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Possibilities and limitations for evaporative and desiccant cooling technologies

samen →!

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interessante tekst
↓
goede uitleg
over ≠ systemen

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interess. opm. van spreker;

Als je demands verstelt

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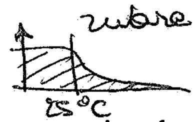

Synopsis

Evaporative cooling is an interesting alternative to conventional compressor refrigeration systems for air-conditioning. However, the use of evaporative cooling presupposes all-air systems and is, to a large extent, limited by ambient conditions as well as the settled demands on the indoor climate. High outdoor humidity levels have a great influence on the supply-air temperature achievable, i.e. cooling loads possible to meet. One way to reduce the influence of these limitations is to use desiccant cooling, i.e. to dehumidify the ambient air before the evaporative stages. Here, a general methodology to describe possibilities and limitations for evaporative and desiccant cooling, is presented. The major advantage of using this methodology is that this may give rise to an increased understanding of these processes. This methodology can also be used for a rough estimation of the energy consumption for air-conditioning using evaporative or desiccant cooling. As an example, this methodology is applied on cooling loads of a base-case office building situated in Stockholm, Sweden.

1. Introduction

One of the primary demands for a good indoor climate in a building is that temperature and humidity are maintained at comfortable levels, regardless of the prevailing outdoor climate. Heating and cooling loads for the building can be calculated when specified requirements are stipulated with regard to room temperature and humidity. The heating and cooling loads are then mainly affected by the combination of building design, activities in the building and the outdoor climate. Commercial and office buildings often have a heat surplus a great part of the year due to internal activities, even in climates with moderate ambient temperatures. This heat surplus has to be compensated for in order to fulfil the specified requirements on the indoor climate. Thus, the specified requirements on the indoor climate and the prevailing outdoor climate have a great influence on the loads for the air-conditioning system. The energy consumption then depends on the choice of technical solution. The focus in this paper is on possibilities and limitations using evaporative and desiccant cooling to satisfy the cooling demands in buildings. A methodology used to give a rough estimation of the energy consumption for air-conditioning using evaporative or desiccant cooling is also described.

2. Indoor climate

Many studies have been carried out with the aim of determining how human beings are affected by different combinations of temperature and humidity. Most studies indicate that an indoor temperature around 24 °C and 30-70 % relative humidity are acceptable [1]. In this context, it is important to analyse the consequences of too strict demands on thermal comfort, as they can result in considerably increased investment and running costs. Thus, demands on thermal comfort, should be defined by an acceptable interval or by the number of hours, for example, when the indoor temperature may exceed or be below the desired level. The methodology presented in this paper, is based on the number of hours when a certain supply-air temperature can be obtained using different evaporative cooling technologies with common boundary conditions.

3. All-air, air-conditioning systems

A building's sensible cooling demand can be met by using an appropriate combination of supply-air temperature and air-volume flow. If the activities in the building generate moisture, and there is a specified upper humidity limit, then the absolute humidity content of the supply-air must be low enough. This internal moisture gain gives rise to the building's latent cooling demand.

The building's total cooling demand would then be the sum of the sensible and latent cooling demands. If a low supply-air temperature is provided for a given sensible cooling demand then a lower airflow can be used. This lower airflow means that the investment cost as well as fan electricity consumption can be reduced. However, too low supply-air temperatures would cause draught problems; therefore there is a lower temperature limit regarding practicable supply-air temperatures.

Generally, a compressor refrigeration system is used to obtain the necessary supply-air temperature in all-air systems. As a result of the greenhouse effect and the ozone depletion debate, the prerequisites for compressor refrigeration systems have been changed. Therefore, other methods of air-conditioning are considered. When the ambient climate conditions are opportune, a suitable alternative may be evaporative or desiccant cooling.

4. Evaporative and desiccant cooling

In arid climates the necessary supply-air temperature can be obtained by humidifying the air-stream in one or more stages (figure 1). In this context this method of air-conditioning is called evaporative cooling. When the humidity in the air-stream is increasing, in this humidifying process, the dry-bulb temperature is decreasing. The reason for this is that the heat necessary to evaporate the supplied water into vapour is essentially taken from the air-stream. There are different types of humidifying equipment available for this purpose.

The humidifying process is essentially an adiabatic process and therefore the wet-bulb temperature remains constant. The performance of a humidifier, or in this context an evaporative cooler, is specified by the so called saturation effectiveness. The saturation effectiveness specifies the extent to which the leaving dry-bulb temperature from an evaporative cooler approaches the thermodynamic wet-bulb temperature of the entering air. This dry-bulb temperature decrease can be used as direct evaporative cooling (figure 1a) by humidifying the outdoor-air stream. The evaporative cooler can also be located in the exhaust-air stream as so-called indirect evaporative cooling (figure 1b). The outdoor air-stream temperature is then decreased by using a sensible heat recovery device, i.e. a heat exchanger that does not transfer moisture. These two types of evaporative cooling configurations can be combined into indirect + direct evaporative cooling (figure 1c).

High outdoor humidity levels as well as the demands on the indoor climate have a great influence on the supply-air temperature possible to reach when using evaporative cooling. There are, thus, physical limitations with regard to the supply-air temperatures possible to achieve.

→ no moisture in input stream

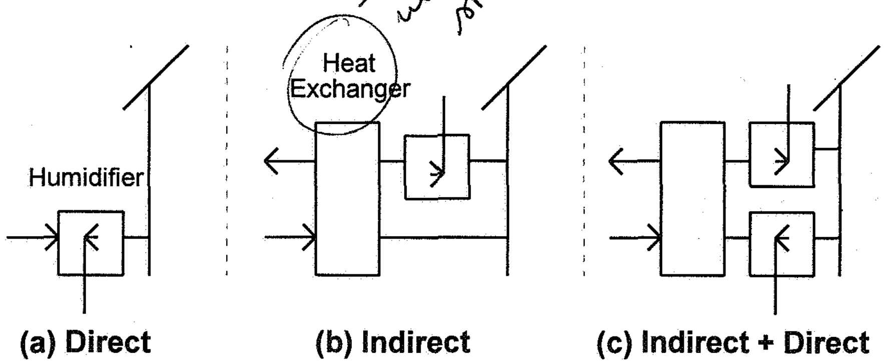

Figure 1. Evaporative cooling configurations.

One way to reduce the influence of these physical limitations is to use desiccant cooling, i.e. to dehumidify the ambient air before the evaporative stages with a desiccant dehumidifier. This dehumidification paves the way for the subsequent evaporative cooling system. The physical limitation regarding ambient conditions is, therefore, reduced.

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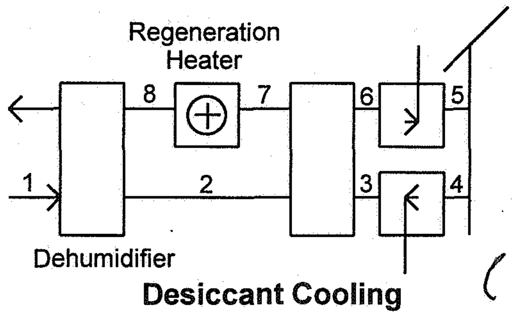

(pennington cycle)

Figure 2. Desiccant cooling, a combination of indirect + direct evaporative cooling and a desiccant dehumidification (in this case a desiccant wheel).

↳ or liquid system → zie Essen

There are mainly two different types of desiccant dehumidifiers, either based on solid desiccant materials or desiccants in liquid form. In both cases thermal energy is used to achieve the desired dehumidification. From here on in the report, the term dehumidifier will primarily be used to refer to a dehumidifier based on solid material, a so-called desiccant wheel. An ideal dehumidification process, in this case, is assumed to be a constant enthalpy process. In the real dehumidification process, the enthalpy would increase due to the so-called heat of adsorption as well as ordinary heat transfer.

In order to achieve the necessary dehumidification, the desiccant material has to be regenerated, i.e. the adsorbed moisture has to be removed. For this purpose thermal energy must be supplied to the regeneration heater (figure 2) to raise the temperature t_8. The amount of thermal energy necessary, is determined by how much moisture has to be removed as well as component performance. Different sources of energy can be considered for this regeneration. If a combustion process is used then it is possible to achieve just about any temperature t_8. Another source would be district heating, but in this case an upper temperature limit of approximately $t_8 = 60$ °C occurs.

Sweden !

Even a desiccant cooling system has physical limitations with regard to the supply-air temperatures possible to achieve. If the proposed thermal source causes limitations to possible regeneration temperature, then additional limitations will be experienced for the desiccant plant.

5. Building's cooling load

The building's total cooling load, i.e. the necessary heat extraction rate $\dot{Q}$, can be expressed:

$$\dot{Q} = \dot{M} \cdot (h_5 - h_4) \tag{1}$$

Where $\dot{M}$ is supply-air mass flow and h is specific enthalpy, with indices, 4 refers to the supply-air stream and 5 refers to the exhaust-air stream.

A useful expression for handling the relationship between sensible and latent cooling load is the sensible heat ratio *SHR*. *SHR* is defined as the ratio of sensible heat to the total value of heat. In equation 2 the expression for *SHR* for the building cooling load is given.

$$SHR = \frac{\dot{Q}_{sensible}}{\dot{Q}_{total}} = \frac{c_p \cdot (t_5 - t_4)}{(h_5 - h_4)} \tag{2}$$

Where t is dry-bulb temperature and c_p is specific heat.

SHR = 1 means that no moisture is generated from the activities in the building. Office buildings are an example of buildings with small internal moisture gains. The origin of the heat surplus in office buildings is mainly from human beings, equipment, appliances, electric light and solar gains. Of these internal heat gains, only human beings normally contribute to an internal moisture gain. If human beings carrying out moderately active office work at normal room temperature were the only contributor to the internal gains, then the *SHR* would be approximately 0.55 [1]. If no more than 40 % of the internal heat gains were assumed to originate from human beings then the *SHR* would be greater than 0.8 in an office building.

6. Limitations for evaporative and desiccant cooling

The limitations caused by the ambient climate have been studied with regard to the supply-air temperatures possible to achieve. In some of these systems, the prevailing exhaust-air condition also affects the reachable supply-air temperatures and this fact must be taken into consideration. Certain combinations of ambient temperature and humidity mean that it is possible to reach a certain supply-air temperature. These ambient-air states can be identified if the room temperature, *SHR* and the effectiveness of the components are specified. These valid combinations of ambient temperature and humidity can then be combined in the psychometric chart as a limit-line.

sensible heat ratio : int. moisture gains (lage ! waarde)

In this case a room temperature of 24 °C and a *SHR* of 0.8 have been presumed. For the evaporative as well as the desiccant system, the heat exchanger sensible effectiveness is 0.8, and the humidifier's saturation effectiveness is 0.8. In this paper the performance of a commercial available desiccant wheel has been applied. With regard to the regeneration temperature, a maximum temperature limit has been assumed to exist.

In figure 3, limit-lines are shown on the psychometric chart describing the outdoor conditions when it is possible to reach a supply-air temperature of 17 °C. If the ambient climate is in the area in between this limit-line and the desired temperature level, in this case 17 °C, then it is possible to reach a supply-air temperature of 17 °C or lower . From here on, such an area is referred to as the psychometric area for each system or subsystem.

In figure 3, the boundary conditions of the Stockholm climate have been visualised, as well. The Stockholm climate is based on hourly measured values from 1983 to 1992.

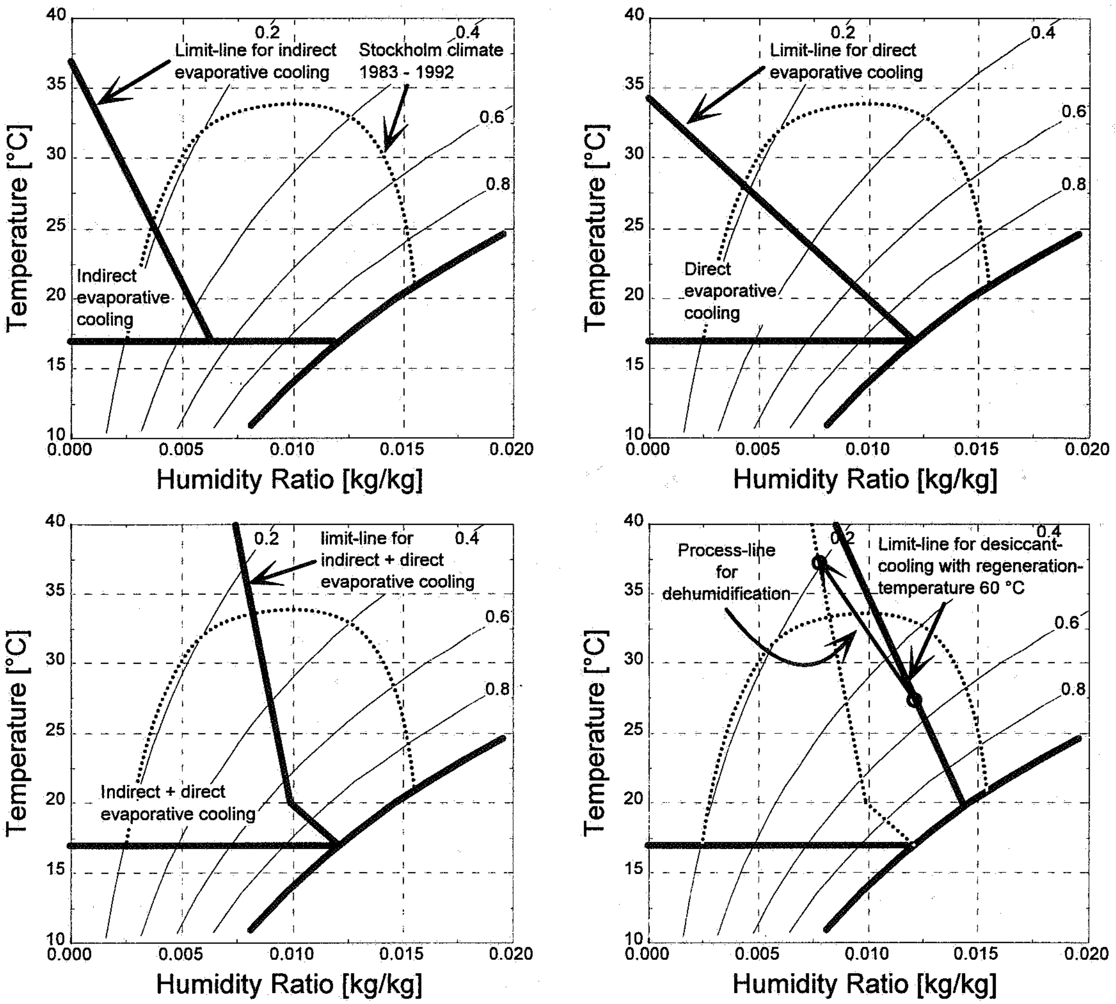

Figure 3. Limit-lines and psychometric areas.

The psychometric area of indirect evaporative cooling covers just a small part of the total area which describes the Stockholm climate in the psychometric chart. The corresponding psychometric area for direct as well as indirect + direct evaporative cooling covers a substantially greater part. The major part of the Stockholm climate area is covered by desiccant cooling, despite the regeneration temperature limit. There are, thus, limitations for all systems related to the ambient climate condition.

If climate data is available, for any location, it is possible to calculate the number of hours when the combination of ambient temperature and humidity is in each psychometric area. As an example, the Stockholm climate data is used. In this case the influence of different desired supply-air temperatures in between 14 and 18 °C has been studied. The number of hours when it is possible to reach a specific supply-air temperature, is shown in figure 4, i.e. the number of hours in each psychometric area. In this figure it is also possible to read the total number of hours, for an average year, when the ambient temperature is above the desired temperature.

In figure 4 it is shown that the ambient climate restricts the use of low supply-air temperatures when dimensioning an evaporative system in particular. By dehumidifying the ambient air this climatic restriction can be reduced.

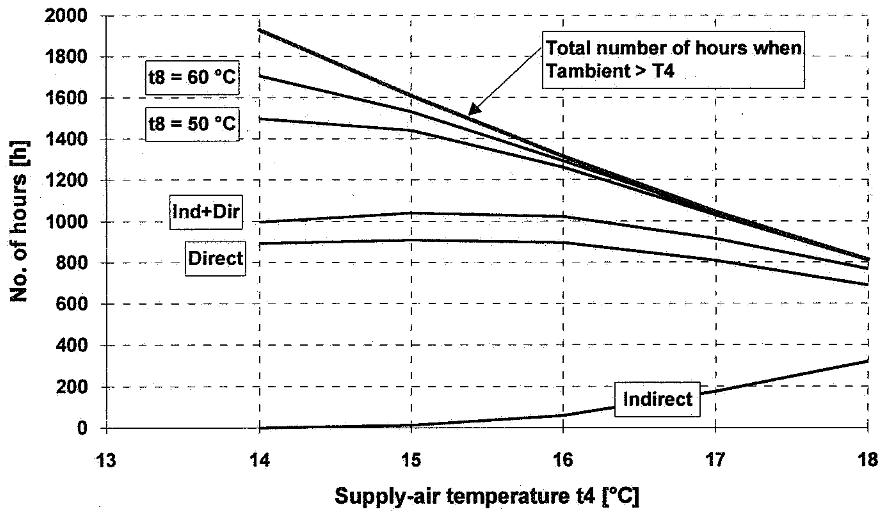

Figure 4. Number of hours when different evaporative and desiccant stages can be used to reach a specific supply-air temperature.

In this case it should be observed that the temperature referred to as supply-air temperature is the temperature of the air entering the supply-air fan. The magnitude of the temperature increase, when the air-stream passes the supply-air fan, is dependent on the dimensioning of the whole air-conditioning system, i.e. plant, selection of fan, duct-system, etc. This temperature increase is, in general, about 1 °C.

7. Ambient conditions and building's cooling load

The previously described psychometric areas can also be used for a rough estimation of the energy consumption for air-conditioning, using evaporative or desiccant cooling. If hourly values of the building's cooling load as well as ambient conditions are available, then the total energy demand can be calculated for each psychometric area. This information can then be used to estimate the energy consumption for air-conditioning, using evaporative or desiccant cooling.

As an example of this, a calculation of a building's hourly cooling load has been carried out. In this case the building model (Type56) in the simulation software TRNSYS has been used to calculate the hourly cooling demand for a base-case office building situated in Stockholm. A detailed description of this office building can be found in reference [2]. The internal sensible heat gain was defined as 12 W/m^2 during office hours (08 - 18), and 2 W/m^2 during night hours (18 - 08). The model was used to calculate the necessary sensible heat extraction rate to keep the room temperature below 24 °C day and night. Calculations were carried out with the same weather data as mentioned earlier, Stockholm 1983 - 1992. The maximum cooling load was calculated to be 22 W/m^2 during this 10 year period and the building's annual cooling demand was 24.6 kWh/m^2.

The cooling load was then calculated for each psychometric area. In figure 5, average values for the 10 year period are shown.

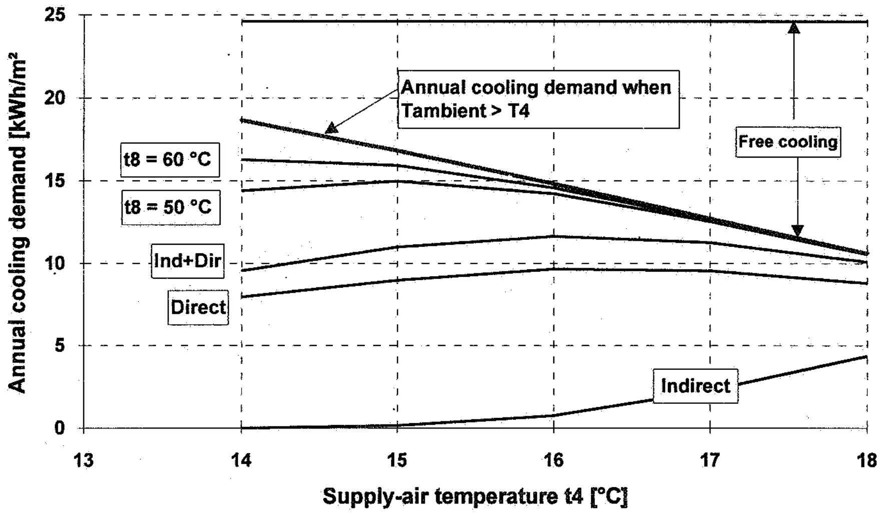

Figure 5. Annual cooling demand for a typical office building and the fraction possible to meet by evaporative or desiccant cooling.

The curves that describe the fraction of the building's total cooling demand possible to meet by evaporative or desiccant cooling, are shown in figure 5, and look similar to figure 4. The frequency of different ambient climate conditions, thus, has a great influence on this fraction.

8. Humidifying the supply-air stream

A commonly raised objection against using the direct humidifying stage, in an evaporative or desiccant plant, is that moisture would be added to the supply-air stream. This is expected to cause a worse indoor thermal climate. However, the maximum content of humidity in the supply-air, though, is restricted to saturated state at the prevailing temperature. In figure 6 is shown the maximum relative humidity that could occur in the room at different supply-air temperatures. This figure is valid for a room temperature of 24 °C and the internal moisture gain is specified by the *SHR*.

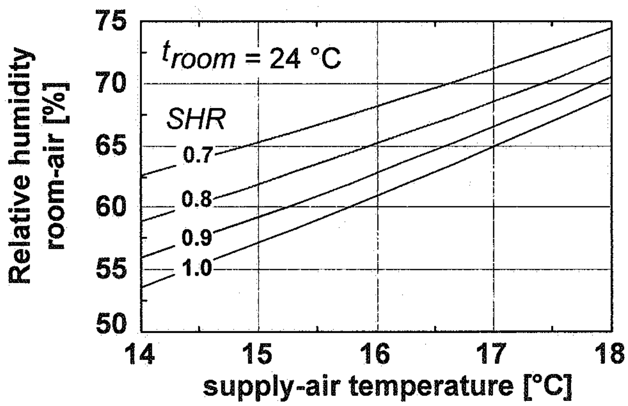

Figure 6. Relative humidity in the room-air when using a direct humidifying stage.

For a supply-air temperature of 15 °C, the maximum humidity content is 10.7 g/kg (100 % RH). If $SHR = 1$, the same absolute humidity would arise in the room-air, and for a room temperature of 24 °C the relative humidity would be 57 % RH. For $SHR = 0.8$, a supply-air temperature of 17.5 °C would give rise to a relative humidity of 70 % RH.

In this case, no consideration is taken to the temperature increase over the supply-air fan. This temperature rise would not influence the principal discussion regarding humidity in the room, though it would affect the sensible cooling load for the air-conditioning system.

9. Energy consumption

Use of the methodology described in this paper to discuss possibilities as well as limitations of evaporative and desiccant cooling technologies may increase the understanding of these processes. The methodology can also be used for a rough estimation of the energy consumption expected for air-conditioning when using evaporative or desiccant cooling. The expected number of hours in each psychometric area can be used to estimate the total energy consumption. The water consumption would be constant for each evaporative stage and the electricity consumption for the fans could be estimated with a value of specific fan power, *SFP*. The *SFP*-value, though, is dependent on the dimensioning of the whole air-conditioning system. It would also be possible to estimate the regeneration heat load by using limit-lines for different thermal coefficients of performance, COP_{th}. The COP_{th} is in this case defined as the total heat extraction rate from the building divided by the necessary regeneration heat rate. These limit-lines would resemble the limit-lines for the regeneration temperature shown in figure 3. However, the total regeneration heat demand is still dependent on the number of hours when desiccant dehumidifying is necessary. In arid climates the cost for the regeneration may be of minor importance in some cases.

A common way of calculating the energy consumption for air-conditioning is to simulate the combined effects of building design, activities in the building and the outdoor climate. This seems to be the best way but the accuracy is always dependent on the used simulation models as well as inputs to the model and the control strategies, in particular. The calculated result would, to a great extend, be dependent on the used control strategy if settled without taking the physical limitations into consideration.

It is also important to take the physical limitations into consideration when comparing evaporative or desiccant cooling to, for example, a conventional compressor refrigeration system. In the conventional system there is usually no limitation regarding supply-air temperatures possible to reach. Different control strategies may be necessary in order to carry out an objective comparison of total energy consumption. Preference of the system chosen is, in the end dependent on the local prices of water, electricity and heat.

References

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