UNIFLAIR™

New Design Strategies for Energy Saving

Intelligent free-cooling

New strategies for energy saving

When designing mission critical systems for processing applications or highly technological environments, reliabilty and energy saving are fundamental. Intelligent free-cooling is the ideal solution.

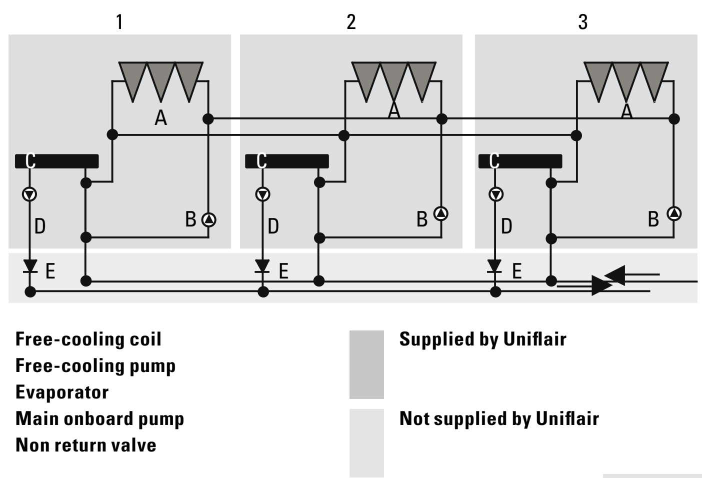


FIGURE 1

FIGURE 1. Diagram showing units with free cooling and an onboard pump for the primary circuit.

Technological environments which house hi-tech equipment and/or particular processes requiring guaranteed uninterrupted optimum operating conditions, as well as many industrial processes, very often have higher breakdown costs than the cost of the equipment itself.
Designing a reliable system means choosing a unit which is intrinsically reliable, and therefore designed and built in such way as to guarantee an extremely low breakdown and inefficiency rate, as well as creating suitable reserves by having one or more additional units. The "n+1" logic ensures that there is always a unit in "stand-by" which guarantees emergency intervention in the event of any type of problem.

Free-cooling

If the system involves technological systems or industrial processes which operate continuously throughout the year, and therefore also with low external temperatures, it is energetically convenient to use systems which have been designed to exploit these conditions; cooling systems with a free-cooling device are a typical solution. Not only do these units have a lower energy consumption than traditional systems, they also limit the quantity of indirect CO^2 emissions into the atmosphere and, therefore, contribute to safeguarding the environment and reducing green house gases.
If the external temperatures are low enough, it is possible to reduce or even eliminate, depending on the external temperature, the use the "refrigerant" part of the chiller, i.e. the compressors, which are the components principally responsible for energy consumption, by exploiting the air/water exchangers which are integrated in the unit itself.
Analysis of the climatic profiles of the main European cities shows that the most frequent temperatures are between 0 and 15°C; this analysis has enabled the creation of free-cooling methods which maximise performance within this temperature range.
For this reason, Uniflair units which are equipped with

free-cooling devices allow operation even when the external temperature is able to guarantee only partial rather than complete dissipation of the thermal load.
In these cases, operation is referred to as mixed: the chiller uses external air to pre-cool the water in the system, allowing the compressors to work less and create energy savings. There are, therefore, three operating modes:

• **Mechanical cooling.**
With temperatures higher than 15°C, the free-cooling unit operates as a traditional chiller, dissipating the thermal load of the evaporator with the compressors (fans and compressors operating);

• **Mixed cooling.**
When the external temperature is between 5 and 15°C, the air guarantees only partial, rather than complete, dissipation of the thermal load. At lower temperatures the control system activates the free-cooling pump at 15°C and the water is routed to the air/water exchangers which are placed in series in the evaporator, so that it has to dissipate a lower thermal load (fan operation, free-cooling pump and, in part, the compressors);

• **Free-cooling.**
When the external temperature is low enough, the air/water exchangers allow the complete dissipation of the thermal load without needing the compressors (fan operation and free-cooling pump).

Intelligent free-cooling

By combining the above concepts in applications where uninterrupted operation is required, units equipped with a free-cooling device featuring a redundancy logic can be installed and therefore part of the available cooling capacity is in stand-by.
The same consideration can be made regarding the available free-cooling capacity. The principle which forms the basis of intelligent free-cooling is that of also exploiting, when external temperatures allow, the air/water exchangers of the unit/s in stand-by.
By linking all of the air/water exchangers together, it is possible for the water which is to be cooled to flow through all of the free-cooling coils which are available. Since, in Uniflair free-cooling units, the water is sent to the free-cooling coils by a pump and not by a simple three-way valve, it is in fact also possible to use the exchangers of the units in stand-by and therefore increase the free-cooling capacity which is available and, consequently, its application, with evident advantages in terms of energy saving.

Hydraulic circuits

When carrying out the hydraulic connections between the air/water exchangers, two separate cases need to be identified:
• Units equipped with an on-board pump on the primary circuit
• Installations supplied with a primary pump outside the unit (placed on the suction or discharge side).
The system design can vary depending on each particular situation.

Units equipped with an onboard pump

Figure 1 shows the solution when there is an onboard pump for the primary circuit.By analyzing a situation such as the one shown, where unit 1 is in stand-by, units 2 and 3 are operating and the three units are connected together with an intelligent free-cooling solution and when the external temperature is low enough for free-cooling to be activated, the control of the two units which are operating activates the fans in the stand-by unit (1) and the free-cooling pump (B) of the units themselves (2 and 3); this happens in such a way that the water arriving from the system is sent to all of the available the free-cooling coils. See Figure 2.
Finally, the difference in pressure, which is due to the fact that the pump which is installed onboard the stand-by unit (1) is at a standstill, prevents a by-pass through the evaporator of this unit.

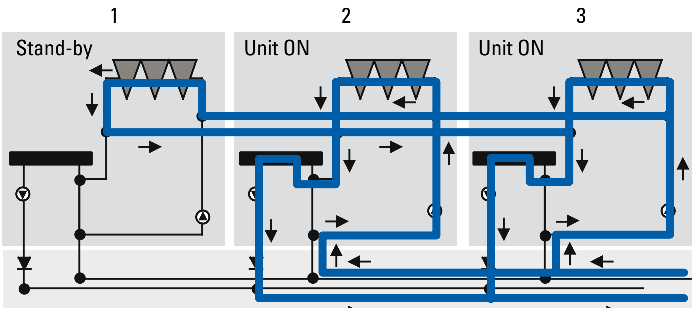


FIGURE 2

FIGURE 2. Diagram showing the flow of water to all of the available free cooling coils, including the one on the stand-by unit.

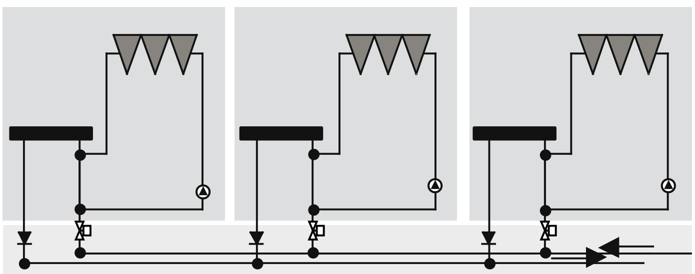
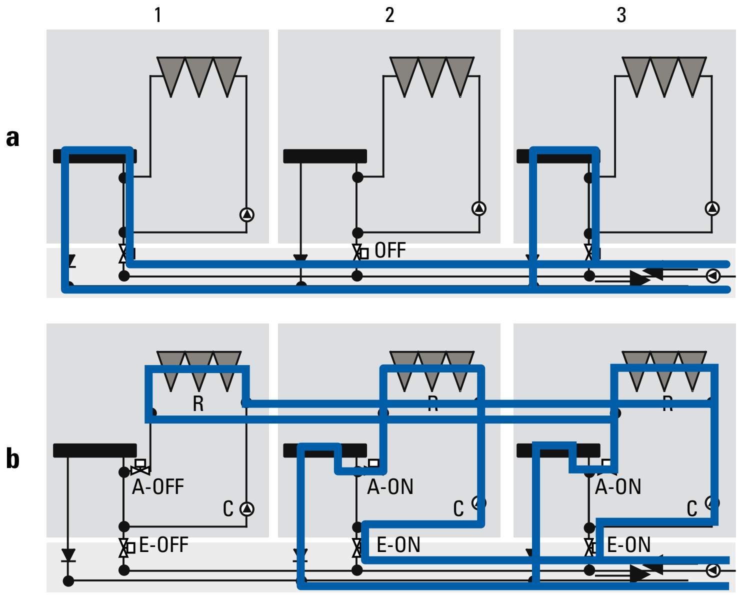


FIGURE 3

FIGURE 3. Diagram in which the units are without onboard pumps but with a pump for the primary circuit up or down stream of the refrigerant group. In this case, it is necessary to equip the units with devices which isolate the stand-by unit. For this reason a motorized valve is placed on the inlet line and a non return valve on the outlet line.



A	**Motorized valve**		**Supplied by Uniflair**
B	**Coil**		
C	**Free-cooling pump**		
D	**Evaporator**		**Not supplied by Uniflair**
E	**Motorized valve**		
F	**Main pump**		

FIGURE 4

FIGURE 4. An example of the circuit outlined in the previous diagrams where units 1 and 3 are operating and 2 is in stand-by. The units are equipped with an additional internal motorized valve in order to prevent an eventual by-pass through the evaporator of the stand-by unit.

FIGURE 5. An example of a unit with intelligent free cooling.

Installation equipped with a pump for the primary circuit outside the unit

If there isn't an onboard pump, but one has been mounted up or down stream from the chillers, it is necessary to equip the unit with devices which isolate the stand-by unit.
For this reason, a motorized valve is usually placed on the inlet line and a non return valve on the outlet line, as can be seen in figure 3.
During operation, the stand-by unit is isolated by the motorized valve which is placed on the aspiration line and the non return valve which is placed on the discharge line.
In figure 4, operation with units 1 and 3 operating and unit 2 in stand-by is shown. When considering an intelligent free-cooling solution for installations of this type, it is necessary for the units to be equipped with an additional internal motorized valve in order to prevent an eventual by-pass through the evaporator of the stand-by unit.

Comparative analysis

In order to verify the economic convenience of an intelligent free-cooling solution, two different solutions have been compared using a Uniflair BRAF1306A unit, which can be seen in figure 5. This unit has the following characteristics:
- Cooling capacity: about 300 kW
- Partialisazion steps: 6 (the units are equipped with 6 scroll compressors)
- Number of fans: 6

A common type of installation has been chosen as an example featuring 3 units of which 1 is in stand-by:
- 2 units operating singularly
- 2 + 1 units in intelligent free-cooling mode

There is a noticeable increase in the heat which is exchanged in both types of systems with intelligent free-cooling compared to an installation where the units are not linked.
This increase allows an added annual energy saving of between 3% and 7% according to the diametric profile when compared to a traditional free-cooling installation. Moreover, when compared to a traditional system, the energy saving can reach 50%.
The installation will now be analysed in detail by examining the following points:
- Pressure drop
- Water flow
- Heat exchange capacity
- Energy efficiency

Pressure drop

When comparing the two situations, a first analysis must be carried out regarding the difference in water flow in each of the two cases. See figure 6.
Since connecting the free-cooling coils to each other increases the cross section of water flow by 1/5 for each pump compared to that for a single unit, the pres-

sure drop which each pump meets is halved. In the solution with connected units it is also necessary, however, to consider the pressure drop which is due to the interconnected collectors.
Provisionally, these pressure drops can be estimated at being about 20% of the total pressure drop and with the following result:

$$PC_{(2+1)} \cong \frac{PC_2}{2} + 20\%\ (PC_2)$$

The decrease in the pressure drop implies an increase in the water flow and it is therefore necessary to compare the water flow in both cases.

Water capacity

Given that the water flow at nominal conditions is 70 m^3/h, and considering the reduction in the pressure drop (which changes from 24 m w.c.m to 16.8 w.c.m), it is possible to obtain a new resistive curve and consequently the new water flow with the connected units, which is about 80 - 81m^3/h. The water flow for each group of free-cooling coils is: (81 x 2)/3 = 54 m^3/h.
There is, therefore, a reduction in the flow per group of free-cooling coils from 70 m^3/h to 54 m^3/h and therefore a reduction of about 23%.

Heat exchange capacity

It is now necessary to analyse how the water flow varies the heat transfer capacity of the free-cooling coils. By using analytical procedures, which for reasons of brevity are not shown here, it is possible to demonstrate how when considering the water flow in the two cases:
1) for single units:
water flow = 70000 l/h
2) for connected units:
water flow = 70000 l/h - 23% = 53900 l/h
it is possible to establish the thermal exchange co-efficient value which, by interconnecting the free-cooling exchangers, can theoretically increase by up to 40%.
The heat exchanged in the free-cooling coils will now be examined.
This is given by:

$$Q = K \bullet S \bullet \Delta T_{acqua/aria}$$

It can be observed, therefore, that the heat exchanged depends not only on the capacity of the K•S exchange, but also by the difference between the temperature of the inlet water and the ambient air. Since the system is sized according to the water flow at nominal conditions, if this value increases, a by-pass situation will be created.
Given that the nominal water flow is 70000 l/h, and that the system is sized according to this flow, if this flow increases, a certain amount of this flow will be re-circulated, as shown in figure 7.
If an external temperature of 5°C (total free-cooling temperature) and a water temperature of 15°C (ΔT = 5 with set-point: 10°C) are hypothesized, the temperature before the free-cooling pump is calculated proportionally:

$$T_{in} = \frac{10°C \bullet 11\ l/h + 15°C \bullet 70\ l/h}{81\ l/h} = 14{,}3°C$$

Therefore, the relationship between the heat which is effectively exchanged in the two cases is:

$$\frac{Q_{(2+1)}}{Q_{(2)}} = \frac{(K_{(2+1)} \bullet S_{(2+1)})}{(K_2 \bullet S_2)} \bullet \frac{(\Delta T_{(acqua/aria)})_{(2+1)}}{(\Delta T_{(acqua/aria)})_2} = 1{,}43 \bullet 0{,}93 = 1{,}33$$

$$Q_{(2+1)} = 1{,}33 \bullet Q_2$$

Therefore, by interconnecting the free-cooling exchangers, the heat exchanged can increase by up to 33%.

TABLE 1

Energy saving in terms of MW/h and economic saving % for annual operation between an intelligent free-cooling system and traditional free-cooling

	Energy saving	
	[kWh]	[%]
Frankfurt	34560	5%
Rome	31587	3%
Milan	29132	4%
Manchester	46008	6%
Paris	36954	4%
Amsterdam	42558	7%
Stockholm	28167	5%
Madrid	36743	4%
Berlin	31525	4%
London	46018	6%
Copenhagen	38077	6%

FIGURE 6. Comparison examining water flow in each of the two cases. Since connecting the free cooling coils to each other increases the cross section of water flow by by 1/5 for each pump compared to that for a single unit, the pressure drop which each pump meets is halved.

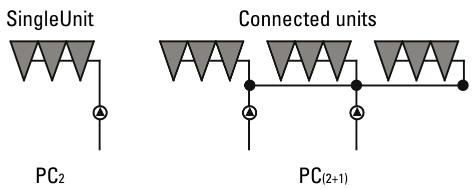


FIGURE 6

TABLE 2

COMPARISON BETWEEN THE ENERGY CONSUMPTION OF STANDARD CHILLERS, FREE-COOLING CHILLERS AND INTELLIGENT FREE-COOLING CHILLERS

	Absorbed power [MWh]		
	Standard Chillers	Free-cooling Chillers	Intelligent Free-cooling Chillers
Frankfurt	1107	747	712
Rome	1245	1056	1025
Milan	1144	815	786
Manchester	1116	789	743
Paris	1178	910	873
Amsterdam	1062	651	609
Stockholm	1001	541	513
Madrid	1204	938	902
Berlin	1088	707	676
London	1103	154	708
Copenhagen	1061	638	599

References:
- Cooling capacity to be supplied: 568 kW
- Outlet water temperature with external temperature less than 15°C: 15°C
- Outlet water temperature with external temperature higher than 15°C: 7°C

TABLE 3

COMPARISON BETWEEN THE ENERGY CONSUMPTION OF STANDARD CHILLERS AND INTELLIGENT FREE-COOLING CHILLERS

	Energy saving	
	Standard Chillers Vs	Intelligent Free-cooling Chillers
	[MWh]	[%]
Frankfurt	394	36 %
Rome	220	18 %
Milan	357	31 %
Manchester	373	33 %
Paris	304	26 %
Amsterdam	452	43 %
Stockholm	487	49 %
Madrid	301	25 %
Berlin	411	38 %
London	394	36 %
Copenhagen	462	44 %

References as in table 2

FIGURE 7

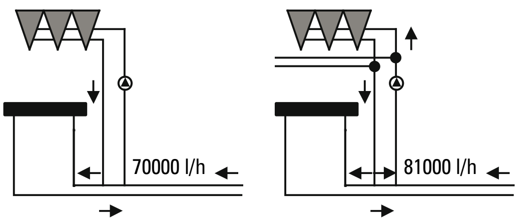


FIGURE 7. RECIRCULATION OF A CERTAIN AMOUNT OF THE NOMINAL WATER FLOW WHEN COMPARED TO THE PREDICTED VALUE IF THE EFFECTIVE WATER FLOW INCREASES AS DESCRIBED IN THE TEXT.

Energy efficiency

When comparing the absorbed power for both cases in free-cooling mode, it is necessary first of all to divide the analysis into two types of operation: total free-cooling or mixed free-cooling.
In order to do this, a reference value must be hypothesized for the cooling capacity which is to be supplied to the system; this value can be reasonably considered that of the cooling capacity of the two units with:
- External temperature: 5°C
- Inlet water temperature: 15°C

which is therefore, according to the characteristics of these units, 2 x 284 = 568 kW. By taking 568 kW as a reference value, it is therefore possible to evaluate at which external temperatures this capacity can be supplied by the units using only free-cooling coils or if it is also necessary to use a part of the refrigerant circuit capacity.
From this comparison, it can be noted that when using two single units the cooling capacity is fully supplied by the free-cooling coils only. At Text ≤ 5°C; with three interconnected units the cooling capacity is fully supplied by the free-cooling coils at Text ≤ 7°C. In fact, the cooling capacity supplied by the system if the units are connected with an intelligent free-cooling system is higher by 33%. With external temperatures which are less than 5°C for each single unit, and 7°C for the connected units, the free-cooling coils fully dissipate the thermal load (which is presumed to be constant) and the temperature of the water is controlled by modulating the fan speed. Therefore, to compare the electrical absorption of the two solutions it is necessary to evaluate:
- the fan rotation speed and consequently their absorption
- the power absorption of the free-cooling pump, considering the difference in water flow and therefore the power absorption of the two solutions.

From the diagram shown above, it can be noted that with the units which are linked together with intelligent free-cooling, the power absorption is less than that of the single unit when the external temperature is higher than 0°C, this is due to two factors:
1) not using the cooling capacity of the compressors (from 7 to 5°C)
2) the possibility of decreasing the fan rotation speed to below 5°C compared to the single units.

The power absorption of the two solutions is very similar below 0°C; this is due to the fact that the fan rotation speed, and therefore their power absorption, is very low due to the thermal exchange by natural convection on the free-cooling coils, and that in the total electrical absorption there is extra absorption by the free-cooling pump due to the increase in water flow from the connected units (7 kW instead of 6,5 kW).
With external temperatures which are higher than 5°C for the single units, and 7°C for the connected units, the free-cooling coils do not fully dissipate the thermal load

(which is presumed to be constant) so it is necessary to use part of the cooling capacity of the compressors. Also in this case, however, the increase in cooling capacity due to intelligent free-cooling enables the compressors to be used less as shown in figure 9.
The difference in electrical absorption translates into a significant energy saving, especially considering that a unit which has a free-cooling device already provides higher energy saving levels. It is possible to evaluate the possible energy savings in different European cities on the basis of this data by examining their respective climatic profiles, as can be seen in table 1. Tables 2 and 3 show a comparison with the annual energy consumptions of traditional systems.

Conclusions

European climatic profiles are associated with a concentration in two temperature ranges, around 8 - 12°C and 18 - 22°C. Units or other apparatus which operate in an efficient way throughout the year need to have a higher performance in these temperature slots; this is why in free-cooling in general it is important to maximise the energy saving in mixed operation, rather than at temperatures lower than 0°C - 5°C where there is a noticeable energy saving, but also a reduced possibility of use. According to this logic, intelligent free-cooling installations can be a solution to further reduce total electrical absorption by using the resources which are already available to ensure reliability of the system and therefore limit any extra costs.

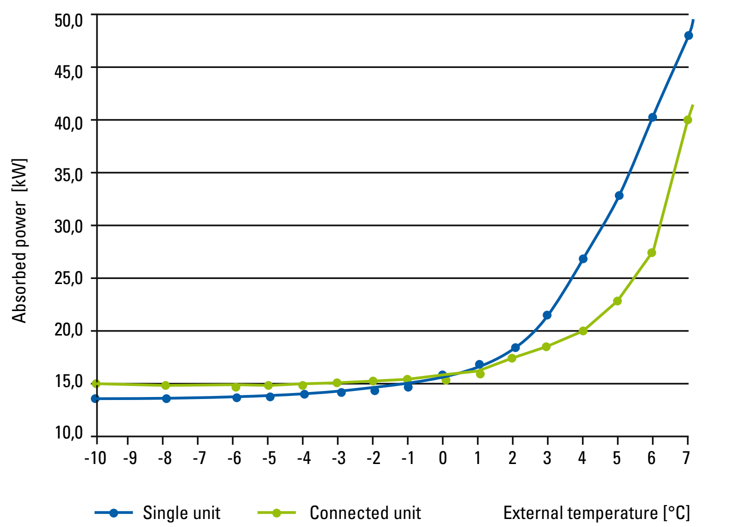


FIGURE 8

FIGURE 8. If the units are connected with intelligent free cooling, the absorbed power is lower than that of single units for external temperatures higher than 0°C, for the reasons described in the text.

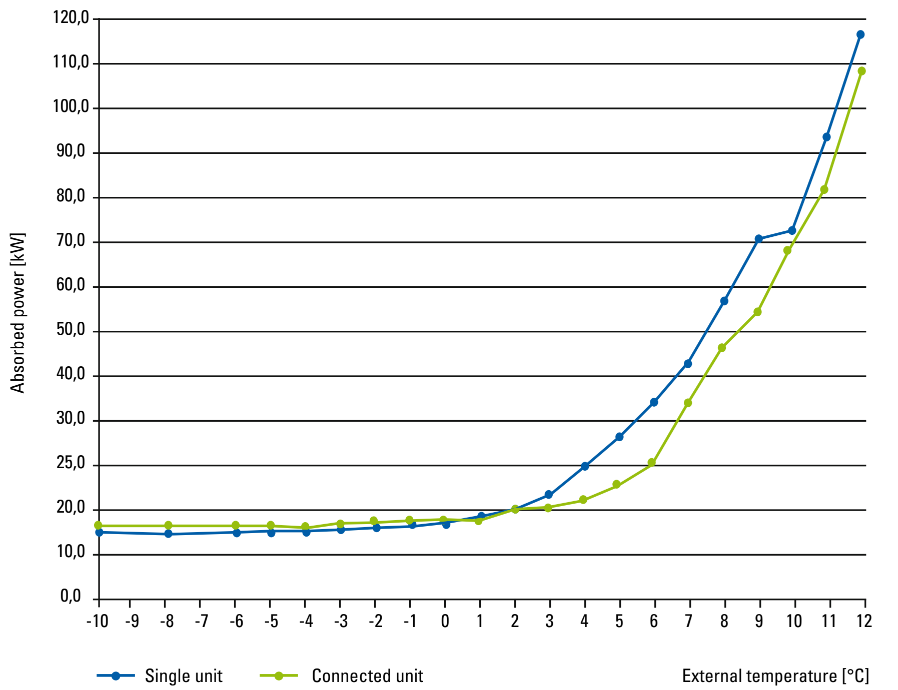


FIGURE 9

FIGURE 9. With external temperatures which are higher than 5°C for the single units, and 7°C for the connected units, the free-cooling coils do not fully dissipate the thermal load (which is presumed to be constant) so it is necessary to use part of the cooling capacity of the compressors. Also in this case, however, the increase in cooling capacity due to intelligent free-cooling enables the compressors to be used less.

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