Stimulation of better summer comfort and efficient cooling by EPBD implementation

"Handling of alternative cooling techniques"

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1. Introduction

The most dominant technique for refrigeration and air conditioning applications is currently the mechanical vapour compression refrigeration cycle. Such conventional refrigeration systems have a high overall global warming potential (GWP) as they make high use of energy and of refrigerants.

The aim of this report, which is part of the work carried out in the framework of the IEE SAVE ASIEPI project, is to evaluate the extent to which alternative cooling techniques are covered by the procedures used by the MS and the way this is done. In the context of this report, alternative cooling techniques are considered to be the cooling techniques that improve summer comfort substantially, without (or in a very limited manner) increasing energy consumption and which in general do not rely on the vapour compression refrigeration cycle.

There are many alternative cooling techniques and systems available in the market today that have limited (or even zero), global warming impact due to limited (or even zero) emissions of green house gases from energy use and use of ozone depleting gases from refrigerants. The main reasons for them not being very popular are related to high cost, limited cooling capacity and unpredictability of performance, compared to vapour compression refrigeration systems. In order to make the application of alternative cooling techniques to a building viable, it is critical that first of all, the mechanical cooling load is minimised.

Even though the benefits from using alternative cooling techniques are significant and their use can help meet the EPBD requirements, most EU countries do not consider them in their national energy performance requirements and calculation methods as integrated and as much as they should. In the context of EPB regulations, systems that give a better performance in terms of the energy performance of buildings than common systems, but whose performance cannot be assessed by the standard EPB calculation methods are defined as ‘innovative systems’ and are further analysed in ASIEPI WP6.

In order to assist in this report, a questionnaire, prepared by the Belgian Buildings Research Institute (BBRI) was distributed to representatives of 13 Member States. Responses were collected from: Belgium, Germany, Spain, France, Greece, Italy, the Netherlands, and Poland for the state of their national regulations in summer of 2008 and from Hungary, Ireland, Lithuania, Romania and the United Kingdom for the state of their national regulations in winter of 2009. The questionnaire included general and specific information regarding the handling of alternative cooling techniques at the time of the survey [1]. From the 13 surveyed MS only 9 (Belgium, Germany, Spain, France, the Netherlands, Italy, Ireland, Romania and the United Kingdom) had an EPB-regulation in effect at that time and are therefore the focus of this study. Italian procedures however, are not included in the following study as at the time of the survey they were generic and qualitative, and no relevant indicators or calculation procedure were defined.

2. Handling of alternative cooling techniques

2.1. Reduction of solar and heat gains

In order to reduce the cooling requirements of a building and therefore ensure viability of alternative cooling techniques, or even avoid the need for cooling completely, it is important that early on in the design process the building is designed in such a way that solar and heat gains in internal spaces are minimised. This should reduce the building energy consumption, minimize maintenance costs (e.g. specialist refrigeration maintenance and water treatment costs), and in many cases reduce the life cycle costs of the building [4], with a reduced cost of implementation.

2.1.1 Handling of reduction of solar and heat gains by MS

Solar gain is often the largest component of heat gain during summer, but it is also rather simple to restrain if some thought is put in it. All 8 countries are aware of this and have set a detailed calculation approach for solar gains, meaning that buildings can easily benefit or be penalised depending on the efficiency of their solar control strategy. For the purposes of solar gain calculations from transparent and from opaque building envelope components, direct, diffuse and ground reflected radiation are considered as separate input variables in the EP-calculation methods of 7 countries.

All countries require for the g-value (solar energy transmittance through windows) of the glazing, the window area, the slope and the orientation of the windows in their EP-calculations. Solar protection devices, self-shading or shading from the surrounding environment are considered by 8 countries. For fixed shading devices the solar transmittance (which may vary between heating and cooling season) is inputted. For fixed shading devices Ireland considers shading correction factors related to orientation and geometry while the Netherlands assume that the effect of the shading device is integrated in the g-value of the glazing. In Belgium for awnings, if the normal-hemispherical solar transmittance is smaller than 0.3, the device is considered as fully opaque, otherwise as fully transparent. For mobile shading devices the solar transmittance of the shading device, or the g-value for the Netherlands, is time dependent. In France the calculation approach for mobile shading devices is simplified. Belgium considers "use factors" (fixed values, independent of slope or orientation) that give the fraction of the incident radiation at the "closed" and "open" states of the solar protection device. The use factors for Belgium vary between heating and cooling/overheating calculations, and between residential buildings and offices & schools, in order to account for different types of operation. They also differ between manual or automatic control, in order to reflect different user behaviour/control strategies. For both fixed and movable shading devices calculations Romania advices Annex H of EN 13790.

6 countries also consider the solar absorptance of opaque envelope components in their calculation method. Specifically, 2 countries use a default value for the solar absorptance of envelope components. 1 country also considers the external radiative heat transfer coefficient.

In 7 countries the air tightness may influence the cooling load. In Belgium however, this is the case only for residential buildings while in the Netherlands for non-residential buildings. For Spain specifically, the airtightness of the opaque part of the envelope is fixed at a default value that depends on the building type.

2.2. Absorption refrigeration

Absorption refrigeration systems rely on the absorption cycle. Compared to vapour compression systems, absorption systems operate without a compressor and have no moving parts, as the compressor is replaced by a heat operated absorber-generator. Also, no refrigerants or other substances with ozone depletion potential or global warming impact are normally used. Furthermore, the COP of absorption systems is generally inferior to that of vapour compression systems. However, it can be improved if their generator is powered by thermal energy, such as from combined heat and power (CHP) systems or solar energy. This accrues from the way the COP for the two system types is measured; while the COP for vapour compression systems is measured in terms of the electrical power input to the compressor, for absorption systems the COP is measured in terms of the thermal energy input. Absorption systems also have quiet vibration-free operation unlike systems that operate with a vapour compressor.

2.2.1 Handling of absorption cooling by MS

Absorption cooling is considered by 7 MS in the calculation methods for non-residential buildings one of which follows a more simplified approach. For residential buildings only 2 countries impose a detailed calculation methodology, while 2 other countries follow a more simplified approach. Also for residential buildings, Belgium considers active cooling in general, only with a fixed, overall system efficiency, independent of the real system in which the overall COP (including all system losses and parasitic consumptions) is taken equal to 2.25.

All countries consider some kind of heat source in combination with sorption cooling. Germany considers the greatest number of such sources amongst which are conventional heat generators, cogeneration, district heating and solar thermal energy. However, the calculation method is more simplified for the case of residential buildings. In the remaining countries conventional heat generators, cogeneration and district heating are mostly considered.

2.3. Free cooling

‘Free cooling’ is an efficient way of minimising the need to operate a refrigeration system when the load and/or ambient conditions are reduced. The cooling medium for free cooling is usually air or water, meaning that apart from free energy, ‘free cooling’ techniques make no use of refrigerants. However, compared to normal refrigerants, larger amounts of air or water are required to be moved and additional fans and pumps are required for heat rejection at a dry air cooler or wet cooling tower [5]. Before selecting a ‘free’ cooling system it should be made certain that it will not consume more energy than a refrigeration system.

Opportunity for ‘free cooling’ and viability of such systems is maximised when they are used in conjunction with a cooling system, which requires higher chilled water and supply air temperatures such as chilled beams, chilled ceilings and displacement ventilation, respectively.

Apart from ground cooling systems, which have average to poor implementation costs, all other ‘free’ cooling systems have good implementation costs.

The main categories of ‘free cooling’ are:

- *Environmental ‘free cooling’*: environmental cooling may be used for direct cooling of a building or a building related process, or if it is not cold enough it may be used as a heat sink for heat rejected from a refrigeration plant or the building itself [5]. Sources (or heat sinks) of environmental cooling include the ambient air, the ground, the sky, rivers, lakes or the sea.

- *Chilled water ‘free cooling’*: when the ambient air temperature is low, the refrigeration system (if one exists) is bypassed and cooling of chilled water is provided, either directly (chilled water is circulated directly though the cooling tower) or indirectly (by the use of plate heat exchanger to separate the cooling tower water from the building cooling system), by separate dry air coolers or the main air supply cooling coil or dehumidification coil [5].

- *Condenser water/chilled water heat recovery*: the heat exchanger is located in series with the chilled water return thus extending availability of free cooling compared to “chilled water free cooling” [5]

- *Refrigerant migration chillers (thermosyphon chillers)*: In refrigerant migration chillers the chiller compressor and expansion valve are bypassed when the condenser temperature is lower than the evaporator temperature and operate in free-cooling mode [5]

2.3.1 Handling of 'free' cooling by MS

5 counties consider a direct central intake of outside air for cooling and ventilation in their EPB-calculation although 3 of countries only consider them for non-residential buildings or use a fixed value for residential buildings. For residential buildings, Germany also takes into account a fixed value for cooling from water-air dry, but also wet heat exchangers, while Spain considers water-air dry heat-exchangers and water-side economizers for the cooling towers in tall non-residential buildings only.

When the ambient air temperature is higher than the return air temperature, 3 countries consider recovery heat exchanger, out of which 2 consider it only for non-residential buildings. When the ambient temperature is lower than the return air temperature, e.g. during the night, 3 countries consider by-pass of the recovery heat exchanger out of which 1 country considers it only for residential and another country only for non-residential buildings.

4 countries consider ground cooling in their calculations for delivered energy. Specifically, 3 countries consider it for non-residential buildings, 2 of which use fixed input value. Only 1 country considers ground cooling for residential buildings calculations and as a fixed input value. Such 'free cooling' techniques considered are mainly ground water (with/without reinjection), closed circuit boreholes and HX (heat exchanger) embedded in foundation pillars. No country considers preliminary passage of incoming air through ground-air heat exchanger in its calculations.

For offices and schools in Belgium it is implicitly assumed that seasonal regeneration is taken proper care of; it is not stated as an explicit requirement, let alone that it is checked.

Even though ground source heat pumps are often an active system, they may operate with the compressor turned off as a kind of heat pipe. The Netherlands and Germany consider ground source heat pumps in reverse operation for both residential and non-residential buildings, while Belgium and the UK only consider them in the EP-calculations for non-residential buildings. Note however that the values used in the calculation for residential buildings in Germany and non residential buildings in the Netherlands are fixed. Belgium, the UK and the Netherlands for non-residential buildings and Germany for residential buildings also consider by-pass heat exchanger to ground source heat pump. Values for Belgium, Germany and the Netherlands are again fixed.

Furthermore, extra radiative losses to the sky referring to the building envelope are considered in the EP-calculations of 3 countries, but radiative losses to the sky from systems that circulate water or air are not considered by any country.

No country takes surface water cooling (river, lake, sea) into consideration in its EP-calculations.

The calculation procedure of 3 countries can deal with any random combination of active devices and passive sinks (hybrid cooling).

2.4. Evaporative cooling

Evaporative cooling is based on the thermodynamics of evaporating water. In order for evaporation to happen, water requires energy, the so called latent heat of evaporation, to assist in its phase change, from liquid to gas, at constant temperature. The necessary latent heat for evaporation is provided by air comes into contact with the water, and as a result it is cooled.

Evaporative cooling can be:

- *Direct*: the primary supply air stream comes into direct contact with water. As a result the dry bulb temperature of the air is reduced adiabatically and its humidity is increased.

- *Indirect:* the primary supply air stream comes into contact with an air-to-air heat exchanger, through which a secondary air stream that has been cooled through direct evaporation is circulated. As a result the dry bulb temperature of the primary air stream decreases while its moisture (absolute humidity) remains constant (sensible cooling).

Principle advantages of evaporative cooling include: substantial energy cost savings, reduced peak power demand, improved indoor air quality, life cycle cost effectiveness, easily integrated into built-up systems, wide variety of packages available, provide humidification and dehumidification when needed, easy to use with direct digital control (DDC), reduced pollution emissions and no chlorofluorocarbon (CFC) usage [3]. However, compared to conventional systems, evaporative cooling systems require for higher air flow rates and therefore more fan energy and larger ducts and cannot deal with latent cooling loads.

2.4.1 Handling of evaporative cooling by MS

For tall non-residential buildings Spain considers both indirect and direct evaporative cooling in the incoming air stream. Apart from Spain no other country considers evaporative cooling, either direct or indirect, in its EP-calculation method.

2.5. Passive cooling techniques

Passive cooling techniques make use of naturally occurring energy, by utilising various features of the building itself and its surrounding environment. The most common approaches involve the intelligent use of natural driving forces (wind and buoyancy) in the building ventilation strategy but also the intelligent control of solar shading. Thermal mass and night ventilation enhance the efficiency of such systems further.

The main advantages of passive cooling techniques compared to conventional cooling techniques are the reduction of the cooling needs (especially when used with night ventilation), the reduction of mechanical ventilation requirements (i.e. fans and ductwork) and the reduction in fans and cooling plant energy consumption. The main disadvantages are: pollution and noise ingression, security issues, nuisance draughts, difficulties in maintaining desirable temperature and humidity levels, difficulties in predicting thermal performance. However, most disadvantages of passive cooling techniques apply to buildings that are located in city centres. These issues are mainly air pollution, noise and higher external temperatures as a result of urban heat island. With the proper site selection, natural ventilation

2.5.1 Handling of passive cooling techniques by MS

Naturally driven intensive ventilation is considered in the EP-calculation for residential buildings by 4 countries, but 2 countries consider it for non-residential buildings as well. For the 2 countries that consider naturally driven intensive ventilation for residential buildings only the input variables are fixed. For Spain specifically, a default value of 4 ach is considered for night-time cooling.

The French calculation methodology for natural ventilation is the most detailed as it is the only methodology that considers the area of the ventilation openings, the grid flow characteristics, the exhaust openings and stacks, but also the acoustical aspects of natural ventilation. However, it does not have special specifications for ventilation during absence (i.e. night ventilation). On the other hand, Spain considers natural ventilation during absence in its EP-calculation methods in detail, for tall non-residential buildings and as a fixed value for residential and small non-residential buildings. In the Netherlands, openable windows or grids add to the amount of ventilation in the calculation of the cooling demand.

All countries consider conventional use of thermal mass (sensible heat storage), although the calculation method that the Netherlands uses is simplified as opposed to that of the other countries. The calculations for residential buildings in Germany are performed at building level. No country considers Phase Change Materials (latent heat storage) in their calculation methods.

Sensible storage (i.e. cold water tanks, rock/pebble beds) is only considered for the non-residential buildings in Germany. No country considers latent storage in its calculations (i.e. ice storage).

3. Conclusions & Recommendations

The most dominant technique for refrigeration and air conditioning applications is currently the mechanical vapour compression refrigeration cycle. Such conventional refrigeration systems have a high overall global warming potential (GWP) as they make high use of energy and of refrigerants. Furthermore, if they are not maintained well they may cause significant problems to air quality. The harmful impacts of this technology are compensated by the fact that they have high cooling capacities that they are capable of meeting the cooling requirements at all times, something that makes this conventional cooling technique a tough competitor for most of the alternative cooling techniques. Not only is this technique dominant in practical applications, it is also considered by all MS EP-calculations.

Many benefits accrue from the use of alternative cooling techniques the most significant of which are: considerable energy and cost savings, reduced peak power demand, improved indoor air quality, life cycle cost effectiveness, in most cases easily integrated into built-up systems, some provide humidification and dehumidification when needed, reduced pollution emissions, no chlorofluorocarbon (CFC) usage [3].

Overall, MS consider more alternative cooling techniques in their EP-calculations for non-residential buildings than they do in their EP-calculations for residential buildings. In many cases, when a cooling technique is considered for all types of buildings, for the same country, the calculation method is often more detailed in the case of non-residential buildings and a more simplified approach is followed for residential buildings.

Policy makers:

It is suggested that financial incentives, similar to those given for renewable energy (e.g. photovoltaics) could be given for the use of alternative cooling techniques. The greater the benefit in areas such as energy savings, emissions reduction and life cycle cost effectiveness compared to conventional cooling systems or techniques, the greater the funding could be.

It is also recommended that more alternative cooling techniques are considered by MS EPB-national regulations in order to further motivate their use in buildings and to stimulate a market transformation.

It is strongly advised that conventional cooling systems are put in second place in EPB-regulations as opposed to alternative cooling techniques. A comparison report justifying the selection of conventional cooling systems against the alternative techniques aforementioned in this report could be made mandatory in MS national regulations. A hierarchy of performance requirements like energy savings, emissions reduction, life-cycle effectiveness etc could be defined, from which the appropriateness of each system for a corresponding building can be defined.

The possibility of decreasing the oversizing capacity of the A/C installations during the design phase could be considered in EPB-regulations as well to avoid operation of the system in part load and decrease the energy consumption.

Also, a modular pricing policy could be applied for big cooling consumers to promote energy conservation and enhance the potential of the consumers to apply energy saving measures.

It is strongly suggested that solar and heat protection, modulation and dissipation cooling techniques and good building design are made obligatory above the use of mechanical cooling and air-conditioning systems to prevent overheating and reduce peak electricity demand and the overall energy consumption for cooling. For example, the use of shading and natural ventilation could be made mandatory in order for the installation of AC system to be allowed.

Developers of calculation methods:

It is recommended that as more experience is gained in the operation and performance of such techniques, their calculation methods are further developed and brought to the same level of calculation methods as those of heating techniques.

Furthermore, it is important that developers of calculation methods base their calculation methods on the same EN standards and use the same nomenclature so as to ensure consistency between MS national regulations and wherever feasible allow for intercomparison of outcomes.

Building practitioners:

In order to reduce the cooling requirements of a building and therefore ensure viability of alternative cooling techniques, it is important that early on in the design process building practitioners design the building in such a way that heat gains in internal spaces are minimised. This should: reduce the building energy consumption, minimize maintenance costs (e.g. specialist refrigeration maintenance and water treatment costs), and in many cases reduce the life cycle costs of the building.

Building practitioners are also advised to give priority consideration to passive cooling techniques for buildings in locations with reduced noise ingression and air pollution issues, but also in locations where urban heat island occurrence is limited.

Associations of architects and building practitioners:

Finally, associations of architects and building practitioners are advised to develop and distribute best practice guidelines on the use of alternative cooling techniques.

4. References

[1] http://www.asiepi.eu/fileadmin/files/WP7/ASIEPI_survery_cooling_determination_methods_20100210.xls

[2] ASHRAE Handbook – HVAC Applications: 2003

[3] ASHRAE Handbook – HVAC Systems and Equipment: 2004

[4] ASHRAE Handbook – Refrigeration: 2006

[5] CIBSE Guide B – Heating, Ventilation, Air Conditioning & Refrigeration: 2005

[6] CIBSE Knowledge Series: KS3 – Sustainable low energy cooling: an overview

[7] Natural Cooling Techniques, A. Argyriou, M. Santamouris

[8] The Energy Performance of Buildings Directive – CIBSE Briefing 6

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