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Coatings to Prevent Frost: Less Defrosting - More Energy Efficiency

Stefan Holberg[1], Ricardo Losado[1], Jesper Weinkauff Kristoffersen[1], Klavs Kamuk[2], Finn Nielsen[2], Noemí Arconada[3], Marta Hernais[3] & Jacob Ask Hansen[1]

[1] Danish Technological Institute, Aarhus, Denmark (E-mail: SHG@teknologisk.dk / www.dti.dk).

[2] Exhausto A/S, Langeskov, Denmark (www.exhausto.com). [3] TEKNIKER, Eibar, Spain (www.tekniker.es/en).

Abstract

In laboratory tests on real heat exchangers, novel anti-ice coatings have shown great potential to save energy. In winter, heat exchangers for heat recovery ventilation and heat pumps accumulate ice and require periodical defrosting. The applied organic-inorganic hybrid coatings increased the time between two defrosting cycles by a factor of about 2.5.

Introduction

Frost affects various devices such as wind turbine blades, airplane wings, electrical power lines or pipelines. The present work in the frame of the EU FP7 project EnE-HVAC originated from two specific heating and ventilation problems. The first is air-to-refrigerant heat exchangers of heat pumps using outside air as heat source (evaporator in fig. 1). Typically, the heat exchanger fins are cooled below 0°C when the outside temperature is below about 7°C. The second is air-to-air heat exchangers of heat recovery ventilation (HRV in fig. 1). Typically, at outside temperatures below about -3°C, the more humid outgoing air is cooled to temperatures below 0°C. In both cases, ice accumulates on the respective surfaces, impairing the heat transfer and requiring periodic defrosting by heating, thus consuming energy.

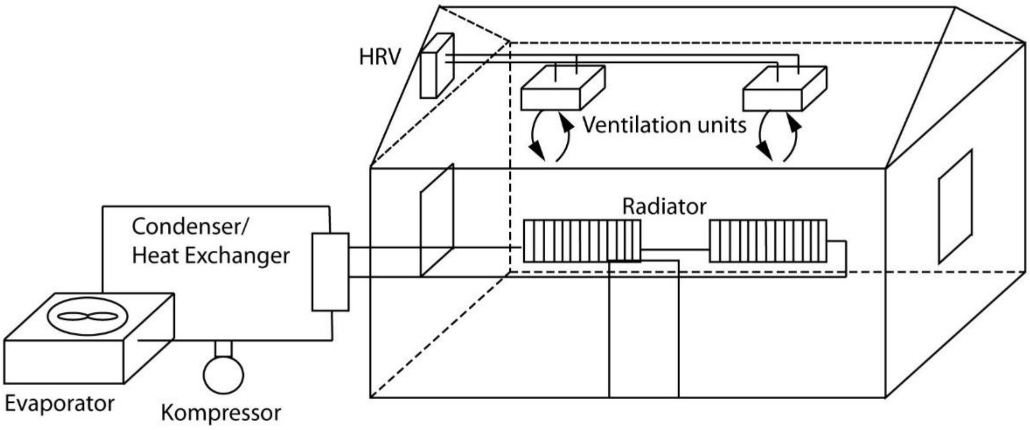
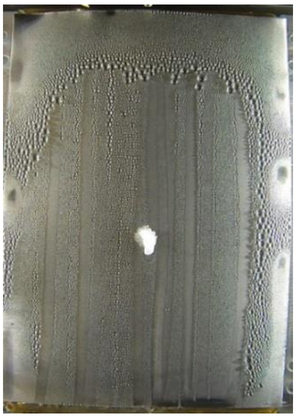


Figure 1: Schematic of a building with heat pump and heat recovery ventilation

Anti-ice effect

Scientists have put effort into anti-icing surfaces, either to reduce ice adhesion or to depress freezing, i.e. to retard the first ice nucleation on a wet surface [1] [2]. However, the efficiency of frequently applied superhydrophobic surfaces under conditions of high humidity, airflow or icing/de-icing cycles has been critically questioned [2] [3].

We followed a different approach. We tolerated freezing, but inhibited the spreading of the frost and improved the drainage of liquid water. On aluminium fins or plates of heat exchangers between 0°C and about -10°C, humidity condenses as liquid water and freezes only occasionally at distinct spots. However, when the first spot freezes, the frost distributes almost instantly over the whole surface below 0°C. This is due to a continuous water film on the surface. Further humidity deposits directly as frost and subsequently blocks the flow. By applying an about 3 µm thick, hydrophobic, organic-inorganic hybrid coating to the surface, the condensed water forms distinct drops that are not connected; frost spreads about 1000 times slower (see fig. 2, left). The tested coating is smooth (no lotus effect, not superhydrophobic), but provides high advancing (104°) and receding (87°) water contact angles and a rather low contact angle hysteresis (CAH). CAH is the difference between an advancing and receding contact angles. Low CAH is not only advantageous to inhibit frost spreading, but also improves drainage by making it easier for drops to slide down (see fig. 2, right). A further improvement of the coating is expected.



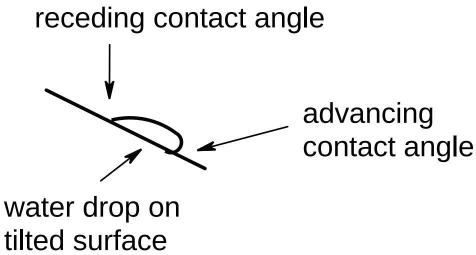


Figure 2. Left: Aluminium plats (10 x 15 cm) with anti-ice coating hold at -4 °C for 20 min after placing ice in the middle. The frost did not spread. Environment +12°C, 90% rel. humidity
Right: Schematic of a water drop on a tilted surface

Test on a real heat exchanger commonly applied in heat recovery ventilation

A heat exchanger coated with the anti-ice coating was compared to an otherwise identical reference with a bare aluminium surface. In test runs under identical conditions, the outgoing air on the cold side was cooled to approximately -5 °C, heat transfer of both heat exchangers was identical. The flow was held constant and the pressure drop was monitored. A pressure drop over 400-500 Pa indicates that the heat exchanger is blocked and defrosting is necessary. As shown in fig. 3 (left), the coating increased the time between defrosting cycles from about 1 h to about 2.5 h. On the reference, frost forms mainly inside, between the plates. On the coated heat exchanger, water froze at and after the outlet, forming icicles as shown in fig. 3 (right). The icicles do not necessarily block the flow.

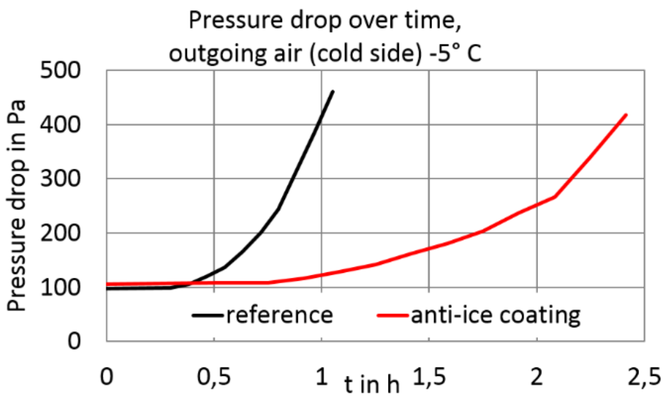


Figure 3: Left: Test run with a heat exchanger with anti-ice coating and an uncoated reference showing the time until the pressure drop reaches about 450 Pa due to frost blocking the flow
Right: Icicles at the outlet of the heat exchanger with anti-ice coating

Acknowledgement

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