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FUELS SAVING USING DIRECT ADIABATIC COOLING INSTEAD CONVENTIONAL AIR CONDITIONING FOR A TRACTOR CABIN

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Abstract:
The air conditioning of vehicle cabins is now standard equipment for vehicles. Increasing the consumption of fuel, the air conditioning also raises difficulties and costs with its integration in the electric and hybrid vehicles, because of the continuous or punctual absence of hot source as is the internal combustion engine. In this paper, we study the interest of the techniques of adiabatic cooling to cooling down a cabin of an agricultural machine. Recordings of the activity of a tractor in real situation are used for studying the temperatures inside the cabin along a typical working day. From these observations, we adapted a model to estimate the thermal exchanges of the cabin with the environment. The solar incomes are estimated under various countries in France and the ventilation rate is taken into account. We substitute then the air conditioning by a system that mists water droplets on the air admission for the cabin. The efficiency of this cooling system depends mainly of the atmospheric conditions and we establish, for various weather situations, the cooling capacity of this process. So the temperatures inside the cabin are assessed, as well as the water consumption. These results add to efficiency assessment about adiabatic cooling systems for industrial vehicles.

Keywords: *adiabatic cooling, vehicle compartment, thermal balance, fuel savings*

1. Introduction

Since years, attention is paid to the air conditioning systems used in automotive application because of their costs in fuel [1-4]. With the development of hybrid and electric vehicles PEV (Plug-in Electric Vehicles), the power costs related to air conditioning are more building: indeed, the energy required to provide cabin cooling for thermal comfort can reduce the range of PEVs from 35% to 50% depending on outside weather conditions [5]. New cooling systems are studied in order to reduce the energy needs for thermal comfort [6, 7].

This paper aims to study an alternative cooling system based on the adiabatic cooling: water droplets are sprayed in air and refresh it along their evaporation. The principle has been studied elsewhere for air conditioning in buildings [8, 9]. For transposing the system to vehicles, it is necessary firstly to describe it efficiency and pay attention to the autonomy regarding water. As the power consumption of HVAC (Heating, Ventilation and Air-Conditioning) systems directly depends on the thermal load of the vehicle cabin, the temperatures is of first importance. Field measurements of cabin temperature have been made in a tractor during one year. A specific behaviour is observed for this highly powered and low speed automotive application. From the analysis, we adapt a model to estimate the thermal exchanges of the cabin with its environment. Based on the model in [10], modifications have been proposed to account for the ventilation rate in the cabin. Our static model can then be used to assess the solar incomes in the cabin and resolve the dissipation of the thermal load inside. A sub model is added to describe the evaporative cooler and its effective cooling power.

2. Typical daily thermal load of the cabin of an agricultural vehicle

A tractor (Massey Ferguson 6480) was equipped with embedded sensors monitoring temperatures at different locations: three measurements are used in this analysis: a temperature sensor is located behind the driver seat to check for the tractor cabin temperature T_{cab}. Another one is based in the admission pipe just after the air filter and gives an idea about the air temperature T_{air}. A shell temperature T_{veh} is also monitored: the corresponding sensor is put in a thermo gum bath and fixes under the engine compartment.

This T_{air} value was compared with some meteorological data gathered at a meteorological station in the vicinity: a good agreement was found when the engine speed is high and air flows around the thermocouple. More discrepancies are observed on idling and starting periods, when the sensor undergoes the influence of high engine's temperature. The experiment ran one year, so it is possible to extract the thermal data over various weather conditions encountered in rather temperate region near Paris.

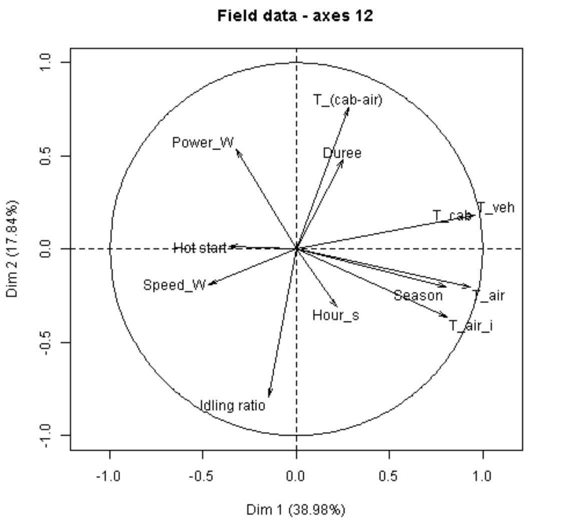

Figure 1. Principal component analysis results for temperature data of air, cabin and shell

A principal components analysis was made for 46 operations and Figure 1 shows the 2 first principal axis explaining 56% of data variance. The first axis is linked with a seasonal effect: the temperature of air increases, at the initial start as well as in average, when the season is hot. Both engine and cabin temperature undergoes the influence of the engine and tend to be higher when engine power is high or when operation duration is long. This trend is underlined when looking at the gradient between cabin and air temperature, which is highly correlated with operation duration. Hot starts $((T_{veh}-T_{air}) > 12.5$ °C) are often linked with transport operation with high speeds. These latest seem uncorrelated with high average of temperature for engine and cabin. Low gradient between inside and outside is also found when the idling ratio (idling time / total time) is elevated. The explanation is found when we look at the temperature evolution, reported in Figure 2. Black (ploughing) and red (sowing) curves correspond to winter operations and air temperature is around 15°C for both days. During ploughing, the cabin temperature increases slowly but continuously along the work. When sowing, temperature growing is often interrupted and then, the cabin is sharply cooled down: this is because the driver needs to get outside for operating manually: each temperature drop is linked with a period of idling. In blue, the air temperature is sweet (25°C) when the rollers were crossed. Although it is a sunny day, solar incomes are limited because work was done early in March. The temperature inside remains quite steady at 28°C and temperature drop on opening exists, but it is smoothed and very hard to detected. On the green curves, the air temperature is under 20°C but the day is in June, so that the cabin temperature increases above 30°C, showing the important effect of solar incomes. Temperature drops on this day are related to windows opening and not door.

From these measurements, it comes out that, as for cars, the high glass surface, needed to operate with tractors, results in high solar income in sunny days. A positive correlation is found between the power delivered by the engine and temperatures in both cabin and engine compartment.

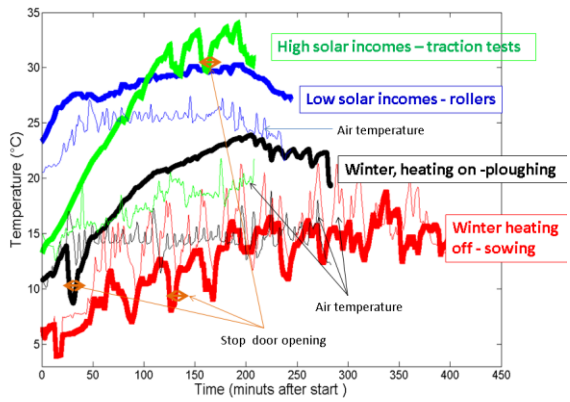

Figure 2. Measured temperatures versus time use in various and contrasted weather situations (winter w/o heating: red, winter heated: black, summer cloudy: green, summer sunny: blue, thin lines for air temperatures, thick lines for cabin temperatures)

But power has less effect than the impact of ventilation in the cabin. The ventilation rate is affected by windows and doors opening and sudden drops of the temperature cabin show that the thermal inertia of the cabin might be of less importance than the ventilation rate. Therefore, to study air conditioning in the cabin, we have first to adapt a static thermal model for cabin temperature and then modelling the cooling system, what is done in the next section.

3. Cooling effect of the adiabatic system on the cabin temperature

Air conditioning aims to offer driver good conditions for operation, by dehumidifying the air, heating in cold weather and cooling in hot climate. Cooling is the unique function that can achieve an adiabatic cooling system. This latest is indeed proposed, mainly for used vehicles, and recommended by the French Agency for Energy. As this system is poorly documented, we aim to study its beneficial impact and its water and energy consumption. That's why our attention is focused on cabin temperature control in hot climate. The assessment of temperature inside the cabin is based on the thermal balance of driver compartment between convection losses at walls and solar incomes through windows.

3.1 *Thermal exchange between tractor cabin and ambient air*

The thermal balance is inspired from the Marcos's work [10] but adaptations have to be made for dealing with agricultural vehicles. Changes are concerning the following items:

- Thermal equilibrium is supposed at each time step and the thermal inertia of the cabin base is neglected.
- Cabin ventilation is taken into account by introducing a ventilation flux that acts on the convection exchange coefficients.
- Thermal conduction within thin walls (windows) is neglected
- We distinguish the radiative contribution according to its wavelength. The long wave radiation (LWR) fluxes are neglected with regard of the solar contribution (short wave length (SWR). The total solar income is then equally distributed over surfaces according to their area.

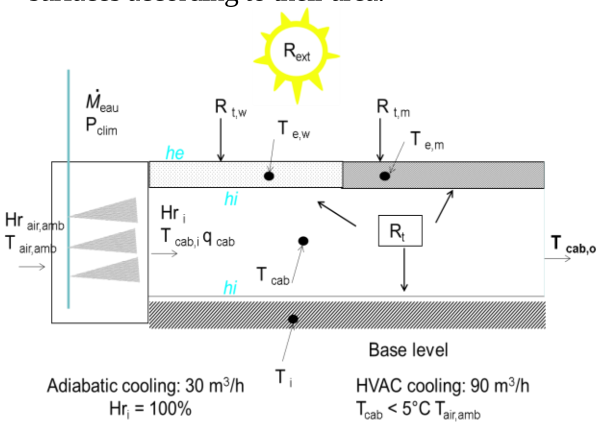

Figure 3. Thermal balance for the air flowing through the cabin

The radiative balance is simplified, so that the surface temperatures are not explicitly computed. These assumptions are made to provide a better fit with our field observations that underlines the role of ventilation. For SWR, the approximation is suitable for summer case where solar incomes are high, i.e., where air conditioning has to cool the cabin. It is also related to the high amount of glasses of cabin walls, that traps solar fluxes inside like a sunroom. The schema in Figure 3 describes both assumptions and notations used to assess the thermal balance inside the cabin. Radiation incomes are balanced with the convection on the entering air flow rate q_{cab}, what increases the air temperature along its travel inside the cabin.

Each of the exchange surfaces (internal, external) is supposed to be at the equilibrium, so that no heat is stored. The base level is adiabatic. Thermal equilibrium is written respectively for the external surface, internal surface, base level and also air, that is heated along its cabin travel through the convective transfer on solid surface. Conduction in solid walls is neglected and internal surface are equal to external surface due to the small thickness of both metal and glass. The cabin temperature is the average between air inlet and outlet temperatures. Rearranging terms leads to the following equation for the cabin temperature:

$$T_{cab} = \frac{2.q_{cab}C_{p,air}T_{cab,i} + T_{air}\dfrac{(A_{it}-A_{base})h_i.h_e}{(h_i+h_e).A_{it}} + R_t\dfrac{(h_i.A_{it}-h_eA_{base})}{(h_i+h_e).A_{it}}}{2.q_{cab}C_{p,air} + \dfrac{(A_{it}-A_{base})h_i.h_e}{(h_i+h_e).A_{it}}} \quad (1)$$

Windows transmit the whole incoming radiation directly to the internal surfaces. We assumed that opaque external surfaces also transmit the absorbed radiative fluxes to the internal surface: this contribution should be in fact in conductive/convective form rather than radiative. But by this way, the total incoming heat is transferred into the cabin and this avoids making the radiative balance for the shortwave radiation. This expression means that all the radiative flux is converted into convective heat evacuated by the air flow.

The radiative incoming flux at each wall is the sum of the direct solar flux (Idn), solar flux diffused by the atmosphere (Rpr) and solar diffused flux on the agricultural soil for vertical surfaces (Dpf, albedo=0.2) [11]. These fluxes are computed for each cabin side, considering the tractor works around on main direction δ_{work} with respect to South. The standard methodology used to assess the solar income is detailed in [11] and gives the incoming fluxes one each faces according to their orientation:

$$\begin{aligned} R_{face} &= R_{direct}(\theta_{face},\beta) + R_{Rpr} + R_{dpf}(\beta) \\ R_t &= \alpha_{glass}\sum_{vertixcal} R_{face}.A_{face} + \alpha_{Roof}S_{roof}.R_{roof}A_{roof} \end{aligned} \quad (2)$$

The transmission coefficient for glass is assumed at 0.86, what is a typical solar gain for simple windows. For the opaque wall, the absorbed flux ($R_{t,m}$) is completely re-emitted, by one part inside and one complementary outside. The part trapped inside is estimated using the solar gain of an opaque wall (see

[11]), with the description of roof layers in [10]. The total transmittance factor α_{roof} is then about 0.19:

$$\alpha_{roof} = \alpha_m \frac{U}{h_e} = \alpha_m \frac{1/\left\lfloor 1/h_i + 1/h_e + \sum_{layers} e_i/\lambda_i \right\rfloor}{h_e} \quad (1)$$

Side surfaces are represented on the Figure 4, which shows that the geometry is somewhat simplified: the metallic structure is not included and the base level is smoothed and treated as a completely plane surface made of 2 panels. The tractor cabin is nearly cubic with 1.5 m width, 1.4 m high and 1.5 m long. Its volume is about 3.74 m^3 and its surface of 11.85 m^2 is made of glass for 55%. The base surface is multiplied by 2 to account for the cabin equipment.

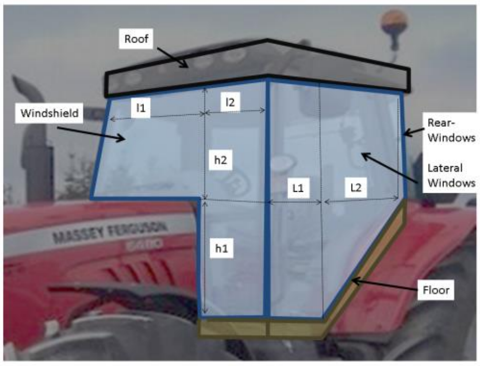

Figure 4. Schematic design of the tractor cabin and dimensions (m^2): A_{front}=1.70, A_{rear}=1.46, A_{lat}=1.73, A_{roof}=2.1, A_{base}=2.86

The air inflow q_{cab} is assessed from the directive 2009/144/CE (or EN 15695-1:2009), that imposes a minimal rate of 30 m^3/h of fresh air in order to protect drivers from pesticide emissions during crop treatments. The additional air flow related to door opening is not taken into account for comparison of cooling systems. When the tractor is parked, there is no airflow inside the cabin.

The convective exchange coefficient drives the air temperature in the cabin: when there is no ventilation, the h_i (internal side) is a low reference value taken for fixed walls in building: 10 W/m^2K. For the external side, the h_e is set at 25 W/m^2K: this takes into account that the tractor speed exists, even if it is rather low (5-8 km/h when working), and wind in open land also has an additional beneficial effect so that the external transfer coefficient is higher than inside. When the ventilation is switched on, air speed significantly raises due to the high air renewal rate imposed by tractor legislation. In this case, turbulent flows are encountered outside as well as inside the cabin. Then, the h_i is then increased up to the external value h_e. At the end, when cold air is provided inside the cabin, large temperature gradients are observed. The correlation provided in [1], for free convection, shows that the exchange coefficient rises up to 35 W/m^2K.

3.2 Adiabatic cooling system

Cooling systems are acting on the air temperature at cabin entry $T_{cab,i}$. Without any air-conditioning equipment, $T_{cab,i}$ is set at T_{air}. Adiabatic cooling consists in spraying water in the admission air: Fine water droplets are evaporated in the air generally within few ten centimeters after spray emissions [8] and air temperature decreases to reach the ideal value of the adiabatic saturation temperature:

$$T_{sat,in} = 0.2831\,.hr_{air}^{\ 0.2735}.T_{air} + 0.0003018\,.hr_{air}^{\ 2} + 0.01289\,.hr_{air} - 4.0962 \quad (2)$$

In this relation, T_{air} is the air temperature, expressed in °C and hr_{air} is the relative humidity of air, expressed in %. Assuming that the adiabatic saturation temperature is reached without any water losses, the required water flow rate is deduced from:

$$M_{eau} = \left(\frac{p_{sat}(T_{air})}{p_{ref}} - y_{air} \right) . q_{cab} \quad (3)$$

The equilibrium vapor pressure is assessed using the Nadeau and Puiggali formula, where T_{air} is in Kelvin:

$$p_{sat} = \exp\left(23.3265 - \frac{3802.7}{T_{air}} - \left(\frac{472.68}{T_{air}} \right)^2 \right) \quad (4)$$

The cooling power introduced with this fresh air is given by:

$$P_{clim} = q_{cab} cp_{air} (T_{air} - T_{sat,in}) \quad (5)$$

3.3 Conventional cooling system

HVAC is used both to cool and dehumidify the air inside the cabin. That’s why is switched on very often, even if the air and/or cabin temperature is low. The dehumidification function of HVAC is out of interest here, because the adiabatic cooling works on contrary to the HVAC and introduces huge amount of water vapor inside the cabin. Instead usual strategy of HVAC control, a simplify approach was used to approach cooling power.

The conventional system offers the advantage to keep the cabin cool even in case of high temperature outside. Therefore, the cooling system is supposed to work here only when the outside temperature is above 30°C. Then, the equation (1) is inverted in order to assess T_{air}, so that it maintains T_{cab} five degrees under T_{air}. This is a simplified way to estimate the thermal comfort linked with HVAC. It is not exactly a comfort temperature as it doesn't take into account for humidity and air speed.

But the resulting temperature at the inlet $T_{cab,i}$ was found very often under zero what is still unrealistic. This means that it is impossible to maintain the cabin five degrees above ambiance with a conventional air conditioner because inside the cabin, convection with the imposed flow of fresh air is not enough to overcome radiative heat. Therefore, an additional constraint on the air flow rate q_{cab} was introduced to ensure that the inlet air temperature is above usual evaporator temperature (3°C). That's why the q_{cab} is set at 90 m^3/h with HVAC.

Then, the cooling power is assessed using the same formula than for the adiabatic system. Extra fuel consumption related to HVAC for cars are detailed in [1]. The global performance of the air conditioning system is the ratio between the cooling power and power for the HVAC compressor. But on contrary to cars, the HVAC condensers for agricultural equipment are often supplied by electricity and not by the engine shaft. Therefore, conversion efficiency is introduced to reflect losses for converting fuel into electricity for the compressor supply. Extra fuel consumption is then written:

$$C_{fuel} = \left(P_{ventil} + \frac{P_{c\lim}}{COP_{HVAC}} \right) . \frac{1}{\eta_{conv}} . \frac{1}{LHV_{fuel}} \qquad (6)$$

Following [6, 7] , COP is about 2 and η_{conv} is set at 0.33 and P_{ventil} = 50 W corresponds to the power needed for fans [4].

4. Results

The static model is used to compute cabin temperature under various weather conditions: meteorological data (T_{air}, y_{air}, Idn and Rpr) are taken from [11] for 8 French countries identified by the name of their biggest cities. The time step of input data is one hour and the whole year (8760 h) of the typical climate is available for each country. Temperature cabin is computed under 4 conditions:

- T_{max} is the value obtained without any ventilation (q_{cab} = 0 m^3/h and h_{ti}, h_{te} are minimal). The Tmax value represent the temperature that can be achieved when the tractor is parked outdoors.
- T_{ventil} is the cabin temperature when air flows without any cooling system: this is the normal temperature in operating mode. (q_{cab} = 30 m^3/h and h_{ti}, h_{te} are intermediate)
- T_{clim1} is the cabin temperature when air is cooled with the adiabatic cooler before going inside (q_{cab} = 30 m^3/h and h_{ti}, h_{te} are high)
- T_{clim2} is the cabin temperature when air is cooled by an HVAC system so that $T_{clim2} = T_{air} -5$ (q_{cab} = 90 m^3/h and h_{ti}, h_{te} are high)

As the input data were also given during night, we had to select only the most interesting results with regard for air cooling. Therefore, in the following, results are selected using 2 criteria:

- hot diurnal situations (HDS): this criteria is proposed to exclude night and select the situations where cooling might be required

T_{ventil} > 25 °C and (Idn+Rpr) > 100 W

- Critical situations (CS): for this following criteria, no ventilation could achieve satisfactory conditions

T_{air} > 30 °C and (Idn+Rpr) > 100 W

First, the radiative solar incomes are computed. As they depend upon the main orientation, a specific analysis is made to check for the directional impact. Then, cabin temperatures are studied in HDS. Inlet air temperature and water consumption corresponding to the adiabatic cooler are examined. At least, both adiabatic and conventional cooling systems are compared for the critical situations.

4.1 Radiative solar incomes

The solar contribution is made of 2 components: direct and diffused flux, that sum varies from 0 up to 1200 W/m^2. Near zero flux is mainly for nights.

For a given direction of the tractor front, the solar incident flux on walls get inside the cabin and the global transmitted flux are reported on the Figure 5 as a function of the solar incident fluxes. The more elevated the solar specific flux is, the more incomes get inside. Solar incomes start at 500 W and can reach more than 2500 W (in South of France). Under hot diurnal situations, its average is about 1700 W.

For sunny days in North of France, the transmitted irradiance is about 2100 W, three times more what is measured in [10] for a car. The window area is also three times higher, what justifies such an elevated flux. The incoming radiative heat comes essentially from the windows, which contribute for 80% to the global income.

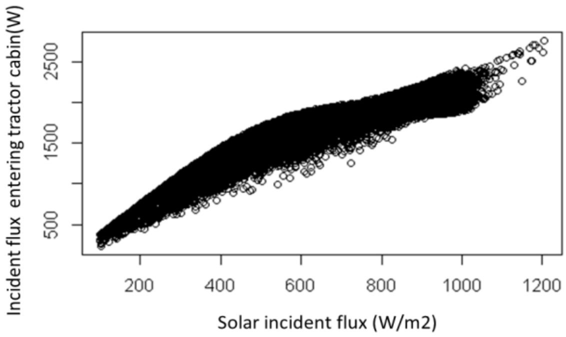

Figure 5. Solar income entering the cabin (W) versus solar incident radiation (W/m^2)

The Figure 6 shows average and maximal value of the solar income according to the position of the tractor with respect to the South: the most sensitive variable is the maximal flux that varies of less than 4% according to the tractor position. The average fluctuates less than 2% with the tractor main direction. As windows areas are quite equally distributed over each face, the solar income is rather independent of the tractor position.

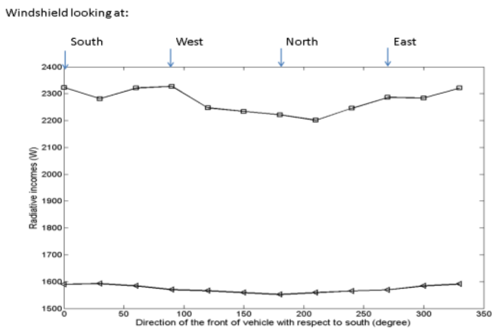

Figure 6. Solar incomes according to the vehicle front position with regards to the sun (square: maximal annual value, triangle: average value of percentile75)

4.2 Cabin temperatures

The solar incomes in tractor cabin are somewhat elevated and the temperature inside are therefore more elevated than air temperature. That is shown on the Figure 7 where the temperatures are averaged on each day for all countries and HDS: these conditions represent about 18% of the annual time. Even if summer's temperatures are higher, conditions for cooling needs exist all year round. Looking at T_{max}, the parking temperature is the highest: it can reach 55°C but its average stays near 38°C.

Hot cabin temperatures are found even with low ambient temperatures (15°C). As soon as the ventilation starts, the cabin temperature decreases and stays half of the time under 30°C. In the middle of the year, cabin temperature increases more frequently above 30°C.

The ventilation is not enough to dissipate the solar heat. With the adiabatic cooling, a significant decrease of the temperature is observed in the cabin: in average, the temperature falls of 3 °C compared to the case "ventilation only", but it is always higher than 20°C and the median is even above 28°C.

We didn't find any situation where the temperature cabin is below the air temperature, although the inlet temperature always is. This means that the cooling power introduced with air is insufficient and higher air flow rates should be used to increase the cooling capacity of the system.

The inlet temperature is represented in Figure 8, part a. In average, the air flowing out of the adiabatic system is 5°C less than ambient air: if the ambient humidity is high, the ambient temperature is near the adiabatic saturation temperature. Hence, the temperature gradient between air and inlet fluctuates accordingly with the humidity of more than 5 degrees.

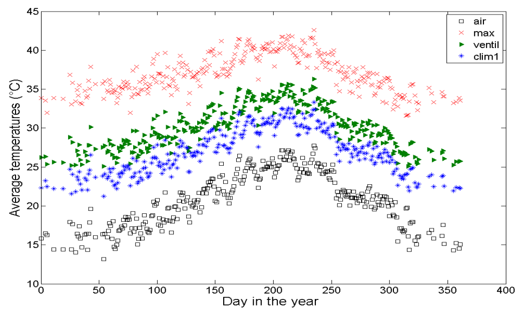

Figure 7. Cabin temperature averages in hot diurnal situations for each day under various climates and related average of air temperature

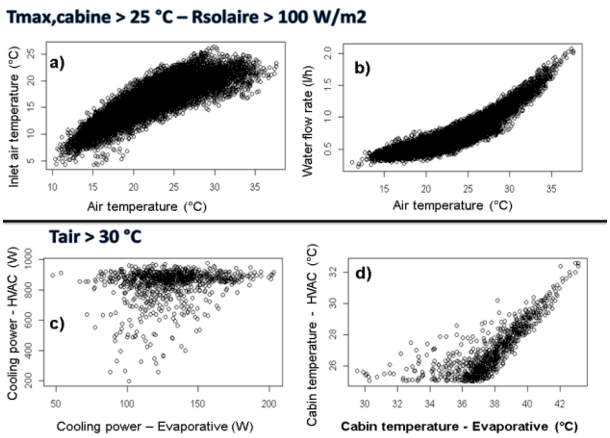

Figure 8. In the upper part, a) - air inlet temperature and b) water consumption of the adiabatic system according to ambient air temperature for common situations – In the lower part, c) cooling power of the conventional HVAC versus adiabatic system in critical situations, d) cabin temperature with HVAC versus adiabatic system in critical situations

In the part b of the Figure 8, is reported the water flow rate needed by the cooling system: water needs increase with the air temperature and can reach 1.2 l/h for 30 m3/h of air flow. Ambient humidity also explains the fluctuations of water rate for a given ambient temperature. Minimal flow rate are found at low ambient temperature (0.1 – 0.4 l/h). As standard human, working light, produces 60 g of water / h and 50 W of sensible heat it is shown that the adiabatic cooling introduce much more water in the cabin than the driver does.

The lower part of the Figure 8 is dedicated to extreme conditions, when air is above 30°C outside. In these conditions, outside air is very dry and the water flow rate need by the adiabatic cooler is high and above 0.75 l/h. The cooling power of the adiabatic system is generally about 130 W and levels out 200 W. The cabin temperature rises up to 36-40°C and the adiabatic system is overwhelmed; 900 W would be needed by a conventional HVAC to maintain the cabin five degrees below the ambiance. This value is rather constant and is corroborated by measurements in [5]. The corresponding extra fuel consumption is about 0.14 l/h. This is one third less than the estimated for diesel cars in [1]: a finer assessment of the COP in high ambient temperature should be required for a better estimate extra fuel consumption.

Table 1. Hours per year of hot common situations (HCS) and critical situations (CS) in different cities of France and average functioning of adiabatic cooling – $\Delta T = T_{clim1} - T_{ventil}$ and HVAC in CS only ($-\Delta T' = T_{air} - T_{clim} = 5°C$])

	HCS Hours Per year	HC Hours Per year	ΔT (°C) Evapor. Sys.	P_{clim} Evapor. Sys (W)	P_{clim} HVAC (W)	M_{water} (l/h)	T_{air} (°C)	Humidity Air (%)
Rennes	1286	79	-3	68	794	0,68	22,3	0,57
Trappes	1328	40	-3	72	789	0,67	21,6	0,53
Nancy	1396	99	-3	74	775	0,72	22,7	0,53
Macon	1520	120	-3	75	777	0,76	23,4	0,54
La Rochelle	1601	68	-3	61	807	0,64	22,1	0,61
Agen	1706	120	-3	73	786	0,72	22,9	0,55
Carpentras	2172	356	-3,3	94	808	0,88	24,7	0,45
Nice	2174	20	-2,9	57	803	0,65	22,9	0,63

In Table 1 are summarized the average cooling power developed by the adiabatic system and compared to the cooling power of conventional HVAC. These, as well as the temperature drop with the adiabatic system, depend weakly of the local climate. The variable that is the most sensitive to the climate is the water consumption, increasing of 30% in arid region. The most significant change with climate is not the way of functioning of the system, but the probability to find hot or critical situations.

5. Conclusion

Field measurements of the temperature inside a tractor are analysed and suggest that conduction could also enhance the temperature near the driver. Observations also stress that the driving in tractor is often interrupted: opening and other constraints for implement monitoring disrupt the thermal comfort and temperature drops suggest that the thermal inertia of the cabin seems weak. Further, the temperature inside is mathematically described by the thermal balance between convection losses at walls and solar incomes through windows.

An idealised system of adiabatic cooling is added and equations are given for estimating the air temperature after the cooler, as well as the water flow rate needed to cool in function of ambient condition. An additional equation is proposed for assessing the equivalent fuel cost of HVAC, so that fuel gains can be established.

Solar incomes are higher in the tractor cab than in cars because of the biggest window area. Radiative incident fluxes are 1.6 kW in average and it is independent of tractor front direction. Roof contribution represents 20% of the incoming energy. The maximal temperature in the cabin is achieved when the tractor is parked outside under the sun. Its average is reached 30° and 55°C is observed on adverse conditions. The ventilation, used alone, is sufficient to drop temperature of 10°C in winter and 5°C in summer. In hot diurnal situation, adiabatic cooling removes 3°C more, by introducing an inlet air being 5°C under the ambiance. The system is sufficient to maintain cabin temperature above 30°C in average, but with an high humidity. Such a system doesn't provide an effective cooling in critical situations. Under high ambient temperature, both significant air cooling and high ventilation rate are required to maintain the cabin above the ambiance.

Producing a cooling power 7 time higher, HVAC can lower the temperature inside the cabin under critical ambient temperatures and the estimated for extra fuel consumption are found very low compared to the hourly consumption of these heavy diesel engine. On the annual basis, the probability of critical situation is mainly dependant on the climate and it gives more contrast on gains that functioning assessment.

The water consumption is about 0.3 l/h and jump up to 1.2 l/h in adverse conditions. A higher efficiency of this system could be found by increasing the air flow rate inside the cabin, but water need would increase in proportion with the air flow rate. It would also lead to elevated air velocity inside the cabin that could also modify comfort acceptance, making cooling need of less importance.

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Nomenclature

Symbol
α: tranmission coefficient
β: wall slope (degree)
δ: tractor orientation with respect to South (degree)
η: efficiency
θ wall orientation with respect to South (degree)

Letters
A: aera (m2)
Cp: specific heat capacity (J/kgK)
COP: coefficient of performance
h: convective exchange coefficient (W/m^2K)
hr: relative humidity (%)
Idn: directionnal solar incident flux (W/m^2)
Rpf: diffused by atmosphere solar incident flux (W/m^2)
Dpf: diffused by soil solar incident flux (W/m^2)
LHV: low heating value (J/kg)
M: water flow rate (l/h)
p: pressure (Pa)
P: power (W)
q: air flow rate (m^3/h)
R: incoming short wave irradiance
T: Temperature (K or °C)
U: overall heat transfer coefficient (W/m^2K)
y: absolute humidity (kg water vapor /kg dry air)

Subscript
- air: ambiant air
- cab: cabin
- conv: conversion
- e: external
- HVAC: conventionnal air conditionner
- i: inlet or internal
- it: total internal
- m: metal
- o: outlet
- ref: reference
- sat: saturation
- t: total

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НАМАЛЯВАНЕ НА РАЗХОДА НА ГОРИВО ПРИ ИЗПОЛЗВАНЕ НА АДИАБАТНА КЛИМАТИЧНА СИСТЕМА ВМЕСТО КОНВЕНЦИОНАЛНА ЗА КАБИНА НА ТРАКТОР

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Резюме:

Климатичните системи са стандартно оборудване за транспортните средства в наши дни. Те водят до увеличаване на разхода на гориво, а интегрирането им при електрическите и хибридните автомобили създава допълнителни проблеми с липсата на автономен източник на енергия. В тази публикация е изследвана възможността за използване на адиабатна климатична система за охлаждане на кабината на трактор. За изследване на температурата в кабината са използвани експериментални данни по време на реална експлоатация на трактора в типичен работен ден. С помощта на тези данни е адаптиран модел за изчисляване на топлообмена между кабината и околната среда. Постъпващата слънчева енергия е изчислена за различни региони във Франция, като степента на вентилация на кабината също е взета под внимание. При симулационните изследвания е заменена конвенционалната климатична система с такава, която разпръсква вода на малки капки на входа на вентилационната система на кабината. Ефективността на изследваната система зависи основно от атмосферните условия, като е направена оценка на възможността за охлаждане при различни климатични условия. Определена е температурата в кабината както и разхода на вода от системата. Тези резултати показват възможност за подобряване на енергийната ефективност на индустриални транспортни средства при използване на адиабатна климатична система.

Ключови думи: *адиабатно охлаждане, автомобилно обзавеждане, топлинен баланс, разход на гориво*