

Auditing the European room air-conditioning systems and potential energy savings

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Abstract

Nowadays, the European Community promotes the energy improvement of the air-conditioning (AC) systems through the compulsory inspection of these facilities in the frame of the Energy Performance of Buildings Directive [EPBD, 2002]. Inspection itself is just a motivating mean for the AC actors to improve the energy efficiency of the systems and reduce energy. Therefore, the aim of the inspection is to follow periodically the correct management of the facility through a quick visit of the plant and a study of the available documentation while the aim of the audit is the research of best efficiency improvements which requires further investigations to evaluate and quantify the savings. Audit differs from the common maintenance activities of the facilities, the aim of which is limited to guarantee the basic operation of the plant. There is an overall lack of methodologies specific for air-conditioning and the improvements proposed are seldom proven with scientific rigour. For room air conditioning systems, the impacts of defect during operation due to ageing and neglected maintenance are considered: fouled condenser, charge leaks, compressor performances reduced, fans degradation, filter fouling and additional pressure drop in liquid line are explored. The over consumption due to these defects is evaluated for different building types and French climates. The results allow to define simple methods that can be used by the auditors to estimate the energy savings due to the correction of the defects.

Introduction

The Energy Performance of Buildings Directive [EPBD, 2002] that states in article 9 the periodic inspection of the existing air conditioning (AC) systems arise several problems and its implementation has been delayed in most member states. The inspection procedure “shall include an assessment of the air-conditioning efficiency and the sizing compared to the cooling requirements of the building and appropriate advice shall be provided to the users on possible improvement or replacement of the air-conditioning system and on alternative solutions” [EPBD 2002].

The assessment of the air conditioning efficiency is in fact crucial but actually very difficult because the assessment of the operating efficiency depends on a lot of factors from the design, the installation until operation and maintenance practices, and in general the operating efficiency is far from the “ideal efficiency” certified in the manufacturers catalogues. If we look at the equipment components all along the life of the air conditioning system, several factors naturally decrease the efficiency of the system. We speak about effects that are most of time unnoticed by the user, because they do not cause immediate failure (even if on longer term they can produce the stop of the system operation) and because they appear gradually. Maintenance activities are performed to maintain the comfort level during the years and they reduce the impact of several of these factors on the system through the periodic inspection and periodic specific actions, but the original aim is “availability” and not “efficiency”.

Maintenance is often (quite always) performed for centralised plant with a minimum set of actions. But for small capacity systems, the maintenance is often irregular, performed only when

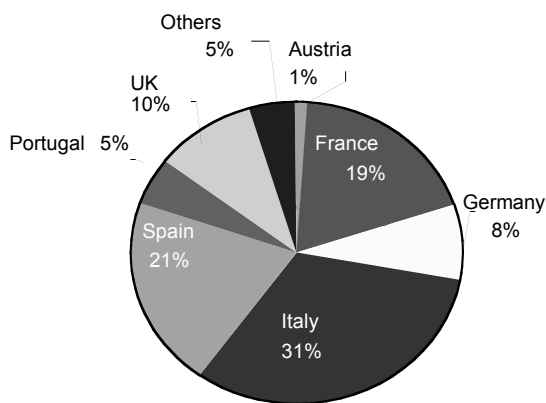


Figure 1: RAC main stock in EU [EERAC]

needed (corrective but not preventive) and for room air conditioners (RAC), performed by non-professional staff (the owner takes care himself of his system). Manufacturers do efforts in this way; basic maintenance actions are described in the users' guides that accompany the system, modern systems includes automated troubleshooting systems in the system command. But there is no guarantee that maintenance is regularly realised and the time period between actions can be very arbitrary.

Although smaller systems as room air conditioners could in most case not enter in the frame of the air conditioning inspection (the inspection is limited to 12 kW of capacity meant as sum of the capacities of the systems present in a building), their importance on the total energy consumption in Europe is very impressive, especially for Mediterranean countries (Spain and Italy 50 % of the total stock) in a total of 7 402 thousands units in 1996, shared as in the figure 1.

The French stock was already important at that time, but its increase has been boost up after the extreme hot climate in 2003 that led to a rapidly market increase: + 80 % units sold in 2004 [ClimInfo 2205].

This is the reason why it has been focused the analysis on this type of system and developed methods for estimate savings and efficiency for these systems. The inspector/auditor needs then to be able to target the most important opportunities for energy savings and comfort improvement for this system type and to be able to quickly individuate the problem and estimate the possible improvements consequences due to the correction. Time being, the audit methods are very scarce and the inspection would require more tools and support. A case of a split systems has been studied in order to define the equipment problems that should be investigated by a professional and their effects on comfort and consumption issues. Stress is put on energy consumption increase and non-comfort consequence in relation with the equipment defects intervening naturally in the life of a system.

Defect characterisation on performances at fixed conditions

The equipment defects that can occur in the lifetime of a package air conditioner have been analysed in the work of Braun and other at experimental level [Chen 2001]. The main objective of the analysis was to define the impact on measurable parameters in order to develop an automated fault diagnosis and detection system. The detection and diagnosis aspects were developed but the answer to the question "how much the system is over consuming?" remain fuzzy. This estimation is crucial in order to quantify the energy savings, and it can further allow to develop an economic assessment of the corrective actions. That is why it has been developed thereafter quantification of the energy impact of the defects and supply indicators that can be useful for auditors, inspectors, and energy advisors to promote a better management of RAC.

The defects identified by Breuker [Breuker1998] for packaged systems can be translated for room air conditioner equipment because of the similar structure of the two systems (air to air systems). The following defects were kept:

1. The refrigerant undercharge
 2. The condenser fouling
 3. The evaporator filter fouling
 4. A restriction in the liquid-line
 5. A worn compressor
- 6./7. Indoor and outdoor fans loss of performance

The thermodynamic simulation software used is the ORNL heat pump design model – MARK V - version 95d [C. K. Rice 1991, 199 and 1998] to simulate the reference (no-defect = reference operation) and degraded operation (introduction of one by one defect) for a room air conditioner with the characteristics in table 1.

The model simply allowed to introduce the modifications in the input parameters translating the equipment degradations and the level of the fault. For each defect, it has been observed the refrigerating cycle modifications (condensation pressure, evaporation pressure, some significant temperatures) and the variations of the cooling capacity, the power to compressor motor and the energy efficiency ratio (EER, ratio between cooling capacity and power to compressor drive). The occurrence of several defects at the same time is not investigated.

The refrigerant undercharge can be due to the loss of the circuit fluid towards outside ambient because the system operates at a pressure level higher of the ambient pressure. In some case the refrigerant leaks can be due to leakages that occur during

Table 1: Simulated split characteristics

Rating Cooling Capacity (kW)	8.56
Rating Compressor Power (kW)	3.15
Rating EER	2.72
Compressor type	Reciprocating
Refrigerant	R22
Expansion device	Thermostatic expansion valve (TXV)

Table 2: Effects on the EER for refrigerant leaks at different indoor and outdoor conditions

Refrigerant charge reduction	-10%	-20%	-30%	-40%
(EER- EER _{ref}) / EER _{ref} %				
T1 -35°C/27°C	-1.4%	-3.0%	-6.2%	-12.3%
T2-27°C/21°C	-0.5%	-1.3%	-3.4%	-9.4%
T21-35°C/21°C	-0.8%	-2.3%	-4.2%	-9.1%
T12-27°C-27°C	-0.2%	-2.3%	-6.2%	-12.1%

Table 3: Effects on the EER for condenser fouling at different indoor and outdoor conditions

Condenser surface reduction	14%	28%	42%
(EER- EER _{ref}) / EER _{ref} %			
T1 -35°C/27°C	-5.6%	-14.8%	-36.2%
T2-27°C/21°C	-5.5%	-15.2%	-34.3%
T21-35°C/21°C	-5.2%	-15.1%	-36.6%
T12-27°C-27°C	-5.4%	-15.1%	-32.6%

operation especially in correspondence of the joints between different components of the system. In some other case, the system charge level is low because the initial charge introduced in the system at the moment of its installation was less than the one recommended by the manufacturer for a human error. An undercharged system is translated in the model by the reduction of the total refrigerant charge of the system.

The condenser fouling is due to an accumulation of debris and dust on the face of the condenser coil: on one side it leads to a reduction of heat transfer increasing the overall thermal resistance of the exchanger and on the other side increase the pressure drops reducing the total mass flow rate of air across the circuits of the condenser. The condenser fouling acts on the airflow rate and on the thermal resistance of the coil. The global effect is difficult to translate and as a first approximation the defect is represented simply decreasing the total exchange surface of the condenser, initially at 0.76 m² and reduced of 14, 28 and 42 %.

The evaporator filter fouling is generated by the accumulation of dust on the filter; it leads to an increased pressure drop at the evaporator and to a reduction of the airflow rate across the evaporator coil, thus lowering the cooling capacity. The level of the evaporator filter fouling is simulated by reducing the airflow rate across the evaporator, initially at 1 269 m³/h, reduced of 12, 24, 36 and 48 %.

A liquid-line restriction can be caused by the accumulation of debris in the expansion device. This fault is simulated by an additional pressure drop in the liquid line, measured as a % of the total pressure difference between the high and low pressure, the value vary from zero to 4.14 bars.

The compressor is very sensitive to maintenance and with operation valves can wear and not guarantee anymore the compressor sealing: the high pressure refrigerant in the compressor cylinder leaks back into the suction line across the suction valve, or the discharged gas leaks back into the cylinder across the discharge valve. These leakages across the compressor valves bring the reduction of the compressor volumetric efficiency. The compressor valve leakage has been simulated by reducing

the compressor volumetric efficiency lowering the curve of the volumetric efficiency from 0.0 % to 34.4 %.

The fans of the condenser and evaporator units are also subject to wearing as all the moving parts: dust in the joints, loss of lubricants etc. This default leads to a difficult removal of the heat at the condenser and a difficult in distribution of the cooled air to the evaporator. This fan malfunction has been simulated by lowering the value of the respective fan efficiencies initially at 45 %, and then reduced of 18, 33, 47, 58 % for the indoor fan and of 16, 27, 40 and 50 % for the outdoor fan.

The behaviour of the degraded split has been defined for different indoor and outdoor air conditions:

- T1: 35°C condenser inlet, and 27°C evaporator inlet
- T2: 27°C condenser inlet, and 21°C evaporator inlet
- T12: 35°C condenser inlet, and 21°C evaporator inlet
- T21: 27°C condenser inlet, and 27°C evaporator inlet

The T1 and T2 correspond to the standard test conditions [EN 14511], T1 tested values are displayed by manufacturers, T12 and T21 are a combination of the T1 and T2 conditions.

The undercharged system (Table 2) begins to show large degradation of performances only for values higher than 20 %, this can be due to a deliberate overcharge of the system by the manufacturer in prevision of the unavoidable leaks that occurs during operation. This is confirmed by the charge calculation performed by the programme for which the optimal calculated charge is 2.4 kg versus the 2.8 kg from the manufacturer, 15 % less. The defect is more relevant for higher indoor temperatures and not dependent on the outdoor conditions.

The reduction of the heat exchange at the condenser surface shows an important effect on the efficiency (Table 3): it should be noted that decreasing the heat exchange at condenser increase the condensing pressure until the stop of the compressor unit for reduction over 25 % of the surface for extreme outdoor temperatures. The indoor and outdoor conditions do not influence the loss of performance.

The filter fouling also reduces the heat exchange at the evaporator (Table 4), in a manner very similar to the refrigerant

Table 4: Effects on the EER for filter fouling at different indoor and outdoor conditions

Airflow reduction	-12%	-24%	-36%	-48%
$(\text{EER} - \text{EER}_{\text{ref}}) / \text{EER}_{\text{ref}} \%$				
T1 -35°C/27°C	-0.2%	-1.0%	-2.2%	-4.1%
T2-27°C/21°C	-0.8%	-1.6%	-3.6%	-6.0%
T21-35°C/21°C	-0.4%	-0.7%	-2.2%	-4.4%
T12-27°C-27°C	-0.4%	-1.0%	-2.0%	-4.6%

Table 5: Effects on the EER for compressor leaks at different indoor and outdoor conditions

Volumetric efficiency reduction	-9%	-17%	-25%	-34%
$(\text{EER} - \text{EER}_{\text{ref}}) / \text{EER}_{\text{ref}} \%$				
T1 -35°C/27°C	-6.1%	-12.6%	-19.1%	-26.4%
T2-27°C/21°C	-5.8%	-12.0%	-18.8%	-25.9%
T21-35°C/21°C	-6.5%	-12.9%	-19.9%	-27.6%
T12-27°C-27°C	-5.5%	-11.4%	-17.6%	-24.4%

Table 6: Effects on the EER for worn indoor fan at different indoor and outdoor conditions

Indoor fan efficiency reduction	-18%	-33%	-47%	-58%
$(\text{EER} - \text{EER}_{\text{ref}}) / \text{EER}_{\text{ref}} \%$				
T1 -35°C/27°C	-0.4%	-0.9%	-1.4%	-2.5%
T2-27°C/21°C	-0.9%	-1.6%	-2.4%	-3.5%
T21-35°C/21°C	-0.6%	-1.2%	-1.6%	-2.4%
T12-27°C-27°C	-0.6%	-1.2%	-1.8%	-2.3%

Table 7: Effects on the EER for worn outdoor fan at different indoor and outdoor conditions

Outdoor fan efficiency reduction	-16%	-27%	-40%	-49%
$(\text{EER} - \text{EER}_{\text{ref}}) / \text{EER}_{\text{ref}} \%$				
T1 -35°C/27°C	-1.5%	-3.2%	-5.1%	-7.2%
T2-27°C/21°C	-1.5%	-3.0%	-4.6%	-6.5%
T21-35°C/21°C	-1.3%	-2.7%	-4.3%	-6.0%
T12-27°C-27°C	-1.7%	-3.5%	-5.5%	-7.6%

charge reduction and that can be considered uniform for all indoor and outdoor conditions.

The reduction of the compressor volumetric efficiency shows a linear reduction of efficiency (Table 5), mainly due to a strong reduction of the system capacity, the absorbed power being quite constant. The indoor and outdoor conditions do not influence the loss of performance.

The system is more sensitive to the reduction of the outdoor fan efficiency than indoor (Table 6 and Table 7), but the global effect is low because of the power absorbed by the fans in comparison to the compressor power is small even when the efficiency decrease. That is probably why few efforts have been done until now by manufacturers to improve their efficiency! For the reduced efficiency of the indoor fan, the decreased

cooling capacity is accompanied by a reduction of the compressor power that keeps the global efficiency quite constant. The main effect is the decreased supplied air temperature of the evaporator that can be source of discomfort for occupants near the system, because of the feeling of a too much cold airflow. This defect will not be analysed furthermore.

For the outdoor fan, the reduction of cooling capacity is accompanied by an increased compressor power due to the divergence of the high and low pressures: the global efficiency is reduced of the same amount for the different conditions, slightly larger for high outdoor temperatures.

Adding more pressure drops in the liquid line does not affect so much the operation of the system (Table 8): the TXV in fact is able to compensate the effect of the additional pressure

Table 8: Effects on the EER for increased pressure drop in the liquid line at different indoor and outdoor conditions

Additional pressure drop (% of total pressure drop at T1 for reference case)	7%	14%	21%	28%	35%
(EER- EER _{ref}) / EER _{ref} %					
T1 -35°C/27°C	0.4%	0.5%	0.0%	-0.4%	-1.2%
T2-27°C/21°C	0.2%	0.1%	-0.2%	-1.1%	-1.9%
T21-35°C/21°C	1.0%	1.1%	1.3%	1.4%	1.3%
T12-27°C-27°C	-0.3%	-1.1%	-2.2%	-3.5%	-5.1%

Table 9: Impact on system parameters of the reviewed defects

Defects	Condenser pressure	Evaporator pressure	Cooling Capacity	Fans Power	Compressor Power	EER
Refrigerant Leaks	↓ (↓)	↓(↓)	↓(↓)	~	↓	↓ (↓)
Compressor Valve Leaks	↓ (↓)	↑ (↑)	↓(↓)	~	↓~	↓(↓)
Liquid-Line Restriction	↓ (↓)	↑ (↓)	~↑ (↓)	~	~↑	~
Condenser Fouling	↑ (↑)	~ (↑)	↓ (↓)	~	↑	↓ (↓)
Condenser fan efficiency reduction	↑	↑	↓	↑	↑	↓
Evaporator Filter Fouling	↓ (↓)	↓ (↓)	↓ (↓)	~	↓	↓ (↓)
Evaporator fan efficiency reduction	↓	↓	↓	↑	↓	↓~

Legend :
 ↑ Increase
 ↓ Decrease
 ~ Stable

drop for in a large manner reducing the influence if some units percents in most critical conditions (T1) when pressure are increased of 35 %. The effect can be positive in certain conditions and negative for others, but in average does not exceed -1.7 % at high defect intensity.

The Table 9 summarizes the effects on the condensation and evaporation pressures of the refrigerant, the cooling capacity, the power of compressor and fans and the global energy efficiency ratio (EER) for all the defects considered. In the same table in the brackets are shown the trends obtained from Breuker and Braun [Breuker 1998].

The results are in good qualitative agreement with the authors except for the liquid line restriction: the effects of a restriction in the liquid line are lowered in our case by the operation of the TXV, while the orifice device used in the experimental tests by the authors is more sensitive to the restriction of the liquid line creating a stronger impact of this defect on the total performances of the air conditioner.

For the considered defects, pressure drop in the liquid line and the decrease of the indoor efficiency fan cannot be considered enough dangerous and will not be investigated furthermore in the study. The other defects will be studied more in detail using dynamic simulations that allow to observe the effects of the partial load behaviour of the degraded system.

Dynamic simulations details

The ORNL program allow us to describe the system in determined outdoor and indoor conditions but does not allow to perform dynamic simulation that can include other aspects such as the regulation, building and occupants or weather data. Then the programme Consoclim [Consoclim 2002] has been

used: it gathers building model, cool production and distribution models and allows annual simulation with determined weather data and occupation scheduling.

The cooling capacity and power at different indoor and outdoor conditions are taken into account using the following relation for cooling capacity (Pc) and absorbed power (Pa) at non rating conditions:

$$Pc/Pc_{rating} = Pc_{rating} * (1 + D1 * (Ti_{con} - Ti_{con_{rating}}) + D2 * (To_{eva} - To_{eva_{rating}}));$$

$$Pa/Pa_{rating} = Pa_{rating} / Pc_{rating} * Pc * (1 + C1 * DT + C2 * DT^2);$$

$$DT = (Ti_{con} / Ti_{con_{rating}}) + (To_{eva} / To_{eva_{rating}})$$

Where:

Ti_{con}=inlet temperature at the condenser

To_{eva}=outlet temperature at the evaporator

C1, C2, D1 and D2 constants

-_{rating} =index for parameters defined or calculated at rating conditions

The partial load behaviour of the air conditioner is taken into account and is characterized by a model load (showed in Figure 2) of the type:

$$EER/EER_{rating} = Load / (Load + \alpha)$$

With $\alpha = 0.1$ [Dougherty 2002] and $0 < Load < 100\%$

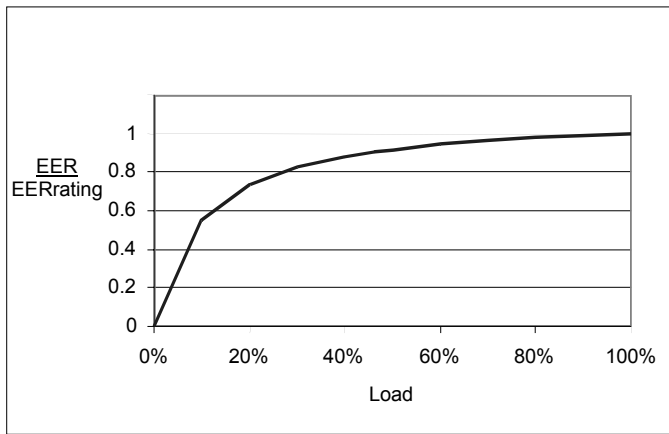


Figure 2: Partial load efficiency ratio in function of the load

Table 10: Simulated building areas

	Office	House
Total area (m ²)	1008	136
Cooled area (m ²)	762	85

Table 11: Annual Consumptions ratios for an office and a house for two climates.

	House: AC electrical consumption (kWh/m ²)	
	Trappes	Nice
Zone2	5.2	19.5
Zone4	x	3.3
Total	5.2	9.1
	Office: AC electrical consumption (kWh/m ²)	
	Trappes	Nice
Zone2	11.0	29.8
Zone3	12.4	30.6
Zone4	2.2	9.6
Total	9.6	25.4

The previous Mark V simulations has been used to define the constant D1, D2, C1 and C2 different for each defect and have been determined for the reference and degraded system.

The degraded characterizations of RAC are so used for further dynamic simulations linking degraded systems with typical French office and house buildings. These buildings have as characteristic to have internal load very similar in general and no specific uses that can strongly differentiate the buildings in the stock. For each building, two French climates are considered representative of two extreme French weather conditions: Trappes as the typical North continental climate and Nice as the typical temperate Mediterranean climate. The buildings try to be representative of existing building with an envelope thermal resistance respecting the French thermal regulation of 1988.

The house is shared in two separate air-conditioned zones the living room and the bedroom equipped with split systems. The office building includes two storeys and three different thermal zones: two separate offices zones with different walls orientation and a meeting room. The total and cooled areas for the buildings are showed in table 10.

REFERENCE CASE

The reference consumption for the two building types takes into account the different zone consumptions and an oversizing factor is applied as it can be easily encountered in the reality: in the office building this oversizing is about the 10 % of the real need, for the house this value can reach the 30 %. The use of air conditioning in the zone 2 of the house (corresponding to bedrooms) in the case of Trappes is not justified, the need being too small.

The reference annual consumption due to the air conditioning for the two buildings in the two separate climates is shown in the Table 11 as a ratio related to the air-conditioned area.

DEGRADATED SYSTEM ANALYSIS

The following analysis allows to estimate the effects of the defects for different defect magnitudes and try to find laws that could be easily applied in an audit procedure to quantify first savings due to correction of the defects, improvement of maintenance without major intervention on the system.

From figure 3, Ea_ref and Ec_ref indicate the annual energy consumption and the total cooling energy for the reference case while Ea and Ec indicate the annual energy consumption and

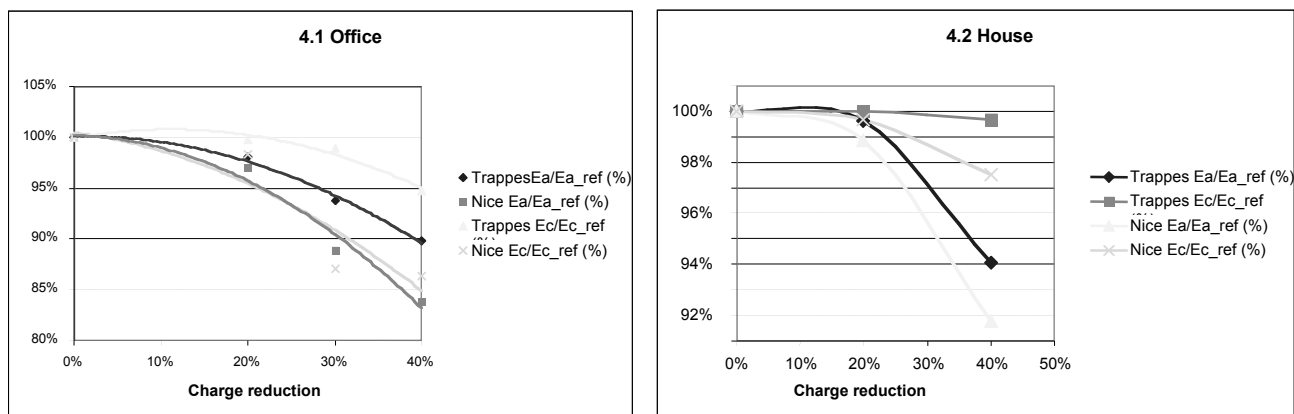


Figure: 3 Effect on the cooling energy and the annual energy consumption for an office building (4.1) and a house (4.2) with a system with reduced refrigerant charges.

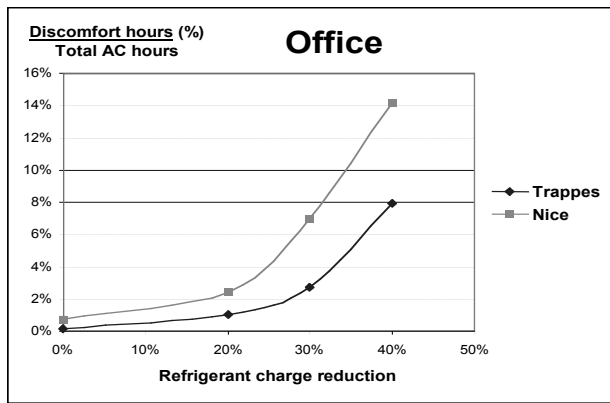


Figure 4: Effect on the comfort for an office building with a system with reduced refrigerant charges.

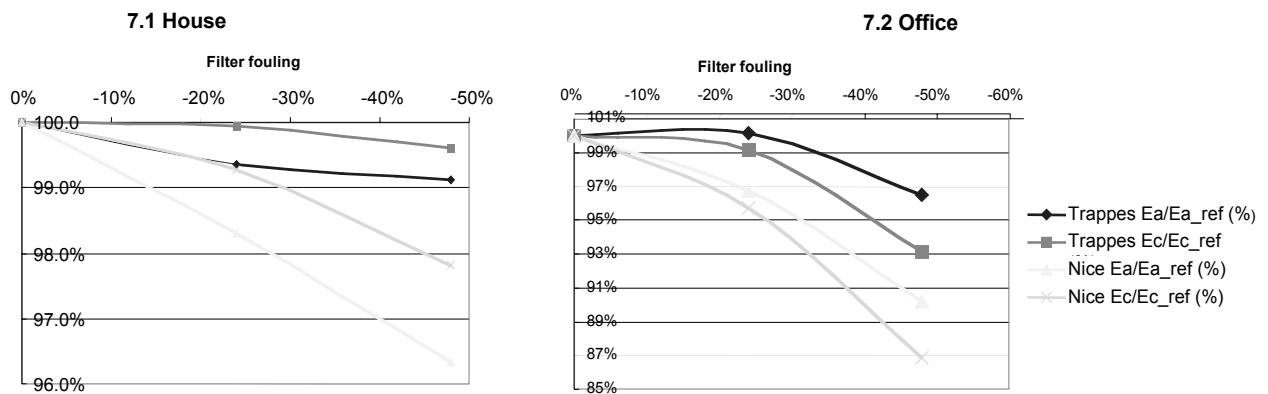


Figure 5: Effect on the cooling energy and the annual energy consumption for a house with a system with different levels of filter fouling.

the total cooling energy for the case of the defect in consideration.

Refrigerant leaks

As it can be saw in the previous static model, the loss of efficiency due to refrigerant leaks are significant for leaks over 20 % of the initial charge. If this defect does not increase the overall consumption (Figure 4.1-2), on the contrary it is decreased and its decrease can be interpreted as quadratic law.

In this case, it is more an issue at comfort level, the capacity being reduced: discomfort periods (considered for indoor temperatures higher of the set point of more than 1°C) become significant for offices building, being 14 % of the occupation cooling time in Nice, 8 % in Trappes for refrigerant loss of 40 % (Figure 5).

The evaporator filter fouling

The fouling of the evaporator filter has an effect similar to the refrigerant leaks: the cooling capacity is reduced, no over consumption is observed, the comfort can be seriously reduced of the order of 14 % of the time for office in Nice and 9 % in Trappes for airflow reduction of the 50 %. In the house building, the effect is less noticeable due to the over sized system.

To distinguish this defect from the refrigerant leaks it can be visually observed the level of dirty of the filter if the auditor has

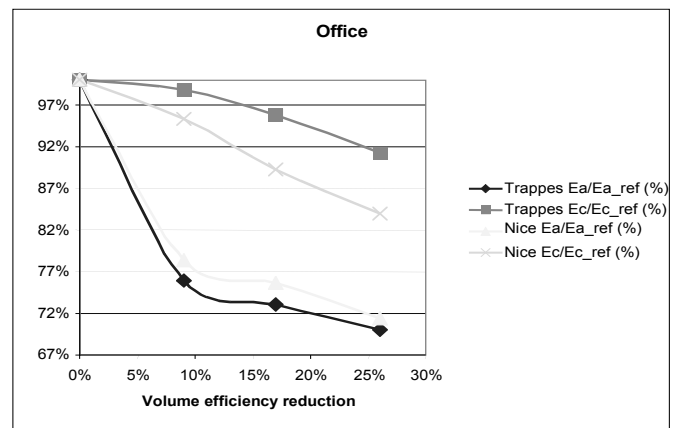


Figure 6: Effect on the cooling energy and the annual energy for an office building with a system with reduced volumetric efficiency of the compressor.

the access to the unit and can open it, or measure the airflow at the indoor unit and compare it to the manufacturer one, the airflow is lowered by the increased pressure drop at the indoor fan. Moreover, the reduction of the airflow at the evaporator due to the filter fouling leads to a decrease in the supplied air temperature that can be source of discomfort when an occupant is in the proximity (feeling of too cold airflow).

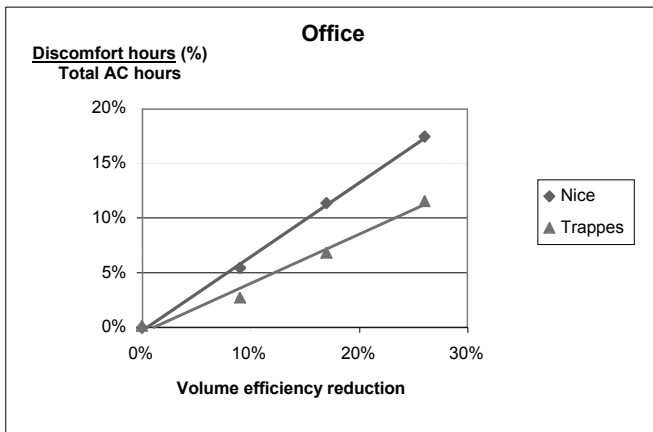


Figure 7: Effect on the comfort for an office building with a system with reduced refrigerant charges

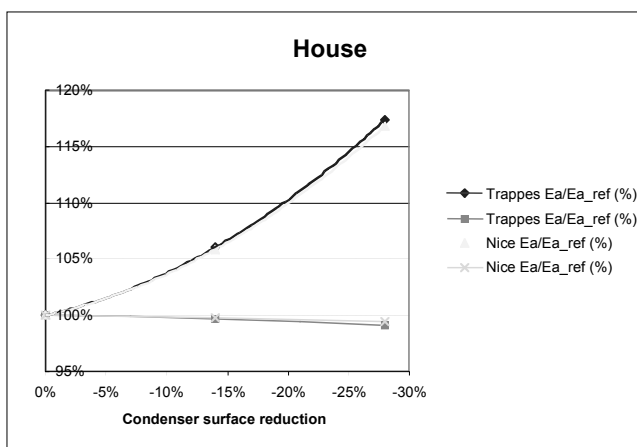


Figure 8: Effect on the cooling energy and the annual energy consumption for a house with a system with reduced condenser surface.

The compressor wearing

The leaks between the valves of the compressor does not lead to over consumption but affect more the cooling capacity of the system.

The consumption decreases while the discomfort hours amount grows in average 17 % for the office in Nice and 13 %

in Trappes for a reduction of the volume efficiency of 26 %. The increase of discomfort period is in very linear with the intensity of the defect as shown in the figure below.

The condenser fouling

The condenser fouling, not having a major impact on the cooling capacity of the system but more on the electrical consumption, hardly leads to non respect of the set-point, but strongly increase the annual energy consumption. The relation between the over-consumption and the surface reduction being quadratic and quite independent from the climate, it has the same impact for Trappes and Nice in both cases of house and offices.

The fan of the condenser efficiency reduction

This defect has an effect very similar to the condenser fouling, having the same type of impact on the reduction of the heat exchange at the condenser, the relation with the efficiency reduction can be considered quite linear and not sensitive to the climate. The loss of fan efficiency is in general a less serious defect: for a reduced efficiency of 40 % (that would lead to a fan efficiency of 0.18), the over consumption would be in the worst case of 5 %. No particularly comfort effects have been noticed.

Conclusions

Existing air-conditioned system are the object of a new attention. On one hand the EPBD that states the inspection of the air conditioning system arises the question on how determine the status of operation of an air conditioning system. On the other hand, taking into account the important existing stock of room air conditioners in Europe, it can be asked what are the energy savings in the existing stock possible only through the best maintenance without main modification? Once identified a set of frequent defects that occur during the normal operation, their impact on the performances of a system has been defined using a static thermodynamic model. The degraded system has been introduced in dynamic simulation in order to investigate the effect on the annual energy consumption and on the comfort of occupants in two typical French building: an office and a house. The following defects has been considered: fouled condenser, refrigerant charge leaks, reduced compressor volumetric performances, fans degradation, filter fouling

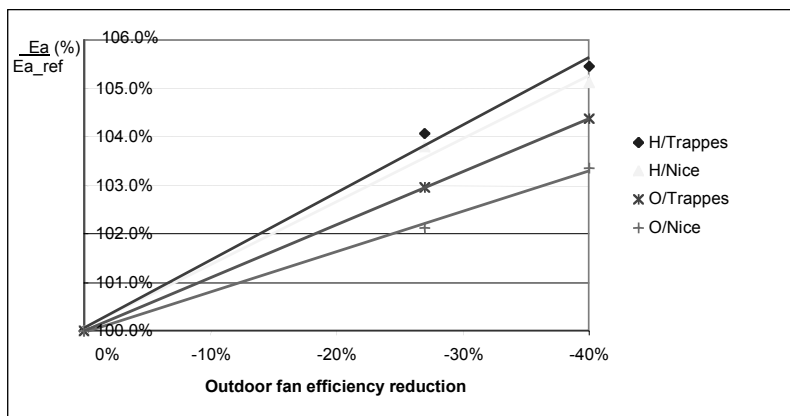


Figure 9: Effect on the cooling energy and the annual energy for an office building with a system with reduced outdoor fan efficiency.

and additional pressure drop in liquid line are explored. In the case of a system using a TXV expansion device the defect of the additional pressure drops in the liquid line can be ignored because compensated by the valve operation. At the same time the indoor fan efficiency reduction reveal to have a very poor impact on the comfort and consumption aspects and the investigation has not been pursued too far.

The operation characteristic for each defect has been defined and coupled with specific building and climates in a dynamic simulation programme.

Several observations have been possible on the calculated annual energy consumption and temperatures. The oversizing factors applied in the common sizing process allows to guarantee the comfort in many cases of defects, and discomfort period becomes important only for extreme conditions. Two defects can be neglected: the liquid line pressure additional pressure drops the effects of which are compensated by the operation of the thermostatic valve, and the indoor fan efficiency decrease which effects can be summarized in a decrease of the indoor air temperature, that can be source of discomfort when an occupant is in the proximity.

The kept defects can be distinguished in two types of defects: defects that can be mainly source of over consumption as condenser fouling and outdoor fans loss of performance, and defects that have main effects on the cooling capacity and comfort aspect (while the annual consumption can be found reduced) as filter fouling, compressor leaks, refrigerant leaks. Following the first observations of the auditor so he can be oriented to observe more in detail one or more defects. General trends can be deduced in many cases to model the discomfort and the over consumption effects. From the nominal operation characteristic of the system (from design and manufacturer data) the inspector should be able to estimate the intensity of the defect and from the curves presented to estimate the consequences in terms of consumption and discomfort. Also he can forecast the future behaviour of the system.

If we could recommend the order of the inspection steps we could resume the results as follow. Refrigerant leaks check should be a priority for the auditor: more than for the energy and comfort considerations also in order to limit the dispersion in the atmosphere of the refrigerant at high global potential warming. The condenser should then inspected with care because it has the most important impact at the consumption level: the inspector can visually estimate the fouling (amount of debris and dust on the fins) and he could be able to acoustically detect bad operation and fan problems. Compressor problems are more difficult to detect and require the catalogue values (often supplied by manufacturers for several outdoor and indoor conditions) as consumption reference, the absorbed power being easily measured. Finally the status of the filter can be visually checked or estimated by asking to the owner the summary of maintenance operations.

More efforts should be done in order to extend this analysis to systems using different technologies (for expansion device and compressor) or refrigerant fluids, the R22 destined to be phased out by the Montreal protocol and being replaced by new fluids, mainly R410a.

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