RETROFITTING OF COOLING SYSTEMS

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ABSTRACT

The faults during design and installation phases are more critical with cooling systems than with normal HVAC systems: direct evaporated systems in particular require experienced engineers and mechanics. The most common fault is oversizing the systems and the design of the year-round-use system without winter conditions equipment. When the outdoor temperature is cold these systems present problems. The aim of this paper is to present the retrofitting concepts of cooling systems together with improved energy efficiency and operation of the system. This paper considers DX cooling systems, water chillers and room- air conditioner packages. The reasons for the typical faults in the cooling systems are analysed and examples retrofitting the systems are presented. Also some practical points for the design of these cooling systems are presented. The dimensioning of the whole system is specially given attention.

1. APPROACH TO DESIGNING COOLING SYSTEMS

It could be said that the faults during design and installation phases are more critical with cooling systems than other HVAC systems. Particularly direct evaporation systems require special expertise. One of the most common faults is to oversize these cooling systems. Normally oversizing leads to operation problems during the average cooling duty cycle when heat gains are quite small. There are two different ways to improve the controllability range: first, by fixing the installed cooling capacity suitable for a normal period of operation, or secondly by using a sophisticated control system. The chosen dimensioning conditions like outdoor enthalpy (temperature and humidity) and set point are significant for the required cooling capacity. It is also possible to reduce the required installation capacity by using alternative cooling systems like indirect evaporative cooling systems.

1.1 DIMENSIONING THE SYSTEMS

The cooling capacity of a system is a combination of many different factors. Some restrictions directly origate from design decisions and others from characteristics of the chosen cooling system. The heat gain is one of the most significant factors, which is the sum of solar and equipment heat loads. In the design phase the first step should be to check if it is possible to reduce this heat gain with, e.g., different shades, special window or energy- efficient office equipment. The second step is then to choose the desired indoor conditions and design weather data for dimensioning. The final third step is to choose the systems and the specific details of the system. It could be said that the most important decisions that effect the energy efficiency of a system are made in the predesing phases, (phase 1 and 2). During the predesing phase it is possible to reduce the required cooling capacity by about 30 - 80 % if the energy efficiency is properly considered. Normally depending on design decisions the range of cooling power is from 15 to 80 W/m^2, floor area in office room.

In Finland systems are normally sized for outdoor conditions which are exceeded about 15 or 10 days during an average normal year. The 15 days' exceess leads to dimensioning enthalpy of 48 kJ/kg and 10 days means using 55 kJ/kg enthalpy in dimensioning. Dimensioning for our extreme conditions means using 60 kJ/kg enthalpy. The principle for choosing the outdoor conditions is of key significance for the cooling capacity: using the short peak conditions means a much bigger installation and increased investment costs.

The dimensioning temperatures largely determine the required cooling capacity. The effect of dropping the temperature of the supply air and average temperature of the cooling coil is presented in Table 1. It can be noticed that, e.g., using direct evaporative cooling instead the water coil leads to a 15-30 % increase in cooling capacity. The reduction of dropping supply air temperature increases the cooling capacity of the water coil by about 30-40 % if the temperature is 14-15 °C instead 17 °C.

Table 1. The required specific cooling capacity (kW/air flow m^3/s) of direct evaporative and water cooling coils with different supply air temperatures. The dimensioning outdoor conditions are 55 kJ/kg and 25 °C.

Supply air	Water coil + 7 / 13 °C			Direct evaporative coil +7 °C		
(°C) temp.	h_{supply} (kJ/kg)	Dh (kJ/kg)	power (kJ/m^3/s)	h_{supply} (kJ/kg)	Dh (kJ/kg)	power (kJ/m^3/s)
+ 17	43.5	11.5	13.8	40.0	15.0	18.0
+ 16	41.7	13.5	16.0	38.1	16.9	20.3
+ 15	40.2	14.8	17.8	36.2	18.8	22.6
+ 14	38.6	16.4	19.7	34.4	20.6	24.7
+ 13	36.6	18.4	22.1	32.5	22.5	27.0

1.2 CONNECTING MECHANICAL COOLING WITH ALTERNATIVE TECHNOLOGIES

One possible way to reduce cooling capacity is by connecting mechanical cooling systems with alternative cooling technologies. For example, an indirect evaporative cooling system is suitable both for new buildings and existing building stock. The main idea of this system is to humidify the exhaust air thus causing drop in air temperature. The energy of a cooled air is then transferred from a exhaust to supply air side with a heat recovery unit.

Table 2 shows the effect of an indirect evaporative cooling system on primary cooling energy. From the table it can be seen that a pure mechanical cooling system needs 3 - 4 times more primary energy than a combination of a mechanical and indirect evaporative cooling system in this case. The effect of the indirect system is higher with relatively high supply air temperatures e.g. when the temperature of supply air is 17 oC about half of energy is produced with the mechanical cooling system. The required energy reduced by 30 % when supply temperature raised to 19 oC.

Table 2. The required specific primary cooling energy (per supply air flow m3/s) of a mechanical cooling system and combination of mechanical and indirect evaporative cooling

systems with different supply air temperatures. The temperature of exhaust air is constant + 23°C. The humidity efficiency is 90 % and efficiency of the heat recovery unit is 50 %. The calculation period is May-September (Helsinki weather data).

Supply air temperature (°C)	Combination of mechanical and indirect evaporative cooling systems		Mechanical cooling system	
	Heat recovery unit (MWh/m³/s)	Primary cooling energy (MWh/m³/s)	Heat recovery unit(MWh/m³/s)	Primary cooling energy(MWh/m³/s)
+ 15	2.0	5.1	0.08	15.5
+ 17	2.0	2.1	0.08	8.1
+ 19	2.0	1.4	0.08	3.7

2. TYPICAL PROBLEMS AND CONCEPTS OF RETROFITTING

The most common faults are oversizing the systems and the design oft the year-round-use system without adequate equipment for winter conditions [1]. These systems have problems when the outdoor temperature is relatively cold or the required cooling capacity is quite small compared to the installed cooling capacity. For the part-load conditions, and particularly if the system is used during cold periods the cooling system should be equipped with special winter equipment. This equipment is (1) sufficient size receiver, (2)-(3) control valves to control the pressure of receiver and condenser, (4) equipment to control the velocity of condenser fans and (5) equipment to override the low-pressure control (suction pressure). The compressor should also be equipped with (6) a heating resistor so the lubrication works properly in all conditions. The pump-down function of the compressor also improves the reliability of the system during winter conditions.

2.1 ALL-AIR SYSTEMS

A cold climate incurs problems in inadequatly equipped mechanical cooling systems. Freezing, start-up and controllability problems are typical faults could arise. Freezing is a grave problem which leads to expensive retrofitting operations. For example, freezing could happen in the indoor unit (evaporator) of a split system. The main reason for this is unsuitable standard-size components that are designed for a hot and humid climate. For cold Nordic conditions the standard indoor unit should be set one size bigger than the outdoor unit. Also the systems should- as mentioned before- be equipped with special winter equipment. The equipment of standard split systems is insufficient and all these changes increase the costs of retrofitting. (Remark: the normal split is equipped with a capillary tube. It is more safe to use an expansion valve in cold climate.)

A cold climate also causes also start-up problems. Figure 1 shows an example of the retrofitting of room-air conditioner packages. The system is equipped with (1) pressure control valve of condenser, (2) pressure control valve of receiver, (3) unidirectional valve and (4) sufficient size receiver. With this concept of retrofitting it is possible to run the system all-year without any start-up problem.

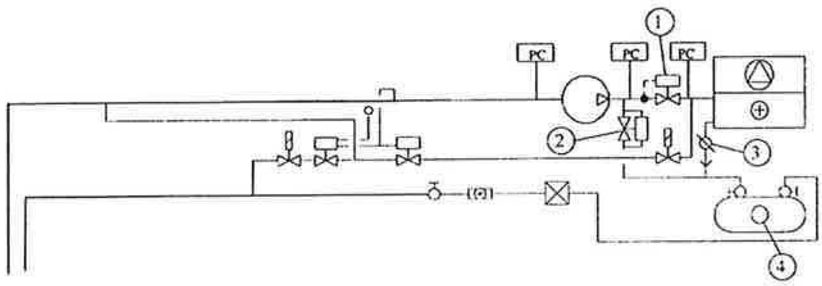

Figure 1.: The retrofitting of room-air conditioner unit

Often it is believed that it is possible with the simple evaporative cooling systems to control accurately the temperature of supply air. But in fact the supply air temperature slid down by about 3 - 6 °C from the set point under part-load conditions. The main function of a mechanical hot-gas valve is only to ensure suitable working conditions for the compressor. The energy economy of the control strategy is poor. Figure 2 illustrates the principle of the hot-gas bypass system in a normal and block- divided coil.

In some way the operation of this kind of systems should be stabilized. This could be carried out by adjusting the cooling load directly from the outdoor or exhaust air temperature. With this arrangement it is possible to achieve stable function of the systems if the small set point deviation of supply air temperature is accepted. An other advantage is to obtain a simple system which is easy to monitor and maintain. If accurate control is required the technical solution is to use a hot gas electronical control system.

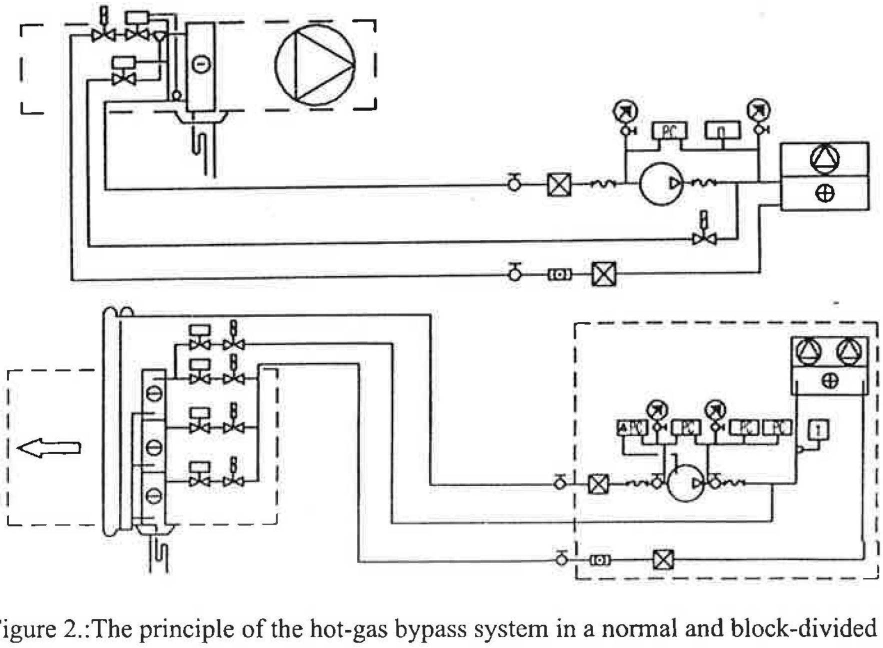

Figure 2.:The principle of the hot-gas bypass system in a normal and block-divided coil

2.2 AIR-AND-WATER SYSTEMS

In air-and-water systems (VAV, fan coil and cool ceiling system) there are two different control loops. The control of supply water temperature is in the sequence of the outer control loop and the inner control in rooms or air-handling units. In normal conditions the accuracy of the whole control system is rather good. The biggest problem is to guarantee suitable working condition of the chiller: the water flow should be constant and in the part-load situation the water capacity should be enough for the smallest cooling power of the compressor. If necessary the system is equipped with an extra water tank (24 l of water per 1 kW of the smallest cooling power). For example, if the smallest controllable cooling power of the chiller is 100 kW the required water capacity is 2 400 l. Figure 3 shows an example of retrofitting a separate water tank in a hydronic network.

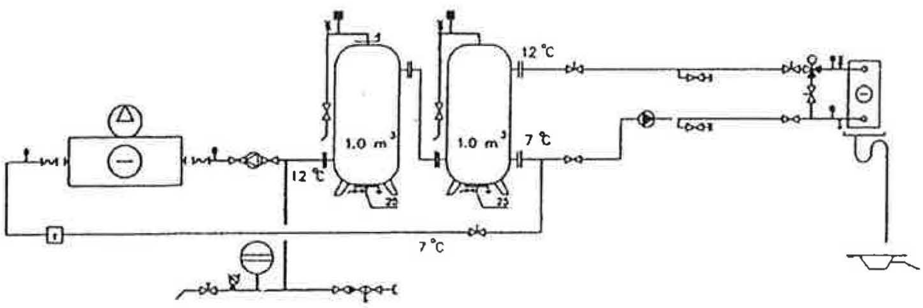

Figure 3.: An example of raising the water capacity of chiller

In water systems it is possible to effectively use the cold outdoor temperature in Nordic countries for free cooling. An example of the free-cooling concept is presented in Figure 4. This system is economic when the cooling demand is relative high during winter, as it is, e.g. in computer centres, laboratories, industrial plants and sometimes in offices.

Free cooling is possible to arrange in many different ways: it is possible to use the air-condenser for free cooling or install a different liquid cooler only for the free cooling mode. Also in some cases it is possible to transfer cooling energy directly from air-handling unit (AHU) to a cool ceiling or fan coil system with the existing hydronic network. In this kind of the system the source of cooling energy is cold outdoor air. The cooling coil of the AHU is like a cooling energy recovery unit and the water tank is a storage of the cooling energy where the energy is transferred to room units.

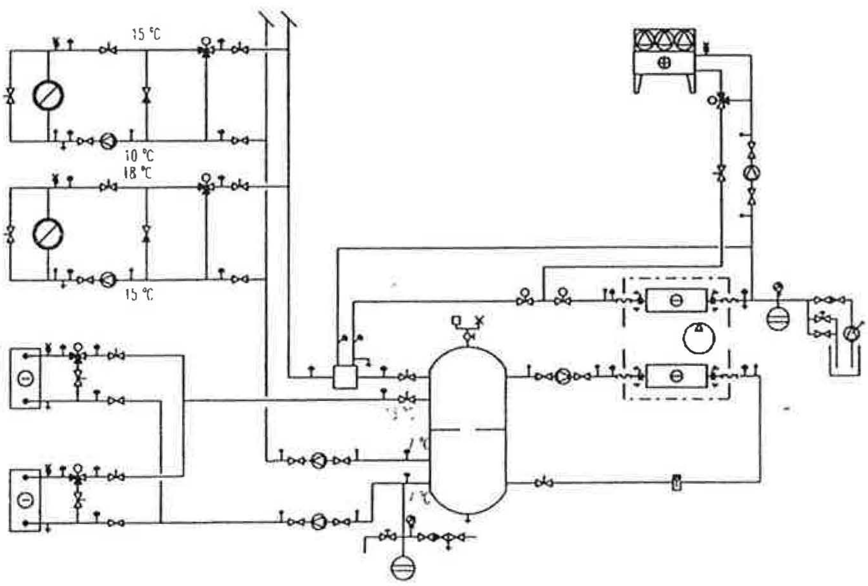

Figure 4.: The free-cooling concept of the air-and-water system. The free cooling energy is taken from the condenser

3. CONCLUSIONS

The dimensioning of systems is critical: with the oversize evaporative cooling system it is impossible to control the cooling capacity during part-load conditions. An other significant point is to equip the all-year-round systems with winter conditions equipment, and thus the start-up problems will vanish. All in all it could be said that the direct evaporative cooling systems are more difficult to control than chillers. If the water capacity is fixed for the smallest controllability cooling power there are normally no significant problems with chillers.

The energy economy of the most evaporative cooling system is not very good. Particularly the mechanical hot-gas bypass system wastes a lot of energy. Electronic control systems are more energy-efficient and are more accurate than traditional systems. In air-and-water systems it is possible to improve energy economy with free cooling. Most of the free cooling concepts do not require expensive investment. Sometimes it is only necessary to change the control strategy.

REFERENCE

[1] Kosonen, Risto, Laitinen, Ari & Kaappola Esko. The methods for improving operation and energy efficiency of HVAC cooling systems. VTT Research Notes 1725. Technical Research Centre of Finland. Espoo 1996. (In Finnish, English abstract).