Going the Extra Mile: Evaporative Refrigeration to Save Energy in Electric Vehicles

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Summary

Evaporative cooling is the most ancient refrigeration system, as it makes use of the enthalpy of evaporation of the water to generate a temperature drop. Compressed-based is the most broadly-extended refrigeration system, but with the current focus in energy efficiency evaporative cooling is fighting for its place in domestic and industrial applications as it overcomes the efficiency limits of compressed-based refrigeration, beeing able to save up to 80% energy.

The purpose of this idea is to import this technology to the automotive industry to strongly reduce energy consumption in refrigeration. The main challenge is to adapt it to the strict requirements of the automotive industry such as packaging, NVH, safety, costs, reliability and comfort; but it has the potential of beeing one more history of success of technologies imported from other engineering applications.

1 Introduction

Evaporative cooling works by employing water large enthalpy of vaporization which is one of the highest known. It is an adiabatic process in which the air temperature drops through the phase transition of liquid water to water vapor using much less energy than a refrigeration cycle. In the trasition the water takes the energy needed for evaporation from the air in the form of sensible heat, whilst the air remains at a constant enthalpy value [1].

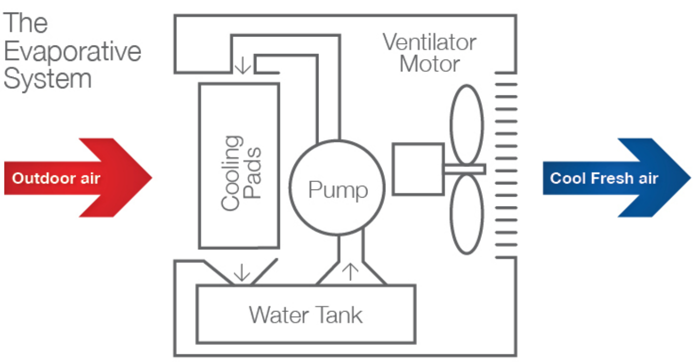

Fig. 1: Direct evaporative cooling working principle

Evaporative refrigeration is the most ancient cooling power generation system. Indeed, perspiration (or sweat) is an example of natural evaporative cooling. Before electric energy and coolants existed our ancestors invented a refrigeration system taking advantage of natural renewable sources to cool rooms or preserve food [2]. Machines that produce cooling from fossil fuels or electricity, which is the current technology, first appeared in the industrial revolution.

Externally mounted aftermarket evaporative cooling devices were popular in automoviles since the 1930s to the 1960s to cool interior air. There were fan-powered coolers and ram-air ones that needed vehicle motion to force the aire into the tube. The cooler was able to provide refrigeration for 160-240 km with 3.8 l of water. However, evaporative cooling in automotive industry disappeared when modern vapour-compression aire conditioning became widely available in the same manner 1900s electric vehicles were set aside by combustion vehicles for decades.

Fig. 2: Car coolers mounted on 1950s vehicles

With the current focus on efficiency, evaporative refrigeration has come back and is a cutting-edge alternative technology for domestic, commercial and industrial applications. Nowadays, many international firms are implementing passive cooling strategies as a part of a movement towards a more ecological and sustainable approach [3, 4]. This can be seen in significant projects such as Masdar City in Abu Dhabi, where various concepts and techniques have been implemented to avoid an increased cooling load [5].

2 Engineering Objective of the Presented Idea

This idea aims to extend the application of evaporative cooling to the automotive industry. The objective is to develop an evaporative cooling system for automotive application as an alternative to the current compressed-based technology.

Vehicle refrigeration is a need in hot weather conditions, but it increases consumption and is especially unfavorable for electric vehicles because it lowers the range. The reduction of cooling consumption is currently a matter of study. For example, the European project IMPROVE in which IDIADA is involved aims to lower electric consumption by 20% through a better control of the energy consumers.

However, even though there is room for optimization, the compressed-based cooling system has a physical efficiency limit that cannot be overcome unless it is replaced by other technology that does not rely on electric energy, such as evaporative cooling. Evaporative cooling domestic applications claim a consumption reduction up to 70-90% in comparison to compressed-based technologies because the only energy consumers are the pump to circulate the water spray and the fan to circulate the air, for this system the consumable fuel is just the water that the system evaporates to take advantage of its latent heat.

As advantages both for electric and combustion vehicle applications:

- The system will produce refrigeration while ventilating the vehicle with fresh exterior air instead of recirculation and provide an adequate level of humidity
- It will also increase its effectiveness as exterior temperature increases, on the contrary to compressed-based refrigeration
- Consumption reduction and range extension for electric vehicles
- It is environmentally friendly as it does not require refrigerant liquids and does not contribute to ozone depletion
- It will not significantly reduce the power available for vehicle traction when using refrigeration

3 Proposed Path towards Results

The main challenge is to adapt this already existing technology sized for domestic and industrial cooling to the requirements of the automotive industry such as packaging, NVH, safety, costs, reliability and comfort. The different alternatives to obtain evaporative cooling, namely direct and indirect evaporation, should be studied as well as their cooling capacity in different locations and ambient temperatures to select the most adequate option for automotive use.

The process should start with a feasibility study in which the following evaporative cooling architectures would be studied for an automotive application:

- Direct evaporative unit
- Indirect evaporative unit
- Direct evaporative unit as support to compression-based unit
- Indirect evaporative unit as support to compression-based unit

The cooling potential for evaporative cooling is dependent on the difference between dry-bulb temperature and wet-bulb temperature. In arid climates, direct evaporative cooling can provide enough refrigeration to substitude compressor-based cooling with the added benefit of conditioning the air with more moisture for the human comfort. In humid climates and hot, indirect evaporative cooling can still mean an advantage without increasing humidity.

The feasibility study would aim at verifying the cooling capability and energy gains in automotive use, as it is a system that is already feasible for domestic and industrial use. Figure 3 shows the results of an study of the potential of evaporative cooling in a representative summer climate for Salt Lake City [6]. The colored lines illustrate the potential of direct and indirect evaporative cooling strategies to expand the comfort range in summer time, while the blue shadowing represents the statistic distribution of the dry bulb temperature and humidity from June to September. Direct evaporative cooling strategies that involve the humidification of the air should be implemented in dry conditions where the increase in moisture content stays below recommendations for occupant's comfort, while indirect evaporative cooling could be applied to higher humidity conditions. The indirect evaporative cooling potential has been proven for a variety of European cities for the statistically more unfavourable conditions [7].

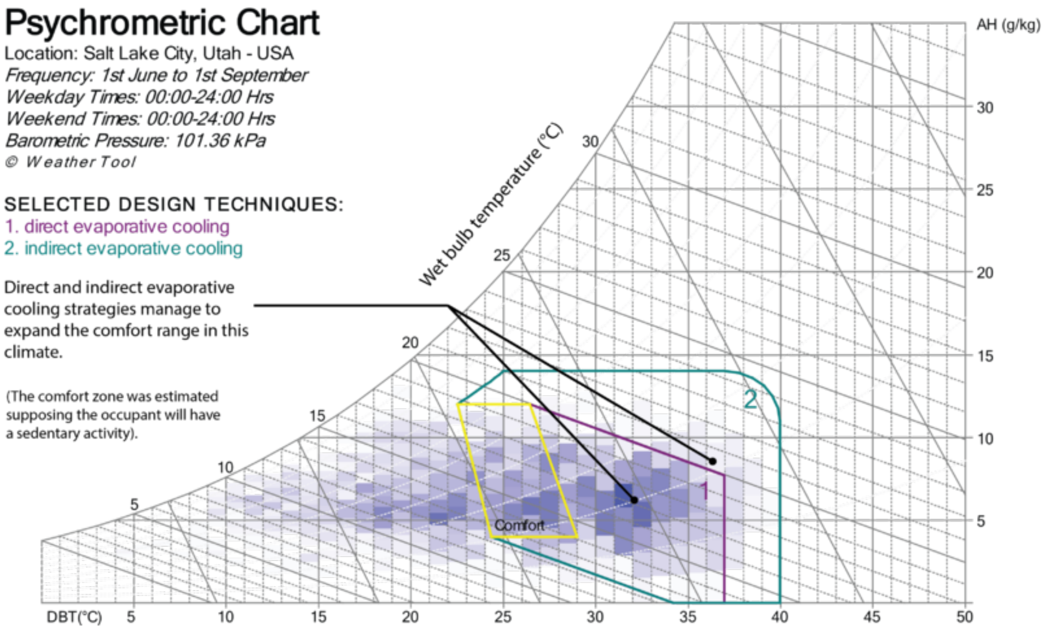

Fig. 3: Psychrometric chart example of Salt Lake [6]

The feasibility study would simulate the cooling capacity, passengers comfort and energy savings with the four abovementioned evaporative cooling architectures in a variety of climate conditions both for electric and combustion vehicles. The results of the feasibility study should conclude with the best architecture option for each climate condition and which is the best compromise solution for an automotive application for a mixed cimate combination.

The feasibility study would be followed by a design phase in which the packaging would be deeply studied as well as the main vehicle functionalities. In this phase the evaporative-cooling component for automotive use will also need to be developed, as it will strongly differ from the domestic use equipments. At the end an automotive prototype of the component should be developed to integrate it into an electric vehicle in order to finally validate the energy efficiency increase and cooling capacity in a variety of climate conditions.

4 Foreseen impact of this study

The foreseen impact is an 80% energy saving in refrigeration with increased effectiveness as exterior temperature rises and avoiding the use of coolant liquids that can affect the environment. The system is expected to produce a temperature drop of up to 20ºC between exterior and interior temperature while ventilating the vehicle and to be able to refrigerate the interior air of a C-segment vehicle for 250 km with 4 liters of water. With these figures, the biggest challenge is to develop a prototype for automotive applications, but the outcome may be very rewarding, especially for electric vehicles.

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