EFFECTS OF FINNED TUBE TYPE AIR COOLED CONDENSERS DESIGN ON ENERGY EFFICIENCY

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ABSTRACT

Decreasing energy consumption and increasing efficiency is one of the most important points in our era. Becoming a matter of primary importance in air conditioning, industrial and commercial cooling applications, supermarket cooling, blast freezing and process cooling applications, energy efficiency affects design of chillers (and its equipment such as condensers, compressors etc.) and urges manufacturers to develop high performance, energy-efficient, environment friendly, economic, and long life products. This paper is intended to provide information on the factors that affects energy efficiency of finned air cooled condensers used on chillers.

1. INTRODUCTION

Becoming a matter of primary importance in air conditioning, industrial cooling, supermarket cooling, commercial cooling, blast freezing and process cooling applications, etc., energy efficiency affects the design of chillers that account for a significant ratio of the energy consumption in plants. Legal legislations that for the short run limit, and in the long run prohibit the use of fluids of high global warming potential, that are detrimental to the ozone layer are also influential on designs. Since air cooled condensers are among the essential components of cooling groups, efforts to improve their energy efficiency are made incessantly, the related national and international standards are upgraded and limitations on their energy consumptions are always increasing.

Our statement will convey –in the light of the latest applicable standards- detailed and comparative information on applications aimed at improving the energy efficiency in air cooled condensers, highlighting the importance of energy efficiency in cooling installations.

2. DESIGN DATA PERTAINING TO AND FACTORS AFFECTING THE PERFORMANCE OF CONDENSERS

The parameters required for the design and selection of air cooled condensers have been listed below [1].

- The Condenser Capacity required for the system
- The type of Refrigerant that will be used
- The Dry-Bulb Temperature of the Ambient Inlet Air
- Design Condensation and Evaporation Temperatures
- The Permitted Values for Fluid Side Pressure Drops
- Unit Size Limits
- The permitted Maximum Noise Level *(is more of a priority in recent times)*
- The desired Energy Efficiency Class *(is more of a priority in recent times)*

- The isolation, heat resistance and protection class properties of the fans *(is more of a priority in recent times)*

By knowing the design data specified above and the additional optional features, manufacturing firms may design and manufacture condensers in line with their own manufacturing techniques. It is highly important for potential difficulties which would not be easily remedied; that the manufacturing firms possess a performance approved design software and design the coils by the help of this software/program.

There are essential design data and criteria which need to be observed for achieving the desired performance in a condenser in an efficient manner over the long run. In the following pages, the parameters and criteria affecting the energy efficiency of condensers have been explained.

2.1 The effect of condensation temperature on capacity

The condensation temperature of the refrigerant is considered to be 6°C – 20°C above air inlet temperature for general purposes. The condensation temperature varies according to the ambient temperature in which the system will operate. This said, the condensation temperature for applications is commonly taken as 30-60°C.

Factors taken into consideration for determining the condensation temperature:

- Ambient temperature,
- Thermophysical properties of the refrigerant
- Properties of the selected compressor
- And the dimensions of the condenser.

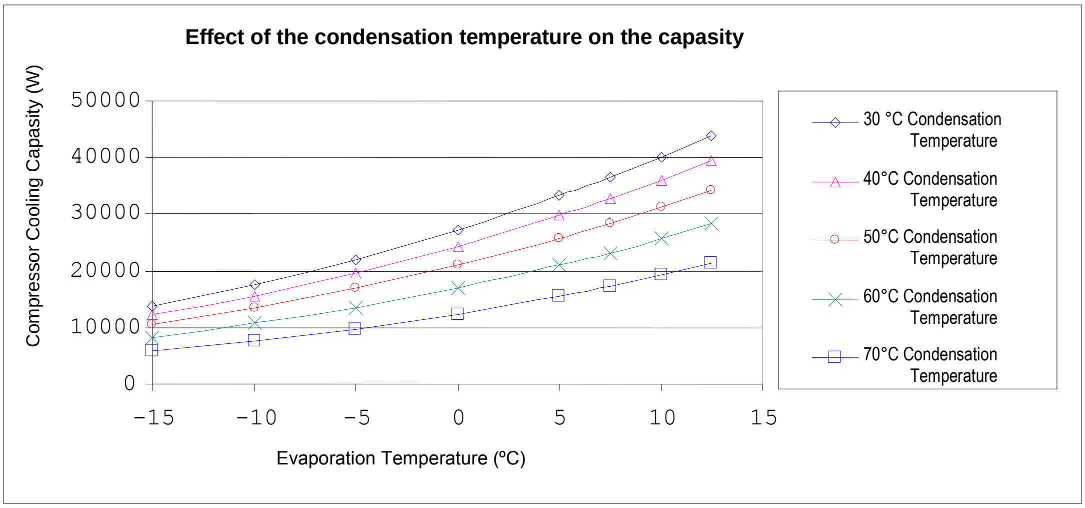
While providing the nominal condenser capacity in condensers as per the Eurovent Standard, the air inlet temperature and condensation temperature are taken as 25°C and 40°C respectively. In other words, ΔT = 15 °C.

A low value should be selected for the temperature differential ΔT, in places of high ambient temperature. For instance, while designing for the conditions of Antalya the ΔT value should be selected within the range of 7° - 10° C. For systems that will operate in outdoor environments in conditions of Turkey, the temperature differential should be lowered as one goes from the north to the south and selections should be made accordingly. It must always be considered that High Compression Temperature creates a load on the compressor that reduces efficiency and shortens its useful life. It will be quite beneficial in the design for the condensation temperature to be specified as low as possible. However, in some conditions it is not possible to take a low value for the condensation temperature. For example in Middle East countries where the outdoor temperature is 50°C-55°C, high condenser temperature is unavoidable.

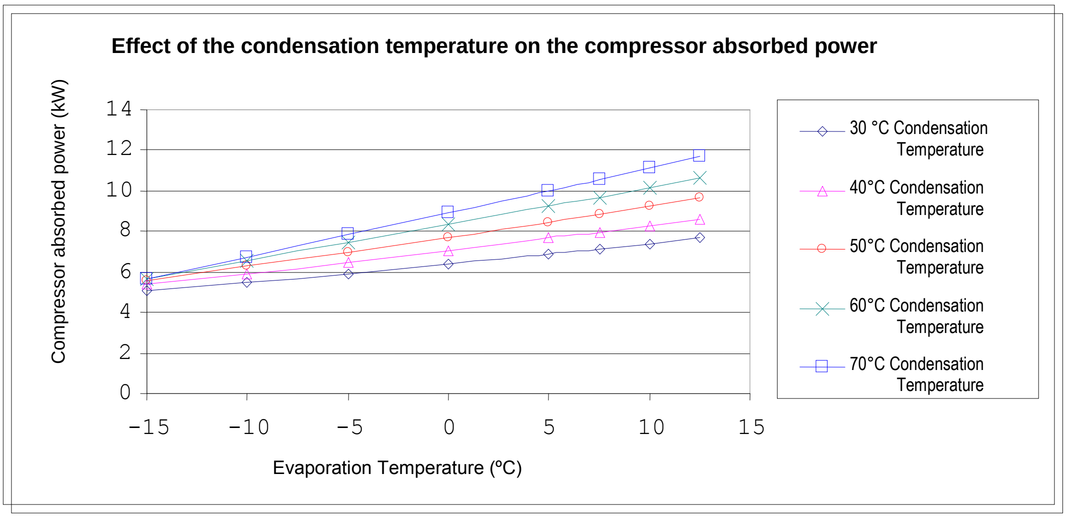
The following example shows the compressor absorbed power at various condensation temperatures and the achieved cooling capacities for a semi-hermetic type HGX4/555-4 model compressor manufactured by BOCK, which uses R134A gas (Table 1) [2]. The cooling gas selected for the example is R134A. As seen from the table, when the condensation temperature rises from 30°C to 60°C, the compressor draws 25% more power while the cooling capacity drops by 38.5%, the COP value (ratio of the cooling capacity to the power drawn by the compressor) decreases by 51% and the a unit that is 38.5% larger must be used to achieve the cooling capacity declared in the design.

Condensation Temperature (°C)	Evaporation Temperature (°C)	Cooling Capacity (W)	Power Drawn by the Compressor (kW)	Cooling Capacity / Power Drawn by the Compressor
30	-5	21,997	5.93	3.71
40	-5	19,665	6.49	3.03
50	-5	16,876	6.99	2.41
60	-5	13,545	7.43	1.82
70	-5	9,586	7.82	1.23

Table 1. Variation in the power absorbtion by the compressor, the achieved cooling capacity and the effectiveness value at fixed evaporation and varying condensation temperatures [2].



Graph 1. Variation in cooling capacity in Various Condensation Temperatures [2]



Graph 2. Variation in the Power Drawn by the Compressor in Various Condensation Temperatures [2]

Sample Comparison: Difference in annual expenditure (EUROS/year) for condensation temperatures of 50°C and 35°C

The Selected Condenser: Class A condenser – will be evaluated for 160 kW refrigeration load
The Selected Compressor: Semi-Hermetic (BOCK HGX7/2110-4 S) Evaporation Temperature: 5 °C

Condensation Temperature(ºC)	Cooling Capacity (W)	Compressor Absorbed Power (kW)	Coefficient of Performance (C.O.P)	Consumed Power due to 160 kW	Differences between the nominal condensation	Consumption Price ($/kW)	Working Hours of the Unit (hour/year)	Compressor Annual Difference($/year)	Difference in Fan Power($/year)	Total Difference in Unit ($/year)	Total Difference in Unit (EURO/year)	50ºC - 35ºC Condensation Difference (EURO/year)
30	186.202	45,47	4,10	39,05	-13,47	$0,13	6000	**-$10,232**	**-**	-	**-**	**13,504 €**
35	173.053	49,00	3,53	45,27	-7,25	$0,13	6000	**-$5,505**	**$607,63**	-$4,897	**-3.588,05 €**	
40	**159.904**	**52,52**	**3,04**	**52,52**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	
45	146.388	55,65	2,63	60,79	8,27	$0,13	6000	**$6,280**	**-$303,82**	$5,976	**4.378,48 €**	
50	132.872	58,78	2,26	70,74	18,22	$0,13	6000	**$13,838**	**-$303,82**	$13,534	**9.915,61 €**	

If the 40°C condensation temperature is taken as a baseline, the difference in annual expenditure (EUROS/year) for condensation temperatures of 50°C and 35°C is 13,500 EUROS/year.

One of the systems used to improve energy efficiency in air cooled condensers is the system of spraying water over a mesh. The mesh and spray system involves the spraying of the amount of water that is required by the system from nozzles placed on specific positions on the wide and fine mesh material located on the front of the air cooled condenser, and lowering the inlet air temperature coming in contact with the heat exchanger surface by the adiabatic vaporization of the sprayed water, thus increasing the efficiency of cooling [3].

The sprayed water leads to adiabatic cooling of the inlet air flow. As the specified set values are exceeded, the control system initiates the water spraying system to lower the temperature of the air entering the heat exchanger. The period of operation and frequency setting of the water spray system is continuously maintained by the controlling unit in order to achieve optimization of system performance and minimization of water consumption. Since the water is not directly sprayed on the heat exchanger surface, but rather on the mesh surface, furring does not occur on the fins. In this way, drops in heat transfer efficiency are avoided. This system also renders any water softening process superfluous.

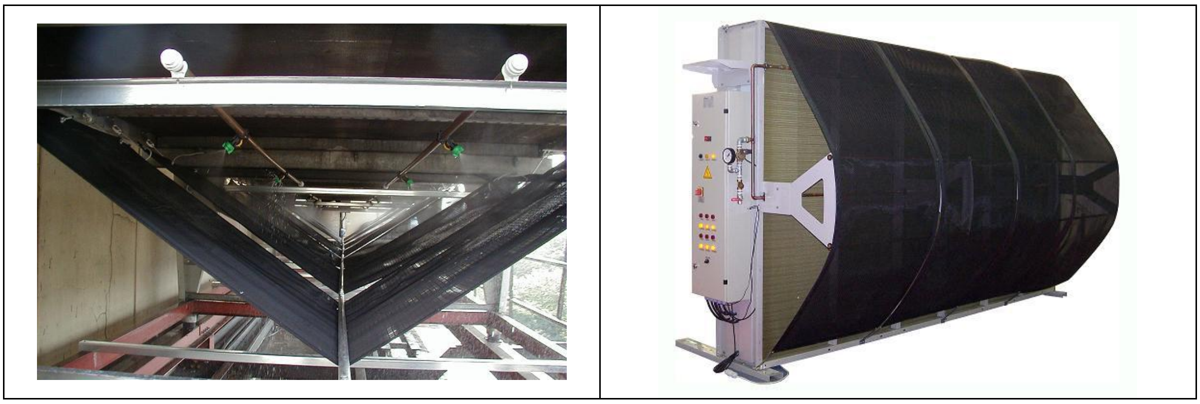


Figure 1.A, 1.B. Vertical and Flatbed Mesh and Spray System Air Cooled Condensers [3], [1]

2.2 Effect of Fin Geometry on capacity

In the design of air cooled condensers, fin geometry which defines the diameter of the tube and distances between tubes influences capacity and pressure losses. The fin geometry is selected among its own standards by the manufacturer so as to provide the required cooling capacity within the appropriate pressure losses.

Geometries with intensive tubing can be said to yield more advantageous capacity/price ratios; however in this case, optimization is required since pressure losses will increase in tandem. Under practical conditions, it must be kept in mind that air cooled condensers having the same heat transfer surface, yet different geometries will yield different cooling capacities and pressure losses under the same conditions.

2.3 Effect of Air Velocity on capacity

Air velocity is an important criterion, since it affects the partial heat transfer coefficient on the air side. Since heat transfer increases with air speed, a smaller heat exchanger will be enough; however, in high speeds, the fan performance drops due to increased pressure loss in the air side. For this reason, the air velocity should be selected at optimum values. The air velocity recommended for air cooled condenser design at standard noise levels is around 3.0-4.0 m/s. In environments where lower noise levels are desired, the air velocity will also be reduced. Air velocities below this figure require the selection of a large heat exchanger. Higher air velocities, on the other hand require stronger and costlier fans.

2.4 The effect of grooved tubes on capacity

The inner surface of tubes used in air cooled condensers can vary with design and cost optimization. Smooth tubes and grooved tubes can be used in condenser coils. The properties of fluid and application to be used for grooved or smooth tubes should be evaluated. Figure 2 shows the measurements involved in the technical specifications of grooved tubes while Figure 3 shows cross sections of grooved tubes of various geometric forms.

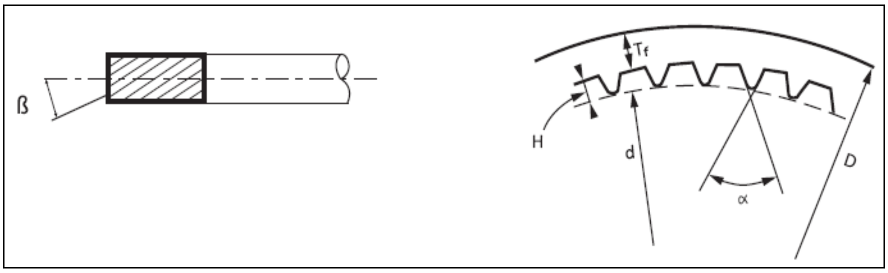


Figure 2. The measurements involved in the technical specifications of grooved tubes [4].

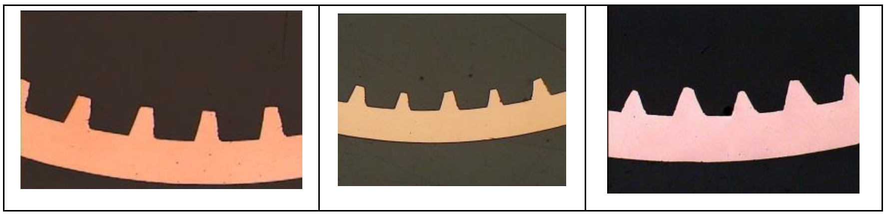


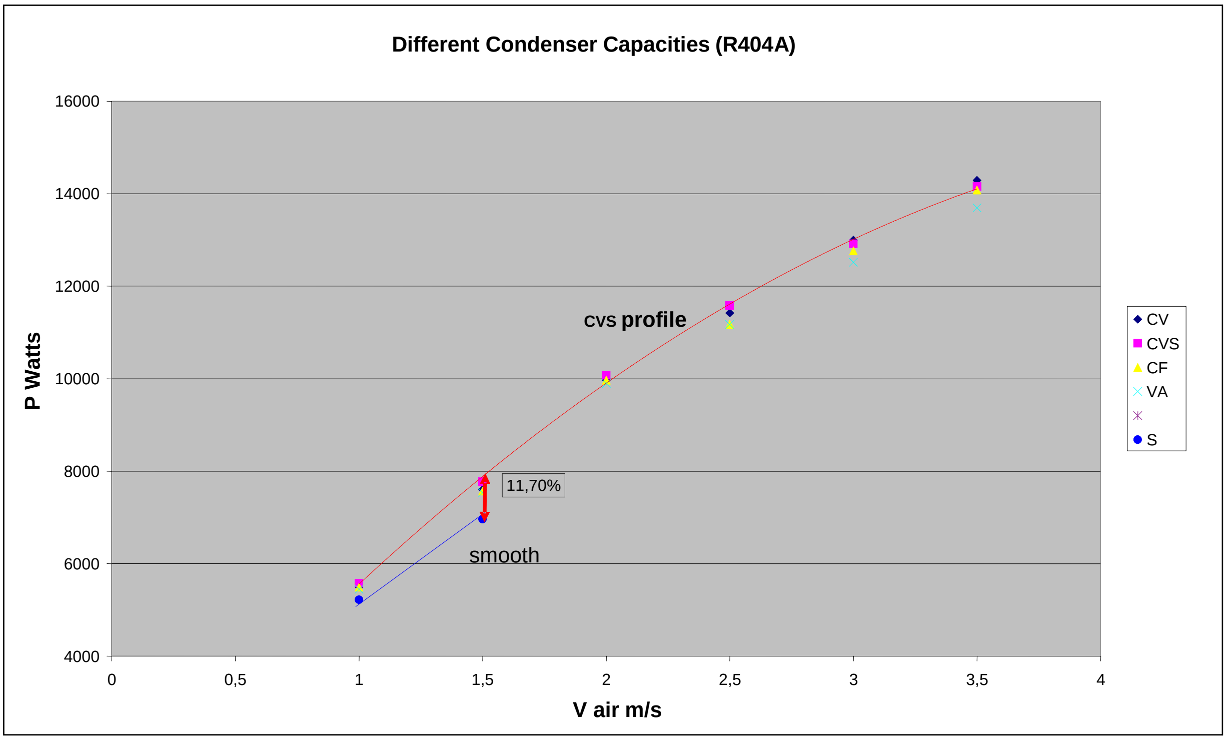
Figure 3. Cross sections of grooved tubes of different geometric forms [4].

An experimental study has been conducted by an international firm manufacturing copper tubes on the variation of capacity as a function of coil surface air speed with the use of grooved tubes in air cooled condensers. Prototype units of five different groove geometries have been used for the study. The working conditions of the tested prototypes and the fluid used have been the same.

Table 2. and Graph 3. give the data and results of the tests. In the comparison between smooth tubes and grooved tubes under conditions of 40 °C condensation, 25°C air inlet temperature and the use of R404A gas, it has been observed that the use of grooved tubes yields 11.70% higher capacity [4].

Test Conditions	**Test n°1**	**Test n°2**	**Test n°3**	**Test n°4**	**Test n°5**	**Test n°6**	**Test n°1**	**Test n°2**	**Test n°3**
Fluid	**R404A**						**R22**		
Fin Type	**Wavy**	**Wavy**	**Wavy**	**Wavy**	**Wavy**	**Wavy**	**Wavy**	**Wavy**	**Wavy**
Test Conditions ENV327									
Condensation Temperature (°C)	**40**	**40**	**40**	**40**	**40**	**40**	**37,4**	**37,4**	**37,4**
Air Inlet Temperature (°C)	**25**	**25**	**25**	**25**	**25**	**25**	**26**	**26**	**26**
dT	**15**	**15**	**15**	**15**	**15**	**15**	**11,4**	**11,4**	**11,4**
Supercooling (K)	**2**	**2**	**2**	**2**	**2**	**2**	**4**	**4**	**4**
Air Flow (m^3/h)	**1069.2**	**1603.8**	**2138.4**	**2673**	**3207.6**	**4347**	**1440**	**1728**	**1958**
Air Velocity (m/s)	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**2.5**	**3**	**3.4**
Capacities – Test Results (Watt)									
CV Type Groove Geometry	**5,492**	**7,600**	**9,967**	**11,422**	**12,998**	**14,288**	**4,563**	**4,802**	**4,950**
CVS Type Groove Geometry	**5,577**	**7,771**	**10,074**	**11,583**	**12,915**	**14,154**	**-**	**-**	**-**
CF Type Groove Geometry	**5,492**	**7,571**	**9,970**	**11,172**	**12,764**	**14,081**	**4,593**	**4,713**	**4,869**
V or VA Type Groove Geometry	**-**	**7,531**	**9,894**	**11,172**	**12,518**	**13,696**	**-**	**-**	**-**
Smooth Type Groove Geometry	**5,219**	**6,960**	**-**	**-**	**-**	**-**	**3,644**	**3,886**	**4,089**

Table 2. Test results of prototypes with different groove geometries for R404A and R22 gases [4]



Graph 3. Results of the experiment conducted for the R404A gas – Graphic representation [4]

2.5 Effect of fan selection on capacity and Noise level & Control Options

Since cooling groups are used in super markets, cold storage facilities, air conditioner, process cooling systems etc. in residential centers, low noise level during the operation of the groups is an important criterion. Condenser fans and compressors are the two components that are sources of noise in cooling groups. The noise level which results primarily from the fan motor and the design of the fan blades is determined by evaluating manufacturer's data and checked in terms of conformance to the prescribed specifications. The sound level may be reduced by decreasing motor rotation, if need be; in this case the heat transfer area of the heat exchanger should be increased in order to provide the required cooling capacity.
Another point which requires consideration in condenser selection is the necessity to assure the adequacy of the design to provide the cooling capacity required in conditions of high ambient temperature. In periods where air temperatures are low, operating all fans at maximum rotation to achieve the desired capacity will be superfluous and costly. In systems monitored by condenser pressure - temperature, operating fans at low rotation or disabling them will provide an air supply of sufficient flow to the system.

2.5.1 Two Speed Fans

The most practical means of supplying air of varying flow is to use a two speed fan. Thanks to these fans that can operate at a secondary speed like 3/4ths of the highest operating rotation, a substantial amount of energy can be saved in periods where the air inlet temperature falls far below design temperatures.

For example a condenser with four fans may be operated with lowered fan rotation when ambient temperature drops from 33 ºC to 20 ºC. In this case, 0.75 kW less of power will be consumed per fan, which means an energy consumption of nearly 40 %. This example pertains to 4 fans; systems of a much higher number of fans are being operated in most plants.

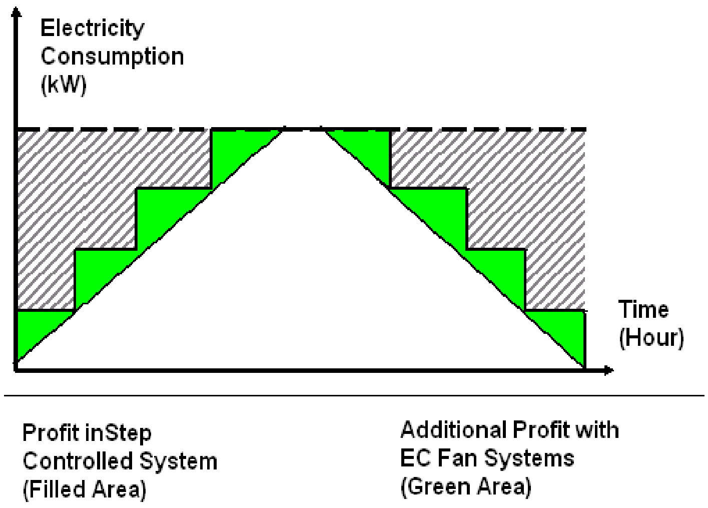
The power consumed by the 800 mm diameter fan in both speed and data belonging to another fan which may be used in lower rotations has been given below [5].

880 d/d	2.00 kW
660 d/d	1.25 kW
440 d/d	0.37 kW
330 d/d	0.20 kW

2.5.2 Use of Frequency Inverters and Step Control Units

With control units used both in single and two speed fans, air flows can be adjusted to needs. In places where sensitive control over fan speed is not required, step control systems where fans are sequentially enabled and disabled are implemented. The working sequence of fans can be determined by the users, and alternatives where fan operating periods are evenly distributed are also available. Since step control units operate on the basis of the fans being enabled or disabled, they can be manufactured at a lower cost than systems monitoring fan rotation. For this reason, this method is widely preferred for systems including a great number of fans and which do not require sensitive control.

The following graph shows the amount of energy saved in a step controlled operation of a dry cooler with 4 fans. It has been assumed that all 4 fans operate at the hottest hours of the day and that a single fan is sufficient at the coolest hours.



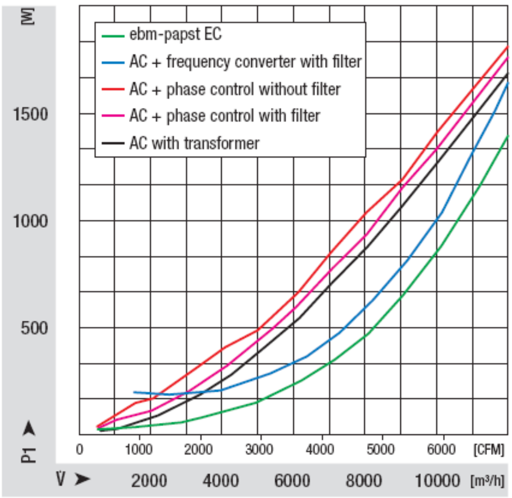
Graph 4**.** Electricity consumption of fans over a period of one day, in a condenser where fans are enabled according to need by way of step control. (The filled area indicates the amount of electricity consumed by not using all fans simultaneously, in terms of kWh)

In cases where the number of fans used is low and where the temperature-pressure differences are sensitive, step control does not yield adequate results. In such cases, systems monitoring fan speed and which therefore offer much more sensitive control over air flow (frequency inverters/converters) are used. Frequency inverters/converters are more expensive than step control unit in terms of initial investment cost; therefore the systems that are widely preferred are those where fans are controlled in groups and step control units and frequency inverters/converters are used together, as opposed to systems where all fans are controlled by separate frequency inverters/converters.

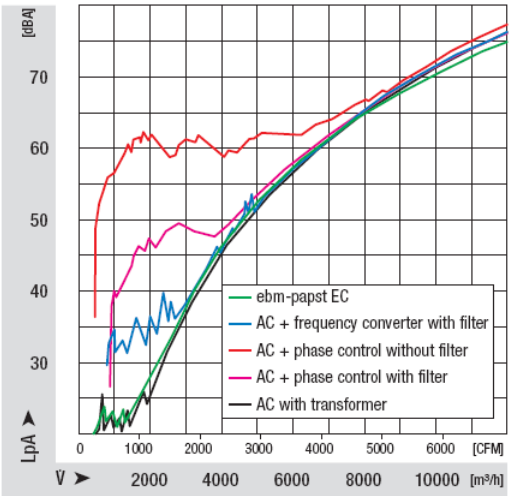
2.5.3 EC Fans

In addition to motor options of various speed ranges, the EC Motor technology whose areas of use have increased significantly over the last few years, are also used in condenser applications. EC fans facilitate controlling the fan motor at all speeds, independently of the number of poles. As seen in Graph 5.A, EC Motor systems save an average of 10% energy at nominal speed as compared to conventional speed control systems such as frequency inverter-step control-transformer frequency.

Due to the acoustically advantageous design of EC Motors, neither the unwanted resonances of frequency converter systems, nor the buzzing of fan controlled systems are observed in EC Motors. Thus, lower noise levels are achieved in EC Motor systems. As shown in Graph 5.B, while EC motor systems offer a minimum of 4 dBA advantage with respect to phase controlled and frequency converter systems, in low fan speeds and air flows in particular, this difference becomes as high as 15~30dBA.



Graph 5.A EC-Motor Power Consumption [6]



Graph 5.B EC Motor Noise Level [6]

3. USE OF FREE COOLING IN COOLING GROUPS WITH AIR COOLED CONDENSERS

As opposed to conventional cooling groups with air cooled condensers, use of groups with integrated free cooling coils has gained popularity of late. Free Cooling is obtaining cooling water without operating or partially operating the chiller compressor of the group by taking advantage of the low ambient temperature [7],[8]. For example in Great Britain, the use of integrated free cooling coil water cooling groups have a significant role in the fact that 62% of the annual cooling demand is met through free cooling. In the country, only 38% of the annual cooling requirement is obtained from mechanical cooling [7], [9].

Groups with integrated free cooling coils are alternative systems for cooling applications used in large computer and server rooms, Internet and telecommunication data centers. They have the capacity for both mechanical and free cooling (partial and complete) [7]. Figure 4.A shows a view of the cased unit of the water cooling group with integrated free cooling coil, and Figure 4 B shows a simplified representation of the structure of this type of unit. The free cooling coil is placed in the front section – according to the air intake direction of the unit- of the air cooled condenser coil. As the ambient temperature drops below that of the return water, the control valve sends the return water to the free cooling coil for pre-cooling or for complete free cooling [7].

Figure 4.A Air cooled water cooling group with Integrated Free Cooling coil [10]

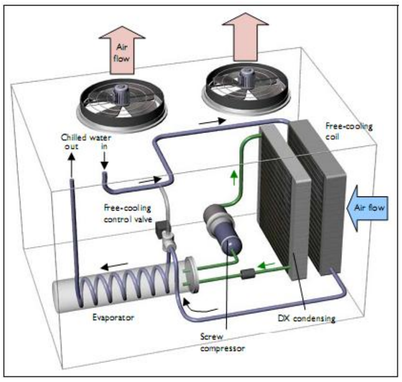
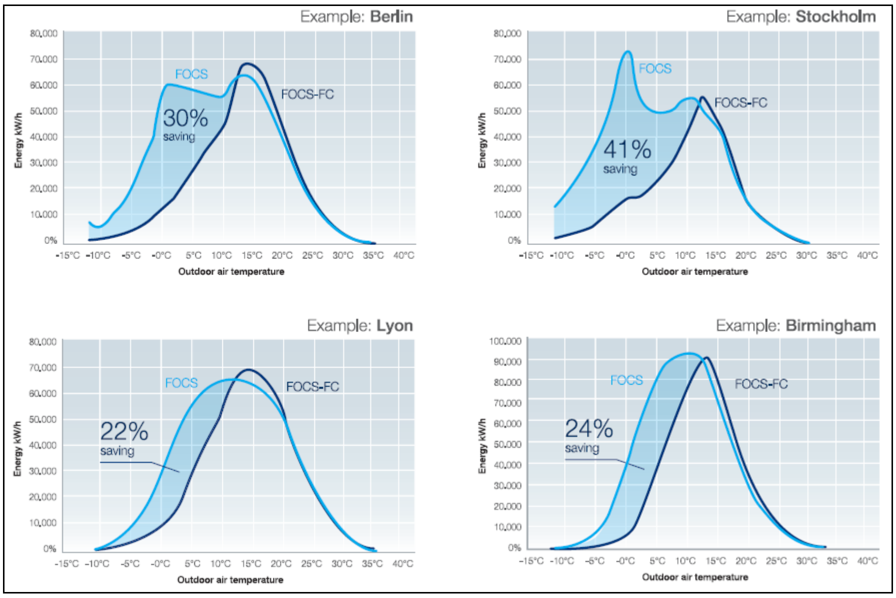


Figure 4.B Schematic for air cooled water cooling group with Integrated Free Cooling coil [7]

The conclusions related to measurements taken in four European cities by a chiller manufacturing firm on cooling groups with integrated free cooling coils in order to demonstrate the gain resulting from the use of Free Cooling in cooling systems have been given in Graph 6.



Graph 6. Energy saving figures as a function of outdoor ambient temperature for groups with free cooling installed in air conditioning systems in four cities in Europe [11]

4. STANDARDS AND ENERGY CLASSIFICATION IN AIR COOLED CONDENSERS

Standard capacities in Air Cooled Condensers are defined in accordance with the conditions set forth in the TS EN 327 (Heat Exchangers-Test Procedure For Establishing the Performance of Forced Convection Air Cooled Condensers) [12].

Condenser coils must be manufactured in conformance to the SEP (Sound Engineering Practice) defined under 97/23/EC PED (Pressure Equipment Directive) and the entire unit must meet CE requirements [13].

Energy efficiency in products may be calculated for the value ranges given in Table 3, as per the EUROVENT Rating Standard for Forced Convection Air Cooled Condensers For Refrigeration “Air Cooled Condensers”) 7/C/002 – 2007 [14].

Table 3. Energy Efficiency Class [9]

Class	**Energy Consumption**	**Energy Ratio (R)***
A	Extremely low	R > =110
B	Very low	70 =< R < 110
C	Low	45 =< R < 70
D	Medium	30 =< R < 45
E	High	R < 30

** The energy ratio “R” is obtained by dividing the standard capacity of the product by the total energy consumption of fan motors.*

There is a significant correlation between increasing energy efficiency and initial investment costs. While the initial investment costs of products with high energy efficiency is relatively high, they can be said to make up for the difference in costs in a short while.

Table 4 shows a sample comparison between two air cooled condensers assumed to use the same type of cooling fluid have the same operating conditions and equal capacities. For the comparison, the condenser capacity requirement of the system has been assumed to be 160 kW and alternative condenser designs have been made accordingly. Basic differences between sample units:

- Heat transfer surfaces,
- Unit dimensions,
- Coil surface air speeds,
- Electrical powers,
- Energy efficiency classes,
- Noise levels and
- Costs.

The unit with a higher initial investment cost has a larger size and heat transfer area. This has a direct bearing on cost. However, low values for the air velocity and consequently for pressure loss on the air side has an impact on the electricity consumption value, which lowers costs of consumption. This increases the energy efficiency of the unit and places the unit in the A, B, C ad D energy Classes.

SPECIFICATIONS	**CONDENSER 1**		**CONDENSER 2**		**CONDENSER 3**		**CONDENSER 4**	
MODEL	FUH YK 80 23 C1 2,1 E		FUH YK 63 24 C1 2,1 Q		FUH YK 50 24 C3 2,1 L		FUH YK 63 23 A1 2,5 S	
Energy Efficiency Class	A	Class	B	Class	C	Class	D	Class
Q (Condenser Capacity)	161,396	KW	163,430	KW	162,250	KW	160,170	KW
Heat Transfer Surface	543.3	m^2	522.6	m^2	461.3	m^2	272.1	m^2
Coil Length	3600	mm	4000	mm	3200	mm	3000	mm
Coil width	2150	mm	1800	mm	1500	mm	1800	mm
Air Flow	39,150	m3/h	40,730	m3/h	39,530	m3/h	57,640	m3/h
Air Velocity	1.4	m/s	1.6	m/s	2.3	m/s	3.0	m/s
Fan Diameter	800	mm	630	mm	500	mm	630	mm
Fan Devri	330	d/d	480	d/d	900	d/d	900	d/d
Number of Fans	6		8		8		6	
Total Fan Power	1.2	kw/h	1.52	kw/h	2.56	kw/h	4.68	kw/h
Sound Power Level (LwA)	68	dBA	72	dBA	78	dBA	84	dBA
Sound Pressure Level (LpA)	36	dBA	40	dBA	46	dBA	52	dBA
Energy Ratio (R)	134.5	-	107.5	-	63.4	-	34.2	-
Unit Price	€8,525	Euro	€6,676	Euro	€5,396	Euro	€4,515	Euro

Table 4**.** Sample comparison of the four assumed condensers [1].

Table 5 shows the difference between the Class A product and the Class D product. It is seen that the Class A product which has a higher initial investment cost, self-finances within 1,7 years as compared to use of a Class D product.

CALCULATIONS	Difference between the Class A and Class D products	
Difference between the electrical consumption of fan motors of units	3.48	kw/h
Difference between the annual electrical consumption of fan motors (20 hours/day)	25,404	kw
Unit cost of electrical consumption	0.13	$/kW
Difference in Total Annual electrical consumption (USD)	0.09	$
Difference in Total Annual electrical consumption (EURO)	2,364.1	€
Difference in unit costs	4,010.0	€
Pay Back Period of the Difference in Unit Cost	1.7	Years

Table 5**.** Comparison of the assumed condensers and the calculation of the payback period of the initial investment cost.

5. CONCLUSIONS AND SUGGESTIONS

Becoming a matter of primary importance in air conditioning, industrial cooling, supermarket cooling, commercial cooling, blast freezing and process cooling applications, etc., energy efficiency affects the design of chillers that account for a significant ratio of the energy consumption in plants. Legal legislations that for the short run limit, and in the long run prohibit the use of fluids of high global warming potential, that are detrimental to the ozone layer are also influential on designs. Since air cooled condensers are among the essential components of cooling groups, efforts to improve their energy efficiency are made incessantly, the related national and international standards are upgraded and limitations on their energy consumptions are always increasing.

Investors, project and application engineers operating within the cooling sector, should be well versed in the issues described above. As the use of products with high energy efficiency spreads, efficiency will rise in our systems. It should also be kept in mind that these systems are environment friendly as well.

6. REFERENCES

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[12] TS EN 327 (Heat Exchangers-Test Procedure For Establishing the Performance of Forced Convection Air Cooled Condensers)
[13] 97/23/EC The Pressure Equipment Directive
[14] EUROVENT Rating Standard (for Forced Convection Air Cooled Condensers For Refrigeration “Air Cooled Condensers”) 7/C/002 – 2007

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