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Thermoelectric Air Conditioned Variable Temperature Seat (VTS) and Effect Upon Vehicle Occupant Comfort, Vehicle Energy Efficiency, and Vehicle Environmental Compatibility

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ABSTRACT

Concerns about air pollution have prompted legislation which mandates electric vehicle availability in California. It is quite possible that other states, as well as other countries, will be implementing similar legislation in the not too distant future, in order to reduce air pollution and reduce depletion of petroleum resources.

The subject of this paper, the Variable Temperature Seat, (VTS), is a potentially significant new solution to the problem of vehicle occupant thermal comfort, as well as vehicle fuel/energy efficiency, and environmental concerns such as the ozone layer and green house gas/global warming.

By removing heat from the occupants' body directly, instead of by relying entirely on vehicle interior space cooling or heating, occupant thermal comfort is greatly enhanced with minimum expenditure of energy. Being that the VTS is based upon Peltier thermoelectric heat pumping, no refrigerants are used, and the only moving parts are blower and fan motors.

The Peltier effect was discovered by Jean Peltier in 1834. In 1838, Heinrich Lenz froze a drop of water when passing electric current in one direction and then melted the drop by reversing the current polarity. Essentially, when two dissimilar materials are carrying an electric current, heat is picked up on one side of the junction and is transported to the other side of the junction. If that heat, plus the Joule heating of the electrical input power, is efficiently removed from what has now-become the hot side of the Peltier device, the device will continue to pump heat. If the hot side is allowed to get too hot, the efficiency of the device, (actually the complete system), which is ~45-60%, depending upon system design details, will drop to unacceptably low levels.

Consequently, to maximize efficiency, it is critical to make sure that when the heat pump is in cooling mode, the hot side of the system is as cool as possible, and, when the heat pump is in heating mode, to make sure that the cold side is as warm as possible, taking into consideration other factors such as, weight, volume, noise, cost, and total energy consumption. What this will generally result in is that the auxiliary heat exchanger, which is the heat exchanger that rejects heat to ambient air in cooling mode, and absorbs heat from ambient air in heating mode, ends up being approximately twice as large as the main heat exchanger, which is the heat exchanger that conditions the air that is being used to cool or heat the VTS user. Fig. 1 illustrates this.

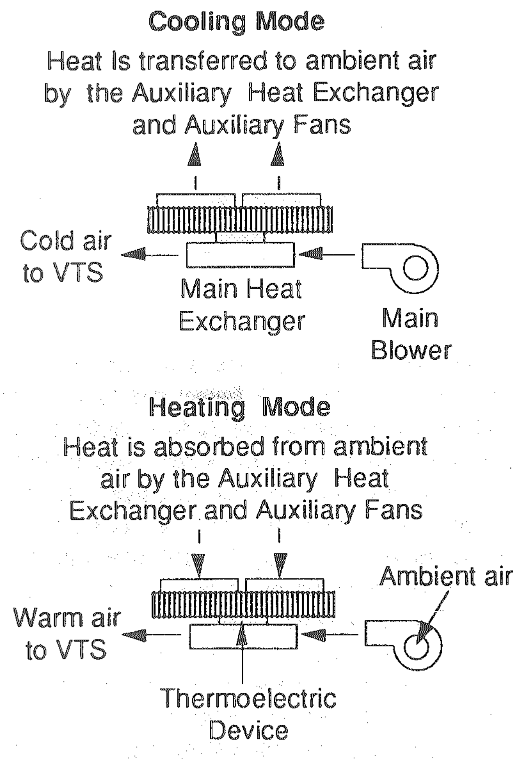
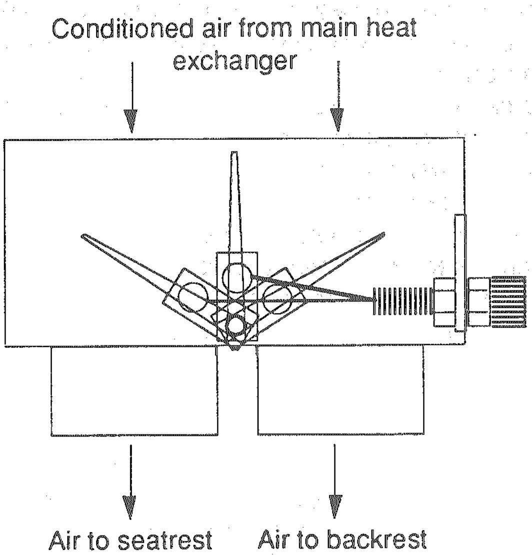


Fig. 1

Figure 1 also shows the thermoelectric device clamped between the main heat exchanger and the auxiliary heat exchanger. The main blower blows ambient air through the main heat exchanger and further on through the VTS seatrest and backrest plenums, which are the air flow elements located under the VTS cover material. Two auxiliary fans, also shown in Figure 1, blow ambient air across the auxiliary heat exchanger fins. For VTC systems with the heat pump mounted horizontally under the seat, the main heat exchanger housing contains a condensate trap consisting of a piece of felt, which absorbs condensate that drips off of the main heat exchanger in cooling mode, when relative humidity is sufficiently high. Condensate drain tubes, leading to a condensate trap under the seat, are required for VTC systems where the heat pump is mounted vertically inside the backrest. Condensate continues to evaporate away when the VTS heat pump is turned off.



Plan view of Air Flow Bias Flap Valve

Fig. 2

Figure 2 shows the VTS heat pump output air flow bias flap valve, which is located inside the heat pump outlet air manifold, which has two air outlets, one for the seatrest, and one for the backrest. The purpose of the valve is to allow the vehicle occupant to control the amount of conditioned air, whether cooled and de-humidified, or heated, flowing through the seatrest and the backrest. In a number of interviews and tests, it was found that women generally prefer more cooling or heating on their posterior than on their back, while most men seem to prefer more cooling or heating on their back than on their posterior. The bias flap valve directs more of the conditioned air to either the backrest or the seatrest, as determined by the occupant. The valve can be operated with a rotary knob and cable, or electrically via a pushbutton and servomotor or "memory metal" actuator. To maximize heat pump efficiency, wherever possible, parts that are in contact with conditioned air are made of plastic to minimize heat leakage in both cooling and heating modes.

Figure 3 shows how fast the VTS cools down in cooling mode compared to a vehicle interior cooled by conventional A/C under hot, sunny weather conditions. Long before the average interior air temperature drops to a comfortable level, the VTS has reached effective cooling ΔT, which does three things:

1- The surface of the seat cools down fast.

2- The VTS starts absorbing heat from the occupant, reducing or eliminating perspiration, and reducing the usual initial heat stress that occurs when entering a vehicle that has been soaking in the sun.

3- The occupant is effectively cooled by the VTS, reducing, and in some instances, eliminating the need for conventional A/C in order to maintain thermal comfort.

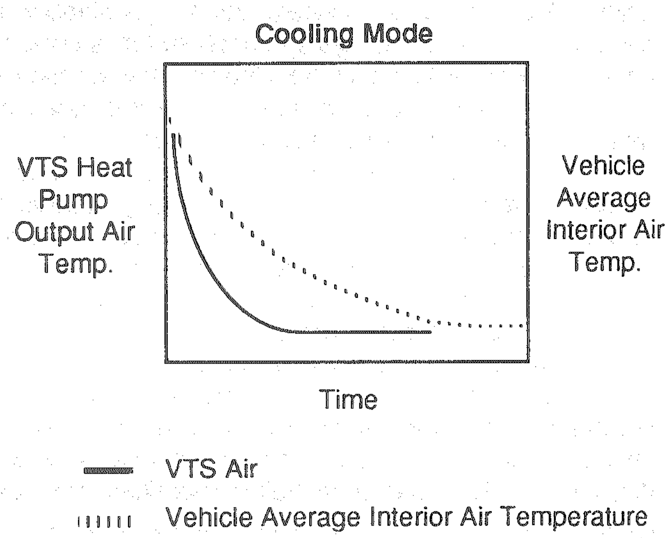


Fig. 3

As the interior of the vehicle cools down, VTS heat pump output air temperature will drop further, but not proportionally, because heat pump C.O.P. or Coefficient of Performance, drops as ambient temperature drops. This fact is a bonus in cooling mode because it effectively reduces heat pump cooling power as ambient temperature drops, which reduces the need for involved controls. It is, however, not a bonus in heating mode, because as ambient temperature drops, a higher C.O.P. would be desirable. The saving grace is that thermoelectric devices are considerably more efficient in heating mode than in cooling mode because input power I2R, or Joule heating is additive in heating mode, so VTS heating performance is good in all but the most severe winter conditions. This issue will be addressed further on in this paper. VTS heat pump C.O.P. may rise as high as >1.5

in heating mode, which is more efficient than resistance-wire type heated seats.

Figure 4 shows how fast the VTS heats up in heating mode versus the interior of a vehicle being heated with engine heat. As vehicle interior air temperature rises from engine heat, VTS heat pump output air will rise also. Figure 4 also shows that, if heat pump output air temperature is too high, the net VTS heating power may be controlled by varying heat pump main blower speed to control the amount of heated air blown through the VTS. This is the least expensive approach because the main blower is rated at 1.2 W, while the thermoelectric device input power ranges from 66-111.0 W at an input voltage of from 12-15.0 VDC. A simple 1.0 W potentiometer is sufficient to control the main blower versus a bulkier, heavier, and considerably more costly linear or switching mode type Peltier input voltage controller.

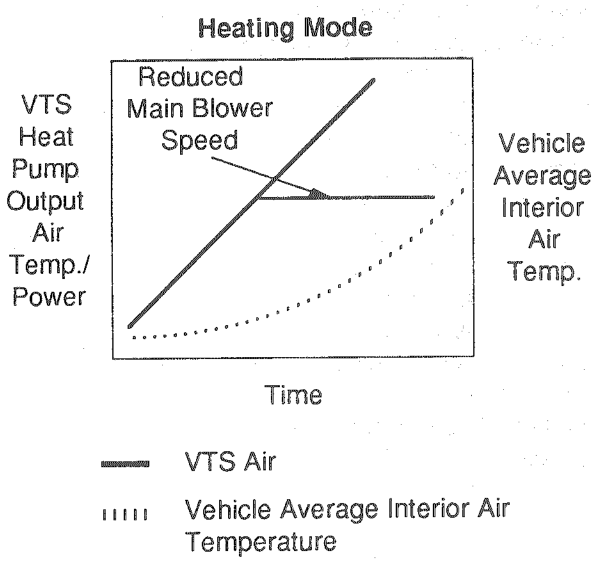


Fig. 4

Fig.5 shows the basic structure of the VTS seat and backrest plena. The primary air flow space is created by steel coils of ~12.7 mm diameter, wound to a pitch of .8-1.6 coils/cm. Coil wire diameter is .8 mm. Each succeeding row of coils is interlocked with the preceding row, much the same as with chain link fence, to increase the stability and durability, as well as smoothness, of the coil mat. The VTS plenum is a critical element because it must allow air to flow freely with minimal pressure drop, while presenting a suitably smooth and comfortable seating surface to the occupant. Fig. 5 shows an airtight backing layer. This layer prevents conditioned air from leaking out of the back of the plenum, and is made of vinyl or tightly woven synthetic cloth. The fine metal cloth layer, which is made of ~.1 mm diameter copper or aluminum wire with a mesh of 16-32.0 wires/cm x 16-32.0 wires/cm, is the primary load spreading layer, it spreads the occupants weight over the medium heavy plastic mesh layer, which is made of plastic filaments of .7-1.0 mm diameter with a mesh of 3-4.0 filaments/cm x 3-4.0 filaments/cm, which, in turn, spreads the occupants weight over the plenum coil mat. One of the characteristics of the VTS plenum structure is the "Snowshoe Effect". This is the result of efficient occupant weight spreading over the seat plena, which further results in a reduction in the occupants' usual weight concentration, especially around the ischial tuberosities, on the seat foam. This means that, because of the Snowshoe Effect, for the same effective seat firmness, VTS foam durometer must be reduced below that of a conventional seat.

In addition to supporting the occupant on the plenum coil mat, the metal cloth layer promotes some thermal transfer by conduction, however, the major thermal transfer mechanism in the VTS is convection, both free and forced. The relatively open plastic mesh serves a primarily mechanical support function, and, because of its relatively open mesh, has little effect upon convection thermal transfer. The plenum coil mat assemblies are produced by Flexolators, Inc. to specification. Early VTS prototypes were made with plenum coil assemblies of relatively low quality, with uneven coil diameters and pitches. This necessitated the use of an additional cushion on the VTS seat rest. The additional cushion was a Sorbothane pad, 6.4 mm thick, molded with a multitude of ~ 6.4 mm diameter holes. Some of the problems with the Sorbothane pad, in addition to the added cost, were weight and, more importantly, recyclability, as well as potential increases in cool-down and warm-up time of the seatrest. The backrest plenum has no Sorbothane pad, since less weight is applied to the backrest, and that weight is relatively evenly distributed over the backrest.

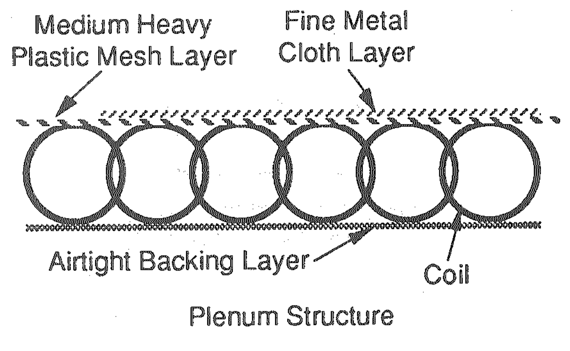
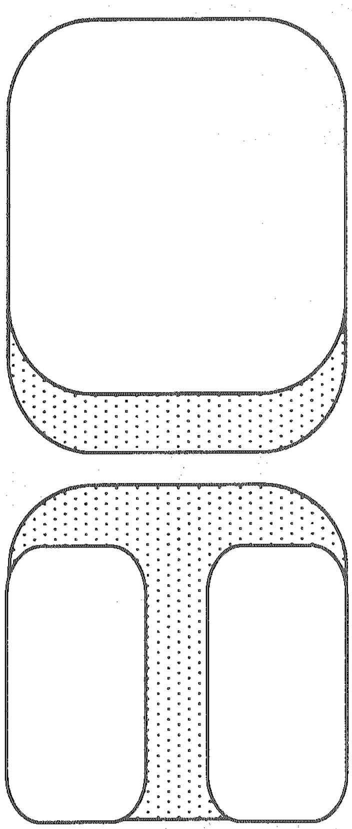


Fig. 5

Sorbothane is a visco-elastic polymer. It is a solid that behaves a bit like a liquid. It is very close to human flesh in terms of its force/displacement/hysteresis characteristics. Unfortunately, Sorbothane is very difficult to recycle, and is dense, so a typical Sorbothane seat plenum pad adds ~1.4 kg to the weight of a VTS. In this age of environmental concerns, eliminating the Sorbothane pad became an important challenge. Given the refinements in both design and quality of the plenum coil assemblies the Sorbothane pad should be a thing of the past. The latest plenum coil assemblies are smooth and comfortable with just the metal cloth and plastic mesh layers under a standard cloth and foam seat cover. It is important to note that whatever fabric is used, it must breathe. The more the fabric breathes, the better. Foam backings should also breathe well. The maximum uncompressed seat cover backing foam thickness for good VTS performance is ~12.7-19.0 mm, which allows for surface contouring but preserves VTS efficiency and minimizes cool-down and warm-up times.

Fabrics are generally much better for VTS performance and efficiency than hides. If leather is to be used, it should be as thin as possible while maintaining appropriate durability. Leather also must be cleanly perforated, not pierced. If leather is pierced, no material is removed, and the material that is torn in the piercing process tends to fold back into the hole, closing it back up. Clean perforations are required. As far as fabrics are concerned, the best fabrics appear to be natural fibers or natural and synthetic fiber blends. Wool is a very good fiber because it assists in wicking moisture. As of today, four seats have been built using fabrics with wool fibers blended in, and the results have been very good.



VTS Air Plenum Air Barriers

Fig. 6

Figure 6 shows the VTS plenum air barrier layers. The shaded areas are layers of tightly woven nylon or natural fibers, or thin vinyl sheets glued to the plenum metal cloth under the VTS seat cover cloth and cover cloth foam backing. The barrier layers significantly reduce air leakage through the seating surface in areas that are rarely fully covered by an occupant, especially occupants of small and/or slim proportions. The bite line area is a major potential air leakage path because there is usually a gap between the occupant and the surface of the biteline area on both the the backrest and the seatrest. Another area of potential leakage is the seatrest area between the occupants legs. The conditioned air barrier layers significantly reduce air leakage and promote increased VTS efficiency by ensuring that most of the conditioned air travels the full length of the air plenum, absorbing heat in cooling mode, and releasing heat in heating mode, over the maximum seating surface area. It may be feasible to silkscreen the air barrier layers to the metal cloth before the metal cloth is sewn onto the plenum, speeding production.

Figure 7 shows how VTS thermoelectric heat pump C.O.P., in both cooling and heating modes, rises as vehicle interior temperature rises. Increased C.O.P. is reflected by a decline in constant voltage thermoelectric device current for the same amount of heat pumped as interior temperature rises. Again, this is a blessing in cooling mode, but a disadvantage in heating mode. Again, the disadvantage is tolerable because thermoelectric devices are so much more efficient in heating mode than in cooling mode. By careful attention to engineering and design detail, such as the air barrier layers, for example, it is possible to cool an occupant effectively with a relatively very modest power input.

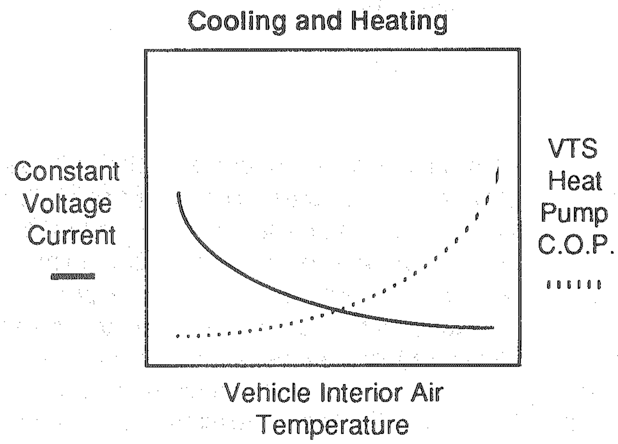


Fig. 7

At 13.0 VDC, the VTS heat pump puts out ~10.2 m3/h at a ΔTamb. of ~10.0-14.4 K, depending upon ambient temperature and relative humidity. This translates into ~.26-.38 Driver Metabolic Unit, or .26-.38 DMU. 1.0 DMU, based upon a healthy 25 year old male is ~125.0 watts which is the average metabolic rate at which the occupants' body needs to release heat while driving. The Passenger Metabolic Unit, or PMU, will be smaller on average, because the passenger is not operating the vehicle, and is not, generally, as concerned mentally with traffic as the driver. Since the VTS user is loosing heat at a relatively efficient rate through the seat, which is ordinarily an area where the body looses the least heat, the areas of the VTS user that are exposed to vehicle interior ambient air don't have to release as much heat, resulting in two phenomena:

1- Perspiration is significantly reduced, or eliminated entirely.

2- The user feels more comfortable in two ways:

a- Lack of perspiration, or evaporative cooling mode = dry feeling.

b- The occupant feels cooler because it is easier for the occupant to dissipate the required metabolic heat at reduced body surface temperature.

The VTS has certain advantages over other means of heating seats, in addition to the unique cooling function.

1- There are no heating wires to break or short, from either use or sewing machine operator error.

2- No hot spots. More gentle, yet very effective heating effect.

The VTS heat pump uses a single thermoelectric device which runs at approximately:

5.5 A, 12.0 VDC, 66.0 W

6.3 A, 13.0 VDC, 82.0 W

6.9 A, 14.0 VDC, 96.6 W

7.4 A, 15.0 VDC, 111.0 W

As shown in Figure 7, variations in vehicle average interior air temperature, in addition to variations in relative humidity, will cause slight variations in the above figures, for that particular Peltier device. The VTS heat pump main blower and auxiliary fans run at .3 A total at 12.0 VDC, or 3.6 W total at 12.0 VDC. The main blower is rated 1.2 W. The reason such a low power main blower is feasible is because of attention to design detail, such as the air barrier layers, and careful design of all air flow ducts and nozzles. The plenum coil assemblies are also relatively efficient from an air flow standpoint. The latest VTS heat pump weighs .91 kg, and is roughly 209.6 mm x 92.1 mm x 57.2 mm in dimension.

Figure 8 illustrates the importance of proper VTS plenum venting. When an occupant is seated on the VTS, conditioned air must be able to continue flowing freely through the plenums. When the VTS is turned on in cooling mode without anyone sitting on it, the surface will get noticeably cool within ~3-4.0 minutes. This is because plenum air tends to diffuse out through the cover material instead of flowing past it on the inside. When the occupant sits on the seat, convection and conduction occur, as conditioned air flows through the seat plena and out the plena outlet vents, in relative proportion to the total ΔT and the thermal conductivity and porosity/permeability of the VTS cover material. The plenum outlet vents, as shown in Figure 8, are very important for proper functioning of the VTS system, as the seat is virtually non-functional without them. Figure 8 also illustrates, albeit to an exaggerated extent, how the area of the bite line is open even when an occupant is seated, necessitating an air barrier layer to prevent conditioned air from leaking out of the bite line area before it has a chance to cool or heat the occupant. Although the VTS heat pump takes approximately 3.0 minutes to reach maximum ΔT in both cooling and heating modes, the time that it takes for the occupant to perceive cooling or heating is also influenced significantly by the cover material and cover material backing foam.

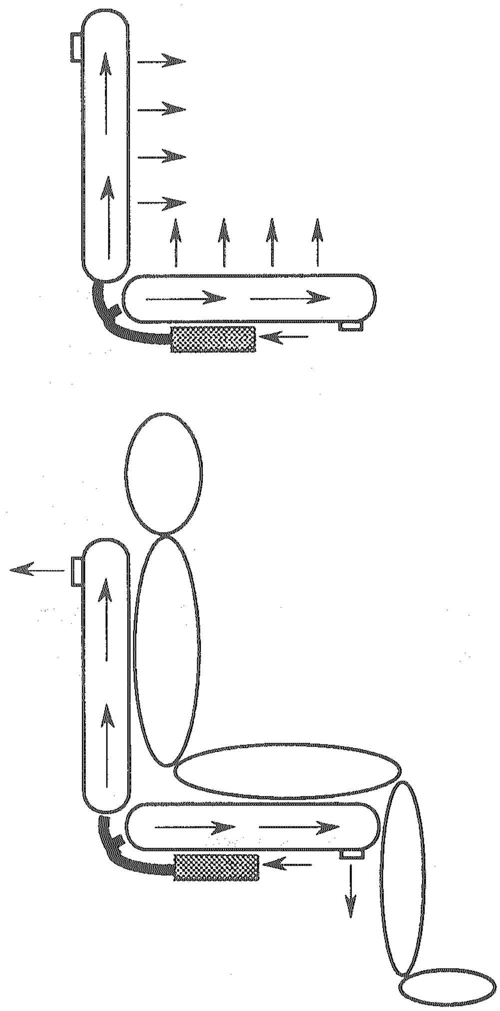


Fig. 8

Specific VTS cover material characteristics to consider are:

1- Porosity/permeability.

2- Thickness.

3- Thermal conductivity.

4- Density.

5- Specific heat.

6- VTS plenum linear area.

7- Vapor transmission/wicking characteristics.

Figure 9 is an assembled VTS with the heat pump mounted inside the backrest. Although the heat pump may be mounted under the seat, several important issues are successfully addressed by mounting the VTS heat pump inside the backrest:

1- Limited space under the seat. In some vehicles, there just isn't enough space under the seat to fit the VTS heat pump.

2- Rear seat passenger foot space. In some vehicles, rear seat passenger foot space may already be relatively restricted.

3- It is less likely that the heat pump will be damaged during installation of the VTS into the vehicle if it is safely located inside the VTS backrest.

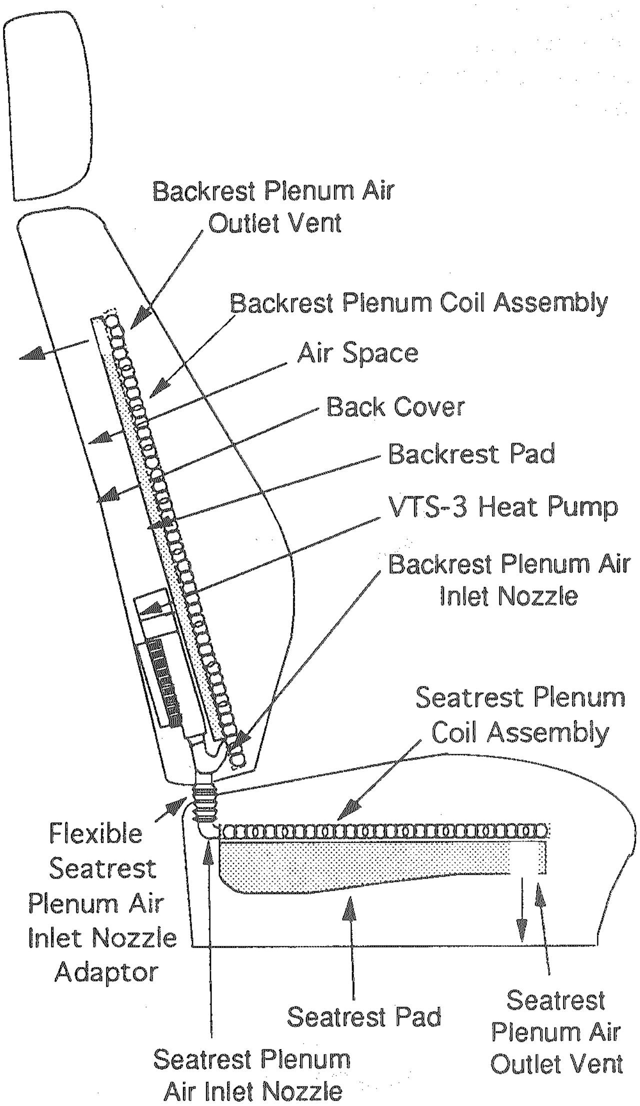


Fig.9

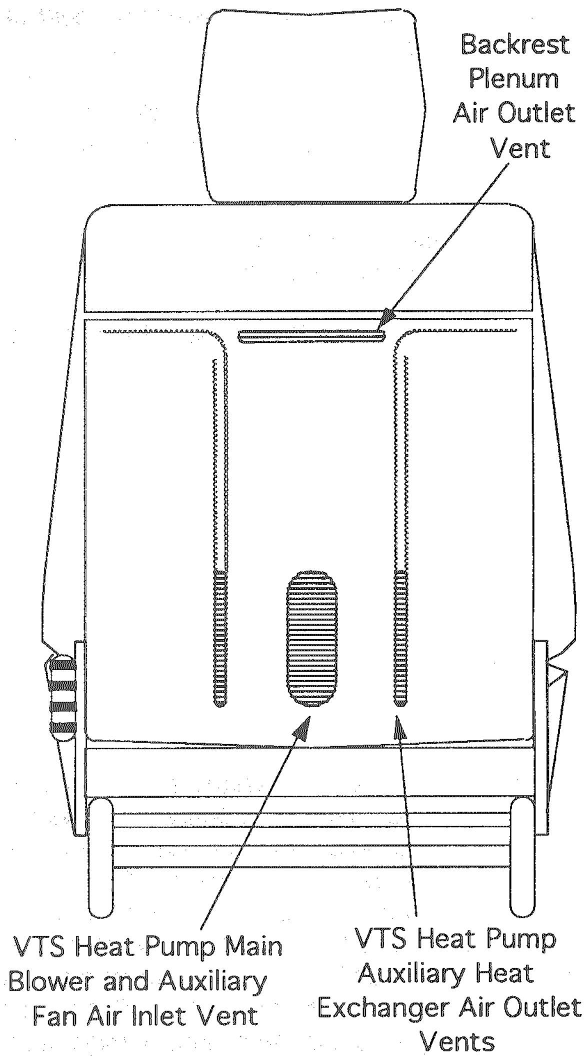


Fig. 10

4- It will be easier to install and, if necessary, service the

VTS heat pump if it is located inside the backrest instead of underneath the seat.

5- Mounting the VTS heat pump inside the backrest shortens and simplifies air ducting from the heat pump to the VTS plenums, resulting in reduced air duct cost as well as better air flow performance and reduced air duct heat leak.

Figure 10 is a rear view of a VTS with heat pump mounted inside the backrest. The purpose of Figure 10 is to illustrate the need for proper venting of the heat pump when it is enclosed. The VTS Main Blower and Auxiliary Fan Air Inlet Vent is where air is drawn in by the main blower, then is blown through the main heat exchanger, and on through the VTS plenums. Air is also drawn in by the two auxiliary fans, where it is blown through the auxiliary heat exchanger and then exits through the VTS Heat Pump Auxiliary Heat Exchanger Air Outlet Vents. The Backrest Plenum Air Outlet Vent is where conditioned air that has traveled through the backrest plenum vents back to vehicle interior ambient air. As shown in Figure 9, seatrest plenum outlet air is vented at the Seatrest Plenum Air Outlet Vent straight down. This is a small, but important feature because if the seatrest plenum outlet air were to vent straight out, it would impinge upon the occupants calves. The amount of air vented from the VTS Heat Pump Auxiliary Heat Exchanger Air Outlet Vents is so small that a rear seat occupant will not notice it.

Figure 11 is a view of a VTS heat pump with afterheater. The afterheater is based on a PTC, or Positive Temperature Coefficient ceramic heating element, clamped between two heat exchangers consisting of folded aluminum fins brazed to aluminum baseplates. The afterheater is mounted downstream of the main heat exchanger, and upstream of the air flow bias flap valve.

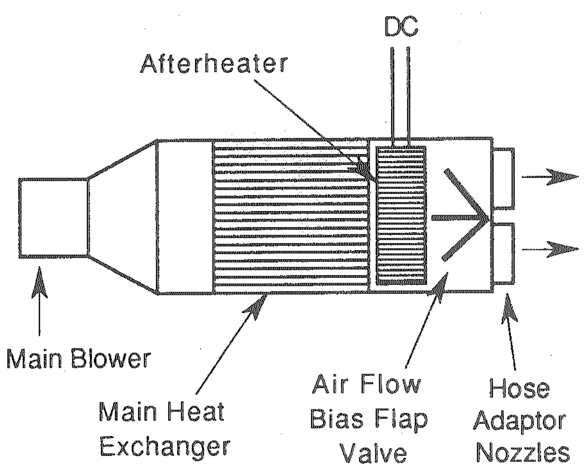


Fig. 11

The purpose of the afterheater is to produce warm air very quickly in extremely cold weather. As shown in Table 1, the VTS-3 heat pump produces 297.3 K air at an ambient temperature and relative humidity of 257.0 K and 41.0 % respectively, which results in relatively good occupant heating performance, especially since engine heat increases over time, resulting in increasing heat pump output air temperature beyond the 3.0 minute point in Table 1. For ambient temperatures significantly below 255.0 K, when heat pump C.O.P. drops further, the afterheater will provide warmer VTS air sooner.

Figure 12 shows the advantage of using a PTC type heating element for this purpose. As average vehicle interior ambient temperature rises, VTS heat pump C.O.P. will rise, resulting in higher heat pump output air temperature. As shown in Figure 12, PTC temperature goes up very steeply with time, while heat pump output air temperature rises less steeply. As heat pump thermoelectric output air temperature rises, afterheater temperature also rises because the afterheater is downstream of the heat pump main heat exchanger. When afterheater temperature rises to the Curie or anomaly temperature, its resistance rises linearly at ~ 20%/K, in effect, seeking thermal equilibrium by reducing current flow to maintain a relatively constant temperature. The advantage of using a PTC device is to reduce the complexity and cost of controls required to prevent over-heating the heat pump or to prevent overheating the VTS as average vehicle interior air temperature rises from occupant use of engine heat.

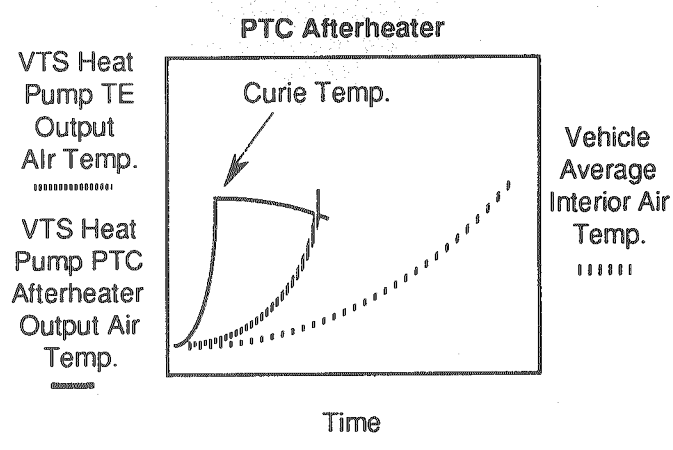
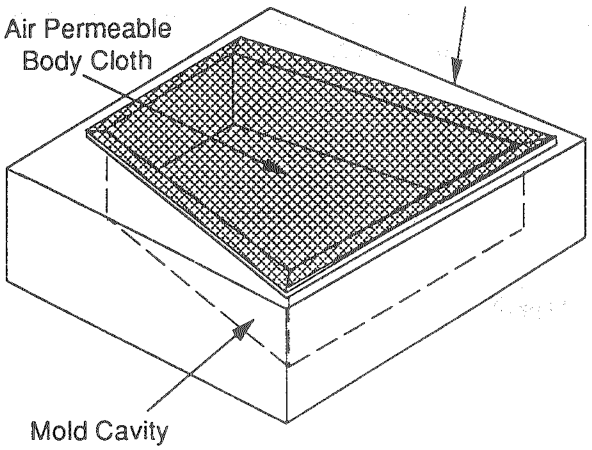


Fig. 12

A fixed or occupant-adjustable thermostat may be used to switch the PTC afterheater out entirely when vehicle average interior air temperature reaches a sufficiently high value, and, consequently, VTS thermoelectric heat pump output air temperature is sufficiently high.

Figures 13, 14, and 15 illustrate the use of the VTS plenum coil assembly with Foamed-in-Place type seat cushions. Foamed-In-Place type seats have been known to be a problem from a thermal comfort standpoint for some time now. The body cloth is made with a membrane to prevent the foam from weeping through the body cloth while the seat foam is expanding and curing. This membrane tends to trap body heat and moisture, resulting in a relatively uncomfortable seat, especially in moderate to hot weather, in terms of thermal comfort. Figures 13-15 show how to make use of the advantages of Foamed-In-Place as well as the VTS, eliminating the thermal problems associated with the Foamed-In-Place process. If surface contouring is necessary or desired in the area of the plenum, pre-contoured foam may be placed on the body cloth before or after placing the body cloth into the mold. Then the VTS plenum can be placed on top of the pre-contoured foam body cloth backing layer in the mold. Body cloth is readily available with foam backings, of varying thickness, that are adhesively or flame bonded to the back side of the body cloth while still maintaining very good breathability.

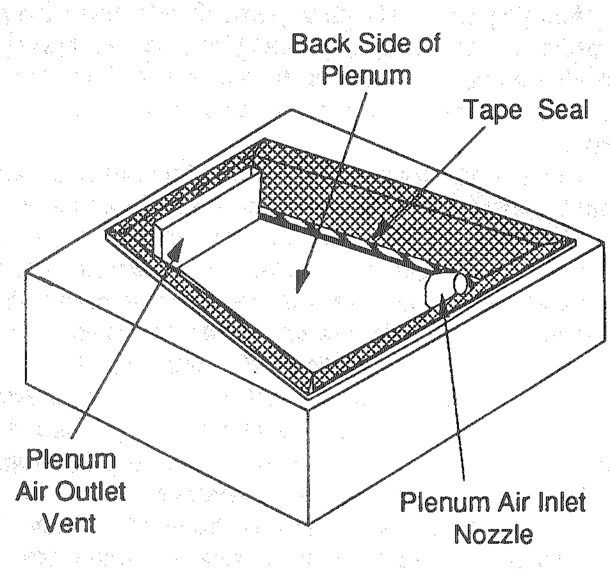
Figure 13 shows a basic mold cavity, shaped to the final shape of a VTS backrest. Air permeable body cloth is secured inside the mold cavity.



Foamed-In-Place Type VTS

Fig. 13

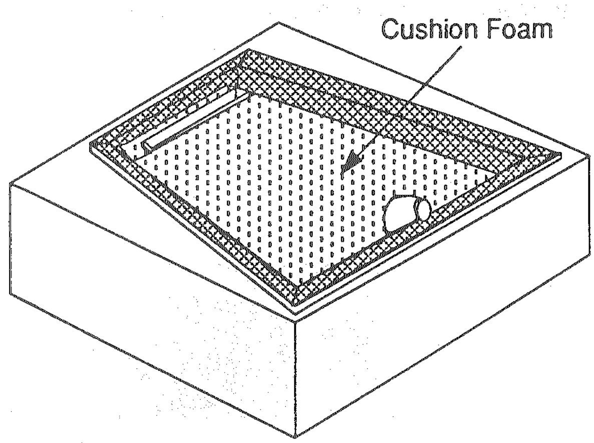
After securing the air permeable body cloth into the mold, a seatrest or backrest plenum coil assembly is placed into the mold on top of the body cloth, with the metal cloth/plastic mesh side facing the bottom of the mold, as shown in Figure 14. Figure 14 also shows a Plenum Air Outlet Vent and Plenum Air Inlet Nozzle attached to the back side of the plenum coil assembly, or Plenum Backing Layer, while a tape seal is secured around the perimeter of the plenum between the plenum edge and the body cloth, to prevent leakage of foam around the sides of the plenum into the front and between the plenum and body cloth.



Foamed-In-Place Type VTS

Fig. 14

Figure 15 shows the mold filled with cured foam up to the level of the Plenum Air Outlet Vent and Plenum Air Inlet Nozzle, before finishing the back side with cloth or a molded back.



Foamed-In-Place Type VTS

Fig. 15

Table 1 shows basic thermoelectric VTS air-to-air heat pump performance in cooling mode and heating mode.

Table 1- Basic Thermoelectric Variable Temperature Seat (VTS-3) Heat Pump Data

		Cooling Mode:	
Ambient Temperature: 300.4 K.		Relative Humidity: 67.0 %.	Heat Pump Air Flow:10.2 m3/h.
Cool-Down Time	ΔT	~Sensible Watts	~% Driver Metabolic Unit*
1^m30^s	10.0 K	33.3	26.7 %
1^m59^s	10.6 K	35.2	28.2 %
2^m49^s	11.2 K	37.2	29.8 %
At 13.6 m3/h, the dT drops to ~8.9 K, but W and % DMU* increase to 38.1 W, .31 DMU, heat pump output. At higher ambient temperatures, and lower relative humidity, max. dT may reach 14.4 K.			
		Heating Mode:	
Ambient Temperature: 257.04 K.		Relative Humidity: 41.0 %	Heat Pump Air Flow: 10.2 m3/h.
Warm-Up Time	ΔT	~Sensible Watts	~% DMU
30^s	14.4 K	56.5	45.2 %
1^m	24.2 K	94.6	75.7 %
3^m	41.9 K	163.9	131.1 %

CONCLUSIONS

The Thermoelectric Variable Temperature Seat is a fully functional technology that is capable of producing very meaningful energy/fuel savings while providing significant occupant comfort enhancement. Energy/fuel savings will also result in reduced air pollution because less fuel is consumed. Because the VTS is capable of efficiently heating the occupant, it is possible to delay using engine heat, which will result in faster engine warm-up, which will result in reduced engine cold-start emissions and wear. Because the VTS uses no refrigerants, and because the VTS enables the use of smaller air conditioning systems, or enables the elimination of air conditioning systems in some instances, the environmental compatibility of a vehicle equipped with a VTS is improved. Because smaller air conditioners use less fuel, the vehicle has the potential to operate at reduced fuel cost as well as reduced air pollution. Since the VTS is so much lighter than standard A/C equipment, it should contribute to reducing the weight, and hence the amount of power required, to accelerate a vehicle, resulting in further fuel savings and further reduced emissions. Another way in which the VTS can improve vehicle fuel efficiency and reduce air pollution is by reducing the size of standard space cooling A/C equipment, the aerodynamic losses associated with large condensers and engine coolant radiators may be reduced, thereby reducing fuel consumption and emissions reducing aerodynamic drag.

Solar powered stand-by ventilation to reduce vehicle interior air superheat, as well as improved selective coatings for vehicle glazing in combination with the VTS, should go a long way towards addressing existing and future challenges in vehicle interior thermal management.