Inspection of air-conditioning systems - Results of the IEE HARMONAC project

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Introduction

The energy inspection of Air-conditioning (AC) systems has been introduced in 2002 by Article 9 of EPBD (article 15 of the EPBD recast). The practical implementation of AC inspections in most European countries has nevertheless been very slow, due to a number of reasons, clearly identified by the IEE AUDITAC project (Jan. 2005 – Dec. 2006), namely that

- there was little publicly available information on how AC systems consumed energy in practice,
- there were likely to be insufficient qualified Inspectors to be able to examine all AC systems that would fall within the scope of the EPBD,
- that the available international standards on AC inspection were unlikely to be adequate for a cost-effective inspection process (i.e., one that would yield significant energy benefits with respect to the time and money invested in the inspection).

The follow-up project HARMONAC - which ran from Sept. 2007 to Aug. 2010, involving eight EU Member States (Austria, Belgium, France, Greece, Italy, Portugal, Slovenia and UK) - was therefore funded with the following aims:

- to **understand more clearly how air-conditioning systems consume energy**. This was achieved through measurements and investigations of case studies of working AC systems from across Europe – a vital first step for assessing the real energy saving opportunities available from such systems;
- to **assess the opportunities for energy savings** that the current standards for Inspection of Air-conditioning systems would identify in practice, and compare these to the Case Study Energy Conservation Opportunities (ECOs) found. These ECOs are based on, and add to, those initially proposed in AUDITAC;
- to **propose**, as a result of the project, **a series of AC inspection procedures** that provide the project partners views of AC Inspection;
- to provide new **field-tested materials and tools** to aid Inspectors in the Inspection process;
- to ensure the **information is presented to the main actors** in the field concerned with regulating this area; this will help to produce

regulation and legislation in this area that maximises the energy and cost benefits to the system owners, and hence to Europe, from the time and money invested in these inspections.

The project deliverables (newsletters, training material, software tools, etc.) may be found at www.HARMONAC.info. The results of 42 detailed case studies (CS), involving long-term monitoring of entire buildings and AC systems, and nearly 400 more focused field trials (FT), aimed at testing specific aspects of the Inspection procedure, are accessible at http://paginas.fe.up.pt/~HARMONAC/site/.

Energy conservation opportunities

The main purpose of the inspection procedure is to identify a suitable set of ECOs that should lead to significant energy savings, within specified operational and financial constraints.

The HARMONAC partners have identified 141 ECOs, grouped into the following categories and subcategories (**table 1**):

- "Envelope and Loads", aimed at reducing the building cooling load;
- "Plant", involving more or less radical intervention on the AC system (to be carefully assessed in technical and economical terms);
- "Operation & Management" (the costs of such ECOs are generally limited if not negligible: application is therefore normally recommended, provided their technical feasibility is assessed).

More than 3000 ECOs were detected in the 42 case studies and 400 field trials undertaken during

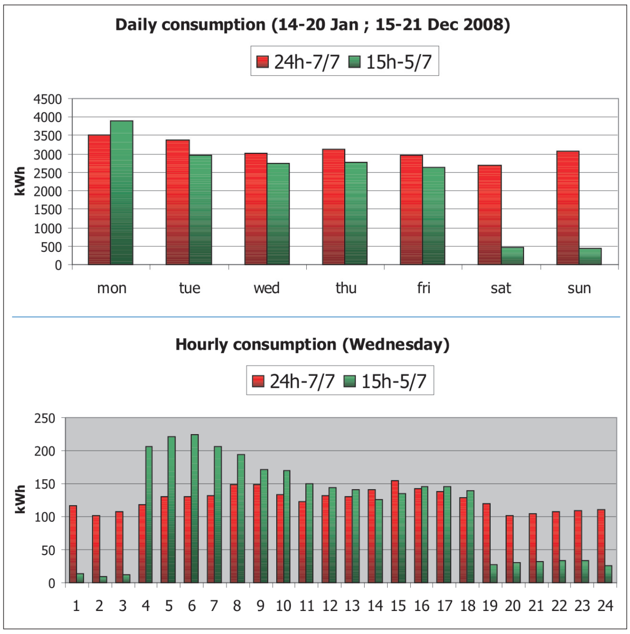

Figure 1. *Daily and hourly electric energy demand of VRF system with different schedules*

Table 1. Structure of the Energy Conservation Opportunities (ECOs) list

Category	No. of ECOs	ECO category description
E. ENVELOPE AND LOADS		
E1	7	Solar gain reduction / Daylight control improvement
E2	8	Ventilation / Air movement / Air leakage improvement
E3	9	Envelope insulation
E4	10	Other actions aimed at load reduction
P. PLANT		
P1	8	BEMS and controls / Miscellaneous
P2	14	Cooling equipment / Free cooling
P3	15	Air handling / Heat recovery / Air distribution
P4	5	Water handling / Water distribution
P5	5	Terminal units
P6	2	System replacement (in specific limited zones)
O. OPERATION AND MAINTENANCE (O&M)		
O1	7	Facility management
O2	9	General HVAC system
O3	20	Cooling equipment
O4	22	Fluid (air and water) handling and distribution

the project. The 54 best documented ECOs are described according to the following format:

- "existing subsystems" on which the ECO may apply, to recognize opportunities on a site visit.
- "technical data to request to owner/manager or to find directly (manufacturer data)" before going on site.
- "technical observation to be made on site", such as data visible on nameplate of system parts to supplement manufacturer or engineering documents.
- "monitoring of existing situations" providing the required measurement to achieve a quantification of the ECO.
- "criterion for ECO applicability" presenting the options of the considered ECO.
- "recommendation for realisation of ECO" gives recommendation to realize the installation/modification of the considered subsystem.
- "additional support" indicating methods, formulas, definitions to help the Inspector to make use of monitoring results.

An example of ECOs evaluation is shown in **figure 1.** The system consumption was measured during two weeks with similar climate but with different operation schedules: without (red) and with (green) night time and weekend control setback. In the specific case, The measured energy savings were 9% on working days and 85% on weekends, yielding a 26.7% weekly saving.

The ranges of savings found for each Category of ECO to date are significant. For example, the annual electricity consumption for typical UK office buildings is around 31 kWh/m^2 for cooling and 226 kWh/m^2 in total:

- Envelope ECOs (including small power equipment). Usual saving ranges appear to be 2 – 9 kWh/m^2 electricity (6 – 29% savings in cooling, and 1 – 4% total).
- Plant ECOs. Most common saving range appears to be 1 – 8 kWh/m^2 electricity (3 – 26% savings in cooling, and 0.5 – 3.5% total).
- Operational ECOs. Most common saving range appears to be 1 – 20 kWh/m^2 electricity (3 – 65% savings in cooling, and 0.5 - 9% total)
- Overall average potential energy savings identified per Case Study system are in the range of 25 – 50% of AC system use.

In European terms, AC systems accounted for 0.75% of the total electricity use in the EU-27 in 2007 (neglecting ventilation systems and circulators which account for a further 3.34% and 1.81% each). If the average 25 – 50% potential energy savings identified by HARMONAC were achieved in AC systems throughout Europe then a 0.19 – 0.38% reduction in the EU MS electricity use would arise. This is equivalent to a reduction of between 5.45 and 10.91 TWh in the EU-27 electricity consumption of 2,870 TWh in 2007. If we were to introduce the savings achievable in ventilation systems as well then the potential savings become more than 1% of the EU annual electricity consumption.

HARMONAC AC Inspection methodology

HARMONAC has used CEN Standard EN15240 "Guidelines for inspection of air-conditioning systems" as the basis for the Methodology it has assembled and tested during the three years of the project. The HARMONAC Methodology breaks the CEN Standard into a number of discrete Inspection items in order to assess the time taken to undertake each item and the associated ECOs.

The HARMONAC Methodology splits the Inspection into two elements – **pre-inspection and inspection**. Pre-inspection items are those which it is considered reasonable for the building owner to know and have available for an Inspector to assess prior to arriving on site, and Inspection items are those that can only be properly assessed by a site visit.

Three versions of "Methodology" have been made available at the end of the project:

- The HARMONAC **FULL** version. The intention is to make available to European Member States all the information derived about the AC Inspection elements from the HARMONAC Project. It contains a number of Inspection items that may not lead directly to energy savings but will provide a greater insight into the interaction of the building and the AC system.
- The HARMONAC **PREFERRED** version. This contains all those Inspection elements that the HARMONAC Partners think in practice might lead to worthwhile energy savings.
- The HARMONAC **SHORT** version. This contains the bare minimum information needed to be

obtained during an Inspection to identify the most likely sources of energy inefficiency in an AC System. It is designed to identify only those ECOs that provide the largest savings and which are the most frequently occurring. It is intended that this version should act as a guide to the minimum set of Inspection items that should be required by Member States.

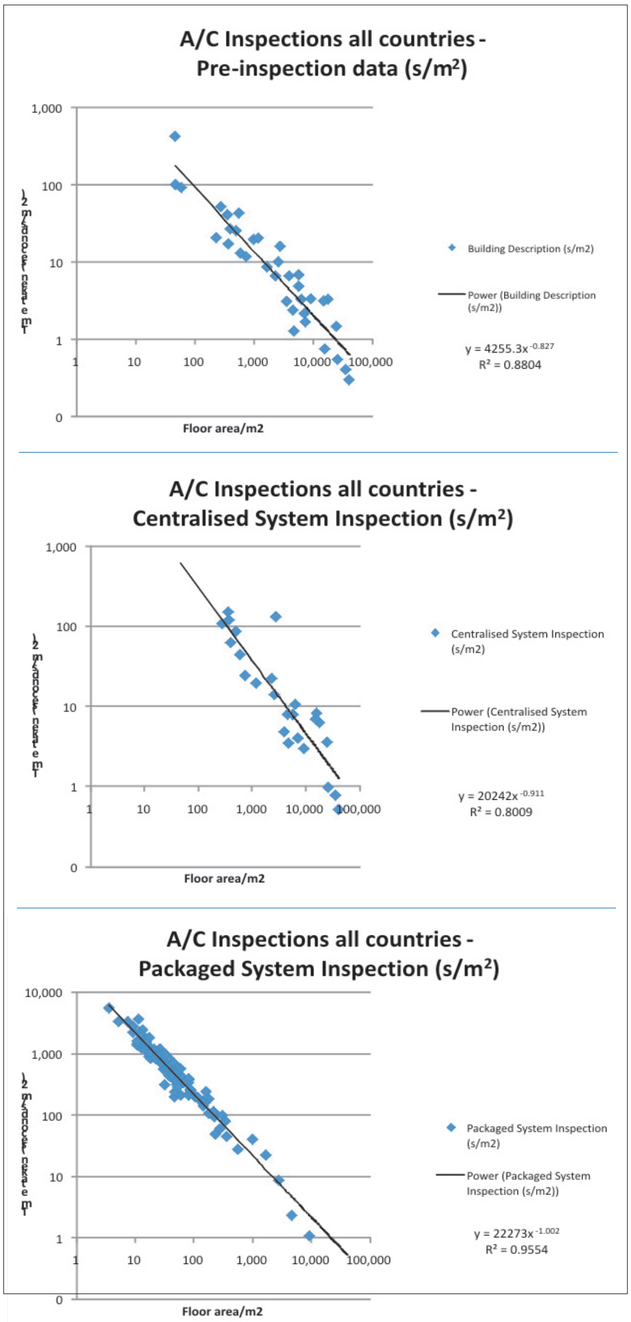

***Figure 2.** Correlation between time taken (in seconds/square meter) for the inspection and floor area. The two graphs on the left / centre refer to centralised system pre-inspection (data gathering) and site inspection; the graph on the right refers to the entire packaged system inspection*

The main elements of the HARMONAC Inspection Methodologies are:

- **Data collection** about the actual building, the installed HVAC system, its current and designed use, and building occupancy. This includes analysis of data to help identify possible areas of concern or just to reassure the Inspector that the system operation is normal and reasonable.
- **Physical inspection – site visit**: Determination of the existence or otherwise of faults or possible improvements to the AC system within the following suggested time periods (determined from HARMONAC field trials):
- Potentially **short tests** of functional performances but without, or with very limited, additional instrumentation (may be just a few checks in order to verify that the main equipment is in "normal" use, that the control system is "normally" active, and that system air flows and temperatures being achieved are those expected).
- **Analysis and reporting:** The final report should summarise all the main findings from the Inspection and be clear as to the ECOs identified to minimise the obstacles to their implementation.

The project showed that there is a good correlation between floor area and time taken to complete an inspection **(figure 2)**. An inspection will take from around **half a day** for a small packaged system to around **three days** on-site for the largest systems for visual verifications, analysis of as-built records, system manuals, possible complaints and operating costs, and report writing.

HARMONAC case studies and field trials

The purpose of the 42 long-term case studies was to provide underpinning 'real-life' data to assist in identifying and quantifying ECOs and to provide boundary parameters for the modelling tools produced in HARMONAC. Typically, the case studies provided measured values of electrical energy consumption of chillers, pumps, fans, humidifiers, etc separately at time intervals of between 5 to 30 minutes, over a period of more than one year where possible.

The almost 400 field trials of the HARMONAC Methodologies have been undertaken to provide understanding of which inspection items identify

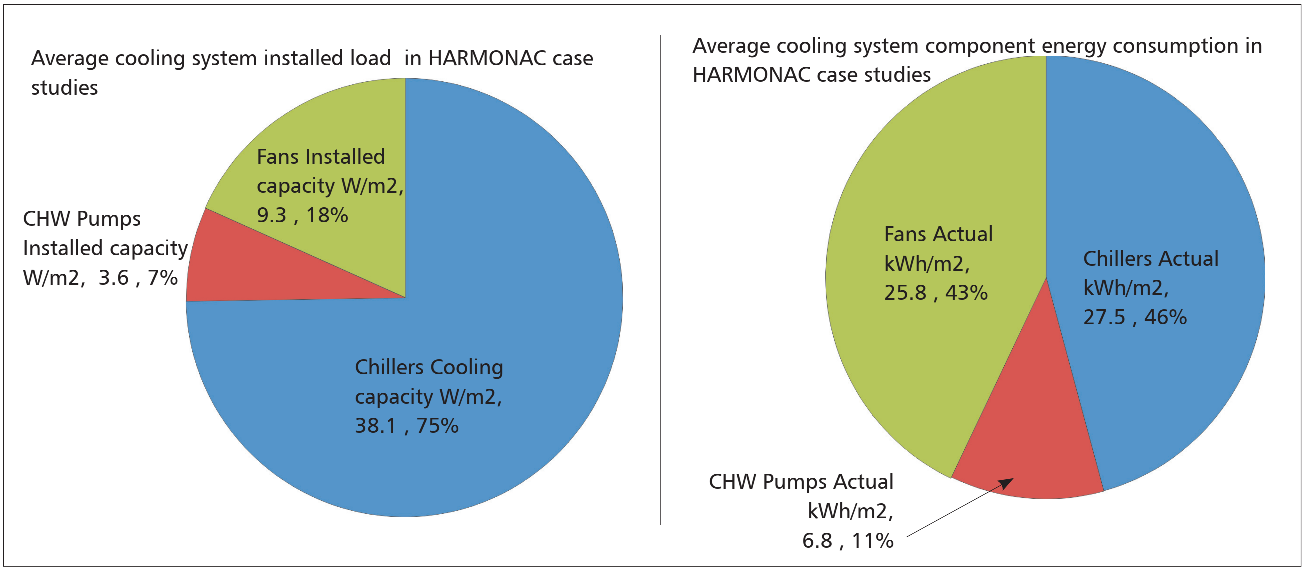

Figure 3*. Average component specific installed power and average system specific energy consumption among the HARMONAC case studies*

ECOs in practice, to understand the time taken for each Inspection item, to inform the development of the Inspection Methodologies so that they are based on practical implementation experience, and to explore use of HARMONAC tools and methodologies in practice and to refine their use. For any Case Study and Field Trial a complete description of the building and system was provided, including: construction type, occupation schedule, services, etc.

The HARMONAC database was made with the purpose to allow all public to have access to the main outcomes of the case studies and field trials. The large majority of the case studies (more than 90%) have centralized HVAC systems, while the majority (67%) of the field trials have packaged systems, for which a quick a simplified inspection is applicable.

The two pie charts of **figure 3** show how the Cooling services components break down in terms of installed loads and actual annual consumptions: while the Chillers comprise 75% of the installed capacity, they consume just 46% of the cooling system energy use. The next highest consumer is the Fans with 43% of the energy consumption from 18% of the installed load, with the final major consumer being the CHW pumps with 11% of the annual cooling system electrical energy consumption from 7% of the installed capacity.

Software tools

Besides a more accurate estimation of the energy flows in the building, simulation tools allow the user to explore innovative solutions and potential improvements of the energy performance of the inspected system. This allows the inspection to be more cost-effective.

The following SW tools to assist the Inspectors have been developed by HARMONAC:

- **AC Cost** is an Excel-based quick tool for looking at economics of potential system-related energy saving options.
- **Bill Analyzer** is dedicated to a preliminary analysis of the recorded data (comparison between actual and reference consumptions, thermal and electrical signatures, degree-days data normalization…).
- **CAT** is a building envelope energy demand tool suitable for first estimation of options for reducing building energy demand through envelope changes.
- **Simbench** The simulation-based benchmarking consists in a comparative evaluation of the building performance realized by means of the developed building energy simulation (BES) model.
- **SimAudit** is a model that requires a calibration of the energy model to make it correspond to the reality of the investigated building. The consumption records can be used to adjust some of the parameters of the simulation models.

- **System Performance Calculator Workbook** is an onsite Inspection and Maintenance Tool allowing quick estimation of the actual performance of single room AC systems from simple measurements

Training material

To spread the findings and outputs of the HARMONAC project, a wide range of training and dissemination materials has been developed. The training package is intended to assist those who will be training future AC system inspectors and consists of the following PowerPoint presentations:

- **Purpose of training package**
- **Legal background:** EPBD, EN 15239 / EN 15240 standards.
- **Air-conditioning systems basics:** design data, thermodynamic processes, AC components and systems.
- **HARMONAC Inspection procedures:** most important part of the teaching package, presents the three HARMONAC inspection procedures.
- **On-site data collection and analysis tools:** equipment to be used for system monitoring and available software to simulate the operation of the AC system
- **Inspection report and recommendations**
- **Examples** of use of inspection procedures on real systems.

Conclusions

HARMONAC aimed at establishig how effective the current AC Inspection process is likely to be at achieving substantial energy savings in practice. To achieve this aim, HARMONAC has dissected the AC System Inspection process, undertaken case studies and field trials investigating the use of energy in AC systems in practice, produced modelling tools for AC systems and buildings, and presented its findings to many of the main actors in the area.

From these studies and its other activities, the following main conclusions have been drawn:

- The opportunities for saving energy in AC systems appear substantial and occur regularly across all system types in all areas of Europe.
- Small AC systems appear to offer some of the largest average energy savings with potential average savings of around 60% being identified in the 270 UK field trials of the Inspection Methodology.
- Owner/operators of AC systems are generally not taking energy efficiency seriously. Anecdotally the majority are either simply having compliance Inspections undertaken or are not yet to have an Inspection at all. They appear to see little benefit to them of investing time and effort into energy efficiency and the penalties for non-compliance are generally either non-existent or not persuasive enough to encourage more interest.
- Control ECOs are amongst the most frequently occurring ECOs in the case studies, offering some of the largest savings for little or no investment. However, many of the control ECOs will not be identifiable through the current Inspection process as they occur over time and need detailed metered data to identify.
- Data that relates directly to the system being investigated appears to be the main catalyst in motivating owners/operators to invest time and money into rectifying a situation. General recommendations are too vague and are normally ignored. This is of concern to the EPBD which requires Inspection reports to provide recommendations for improvement. It is very likely that most of these recommendations will be generic in nature – probably using HARMONAC and similar material as a basis.
- An Inspection will generally take between 0.5 to 3 days provided the basic data is available on the building and AC system to be inspected. If this data is not available then for larger systems the Inspection can take months to complete in elapsed time if all the data requested is to be included in the report. For many first time inspections this latter situation is the most likely scenario.
- The European Standards covering AC Inspections appear too cumbersome and time consuming; ask for detail and information that are generally difficult or impossible to obtain for the large majority of systems; cannot address some of the major opportunities for reducing energy use in AC systems.