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МОДЕЛЮВАННЯ ПРОЦЕСІВ КОНДЕНСАЦІЇ ТА ЗАМОРОЖУВАННЯ ПЕРЕХРЕСНОПЛИННОГО ПЛАСТИНЧАСТОГО ТЕПЛООБМІННИКА СИСТЕМ ВЕНТИЛЯЦІЇ

CONDENSATION AND FROST FORMATION SIMULATION IN CROSS-FLOW PLATE HEAT EXCHANGER FOR VENTILATION SYSTEMS

В статті розглянуті питання математичного моделювання процесів конденсації водяної пари та заморожування в перехресноплинному теплообміннику Lossnay систем вентиляції. Результати моделювання представлені у вигляді розподілу температури пластини, залежності критичної відносної вологості в приміщенні від температури зовнішнього повітря.

В статье рассмотрены вопросы математического моделирования процессов конденсации водяного пара и замораживания в перекрестноточном теплообменнике Lossnay систем вентиляции. Результаты моделирования представлены в виде распределения температуры пластины, зависимости критической влажности в помещении от температуры наружного воздуха.

In this article issues of condensation and frost formation simulation in cross flow plate heat exchanger Lossnay in ventilation systems are considered. Results of simulation are presented in the form of wall temperature distribution on heat exchange surface, dependence of critical relative humidity of room air on outside air temperature

In cold climates heat recovery in ventilation systems can significantly reduce the load on the building heating system. Cost-effectiveness of using heat exchangers is evident in the climatic conditions of Ukraine. Thus, the greater the temperature difference between outdoor and room air, the greater the economic benefit from its use. But due to application of modern highly efficient heat exchangers on the surface often occurs condensation and frost formation. Therefore it is very important to calculate heat and mass transfer, take into account these factors and find an optimal freezing control strategy.

Let’s consider the physical nature of these processes. In heat exchanger exhaust air at low outside air temperature is cooled below the dew point temperature and water vapor condenses on the heat exchange surface. If the heat exchanger surface temperature is below freezing point, the condensed water freezes. By-turn constructive measures to improve the efficiency of the heat exchanger lead to reducing exhaust air temperature and thus increase the frequency of condensation and frost formation.

Condensation on the one hand, increases the efficiency of the heat exchanger due to latent heat of water vapor. On the other, in the absence of conditions for condensate removal the layer of condensate reduces the heat transfer. There may cause the reduction of the effective cross-section of heat exchanger channel, which would increase the pressure losses. Frost formation also reduces heat exchanger efficiency and exhaust air will overcome greater pressure loss due to the frost growth that will block air flow. If defrosting system for heat exchanger in ventilation system is not provided, the exhaust air channels will be completely blocked. Most papers on condensation and frost formation are focused on analysis of refrigeration and cannot always be used for air-to-air heat exchangers in ventilation systems.

Following factors have a significant impact on heat exchanger operation in freezing conditions [1]:

• Exhaust fan aerodynamic characteristics;

• Heat exchanger horizontal or diagonal placement;

• Air flow direction;

• Design of heat exchanger (open or channel type).

Prediction of recuperative heat exchanger behavior in such conditions is difficult, because heat-transfer analysis requires the use of specific computational methods. The aim of this work is to simulate the heat and mass transfer in cross-flow plate heat exchanger during condensation and frost formation. Investigation of this problem will help to predict the condensation and frost formation on the surface of heat exchanger and make correct decisions to prevent heat exchanger freezing. Through cross-flow air flows direction the heating and cooling of exhaust and supply air is uneven, which complicates the calculation. The finite element method was used for simulation. As we consider the total heat recovery (energy recovery), then for each cell the equation of heat transfer and heat balance and mass transfer and mass balance can be written. Such simulation shows the "cold corner" presence, where the exhaust air cools the most intense way.

Using this method the following assumptions were accepted:

• Energy of phase transition water / ice was not included in the calculation;

• Condensate temperature and the temperature of the plate are equal (because of the large heat-transfer coefficient of condensate to the plate);

• When condensation occurs without freezing condition condensate is removed with air flow, the condensate is formed in a thin film and its influence on the hydrodynamics of flow is small, the thermal resistance of condensate is neglected.

Let’s consider the effect of heat exchanger placing and flow direction on the process of condensation and frost formation on the example of Lossnay based settings LGH 15 - RX4 Mitsubishi Electric Company. In this case, we deal with channel type total heat exchanger, so the condensate can move only through the channels. In this model there are two possible cases of diagonal heat exchanger arrangement (Fig. 1).

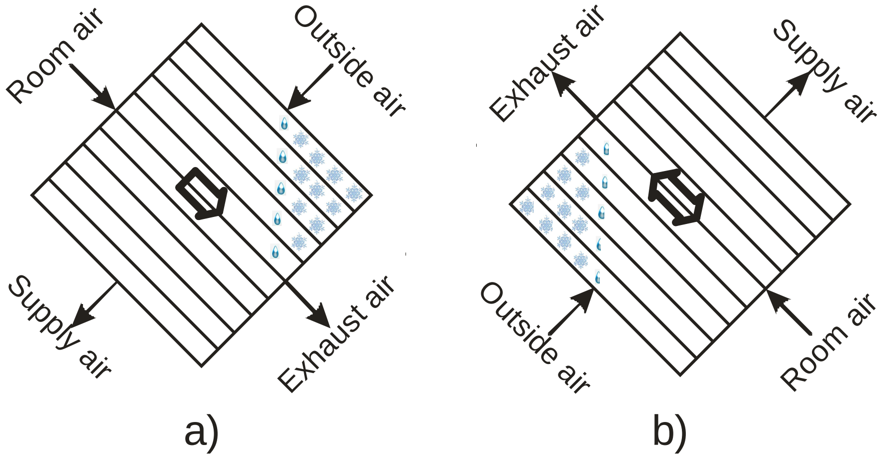

Figure 1 - Diagonal placing the heat exchanger, Room air (RA), Exhaust air (EA), Outside air (OA), Supply air (SA)

When placing a heat exchanger by scheme a) (Fig. 1) gravity and air flow cause the transfer of condensate in the cold zone. Thus the large amount of condensate reduces the freezing risk, while small - increases. If the heat exchanger is placed by scheme b) (see Fig. 1) gravity and air flow acts in different directions. If gravity prevails the air flow, the condensate flows down in a warm zone in another case - the process is similar to the scheme a).

To detect the condensation zone we calculate the dew point temperature of exhaust air in each element and compare it with the temperature of the plate. Necessary condition for condensation:

$t_D \geq t_S$, where t_D - dew point temperature, t_S - surface temperature.

Fig. 2 shows the plate temperature distribution on the side of exhaust air. This figure clearly illustrates this uneven distribution.

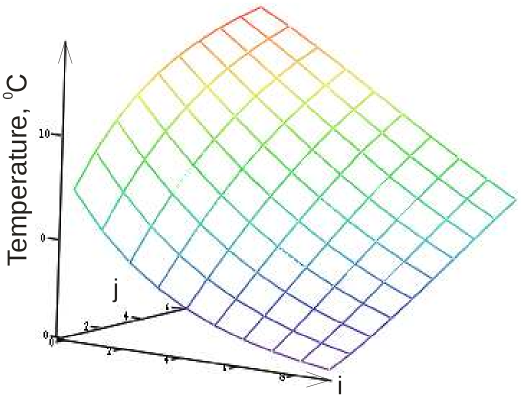

Figure 2 – Plate temperature distribution on the side of exhaust air

Comparing the process of condensation in total and sensible heat exchangers, zones of condensation in this case will be different. In total heat exchanger due to mass transfer between air flows exhaust air moisture is reduced through a heat exchanger. That's why the conditions for condensation occur later than in latent heat exchanger. Condensation zones for these two types of heat exchangers are depicted in Fig. 3.

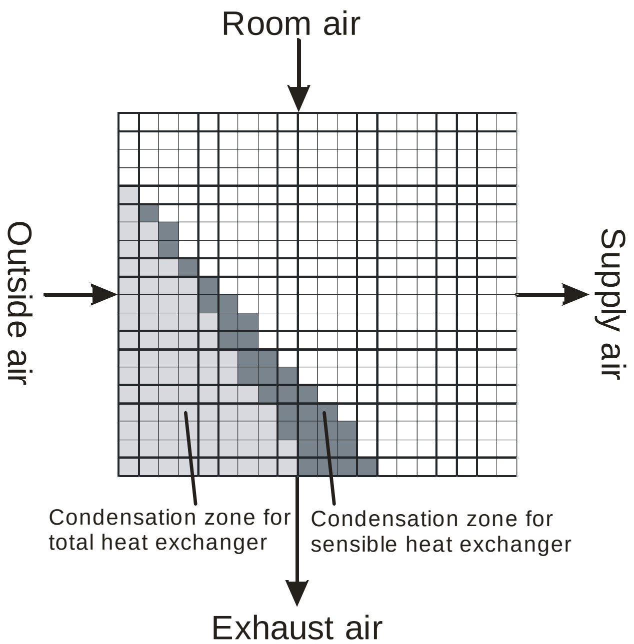

Figure 3 – Condensation zones for two types of heat exchangers

The interesting issue in terms of heat exchanger freezing is boundary room air relative humidity, at which there is substantial freezing of the surface heat exchanger. For example, dependence of boundary room air relative humidity on outside air temperature at constant room air temperature and outside air relative humidity (t_{RA}=20 °C, φ_{OA}=85 %) (Fig. 4) provided that conditions for frost formation occur on 15% of heat exchanger surface.

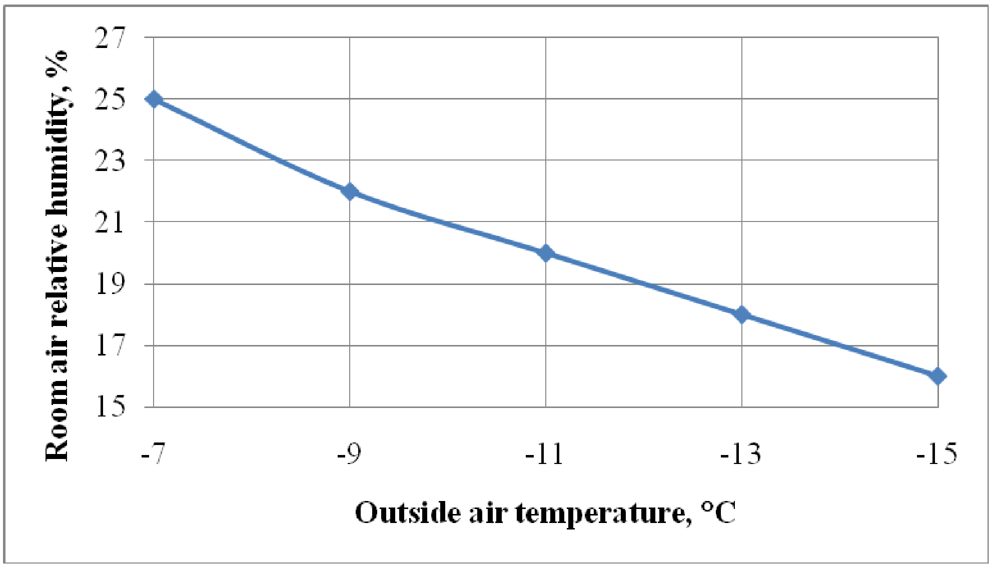

Figure 4 – Conditions for frost formation on 15% of heat exchanger surface

When analysing the data, note that they have a theoretical character, since in practice there may be a deviation from the calculated values.

Methods of frost formation control freezing

Partial heat exchanger freezing is acceptable for several reasons: public buildings do not operate at night when the temperature decreases, the partial heat exchanger freezing in short time has a small influence on energy efficiency, absolute moisture in such areas rarely exceeds 3.8 g / kg, so often there is no condensation.

Supply air preheating

The problems of condensation and freezing can be avoided by pre-heating supply air before heat exchanger, but it reduces utilized heat flux and, thus, energy recovery performance. It is also possible to preheat the supply air only within the "cold corner", but it is structurally difficult to make.

Adjusting the ratio of supply and exhaust air mass flow

Reduced air flow of cold air results in lower exhaust air cooling and reduces the risk of condensation and freezing, but the ratio of air flows must be at least 0,5. This measure, like the previous, lowers energy performance of heat exchanger, but it is used quite often.

Reduced heat transfer coefficient

The point of this method is constructive reduction of heat transfer coefficient within the "cold corner", which reduces the risk of heat exchanger freezing. However, during operation in non-condensing period heat exchanger is also working with reduced efficiency.

Heat exchanger defrosting

There are several ways to defrost the heat exchanger:

• Complete defrosting: in this case, supply fan is turned off and heat exchanger is blown with warm exhaust air over some time (usually up to 10 min.);

• Partial defrosting: for using this method we should be able to open and close individual channels, so the heat exchanger can be defrosted slowly, control system in this case is more complicated than for the previous way.

Methods of regulation

There are following ways of frost formation regulating in heat exchanger:

• Sensor of outdoor air temperature (in this case producer estimates dangerous temperature for typical temperatures and humidity in the room);

• Sensor of exhaust air temperature within the "cold corner", which is more efficient compared to the previous method;

• Sensor of exhaust air differential pressure: using the pre-set value of pressure difference on the heat exchanger, this method is the most accurate and efficient.

References

1) Vishnevskiy E.P. Features of the efficient functioning of recuperative heat exchangers in harsh climatic conditions, Journal «S.O.K.», №1/2005, p. 84-91
2) Lipa A.I. Air conditioning. Foundations of the theory. Modern technologies of air-handling. Izd. vtoroe, pererab., dop., Odessa: OGAH, Izdatelstvo: «Izdatelstvo VMV», 2010. – 607 p., il.
3) Diskin M.E. Efficiency of heat recovery in ventilation systems at outdoor temperatures below the danger of frost, Journal «AVOK», №2/2006
4) R. Ostin, S. Andersson, Frost growth parameters in a forced air stream, International Journal of Heat and Mass Transfer, Vol. 34, No. 4/5, pp. 1009-1017, 1991
5) T. R. Nielsen, J. Rose, J. Kragh, Dynamic model of counter flow air to air heat exchanger for comfort ventilation with condensation and frost formation, Applied Thermal Engineering 29 (2009), pp. 462-468