1 (JANEK) 22 January 2009 (22.01.2009) entire document | 1-23, 27-29 |
| A | US 4,352,456 A (BRANDENBURG JR) 05 October 1982 (05.10.1982) entire document | 1-23, 27-29 |
| A | US 6,789,617 B1 (HASHIZUME et al) 14 September 2004 (14.09.2004) entire document | 1-23, 27-29 |

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 14 May 2014 | 30 MAY 2014 |
| Name and mailing address of the ISA/US<br>Mail Stop PCT, Attn: ISA/US, Commissioner for Patents<br>P.O. Box 1450, Alexandria, Virginia 22313-1450<br>Facsimile No. 571-273-3201 | Authorized officer:<br>Blaine R. Copenheaver<br>PCT Helpdesk: 571-272-4300<br>PCT OSP: 571-272-7774 |

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/015987

**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 24-26, 30-35
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.