ProMot: A Decision Support Tool for the Promotion of Energy Efficient Motor Systems

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Abstract

A decision support tool is being developed, within the framework of a project co financed by SAVE, aiming to aid end users to explore the possibility of energy savings, in motor systems of an industrial or tertiary installation. It has been designed for users having basic technical expertise. Motor systems considered and analysed by the tool include electric motors, pumps, compressed air as well as chillers (heat pumps), while fans and other relevant topics are also addressed. General introductory information is provided on the topics treated. The tool helps in auditing an installation, and performing simple meaningful calculations of purchasing, replacing existing or retrofitting electric motor systems. These technical and economic calculations are based on equipment data retrieved from widely accepted and regularly updated European databases and methodologies.
In this paper, the characteristics of the tool are briefly described. Emphasis is given on the structure, methodology and operational aspects of chillers module.

1 Presentation of the tool

Motor systems in industry and service sector buildings are the largest single type of use of electricity. Electric energy savings potential is huge and has been estimated by European Commission programmes to exceed 100 TWh in each of the two sectors across Europe.

ProMot decision support tool has been designed to help users having basic technical expertise to explore the possibility of energy savings in motor systems of an industrial or tertiary installation. It analyses four basic types of electricity driven systems:

(1) Motors and Drives

(2) Compressed Air Systems (CAS)

(3) Water Pumps

(4) Chiller (heat pump) systems.

Motor and Drive Systems module informs the user about the existing motors efficiency classifications and the benefits of using a high efficient motor and drive system. It also guides the user on proper sizing of a motor system and gives tips on how he can reduce transmission losses. The calculation part of the module is based on the Euro-DEEM database, which currently contains data of over 18,000 motors (provided by manufacturers). The user can calculate the energy and operating cost savings potential of replacing, repairing or buying a new motor (Washington State University 2004).

CAS Systems module takes the user through a “Guided Tour” of the existing system, to identify the priority actions for energy savings. It provides information, cost and saving analyses for three cases:

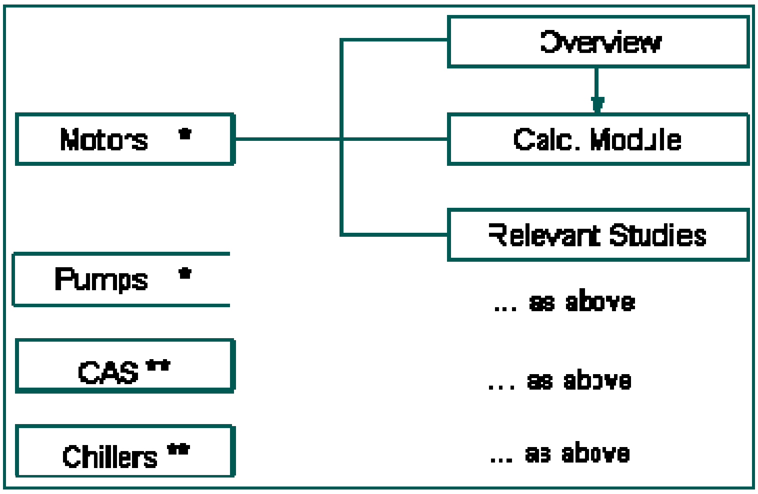
(1) Low cost measures to improve operation and maintenance.

(2) Major repair or extension.

(3) Design, purchase and install a new compressed air system.

The Pumping and VSD Systems module examines the possibilities for energy savings from (clean water) pumping equipment and associated controls. Like other systems, the initial purchase cost of a pump is a small fraction of its operating energy cost. The introductory part of the module provides general guidance on choice of pumps and associated systems. The calculation part lets the user define the nameplate values of pumps and the load profile and calculates the energy consumption based on input data. The benefit of control by VSD (Variable Speed Drives) systems for the given load profile is also treated in this module (Tanner 2005).

Chiller module provides general information on the basic components of a cooling system (chillers, pumps/fans, pipes/ducts, AHUs and FCUs, Ventilation, etc). It provides direct links to the Eurovent-Cecomaf site for up to date information on such products. The calculation part of the Chiller module treats Air and Water Cooled Chillers. In a fashion very similar to the Motors module, the user can calculate the energy consumption and analyze the effect of choosing various chillers for a new or under refurbishment installation. Calculations are based on the Eurovent-Cecomaf database, which currently contains data of about 3600 chillers and is regularly checked and updated.



* Windows type calculation module   ** Web based Calculation module

Figure 1. Layout of the tool

The tool also contains relevant information, such as introductory parts to each module, and results of relevant studies financed by SAVE and other EC programmes. It can currently be found at www.motorchallenge.ch:8181/promot and it will be transferred to DG JRC upon completion of work.

Analysis to follow will focus on the chiller module.

2 Cooling-Heating Systems

A typical cooling or HVAC system comprises of

- Heating or cooling producing equipment (boilers, heat pumps etc)
- Pumps and/or fans
- Piping networks
- Heat exchangers transferring or absorbing heat from a space or a process.

Current analysis will focus on chillers, as a part of a cooling or an HVAC system. Chillers are defined to be heat pumps (HP) used for cooling, possibly reversible able to produce heat. Studies have shown that about 90% of the primary energy for cooling is consumed by the chiller/HP and the rest 10% by peripheral machinery.

Energy consumption for cooling is of outmost importance during the last years, since it is contributing greatly to the electricity peaks in summer, which destabilise the electricity networks of countries – especially in warm climates, such as, around the Mediterranean region. A number of studies estimate that air conditioning contributes to peaks in excess of 40% (Sofronis 2002)

2.1 Chiller and Energy Efficiency

The chiller is a complicated part of machinery, consisting of a compressor, expansion valve and heat exchanger/s. The refrigerant circulating through, is heated or cooled at various stages to produce the required result. Energy efficiency of a heat pump depends on a number of design choices and parameters such as type of compressor, type of refrigerant, type and control of expansion valve, sizing of heat exchanger/s, etc.

Efficiency, by definition, is the ratio of the energy output of a piece of equipment to its energy input, in like units to produce a dimensionless ratio. The relative efficiency of HVAC equipment is usually expressed as a *coefficient of performance* (COP), which is defined as the ratio of the heat energy extracted to the mechanical (and/or electrical) energy input. For heat pumps it has become customary to use *energy efficiency ratio* (EER), during the cooling period and as coefficient of performance (COP) during the heating period.

The overall efficiency of an HVAC system depends on all the parts that comprise the system. For example under sizing of piping networks leads to high energy consumption from the pumps or fans. Pumps, fans and air handling devices are themselves electricity consuming devices. The current document will focus on the “heart” –the highest energy consumer– of the system, namely, the vapour compression heat pump (chiller).

3 Chillers Module Architecture

The chillers module has been setup according to the structure presented in Fig. 2. It has been implemented following a three-step schema that involves (a) the chillers database, (b) mathematical models for energy and water consumption estimation, and (c) the presentation layer.

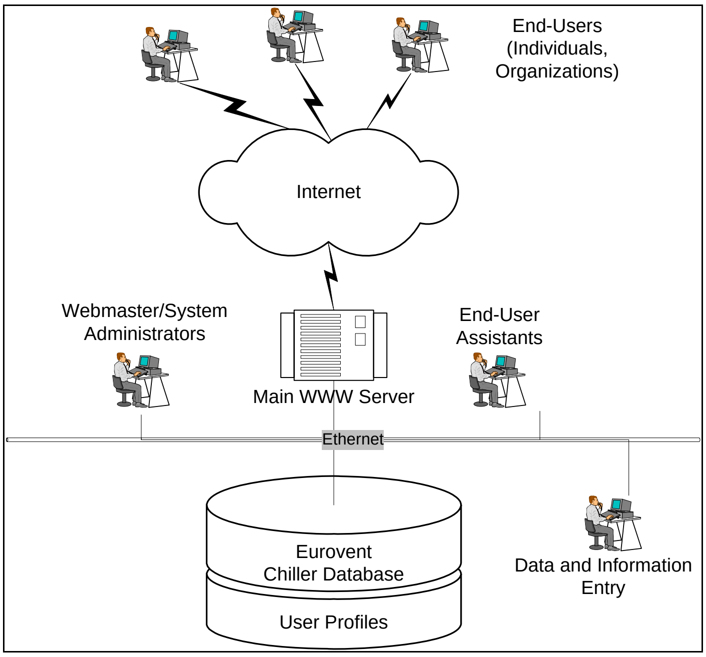


Figure 2: Architecture of the chillers module

Chillers module has been developed and operated as a web based application based on the Microsoft .NET platform (ASP.NET technology). The reason for this choice relies on the fact that web-based applications deliver an enormous range of business advantages over traditional standalone desktop applications.

- Internet powered applications provide companies with significant cost and time savings.
- Deployment is simple and less complicated as clients’ posses their own browser software.
- Support and maintenance is also made easier. Businesses avoid the common maintenance problems associated with local applications. Software updates for example can be instant because the application exists only on the web server. Therefore all users access the same version.

For end-users the advantages are just as clear:

- Web based applications are more intuitive and convenient to work with. It is easier to customise the user-interfaces, making them more visually appealing and easy to use.
- Unlike traditional applications, web systems are accessible anytime, anywhere using a PC with an Internet connection.

3.1 Eurovent database

Analytical evaluation of a chiller performance is a cumbersome task, leading to questionable results. A decision has been taken in the current project to adopt the Eurovent database for the chillers module. This database contains a great number of parameters, including COP and EER for a significant number of products. Data and products are constantly updated tested and improved. The organisation and the database are recognised by many major HVAC component manufacturers. Equipment covered by the database is presented in Table 1.

Table 1: Classification of chillers in the Eurovent database

<table>
<tr><th>Heat Rejection</th><th>Code</th><th>System</th><th>Code</th><th>Operation</th><th>Code</th><th>Duct</th><th>Code</th><th>Compressor</th><th>Code</th></tr>
<tr><td rowspan="2">Air Cooled</td><td rowspan="2">A</td><td>Packaged</td><td>P</td><td rowspan="2">Cooling only</td><td rowspan="2">C</td><td rowspan="2">Ducted</td><td rowspan="2">D</td><td rowspan="2">Centrifugal</td><td rowspan="2">G</td></tr>
<tr><td rowspan="2">Split</td><td rowspan="2">S</td></tr>
<tr><td rowspan="2">Water Cooled</td><td rowspan="2">W</td><td rowspan="2">Reverse Cycle</td><td rowspan="2">R</td><td rowspan="2">Non ducted</td><td rowspan="2">N</td><td rowspan="2">Other type</td><td rowspan="2">O</td></tr>
<tr><td>Remote condenser</td><td>T</td></tr>
</table>

3.2 Energy analysis

The aim of ProMot is to examine energy consumption and propose the most energy efficient equipment, to serve cooling and heating loads. A simple relation to be used for energy consumption (E) is:

$$E = \frac{Pc}{EER_{FL}} \cdot t_{FL,cool} + \frac{Ph}{COP_{FL}} \cdot t_{FL,heat} + \sum_{i} \left(\frac{Pc_{PL,i}}{EER_{PL,i}} \cdot t_{PL,i,cool} + \frac{Ph_{PL,i}}{COP_{PL,i}} \cdot t_{PL,i,heat} \right) \quad (1)$$

where Pc and Ph are the net cooling and heating capacities (kW) respectively, t is the operating time (hrs/yr) and the subscripts FL and PL denote full and part load.

Typically one would discretise time of operation to intervals (i) such as 25-50%, 50-75% and 75-100% and sum the energy consumed during these intervals.

Equation 1 contains more parameters than currently available in the Eurovent database and requires knowledge of operating times in various power range regions. Part load efficiencies are not yet available by Eurovent, but it is foreseen to be included in the data at a later point in time, within the timeframe of the porject. Full load efficiencies may be different than part load ones, depending on a number of chiller characteristics, such as the number and type of compressors, their part load efficiency, existence of inverter controls, sizing of condensers etc. On the other hand, operating hours of the heat pump are difficult to define, especially when in cooling mode. In contemporary chiller systems, operating time for compressors, is registered and can be retrieved from the chiller electronic control devices.

A simplified approach to equation (1) would be:

$$E = \frac{Pc}{EER} \cdot t_{EFL,cool} + \frac{Ph}{COP} \cdot t_{EFL,heat} \quad (2)$$

where t_{EFL} is equivalent full load hours for heating or cooling. The assumption is that EER and COP do not vary greatly under part load operation.

In case time operation of the compressors of the chiller is unknown, for Greece the rule of thumb used is the equivalent full load hours $t_{EFL} = 0.67 \cdot t_{cool}$ or t_{heat}, with t_{cool} = 1100 hrs/yr and t_{heat} = 1300 hrs/yr. Although there is a degree of approximation in the equation above, it must be noted that it is intended for comparative study between two similar chillers, using the same approximations.

Currently the module has been programmed using equation (2). Once part load efficiency data is available in the database, equation (1) will be used.

3.3 Water cooled systems

Water Cooled Systems have undoubtedly higher energy efficiency ratio (EER) than the Air Cooled ones. On the other hand in Water Cooled Systems, incorporating cooling towers, the parameter of water consumption should be estimated and taken into account. Water is commonly used as a heat transfer medium to remove heat from the refrigerant condensers or industrial process heat exchangers. In the past, this was accomplished by using a continuous stream of water - from a utility water supply or a natural body of water – which was then discharged directly to a sewer or returning it to the body of water. Nowadays the cost of utility supply water has become prohibitively expensive. On the other hand, ecological disturbance could make the usage of water from natural body (e.g. lake) under certain conditions unacceptable (ASHRAE 2004).

Cooling towers overcome this problem by circulating water and they require a small fraction of the water otherwise needed with a once-through cooling system (ASHRAE 2004, Thumann 1987). The water consumption in a Cooling Tower is needed basically to replace water losses from evaporation and to safeguard the Tower from the concentration of dissolved solids and other impurities in the water.

According to (Rosaler 1995) the water losses which include evaporation, drift (water entrained in discharge vapour), and blowdown (water released to discard solids) could be estimated as the sum of Drift Losses, Evaporation Losses and Blowdown Losses.

Drift losses constitute a small ratio to the total losses of water. Besides, a portion of them can be subtracted from the necessary blowdown. These losses are estimated between 0.1 and 0.2%. Recent technology drift eliminator systems have managed to limit the drift rate to less than 0.001% of the recirculating water rate. Evaporation losses have decreased with improved design over the years. The evaporation rate from some Cooling Tower's Manufactures manuals was estimated to be between1.6% and 1.25%. ASHRAE (ASHRAE 2004) considers the evaporation rate at typical design conditions approximately 1% of the water flow rate for each 5.5 ºC of water temperature range. The blowdown losses depend on the concentration of dissolved solids in water and range between 0.3 and 4% of the water flow rate (Briganti 1994).

Estimation of total losses rate the values given in bibliography ranges from 3.8% to 1.33% of the water flow. The rate of 3.8% was found in a 1977 edition reference, therefore it is considered too high for the Cooling Towers in the market.

From the above we suggest that a typical default rate of water consumption in modern Cooling Towers to be used in our software is 1.5% of water flow through the tower. This value could be changed, should the user have a different estimate for the application at hand.

3.4 Chiller Economic Analysis

Economic analysis for comparison of alternative investments requires an understanding of several issues. The three most important elements to consider are (i) the investment costs for the systems, (ii) energy costs over the expected life of the chiller, and (iii) maintenance costs (including standstill costs) over the life of the chiller.

There are two general categories for economic analysis. Simple payback analysis and detailed economic analysis (LCC: life-cycle cost analysis). A simple payback analysis reveals options that have short versus long payback, whereas LCC calculates the total cost of each alternative during its lifetime. Although the LCC technique allows a more accurate comparison, it requires the knowledge of detailed information such as present value factor and interest rate.

In the chiller module a simple payback analysis has been used to compare alternative chillers, as it requires fewer data from the user. LCC analysis could be incorporated at a later stage. For comparison of chiller systems, payback technique is applied as:

$$\text{Payback (years)} = \frac{\text{investment cost}}{\text{energy savings} - \text{operating \& maintenance costs}} \tag{3}$$

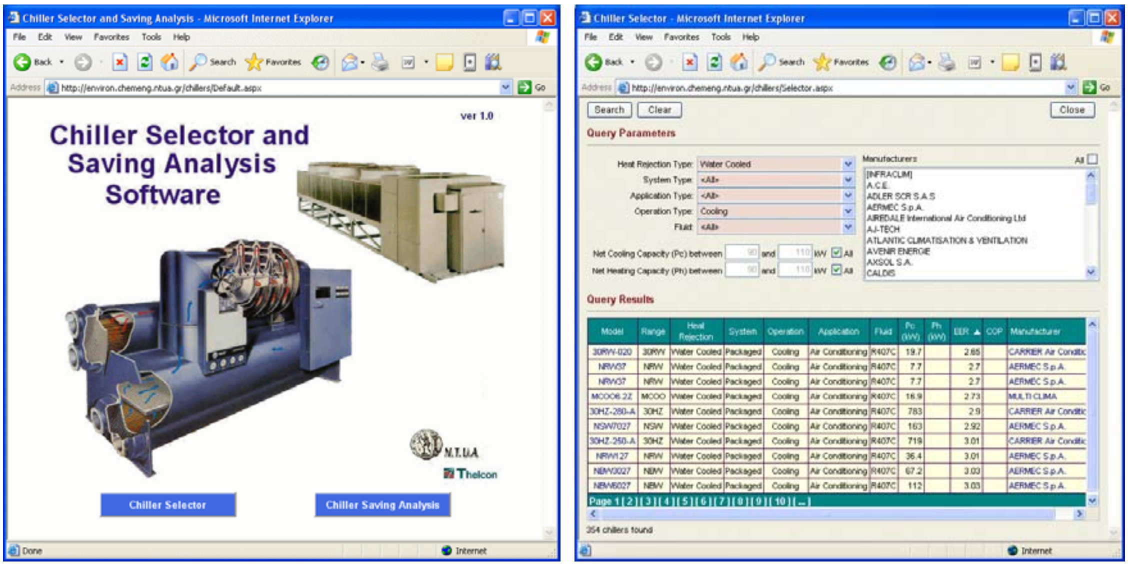
In case of water cooled chillers with Cooling Tower, water consumption has to be accounted as operating cost.

4 Operational Aspects of the Software Tool

The main functions of the chillers module are:

- Allows users to retrieve information for all chillers stored in the database.
- Guide the user in the selection of a specific chiller satisfying user-defined criteria for a specific application.
- Identifying and ranking a number of chillers based on energy consumption for user defined heating/heating loads.
- Calculate the energy and cost savings under different scenarios.

Figure 3.a presents the home page of the tool. Two destination buttons give access either to the Chiller Selector or to the Chiller Savings Analysis sub-module. The two sub-modules contain different program features or functions.



(a) **(b)**

Figure 3 (a): Home page of the chillers module, (b): The Chiller Selector sub-module

The Chiller Selector sub-module (Figure 3.b) provides parameters for selecting and sorting lists of chillers from the database. The available query parameters are those presented in Table 1 as well as the desirable range of cooling and heating capacities. The user can also select chillers from all manufacturers or from one or any combination of selected manufacturers. Detailed information for a specific chiller can be obtained clicking on its model name.

The Chiller Savings Analysis sub-module is used to calculate the annual reduction in energy use and monetary savings given that the user selects a specific Efficient Chiller instead of a standard one for a particular application. It enables the user to identify the most cost-effective alternative under three different scenarios:

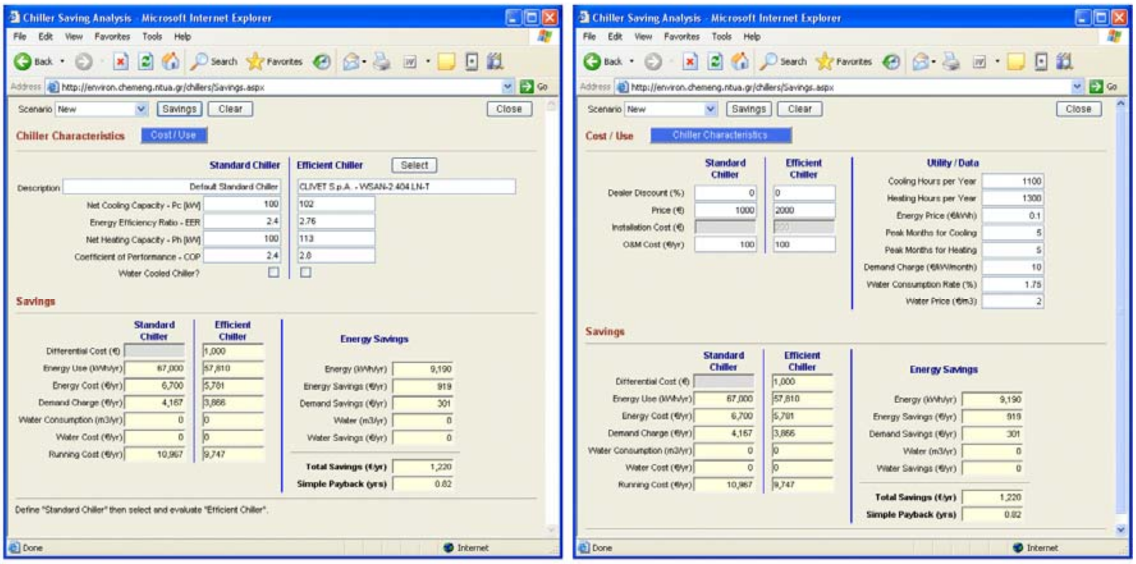
(1) **New (Compare New Chillers)** compares the costs of acquiring and operating a new standard chiller with those of an efficient model. A standard chiller is assumed to be the “base case”. The module determines the energy and cost savings achievable due to purchase of the higher over a lower efficiency chiller mod-

el. Then, assuming that the efficient chiller is also more expensive to purchase, it determines the simple payback on the investment in the efficient chiller.

(2) **Refurbishment (Repair versus New Motor Purchase)** compares the cost-effectiveness of rewinding a standard chiller against the cost of purchasing a new efficient model. This comparison takes into account a reduced efficiency for the rewound chiller attributable to age and rewind losses.

(3) **Replace Existing (Replace Operable Chiller)** analyzes the cost-effectiveness of replacing an operable standard chiller with a new efficient model. This scenario is used to decide if it is cost-effective to immediately replace older, low-efficiency, rewound, and oversized and under-loaded chillers. The analysis considers the entire new chiller purchase price plus installation costs as the chiller price premium when determining the simple payback.

The Chiller Savings Analysis page is designed with two tabs: the Chiller Characteristics tab and the Costs/use tab. The Chiller Characteristics tab (Figure 4.a) allows the user to specify a chiller by entering descriptors, operating parameters and performance values. Values for the standard chiller are entered in the left column. Corresponding values for the efficient chiller are entered in the right-hand column. The user can select the efficient chiller from the database using the Chiller Selector sub-module.



(a) (b)

Figure 4: The Chiller Savings Analysis sub-module

Information necessary for completion of a chiller energy savings analysis are entered at the data entry boxes on the Costs/use tab (Figure 4.b). These include purchase/installation cost, O&M cost as well as data concerning the price of energy and water. Energy and cost savings are shown in the Savings window at the bottom of the Chillers Savings Analysis page.

5 Conclusions

Computer-based tools that perform energy analysis of motor systems are extremely useful. ProMot is a decision support tool aiming to aid end-users to explore the possibility of energy savings in electricity driven motor systems of an industrial or tertiary installation. The main characteristics of the tool were presented and emphasis was given to the Chillers module. This module is a web-based application, helping energy consultants, chiller distributors and end users in planning and carrying out energy management and chiller efficiency improvement actions. The ProMot tool, can currently be found at www.motorchallenge.ch:8181/promot and will be hosted on the web by the Joint Research Centre – DG JRC, upon completion of the current project.

6 REFERENCES

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