Inspection and Energy Auditing of HVAC Systems: Implementation of EPBD article 9

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SUMMARY

The European Directive on the Energy Performance of Buildings states that Member States shall lay down measures to establish a regular inspection of air conditioning (AC) systems of effective output of more than 12 kW. This legislative measure – in conjunction with the fact that about one third of the existing AC system will become obsolete in the next years – opens a vast opportunity for significantly reducing the primary energy use of such systems. This paper presents the main results of the AUDITAC (2005-2006) and HARMONAC (2007-2010) research projects, funded by the EC within the Energy Intelligent Europe program, aimed at developing a set of documents, procedures, and data applicable to the inspection and energy auditing of AC systems.

1. INTRODUCTION

The European Directive on the Energy Performance of Buildings (EPBD) states, at article 9, that *"Member States shall lay down the necessary measures to establish a regular inspection of air conditioning systems of an effective rated output of more than 12 kW. This inspection shall include an assessment of the air-conditioning efficiency and the sizing compared to the cooling requirements of the building. Appropriate advice shall be provided to the users on possible improvement or replacement of the air-conditioning system and on alternative solutions"*. (Bory, 2006)

By examining article 9 it appears that, even if the emphasis of the EPBD is placed on the assessment of efficiency and sizing of the air conditioning (AC) system, it is the long-term goal of the legislator to promote energy efficiency by more radical actions, i.e. by improving or replacing the existing equipment, or by adopting alternative solutions. It is clear that a simple - albeit thorough, - inspection of the AC system would not be sufficient to pursue such more ambitious goal, for which a complete Energy Audit is necessary. The EC, acknowledging the potential of this further step, has provided funding within the Energy Intelligent Europe (EIE) program to the AUDITAC project, whose output has been the development of a set of materials and procedures applicable to the Energy Audit of existing AC systems (Bory and Adnot, 2006). Virtually the same AUDITAC research team is now active in the three-year follow-up project HARMONAC, which will be completed by the end of 2010.

A further opportunity for promoting energy efficiency arises from the fact that part of the stock of AC equipment in use in Europe (Figure 1) will soon become obsolete. Out of the 2.200 Mm^2 of air conditioned building area in use in 2010 in Europe, 800 Mm^2 will date by more than 15 years and will need urgent renewal. A SAVE Study (EECCAC – Energy Efficient Centralised Air Conditioning Systems) indicated that a potential energy saving of about 50% may be obtained with such renovation: this means that AC Systems may be able to operate with about 50% less energy.

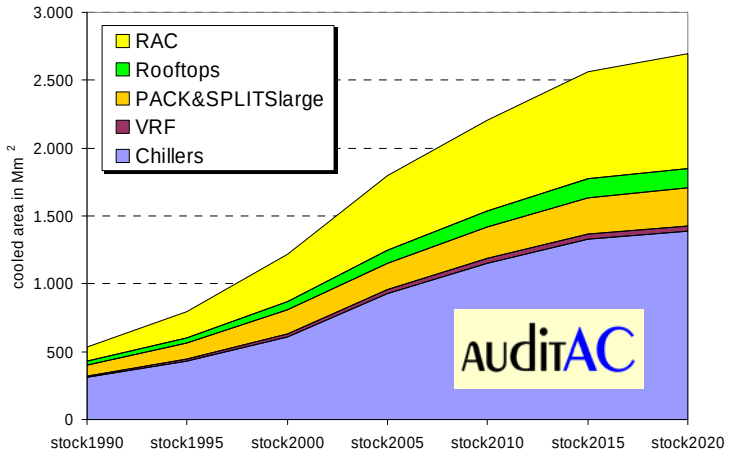

Figure 1 - Cooled area (Mm2) in Europe (source EECAC)

2. IMPLEMENTATION OF EPBD ARTICLE 9 IN MEMBER STATES

Of all the measures foreseen by EPBD, the inspection of AC systems is the one that has proved to be more difficult to implement, and for this reason the EC has agreed to postpone the deadline of article 9 to January 2009. Several technical and contractual barriers to the diffusion of AC inspection and energy audit may be quoted:

- National regulations for AC system inspection are generally still lacking.
- The main energy input for AC systems is electricity used by motors that drive refrigerating compressors, fans, and pumps; generally, electrical energy is centrally metered at the grid interface (main delivery board), without separating the individual users (i.e., lighting, appliances, AC, etc.): reference data on actual energy consumption of AC systems are therefore seldom available.
- Most energy service contracts (particularly in commercial buildings) actually include AC systems. However, while for space heating energy metering is normally required as a means for determining the cost of the service, electricity bills are generally paid directly by the building owner / tenant; the contract therefore includes the AC system operation and maintenance costs only. Consequently, no real reasons exist for implementing a costly and relatively complex procedure of gathering disaggregated electricity use data.

– Calculation methods for assessing the AC energy demand are not as well established as those for winter heating (e.g. the degree-day method), which makes the evaluation of potential energy savings difficult.

Furthermore, most AC system retrofits carried out in the past (at least in Italy) were determined by reasons different from energy conservation, namely:

– Improving the comfort condition in work spaces;
– Solving IAQ problems, or complying with compulsory regulations on air changes (e.g. in hospitals);
– Replacing room air conditioners with a central HVAC system to overcome maintenance problems and to avoid excessive differences in indoor conditions.

Considering the above mentioned factors, the difficulties encountered in establishing viable AC inspection procedures is not surprising, As of June 2008, in fact, only Austria, Portugal, Slovenia and the UK had taken concrete legislative steps for practical implementation of Article 9. As an example, the procedure adopted by the Province of Vienna, largely based on EN 15240, is presented in Table I.

Table I - AC system inspection procedure (Province of Vienna).

Every 3 years:

– Visual check
– Function check and check of the control equipment, especially the thermostats
– Cleaning of the filters and heat exchangers, condenser and evaporator
– Collection of general data like refrigerant, year of construction, cooling capacity, direct or indirect system, integration with ventilation system
– Comparison with A/C system at time of commissioning, documentation of changes, analysis of actual cooling demand and condition of the building
– Check of function:
  - Documentation
  - Check of compressor (function, wastage, density)
  - Inspection of outdoor heat rejection equipment
  - Inspection of heat exchangers
  - Inspection of air delivery systems in treated spaces
  - Inspection of air delivery systems in air handling units and ducts
  - Inspection of air delivery systems at outdoor air inlets
– Inspection of system controls
– Check of function and connection of components
– Check of quantity of refrigerant and density

Every 12 years additionally:

– Measurement of electricity consumption
– COP
– Recommendations to make A/C system more efficient in terms of allocation of energy, distribution, CO2 emissions

Several actions have been undertaken by the EU to promote the implementation of the EPBD, namely developing technical standards, linking with other legislative initiatives, and research funding[1].

2.1 Development of CEN standards

CEN has received mandate to produce all relevant standards for the implementation of EPBD in Europe. Two standards applicable to the inspection of AC systems are now available:

- EN 15239:2007 Ventilation for buildings - Energy performance of buildings - Guidelines for inspection of ventilation systems
- EN 15240:2007 Ventilation for buildings - Energy performance of buildings - Guidelines for inspection of air-conditioning systems

These standards constitute the basis for the inspection and energy audit procedures cuttently being developed in HARMONAC.

2.2 Links with other legislative initiatives

Following the Montreal protocol of 1987, the phasing-out of CFCs has led to the introduction of new families of refrigerant fluids, among which HFCs have presently the largest diffusion. HFCs do not have an impact on stratospheric ozone (ODP = 0), but contribute to global warming (e.g., for R-134a GWP = 1300) and are therefore classified as "Greenhouse gases".

The EU has committed all member States to reduce greenhouse gas emissions by the year 2010, as foreseen by the Kyoto Protocol. A specific set of regulations have therefore been issued, aimed at reducing unwanted release of fluorinated gases in the construction, operation, and disposal of equipment in which such gases are used. The regulations apply both to stationary and mobile refrigeration plants, as well as to stationary fire protection systems. Of particular interest for the AC sector is the *Regulation (EC) No 842/2006 of the European Parliament and of the Council of 17 May 2006 on certain fluorinated greenhouse gases*[2]. Article 1 gives the following definition of the Scope of the Regulation:

The objective of this Regulation is to contain, prevent and thereby reduce emissions of the fluorinated greenhouse gases covered by the Kyoto Protocol. It shall apply to the fluorinated greenhouse gases listed in Annex A to that Protocol. Annex I to this Regulation contains a list of the fluorinated greenhouse gases currently covered by this Regulation, together with their global warming potentials. (omissis)

This Regulation addresses the containment, use, recovery and destruction of the fluorinated greenhouse gases listed in Annex I; the labelling and disposal of products and equipment containing those gases; the reporting of information on those gases; the

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[1] *A complete and updated information of EPBD-related initiatives may be found in the "Building Platform" website http://www.buildingsplatform.org/cms/*

[2] *Published in the Official Journal of the European Union L 161/1 of 14.6.2006.*

control of uses referred to in Article 8 and the placing on the market prohibitions of the products and equipment referred to in Article 9 and Annex II; and the training and certification of personnel and companies involved in activities provided for by this Regulation.

Cross checking of the F-gas regulations and EPBD indicates two important areas of overlap and possible integration:

- Inspection of equipment for leakage detection. Frequency of inspection is specified in Article 3 "Containment", depending on refrigerant charge, equipment construction (hermetically sealed or not), and presence of a leak detection system.
- Training and certification of personnel (Article 5).

The question arises whether, and to which extent, AC inspections according to EPBD Article 9 should be integrated with the more frequent and compulsory F-Gas inspections. Since F-Gas checks are more frequent, these greater frequencies may be exploited to produce information of use to the Inspections as well. A tentative list of items, relevant for energy consumption, that could be part of the F-Gas checks, includes the following items:

- Timeclock and Thermostat control settings;
- Filter cleaning intervals and regimes;
- Regularity of maintenance schedules relative to requirements of each system;
- Refrigerant charge;
- Cleanliness of the internal and external heat exchangers;
- Evidence that there is still a requirement for AC.

2.2 Research

The EIE (Intelligent Energy for Europe) program has been specifically launched to promote EPBD-related demonstration and research projects. In addition to AUDITAC and HARMONAC, the EPA-NR project specifically addresses the issue of energy performance of tertiary buildings. Other relevant research programs are currently ongoing within IEA (Inernational Energy Agency) Energy Conservation in Buildings and Community Systems (ECBCS) implementing agreement, namely Annex 47 and Annex 48. These projects are herewith briefly presented.

EPA-NR

The EIE project "Energy Performance Assessment for existing Non-Residential buildings" (EPA-NR) has developed an assessment method with accompanying tools (including software), aimed at producing the Energy Performance certificate of existing non-residential buildings. The EPA-NR tools comply with the EPBD and reflect the CEN-standards. The method is applicable all over Europe. The method is set-up in such a way that the tools may easily be adapted to local circumstances and specific project conditions.

The accompanying tools of the EPA-NR method are:

- A Checklist for an intake interview, supporting the consultant in order to structure the start of the assessment process;
- The Inspection protocol, giving guidance and examples on how to structure the inspection of the building and how to assure the quality of inspection;

– The EPA-NR software being a flexible and easy to adapt software to calculate the energy performance according to the EPBD and relevant CEN-standards.

The underlying idea is that, in the long run, a unified procedure should be applied in data collecting for all EPBD requirements, i.e. for EP-certification (Article 7), Inspection of Boilers (Article 8), and Inspection of AC Systems (Article 9). This unified approach would definitely help in reaching one of the most critical goals in practical implementation of the EPBD, i.e. cost-effectiveness of the inspection and assessment methods.

IEA-ECBCS Annex 47 Cost-effective Commissioning for Existing and Low Energy Buildings

Commissioning methods and tools are necessary to ensure that buildings reach their technical potential and operate energy-efficiently. However, documented commissioning methods are currently only available for some conventional HVAC systems and do not address the advanced systems and system combinations that are important for low energy buildings. Although the current focus of commissioning practice is to attempt to make buildings work as designed, significant additional energy savings can be achieved by commissioning to optimize building operation based on actual occupancy and use. This approach to "field optimization" of building HVAC systems considers the long-term persistence of savings and benefits achieved during the commissioning process.

The goal of IEA - ECBCS Annex 47 is to enable the cost-effective commissioning of existing and future buildings in order to improve their operating performance. The commissioning techniques developed through this Annex will help transition the industry from the intuitive approach that is currently employed in the operation of buildings to more systematic operation that focuses on achieving significant energy savings. The Annex will also exchange information on commissioning practices in different countries and disseminate relevant information to national practitioners. Key outputs of IEA - ECBCS Annex 47 include:

– Methods and tools for commissioning advanced systems and low energy buildings;
– Methods and tools for field application;
– Information on the costs and benefits that can be used to promote the wider use of commissioning.

IEA-ECBCS Annex 48 Heat Pumping and Reversible Air Conditioning

Substituting a heat pump to a boiler may save more than 50 % of primary energy, if electricity is produced by a modern gas-steam power plant (and even more if a part of that electricity is produced from a renewable source). “Heat pumping” is probably today one of the quickest and safest solutions to save energy and to reduce CO2 emission. Most of air-conditioned commercial buildings offer attractive retrofit opportunities, because:

1. When a chiller is used, the condenser heat can cover (at least a part of) the heating demand;
2. When a chiller is not (fully) used for cooling, it can be (at least partially) re-converted into heat pump.

The retrofit of an existing building and, even more, the design of a new one should take all possibilities of heat pumping into consideration, in such a way to make air conditioning as “reversible” as possible. Different techniques are already available, but a recent survey of monitoring results established in Germany made still appear a lot of faults, lacks of optimisation and surprisingly low COP after, at least, one year of operation. It appears that the many mistakes would not have been discovered without monitoring. It also appears that these mistakes and disappointing results are mainly due to a lack of good understanding of the dynamic behaviour of the systems at design stage, a lack of simulation work, a lack of instrumentation, for satisfactory commissioning, optimal control and fault detection.

The aim of this project is to promote the most efficient combinations of heating and cooling techniques in air conditioning. Specific goals are:

- To allow a quick identification of heat pumping potentials in existing buildings
- To help designers in preserving the future possibilities and in considering “heat pumping” solutions
- To document the technological possibilities of heat pumping
- To improve the operation (including commissioning) of building equipped with heat pumping systems
- To make available a set of reference case studies.

These goals will be achieved by performing five different subtasks, whose content is very briefly summarized hereunder:

Subtask 1: Analysis of building heating and cooling demands and of equipment performances

- Classification among different building types
- Characterization of existing HVAC systems
- Use of simulation models to identify the best heat pumping potentials

Subtask 2: Design

- Elaboration of pre-design rules
- Definition of evaluation criteria
- Project of sequential design methodology (including retrofit)

Subtask 3: Global performance evaluation and commissioning methods

- Development of evaluation methods devoted to heat pump solutions
- Tests with synthetic data and with measured data
- Development of computer-based tool for heat pump system operation

Subtask 4: Case studies and demonstrations

- Documentation of reference case studies
- Use of case studies to test the methods and tools developed in the annex
- Conversion of most successful case studies into demonstration projects.

Subtask 5: Dissemination

- Website

- Paper work (leaflet, handbooks)
- Workshops, seminars and conferences.

3. THE PROPOSED INSPECTION AND ENERGY AUDIT PROCEDURE

A three-step procedure has been proposed by HARMONAC:

- Preliminary Inspection: is based strictly on the examination of documents: as-built drawings, commissioning reports, reports on failures and maintenance, utility bills, users' complaints records, etc.
- Inspection: survey including measurements, leading to identification of candidate Energy Conservation Opportunities (ECOs) taken from a comprehensive list, through a relatively fast and inexpensive survey of the building and AC system
- Energy Audit: is the obvious follow-up to inspection: in-depth analysis leading to the assessment of technical feasibility, energy savings impact, and cost effectiveness of each candidate ECO (Adnot et al. 2006).

The main purpose of an Energy Audit is therefore to identify a suitable set of actions (ECOs) that should lead to significant energy savings, within the specified operational and financial constraints. The ECO list is therefore the core of the entire procedure, and the link connecting the Inspection and Energy Audit phases (Masoero and Silvi 2006a) (Masoero and Silvi, 2007a)**.**

The ECOs are grouped into the following categories and subcategories:

E. ENVELOPE AND LOADS

- E.1 Solar gain reduction / Daylight control improvement
- E.2 Ventilation / Air movement / Air leakage improvement
- E.3 Envelope insulation
- E.4 Other actions aimed at load reduction

In the "Envelope and Loads" categories, ECOs aimed at reducing the building cooling load are listed. These ECOs may be either of the operational type, or may involve renovation work on the building envelope. Therefore, the evaluation methods may be similar to those normally applied either to category "O&M" or "Plant".

P. PLANT

- P.1 BEMS and controls / Miscellaneous
- P.2 Cooling equipment / Free cooling
- P.3 Air handling / Heat recovery / Air distribution
- P.4 Water handling / Water distribution
- P.5 Terminal units
- P.6 System replacement (in specific limited zones)

"Plant" ECOs involve more or less radical intervention on the HVAC system. Their applicability should therefore be carefully assessed both from the technical and economical standpoint.

O. OPERATION AND MAINTENANCE (O&M)

- O.1 Facility management

– O.2 General HVAC system
– O.3 Cooling equipment
– O.4 Fluid (air and water) handling and distribution

The "O&M" ECOs include all actions that may in general be implemented in a building, HVAC system, or facility management scheme. The costs involved by such ECOs are generally limited if not negligible: application is therefore normally recommended, provided their technical feasibility is assessed.

Several of the ECOs of each of the above categories may be effectively implemented with the aid of a Building Energy Management System (Masoero and Silvi 2006b). Such circumstance is highlighted in a specific column of the ECO list.

4. AUDITAC AND HARMONAC OUTPUTS / DELIVERABLES

The following material developed within AUDITAC may be accessed from the web site http://www.energyagency.at/(en)/projekte/auditac.htm:

Training Package of 160 slides on AC inspection, audit and renovation

What you should know if you own or manage an AC plant (downloadable from http://www.energyagency.at/(en)/projekte/auditac.htm)

Database of case studies

A large number of detailed success case studies with different systems and in different climates that demonstrate real savings (downloadable from http://www.energyagency.at/(en)/projekte/auditac.htm)

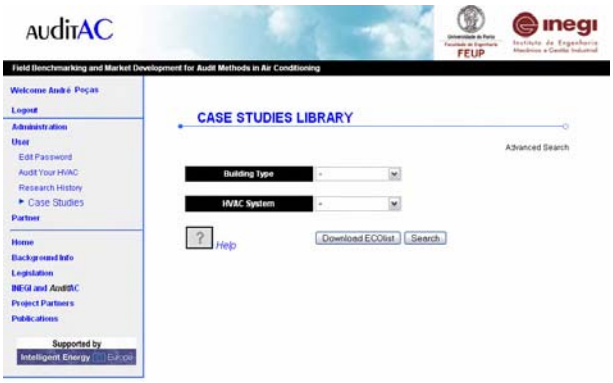


Figure 2 - Front page of Auditac Case Study data base

Examples of actual buildings being investigated in AUDITAC and HARMONAC and case studies results are shown in Figures 3 and 4 (see also Masoero and Silvi 2007b).

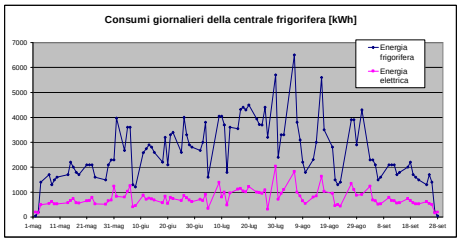
1970's office building

Technology Park (Labs)

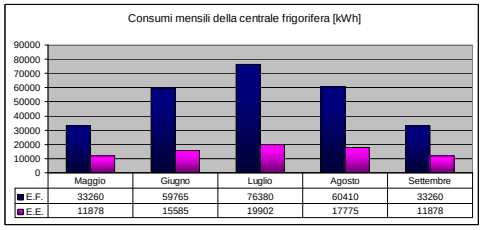
Historical office building

Retirement home

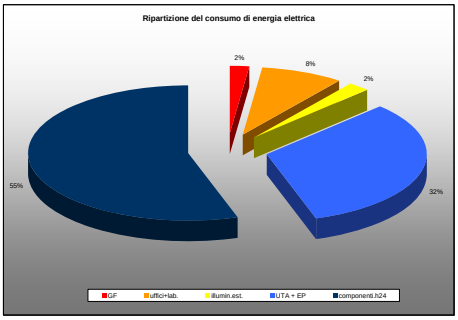
Figure 3 - Examples of Harmonac Case Studies (Italy)



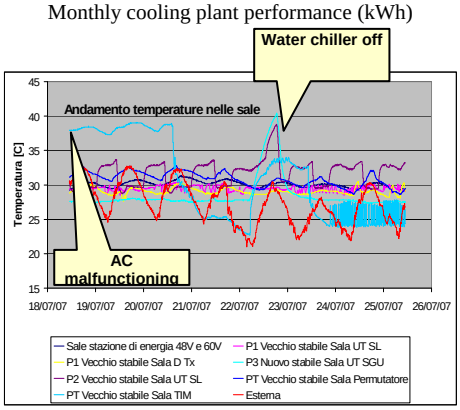
Daily cooling plant performance (kWh)



Monthly cooling plant performance (kWh)



Disaggregation of electrical uses



Air temperature time trend

Figure 4 - Examples of case study results

Database of Eurovent certified equipment

A database has been developed containing performance data of equipment that has been certified by Eurovent in the past but is not currently on the market – and default values for use when equipment cannot be identified or has not been certified. Using information from this database, the inspector can assess the savings that would result from replacement by modern equipment. The front page of the data base, available at http://www.eurovent-certification.com/, is shown in Figure 5.

Figure 5 – Front page of Eurovent Certification equipment data base

Customer Advising Tool (CAT)

This tool provides guidance on the potential for reducing the cooling demand of the building being Inspected or Audited. It achieves this by illustrating how the relative building heating and cooling demand might be altered in percentage terms by changing certain elements of the building design or operation. Examples of CAT outputs are shown in Figure 6.

The tool is based on outputs from the ECOTECT and EnergyPlus building energy modelling software tools. The data in the CAT has been produced using a simple building modelling approach that could be undertaken by anyone with a knowledge of building design, building energy use and these tools. Variable parameters include:

- Location / Region
- Building geometry (form, number of stories, plan depth, glazing ratio, internal layout, thermal mass, etc.)
- Building construction parameters (fabric and glazing U-values, solar heat gain coefficients, air infiltration rate, internal heat gains)
- Heating and cooling system efficiency and emission factor

CAT is available at http://www.cardiff.ac.uk/archi/research/auditac/advice_tool.html.

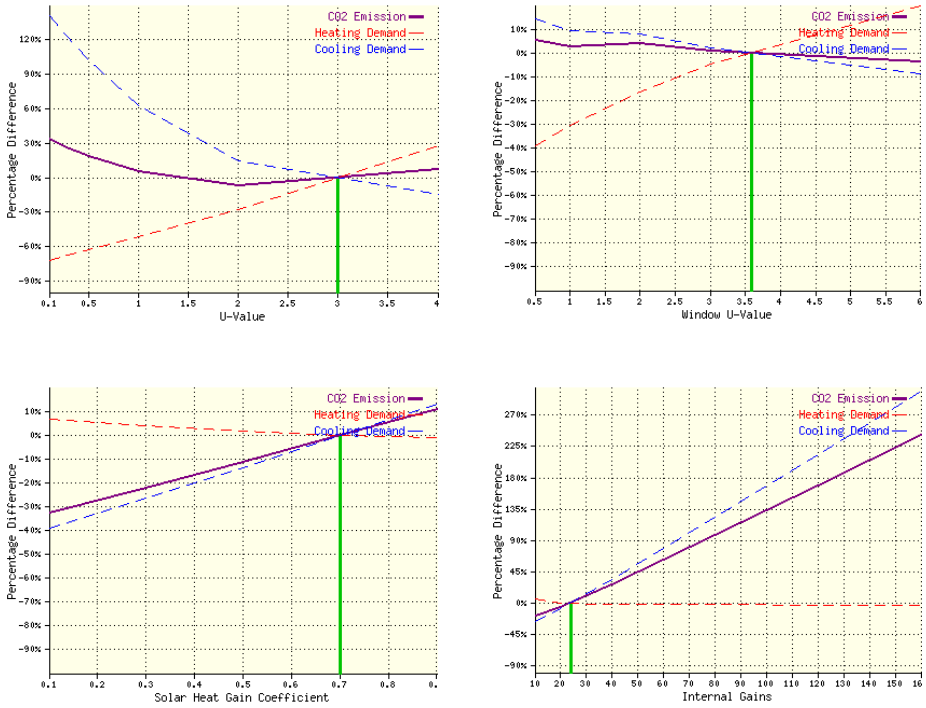


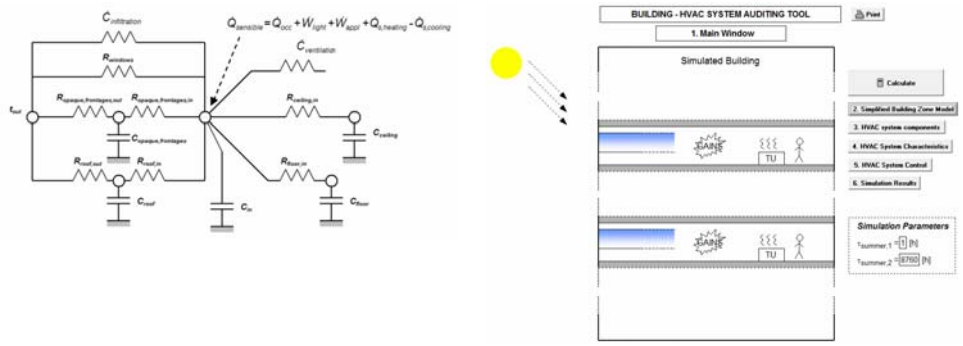
Figure 6 - Customer Advising Tool (CAT) outputs

SIMAUDIT

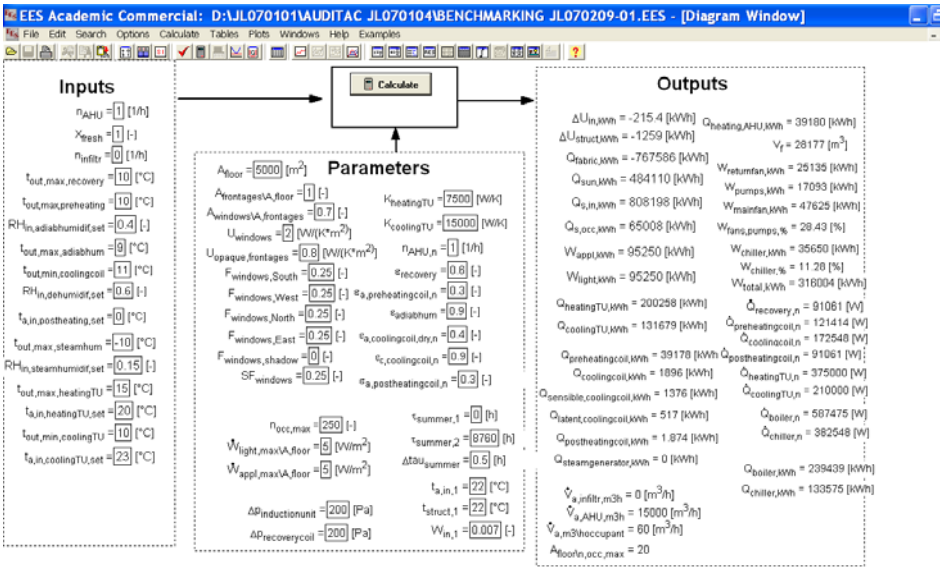
SIMAUDIT (see Fig. 7) is a quantitative audit tool consisting of various distinct modules:

- a routine that generates hourly climatic data suitable for the building and AC system load simulation;
- a single-zone dynamic building model based on RC networks, which allows to calculate the hourly values of building heating / cooling loads;
- a static AC system model that, using the loads calculated by the previous module as inputs, determines the main system operation parameters, including the primary energy consumption.

SIMAUDIT is implemented on the EES (Engineering Equation Sover) software platform and is accompanied by the user manual.
(downloadable from http://www.energyagency.at/(en)/projekte/auditac.htm)



Dynamic 1-zone building model based on RC-network + static HVAC system model



Simulation based on the EES (Engineering Equation Solver) tool

Fig.7 – SIMAUDIT software tool

Tool for cost-effectiveness analysis (AC-Cost)

Implemented as an EXCEL spreadsheet (see Fig. 8), AC-Cost allows to estimate the AC running costs reduction associated with a selected number of ECO's, such as the chiller substitution, the addition of a heat recovery system to the AHU, or the implementation of free cooling strategies. The tool may be downloaded from http://www.energyagency.at/(en)/projekte/auditac.htm).

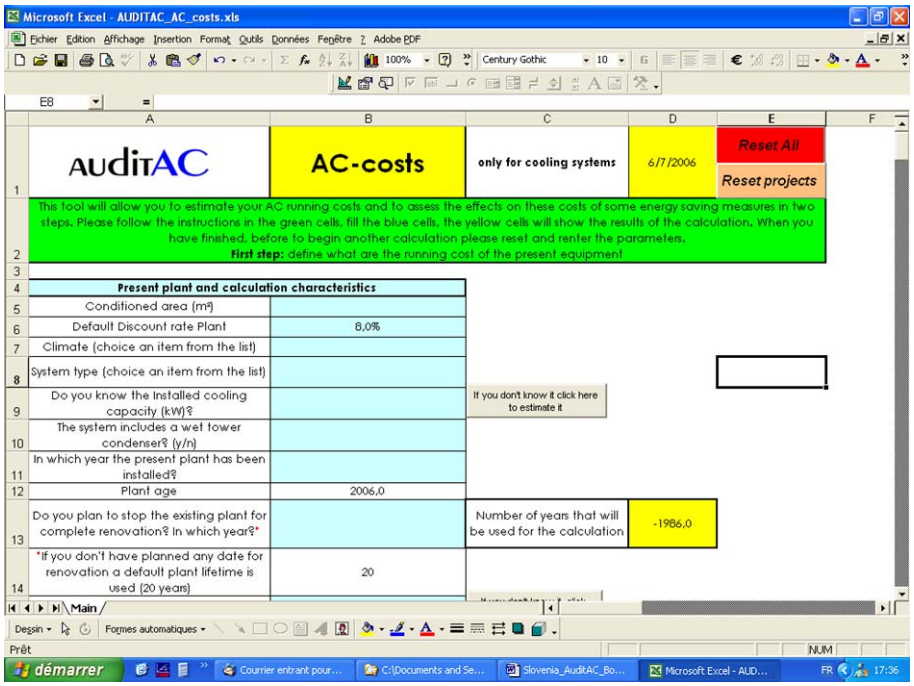


Fig. 8 - A tool for cost-effectiveness analysis (AC-Cost)

Technical Guides

The following technical guides, summarizing the main outcome of AUDITAC, may be downloaded from http://www.eva.ac.at/projekte/auditac.htm.

- TG 1: *Are you sure you are not paying for inefficient cooling?*
- TG 2: *Energy Auditing of Air Conditioning Systems and the Energy Performance in Buildings Directive : what does the new regulation say?*
- TG 3: *System recognition guideline for field visit*
- TG 4: *The AUDITAC method of preliminary audit for air-conditioning facilities.* Preliminary audit involves an interview of the site operating staff, a review of

facility utility bills and other operating data, and a walk-through of the facility. Only major problem areas will be discovered – qualitative estimation of possible savings

- TG 5: *Analysis of Energy Conservation Opportunities (ECOs) for air-conditioned buildings*
- TG 6: How to benefit from the Eurovent-Certification database and to retrieve past equipment data in the audit process
- TG 7: A benchmarking guide for owners and energy managers adapted to air conditioning based on electricity bills
- TG 8 : Recommendations to manufacturers to make audit easier
- TG 9 : Recommendations and competencies for auditors and structures for training
- TG 10: Case studies of improvements in AC systems
- TG 11: A model-supported audit method

CONCLUSIONS

The AUDITAC project has contributed to increasing the awareness of energy use in AC systems, but it has also highlighted a number of open questions, that will have to be addressed before energy auditing in AC will become a widespread practice.

A decisive step forward is expected from the ongoing EIE project HARMONAC (Harmonizing Air Conditioning Inspection and Audit Procedures in the Tertiary Building Sector) that is due for completion by the end of 2010. The planned outcome of HARMONAC include:

- A complete, three-step SC system inspection and audit procedure, thoroughly tested in the field, including guidelines on field data gathering and processing
- A data base summarizing the results of over 500 case studies and field trials that will be carried out in all participating countries (Austria, Belgium, France, Great Britain, Greece, Italy, Portugal, and Slovenia), covering a broad range of AC system types and tertiary building destinations (office, hospital, retail, educational, sport facility, etc.)
- An improved and detailed ECO list, including guidelines on application and expected savings
- An operator training package

Dissemination of HARMONAC results is already ongoing through the project website http://www.energyagency.at/projekte/harmonac.htm.

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