NUMERICAL MODELING OF INTERIOR CAR COMPARTMENT – FIRST ANALYSIS

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Abstract

During hot summer days outside temperature often exceeds 30°C. Without air condition system it is impossible to achieve temperature inside car compartment at the same level or lower than outside, even with high air flow. Driver's efficiency researches indicate that it can be even 35% higher at +20°C than at +35°C. Decrease of efficiency at +5°C can be the same as that at +35°C. Usage of air condition system is the only way to achieve internal temperature lower than external one. The heat flux which should be transferred from the car cabin is about 2 kW. There is no problem to reject even higher he at flux from c abin. The problem is how to ass ure thermal comfort for passe ngers in so s mall space like car compartment. The thermal comfort usually means that near skin air temperature is about 20-22°C and air velocity is below 0.5 m/s.

In this paper first analysis of numerical modelling of air flow inside car compartment are presented. Two types are considered: first one with 2 m/s velocity with inlets situated at front cowl section, front of dashboard and near feet. Second one with 4 m/s velocity with inlets situated at front cowl section and near foot.

Keywords: *transport, road transport, simulation, combustion engines, air pollution, environmental protection*

1. Thermal comfort in vehicles

Car compartment is a place where often thermal discomfort is obvious. In summer, the most important phenomena of energy transfer are sun radiation. In hot summer day radiation heat flux can be even several times higher than convection heat flux. It can be easy to notice when one takes car to shady road after driving in the sun. Coldness and freshness feeling is almost immediate. Temperature in a vehicle cabin is closely related with the occurrence of traffic accidents [1]. In hot summer days internal temperature often exceeds +30°C. Zlatoper [2] has created the ranking list of the factors which affect the traffic accidents in United States and placed the temperature on the third position. So it is obvious, that the thermal conditions in the cabin of vehicles directly influences on the driver's and passengers safety.

Both too high and too low ambient temperature influences human physical and mental state. Driver's efficiency researches indicate that it can be even 35% higher at +20°C than at +35°C. Decrease of efficiency at +5°C can be the same as that at +35°C [2, 3].

It is impossible to ensure temperature at the same level as outside compartment using only ventilation, even with the strong flow. The internal temperature is almost always higher. Radiation heat flux with green house effect in car compartment is higher that heat fluxes which can be refuse with ventilation. Situation is critical during car parking in hot clearly day with direct sun exposure. In summer, internal temperature can even reach 70°C with 30°C outside. It is very dangerous for animals or children left inside car [4].

The techniques of achieving quite good effects of thermal comfort are well recognized in the habitats, but in mobile spaces, like cars, trains and buses are still under development.

There are also additional parameters, which influence on the thermal comfort: air flow speed, air humidity, outer wall temperature and, what is important in vehicles cabins, sun radiation. In many cases thermal parameters are controlled only by regulation of the air temperature and the mass flow rate. Due to that, air flow speed can locally exceed its reasonable value.

It is hard to strictly define the thermal comfort. Usually thermal comfort means that temperature is between 20°C and 22°C, humidity is about 50% and air velocity is under 0.5 m/s. This can be called independent factors.

There is also second group of factors affecting thermal comfort – individual human feelings which are much harder to define, because each person has their own preferences for thermal comfort. One can say there is thermal comfort when amount of people saying "I fell badly here" is the lowest. [2].

The symptoms of thermal discomfort are intensive sweat production, increment of heart beat frequency, and as a result, the decrease of driver concentration and efficiency.

2. Thermal analysis of refrigerator cycle

The heat flux which should be transferred out of the car cabin is about 2 kW. The only way to achieve internal temperature at desire level is use air conditioning systems. An optimum A/C unit should assure thermal comfort under time varying thermal loads with minimal energy consumption. Compressor in the unit is driven by the vehicle engine and therefore considerably increases the fuel consumption.

3. Non controlled cycle

In this case as expansion valve is orifice and everything depends on orifice effective throttle area. If the area is too high the compressor works properly (without fluid droplets) only in some range. If effective throttle area is too low the refrigerant at evaporator outlet is always superheated but the temperature at compressor outlet can be too high. That high temperature involves other problems. First is higher compressor material durability, second is a problem with liquid phase at condenser outlet, especially with higher ambient air temperature.

In this case, at 20°C irrespectively of refrigerant charge, COP is about 5 for 3000 rev/min and 3 for 1000 rev/min and decreases of 1 at 45°C air temperature. For 0.055 kg charge the drop is about 3 for 1000 rev/min and 2 for 3000 rev/min. It is shown in Fig. 1.

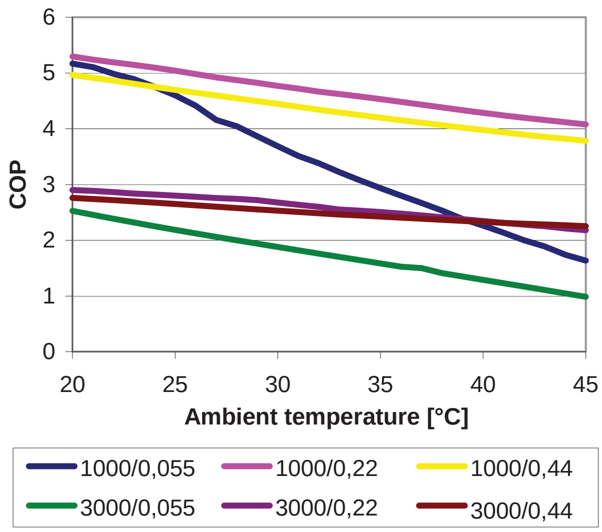

Fig. 1. COP as a function of ambient temperature

Similar trend can be observed with heat transferred in evaporator. For the charge 0.44 kg and 0.22 kg, the heat flux increases with air temperature. It is shown in Fig. 2. For 45°C the heat flux is two times higher than for 20°C. For the charge 0.055 kg the situation is opposite – heat flux decreases with air temperature.

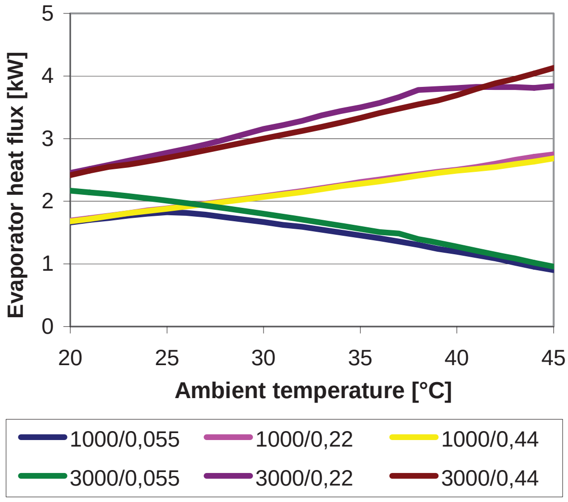

Fig. 2. Evaporator heat flux as a function of ambient temperature

There is one advantage of 0.055 kg charge case: compressor power is low: at 3000 rev/min is below 1 kW while for 0.44 kg is twice higher. But here is almost impossible to achieve required temperature inside car cabin in this case. Heat transferred in the evaporator is just too low (Fig. 2.)

4. Controlled cycle

In this case there is no problem with too high temperature, because expansion valve always assures 1K of superheating at evaporator outlet. So there is no problem with high temperature material durability, because temperature at compressor outlet is lower too. If the temperature at compressor outlet is lower it is also easier to obtain liquid phase at condenser outlet.

One can say the controlled cycle is more “flexible”. In this case heat flux in evaporator can be about 1.5 kW higher than in non controlled one, which means that we can reject 1.5 kW of heat flux more from car compartment. For 0.055 kg charge, compressor inlet (evaporator outlet) temperature is about 40°C at 45°C air temperature. It means that temperature at compressor outlet can be about 100°C. For other charges inlet temperatures are similar and always below 15°C.

COP tendency is similar to non controlled cycle but the values are a little bit lower (Fig. 3). The compressor power is always higher than in non controlled cycle. There is also higher heat flux in evaporator for both 1000 and 3000 rev/min cases (Fig. 4). For the charge 0.055 kg COP is equal to 0.25 at 45°C air temperature.

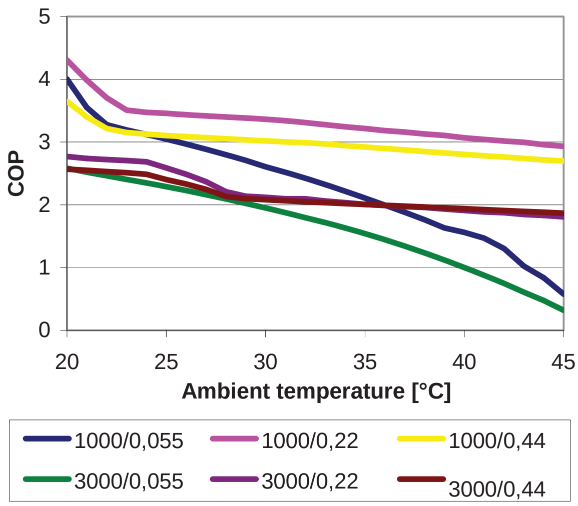

Fig. 3. COP as a function of ambient temperature

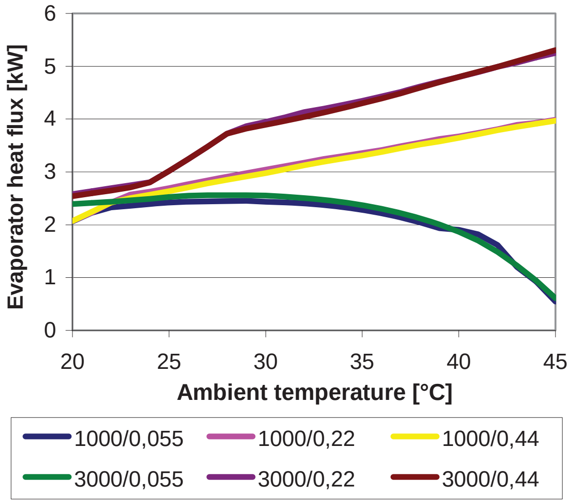

Fig. 4. Evaporator heat flux as a function of ambient temperature

5. Numerical simulations

There is no problem to reject about 2.5 kW of heat from car compartment. The problem is how to do this without thermal discomfort for passengers. It means that near skin air velocity should be below 0.5 m/s and its temperature should be about 20-22°C. With A/C system usage, air flow inlet temperature could reach even 5°C and its velocity up to 6 m/s at inlet nozzle. Distance between air inlet on dashboard and human body is about 0.6 m. In this distance air flow velocity should decrease to 0.5 m/s or lower.

The most important phenomenon in car compartment is solar radiation. Total solar heat flux is about 1.5 kW. Other phenomena are: convection (about 0.5 kW) and internal heat generation, mainly from passengers (about 0.4 kW).

Simplifications in model:

- car speed is 60 km/h,
- four passengers inside, each generate 100 W,
- air inside compartment is transparent for radiation,
- radiation model – surface to surface,
- outside temperature is 30°C,
- air flow inlet temperature is 7°C,
- heat transfer through windows, roof and floor,
- other surfaces are treated as insulated,
- expiration air velocity 1.333 m/s,
- steady state.

Body core temperature at approximately 37°C is generally accepted as normal. Retain proper internal temperature require ongoing heat exchange between skin and ambient. There are four possibilities to heat transfer from skin: conduction, convection, radiation and sweating.

Air conductivity is about 0.02 W/mK so heat transfer through conduction can be neglected.

Participation between three other kinds depends on ambient properties: air temperature, surrounding wall temperature, steam water pressure and air velocity.

In comfort temperature (20-22°C) heat is mainly exchange through convection and radiation. When the air temperature is increase heat transfer through evaporating also increase and decrease through convection.

Assumptions in model:

- temperature at 1 cm depth inside body 37°C,
- human heat generation 100 W/person,
- H_2O mass concentration at air flow expiration 0.03414,

- Expiration air temperature 35°C,
- Expiration air velocity 1.333 m/s,
- H_2O mass concentration at air flow inlet 0.006281,
- Air flow inlet temperature 7°C,
- Air flow inlet velocity 2 (case 1) and 4 m/s (case 2).

Both cases air flow inlet are situated on front cowl section and near feet.

Air flow velocity

Both cases the highest air flow velocity (about 1.5 m/s) occurs near front passenger feet, which are very close to inlet grid. Second area of high velocity values is near front passenger head which is in directly influence of air flow inlet (Fig. 7 - case 2) and near front passenger chest (Fig. 6 - case 1).

For passengers comfort, case 1 is better because velocity near passenger's eyes is lower. High velocity value near chest isn't so adverse - passengers chest are usually clothed.

Both cases velocity in rear part of compartment is low – near human body is below 0.5 m/s.

Fig. 6. Contours of velocity, m/s

Fig. 7. Contours of velocity, m/s

Temperature

Opposite situation to velocity is with temperature field. The highest value is in places where air velocity is the lowest. The lower temperature value is near passenger feet in front seats (air velocity is high) – about 10-12°C. The highest temperature value is near passengers head – about 40°C (Fig. 8 - case 1) and near chest and head (Fig. 9 - case 2).

Higher temperature is in rear part of compartment. Temperature near whole passenger body is about 35-40°C. High temperature value in rear part derives from air nozzle localization only in front part of compartment.

Fig. 8. Contours of temperature, K

Fig. 9. Contours of temperature, K

Humidity

Increase air temperature inside a car directly influence on air humidity level. It can be notice that near eyes which are the most sensitive area, humidity is quite low – about 20-30%.

This low value negative influence on eyes, which strongly increase thermal discomfort level. It is hard to say about thermal comfort in addition to rear passenger because temperature near their body is about 35-40°C. Humidity near rear passenger head is very low – about 15%.

The most important factor influence on humidity level inside compartment is mass fraction of air flow inlet. The mass fraction is low because air temperature decrease from 30°C to 7°C in evaporator which cause condensate water. As a result air flowing in compartment is cold and dries (humidity near 100% at 7°C). When the air temperature is increase humidity decrease significantly.

Fig. 10. Contours of humidity, %

Fig. 11. Contours of humidity, %

6. Conclusion

Thermal discomfort create very unpleasant follow-up's, like: increase sweating and heart beat frequency (even on 23 beats/min) and, as a result, overall weariness. Result in this paper shows how difficult is to assure thermal comfort in so small places as car interior. Low inlet temperature, in addition to high air flow inlet velocity, gives very discomfort conditions for humans. Low air humidity level also creates thermal discomfort widely known as Dry Eye Syndrome. Comfortable conditions for passengers, especially for driver, assure faster reaction time, lower overall fatigue and, as a result, increase safety level during travelling.

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