The Practical Scope for Reducing Air Conditioning Energy Consumption in Europe: Policy Opportunities and Priorities

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Abstract

For a variety of reasons, market penetration of air conditioning and consequently demand for cooling in Europe continues to increase and on a "business as usual" basis would increase by over 50% by 2020, although recent economic events may result in a somewhat smaller increase.

This paper summarises the results of an extensive "Study to assess barriers and opportunities to improving energy efficiency in cooling appliances/systems" carried out by the Building Research Establishment and funded by CLASP. The purpose of the study was to contribute to the development of relevant policy by identifying and quantifying the potential impact of possible measures to reduce the energy consumption of air conditioning in Europe over a ten year period, relative to a business as usual case.

Many of the policy measures relate to the performance of products and equipment, but there is also considerable potential in the areas of load reduction and more effective operation and management of systems. The analysis focuses on quantified realisable savings that reflect technically feasible measures whose rate of introduction is constrained by the replacement rate of air conditioning systems and appliances, refurbishment rates of buildings and different levels of ambition for performance regulations placed on air conditioning equipment and systems. It is disaggregated by country, but this paper concentrates on results for Europe as a whole.

The measures that offer the largest realisable savings formed the basis for recommendations for policy measures, often using existing policy instruments. These measures fall into two groups relating, on the one hand, to policies that impact directly on technical requirements for systems and products and, on the other hand, to those that do not. The second group includes policy measures to incentivize effective operation of buildings and systems, and to influence take-up rates for high-efficiency products.

Additional recommendations relate to the application of policy: consistency of approach between instruments; choice of application at national or European level. The report also identifies areas where further work is needed to improve the robustness of studies similar to this one.

More detailed results and information about the study can be found at
http://www.bre.co.uk/searchresults.jsp?category=5&q=energy+management

Introduction

This paper assesses the realisable potential for reducing energy consumption in Europe over a ten-year period by analysing a number of idealised cases which represent different types of possible measure applied with different ambition levels. The cases which yield the largest potential savings are identified, routes to implementation are discussed and recommendations to support implementation are offered.

The market for air-conditioning in European building is immature in the sense that ownership in most countries is considerably lower than in equivalent climates in North America or the Far East. (see, for example [1] This is reflected in the fact that most sales are for first-time installations in new or existing buildings with relatively few replacement sales. [2] This is very different from the markets for most other forms of building services, such as heating or lighting, where most sales are replacements.

The empirical evidence is that market penetration has increased fairly steadily over several decades with only a few signs of saturation [2] [3]. In consequence, consumer demand for cooling is likely to

1

increase and, other things being equal, so is the associated demand for mainly electrical energy. However, there are many opportunities for reducing demand and improving the efficiency of use. For example, in a growing market, the impact of high-efficiency products is more immediate than in a market where the penetration of efficient products is constrained entirely by the replacement rate. In the study underpinning this paper we have also sought to engage with a wide range of policy options for constraining the growth of air conditioning energy consumption, including minimum performance requirements placed on products, on systems and on whole buildings and their systems. This broad perspective implies a more integrated approach to the development of policy, mobilising in a more deliberate way a comprehensive set of policy elements to form an integrated policy package.

The European market for air conditioning products and systems is far from being homogeneous. Consequently, the same is true of the installed stock of systems. Cooling demand varies with climate and with building type. New building may have higher (or lower) cooling requirements than existing ones. Different types of air conditioning system are more convenient to install in new or existing buildings, and for use in simple or complex buildings.

Categories of Systems

European product policy reflects the recognition that air conditioning systems designed to provide comfort in buildings can be divided broadly into three categories, with different principal applications and supply chains.

- Moveable units: These are appliances bought over the counter or on-line and do not generally require any installation expertise. These appliances are mostly used in dwellings and small commercial buildings.

- Room air conditioners/Packaged systems: These are series-produced self-contained units or systems comprising a unit that conditions a single room. They should generally be installed professionally. These systems are used in both commercial buildings and dwellings.

- Central systems: These are larger systems that serve more than one room (often large numbers of rooms or an entire building). They are generally bespoke systems designed for specific buildings, but are largely composed of standardised component products. In Europe they are predominantly used in non-residential buildings. There are a number of different types of central system, each with particular areas of applicability. For example some types of system are difficult to install in existing buildings.

Categories of Energy Saving Measures

There is no shortage of opportunities for reducing the energy used for air conditioning. Energy saving measures fall into three general categories: reduced loads, higher technical efficiency and improved operation.

- *Reduction of cooling loads* through improved building design and construction, and through the use of more efficient appliances and lighting systems.
  - o The range of economically feasible measures relating to building design is more limited in existing buildings than in new designs. Some measures can only be practicably applied to existing buildings as part of major refurbishment works.
  - o Cooling demand reductions from more efficient appliances and lighting often result from energy-efficiency measures specifically directed at those products.

- Improve the *technical efficiency of air conditioning systems.*
  - o Moveable units and room air conditioners are series-produced products to which performance tests and minimum requirements can be applied in a similar way to other energy-using products.
  - o It is more difficult to devise practicable performance metrics for central systems, which are essentially bespoke. Such metrics can be applied in principle to specific components, but in-use energy use is often dependent on the design of the system as a whole. For example, energy use for air movement is often substantial in central systems and is, to a large extent dependent on the design of the air distribution

system. Component replacement is more frequent than complete system replacement

- ***Reduce wasteful operation*** of air conditioning systems.
  - o In principle, this category of measure is immediately and universally applicable. In practice its application is often constrained by a shortage of easily assimilated information and pressure on building managers to prioritise other operational problems.

Policy Instruments

There are a variety of policy instruments that can be deployed to reduce the consumption of energy for air conditioning, including mandatory minimum performance requirements applied to products, systems or buildings; information provision, including energy labelling; financial incentives and energy pricing. Different instruments bear on different types of system, and on different categories of measures. Some instruments can only be practically applied at a Member State (or region or municipality) level while others are more suitable for a European level of application. The mapping of policies onto the most important cases is discussed later in this paper.

Realisable Savings

Realistic objectives for energy saving must take account of a range of practical constraints, not least the relatively long lifetime of air conditioning products and systems and the long time interval between major refurbishment of buildings. This study assessed "realisable savings" that would accrue over a ten-year period relative to a business as usual base case.

A ten-year period is sufficiently long to include the growth rates of the markets for: new systems in existing buildings; new systems on new buildings; replacement systems; product and system turnover rates; and building refurbishment rates. It is sufficiently short to constrain uncertainties due to long-term market projections; changes in policy priority; and changes in technology and pricing. During a ten-year period most of the initial stock of room air conditioners and moveable air conditioners will have been replaced, but a significant proportion of the original energy-using components of central systems will remain in place at the end of the period. In addition, many buildings will not have undergone major refurbishment during this period. In consequence there is considerable remaining potential for savings from building-related load reductions and from the complete replacement of central systems as part of major refurbishments.

Analysis Approach and Data Sources

General approach

This section of the paper provides an overview of the modelling process and data sources.

The core of the analysis is explicit, disaggregated modelling of energy consumption for a range of different assumptions, denoted "cases". The modelling takes into account the replacement rate of air conditioning systems and appliances, refurbishment rates of buildings and rates of market growth. Levels of realisable savings were estimated for different levels of ambition for performance regulations placed on air conditioning equipment and systems, for practicable load reductions, and for improvements to operational efficiency.

We have calculated savings as if policy instruments were introduced instantaneously at the start of the period (the base year for the modelling is 2010.) This is obviously not realistic, but provides directly comparable estimates and avoids the complication of assessing the timescale for policy to be agreed and implemented. In addition, national data were sparse for some countries with smaller market potential and it was necessary to make estimates based on parallels with other apparently similar countries. For example, the figures for Norway are derived from market statistics for Sweden, scaled for population. The realisable savings are therefore to be viewed as idealised indicators of the scale of savings that are possible within the 10-year time frame.

The model generates estimates of annual energy consumption for the cooling and air movement functions of air conditioning systems. The calculation is disaggregated in a number of ways:

- Country
  - In order to capture the different national market dynamics, climates and national energy requirements for air conditioning, each of the EU-27 Member States and the EEA countries was separately modelled.
  - This paper, however, focuses on the EU-wide results.
- System type
  - The three broad categories described above were further disaggregated into 14 specific system types.
- Building type
  - Buildings of different age and use have different cooling demand levels. It was not practicable to include all building types and ages.
  - The stock was disaggregated into the three types of building that market research revealed to represent the largest shares of equipment cooling capacity: dwellings, offices and retail buildings. Each of these was represented in both a new-build and existing building form.

Air conditioning system energy consumption was calculated for a ten-year period for each combination of country, system type and building type, based on the aggregate installed cooling power, the aggregate air conditioning system efficiency characteristics, and the climatic and building design features were specific to each combination. This was repeated for both a base case and a number of variant cases which included energy-saving measures.

28 different combinations of plant (system energy performance), fabric and equipment energy saving measures were modelled, representing different energy saving measures and levels of ambition (for minimum performance requirements for example). Some cases represented combinations of measures since the combined impacts are not simply additive. These cases represented typical operating practice: the impact of more effective system operation and management was then explored as variations to these "technical" cases. A separate analysis explored the theoretical scope for savings if less-efficient types of existing central systems were replaced by more efficient alternatives (separately from simply replacing components).

Methodology overview and data sources

Stock and sales

The existing and future stock of air conditioning systems drew on previous studies by the authors [2] [3], The general approach was to obtain historical sales figures from market research sources, and by a process of fitting these to a market diffusion equation for each country and comparing reported proportions of sales in to new buildings, first-time sales into existing buildings and replacement sales, to build up sales trajectories and levels of installed cooling capacity. Aggregate floor areas of cooled space were not explicitly estimated, as suitable data sources are extremely limited. However, the resulting base case estimates of total energy use for air conditioning are consistent with published assessments based on floor area estimates which are summarised in the "results" section below).
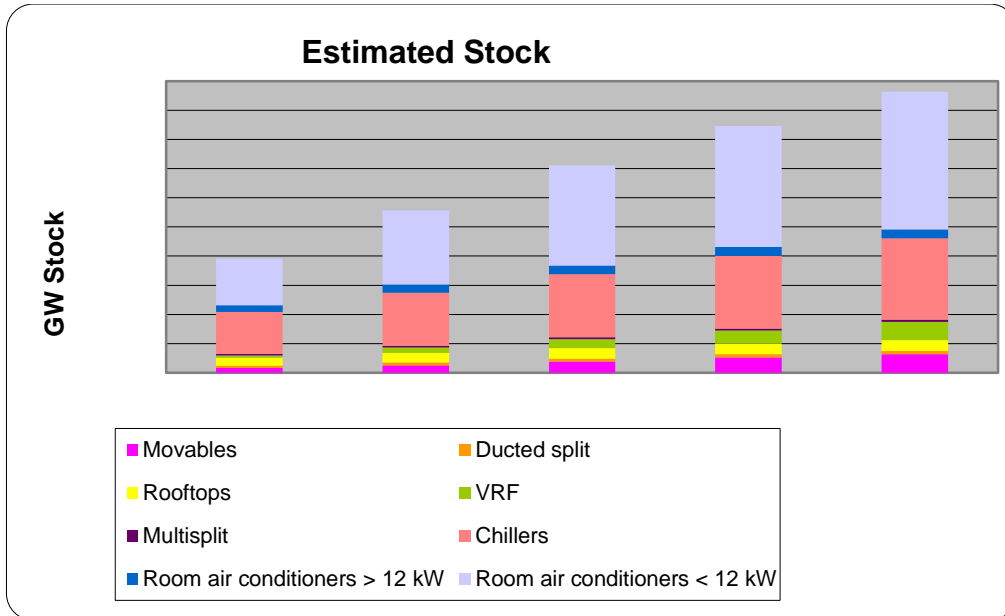
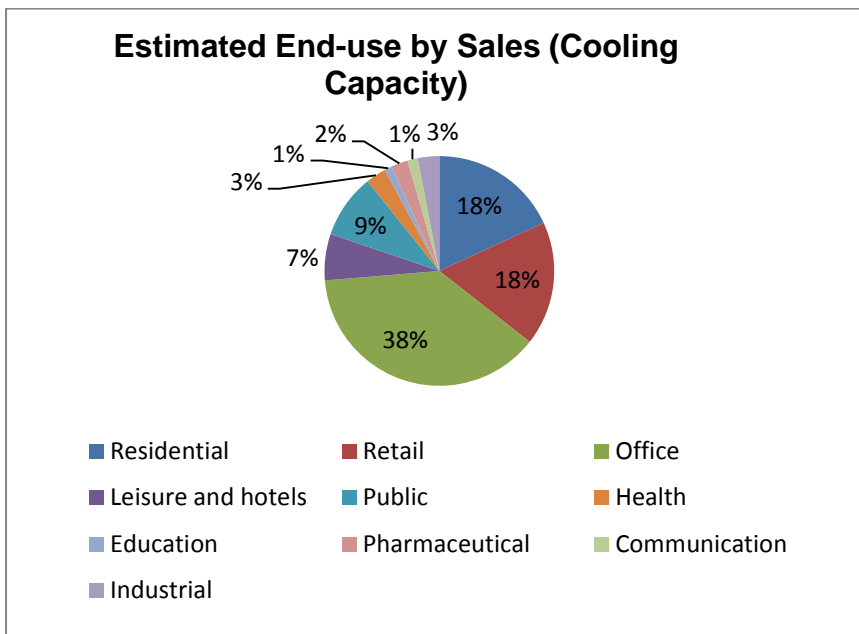**Figure 1. Installed cooling capacity (EU-27, ref [2])**

Figure 2. Sales by end-use (cooling capacity) (EU-27, ref [2])

System energy consumption and efficiency

In order to estimate annual energy consumption from the installed aggregate cooling power it is necessary to first estimate the load factor or "equivalent full-load operating hours" (EFLH) of the cooling plant.

The energy efficiency of moveable and fixed room units is defined by a seasonal energy efficiency ratio value (SEER) for a standard climate. In this project the values reflect the specific standardised climate assumptions of the ESEER metric. [4] The estimated energy savings for these products are derived from modelled changes in the mixture of products of different SEER in the installed stock of systems.

Central systems cannot be adequately represented by a single efficiency metric, not least because there are a number of system configurations and within each general configuration there are variations to match the needs of the specific building in which they are installed. The energy modelling is consequently also more complicated. The calculation procedure uses a set of algorithms originally developed for use in software for the implementation of the European Energy Performance of Building Directive (EPBD): SBEM [5] [6]. The software was developed specifically to estimate annual energy consumption taking into account *inter alia* HVAC system characteristics, and consequently has different objectives, structure and capabilities from software developed primarily to support detailed building design. The annual consumption of each combination of system, building, and climate is estimated by combining the total installed cooling power with an aggregate seasonal energy efficiency ratio (SEER) of the cooling plant and with a number of system characteristics that can lead to energy wastage [7]. These characteristics include: fan energy consumption as a function of specific fan power (itself a function of ductwork design), heat energy gains from fans, heat transfer to distribution duct- and pipe-work, control imperfections and duct leakage. For the UK, it produces energy consumption figures that are a close match to empirical benchmarks, including energy use for air movement associated with the air conditioning system. In this study the fan energy used to supply outdoor air (for ventilation) has been separately accounted: air movement for air conditioning is the additional air movement that is used to distribute cooling in some system types. The cooling algorithms have been modified to allow the use of different climates and design conditions. The basic UK load factors (expressed as equivalent full-load hours) for each building and climate combination are consistent with empirical consumption benchmarks. For other countries, they have been modified to reflect differences between building types and climates by scaling them according to the results of previous building simulations carried out by the University of Athens in support of Ecodesign projects. In addition, stand-by and off-mode consumptions have been added.

A general flow diagram for the central system model shown below in Figure 3 illustrates the structure of the central system model.
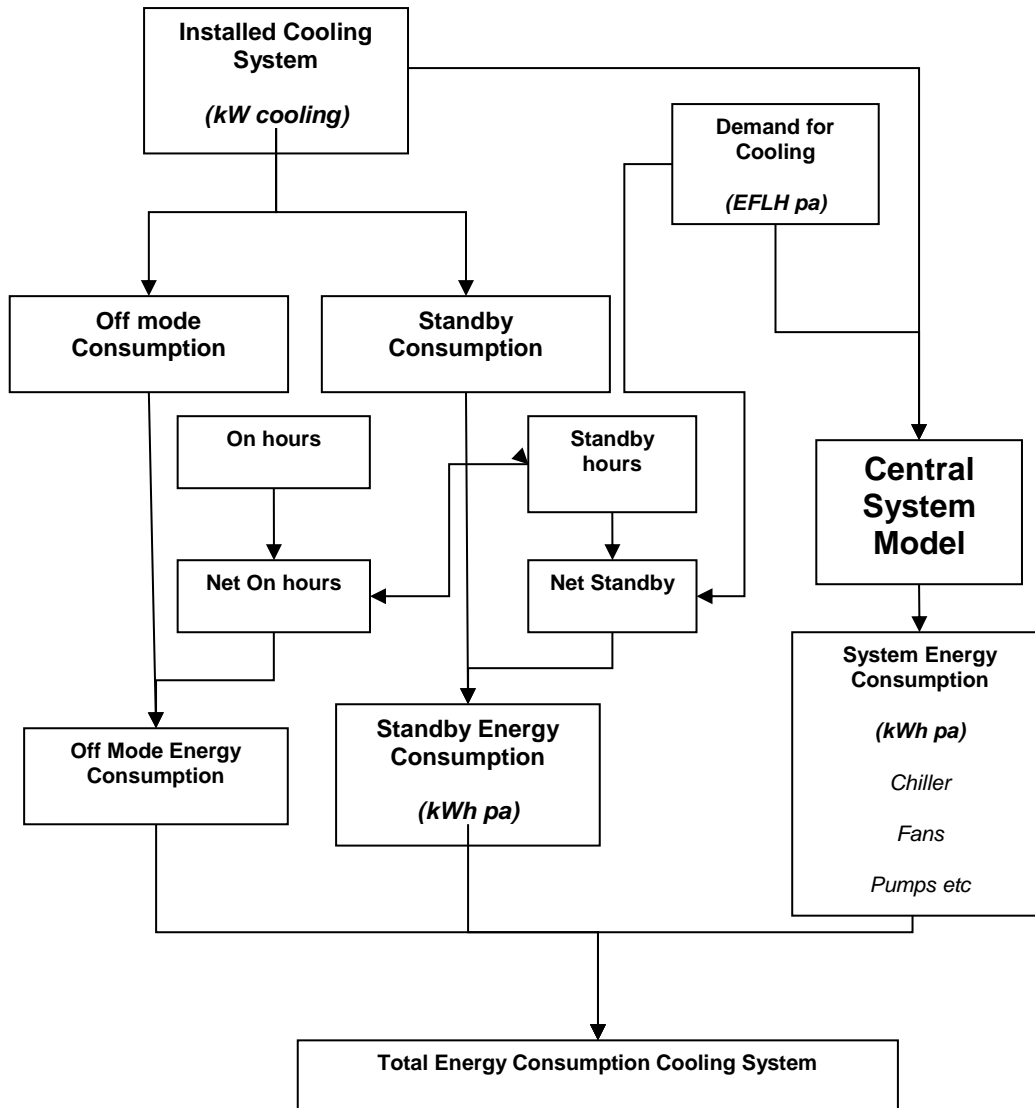
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┌─────────────────────┐
│  Installed Cooling  │
│       System        │                                    ┌──────────────┐
│                     │                                    │  Demand for  │
│    (kW cooling)     │                                    │   Cooling    │
└─────────────────────┘                                    │              │
                                                           │  (EFLH pa)   │
                                                           └──────────────┘

   ┌──────────────┐      ┌──────────────┐                  ┌──────────────┐
   │   Off mode   │      │   Standby    │                  │   Central    │
   │ Consumption  │      │ Consumption  │                  │   System     │
   └──────────────┘      └──────────────┘                  │    Model     │
                                                           └──────────────┘
        ┌──────────┐      ┌──────────┐
        │ On hours │      │ Standby  │
        │          │      │  hours   │
        └──────────┘      └──────────┘
        ┌──────────┐      ┌──────────┐              ┌────────────────────┐
        │ Net On   │      │   Net    │              │   System Energy    │
        │  hours   │      │ Standby  │              │    Consumption     │
        └──────────┘      └──────────┘              │                    │
                                                    │     (kWh pa)       │
   ┌──────────────┐      ┌──────────────┐           │                    │
   │  Off Mode    │      │   Standby    │           │      Chiller       │
   │    Energy    │      │    Energy    │           │                    │
   │ Consumption  │      │ Consumption  │           │       Fans         │
   │              │      │              │           │                    │
   │              │      │  (kWh pa)    │           │    Pumps etc       │
   └──────────────┘      └──────────────┘           └────────────────────┘

              ┌──────────────────────────────────────────────┐
              │  Total Energy Consumption Cooling System     │
              └──────────────────────────────────────────────┘
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Figure 3. Schematic of Central System Model

Aggregate SEER values for products were derived where possible from the distribution of values weighted by sales figures for each product type. More commonly, sales-weightings were not available and aggregate figures were estimated from the distribution of products listed on the Eurovent database, [8] converted from EER values where necessary. An example of the source data is shown in Figure 4 below.
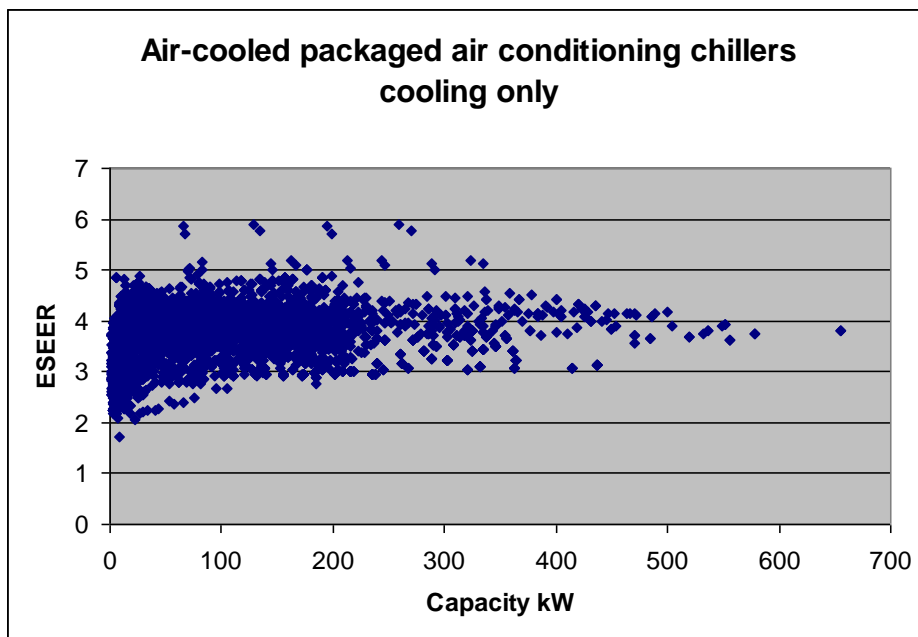
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Figure 4. Example of ESEER distributions (air-cooled chillers)

The impact of energy efficiency measures such as minimum performance requirements and energy labelling on the aggregate SEER values were represented by changes to the relative frequencies of products of different performance.

Similar processes were used to estimate other parameter values.

Load Reduction Measures

The principal data sources for estimates of load reduction – both from building envelope measures and from the use of equipment and lighting systems with reduced heat gains – were two previously published studies: KeepCool [9] and Harmonac [10].

The KeepCool project assessed the potential for reducing cooling demand in existing offices across Europe from a number of measures in the following categories:

- Reduced solar gain
- Enhanced ventilation
- Improved equipment and lighting efficiency
- Reflective surfaces and added insulation
- Windows

The study assessed the potential savings by carrying out energy demand simulations for example buildings to which various load reduction measures had been applied in each of five climate zones across Europe. The results were generalized by the KeepCool project assigning each country to one of the zones.

The KeepCool study used energy simulations to assess the potential savings in example buildings in each of five climate zones across Europe. The results were generalized by the KeepCool project by assigning cities in each European country to one of these climate zones.

In the present study, these results were taken to represent the theoretically available savings if there were few practical implementation barriers (including cost). In practice, this theoretical potential is constrained by practical and financial constraints. These constraints were represented in the present study by using additional information from the Harmonac project. The Harmonac project carried out detailed assessments of the practical potential for reducing air-conditioning energy consumption in 42 "Case Study" air–conditioned buildings, including but not restricted to office buildings. The frequency with which measures appeared in these buildings was taken to represent a "technically feasible" level

of implementation which might be included in new buildings or in existing ones during major refurbishment.

A second, lower, estimate of realisable savings was developed from the Harmonac project. The project carried out several hundred inspections of air-conditioned buildings in order to determine what energy saving opportunities were identified and the time required to identify them. These were much less detailed studies than for the Case Study buildings, carried out by air-conditioning technical staff (who were briefed to look for demand reduction opportunities) and identified fewer measures, and generally lower-cost variants (for example adding shading film to windows rather than external shading). These measures, and the frequency with which they were identified, were used to represent the effect of generally feasible and identifiable measures.

The impact of the load reduction measures was represented by reducing the EFLH figure to represent the (aggregate) reduction in consumption.

Improved system operation

The EFLH figures used in the energy consumption calculations are consistent with empirical benchmarks and therefore implicitly reflect typical usage. The inspections and Case Study analyses carried out by the Harmonac project confirmed that there is often substantial energy wastage through imperfect operational practices: such as poorly-set temperatures controls and time clocks, missing controls and filters that are in need of cleaning.
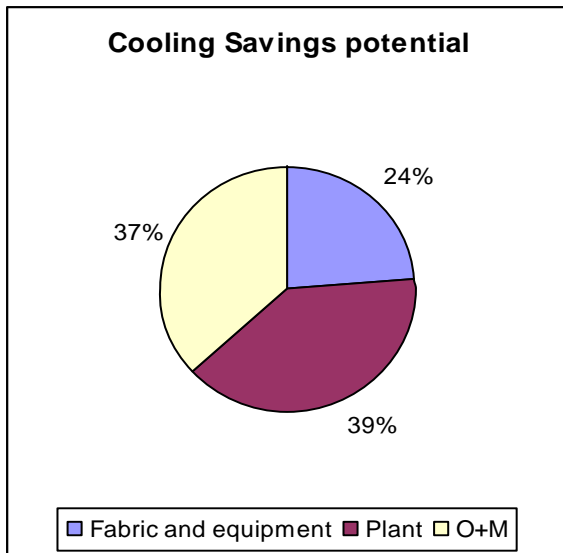

Figure 5. Harmonac Summary of Types of Cooling Energy Saving Potential

The empirical estimates of potential savings from this project were used to estimate the potential savings from better operational practice. "Practically realisable" savings were based on additional results from the project that identified what proportion of this theoretical potential was actually identified by air conditioning inspections.

Cases Examined

The cases examined included the introduction of different levels of minimum performance requirements (including "best available technology"), with and without energy labeling and with and without financial incentives for each of:

- Seasonal energy efficiency ratios for
    - Movable air conditioners
    - Room air conditioners
    - Central system chillers
    - Complete central systems
    - Central system fan coil terminal units

- o Central system pumps
- Specific fan power factors for central system air handling units
- Air leakage requirements for ductwork and air handling units
- Reduced fresh air requirements to reflect smoking bans
- Load reductions from building and equipment improvements
- Measures to improve operational management of systems

The possible take-up rate of measures will clearly be different according to whether they apply to first-time installations of products or systems, replacement products or systems, new buildings or existing buildings. This is reflected in the modeling of the theoretically realizable 10-year savings. In particular, the rate of implementation for measures that would not realistically be likely to be introduced except as part of major refurbishment was controlled by assumed refurbishment rates.

Principal Results:

Base Year: comparison with other estimates

Table 1 compares the estimated aggregate energy consumption for the base year from the present study with figures from other studies and shows generally good agreement, given the different definitions of scope used and the different dates of estimates. The Ecodesign Studies use a similar approach as the present study, while the other figures are derived from estimates of air conditioned floor area and consumption per unit floor area.

The figures in this section relate only to the annual consumption in the base *year* – although this study uses base case covering a ten-year base period, comparable figures are not available from other studies.

Name of Study	Total estimated Annual Energy Consumption TWh pa	Comments
This study	76.91 (moveables+ Room ACs + central systems) plus 63.6 for air movement energy consumption (140.5 cooling and air movement)	"Air movement" excludes that attributable to fresh air supply
EcoDesign Preparatory Studies [12].[13],[14]	Cooling only: 38.6 (Lot 10 but for earlier year) + 74 (Lot 6) = 112.6 Ventilation (not only associated with air conditioning) 100 TWh [1]	Ventilation figure includes use in non-air-conditioning applications
EECCAC study [4]	94.7	EU-12 only, 2003
Harmonac study [10]	198	
Electricity Consumption and Efficiency Trends in European Union - Status Report 2009, European Commission Joint Research Centre Institute for Energy [14]	38.6	Appears to only include room units < 12kW (Lot 10 study)

Table 1. Comparison of estimated annual air conditioning energy consumption for EU from various studies

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[1] This figure is not explicitly stated in the report but has been inferred from data in the report)

Energy Consumption for Cooling and Associated Air Movement

2% 17% 31% 50%

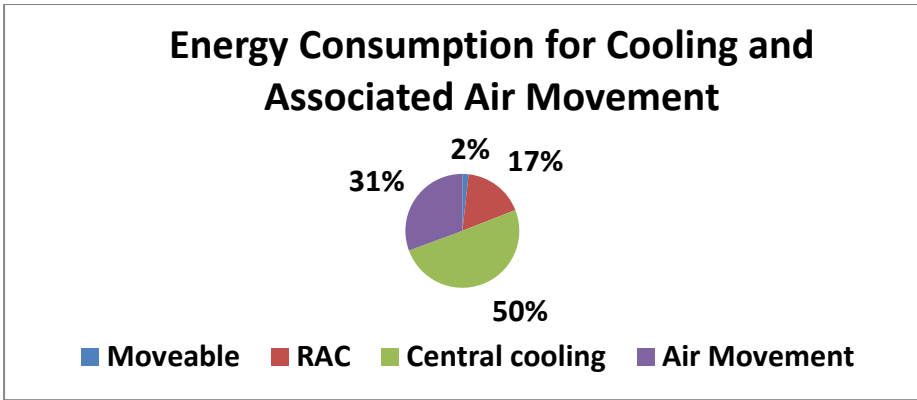Moveable ■ RAC ■ Central cooling ■ Air Movement

Figure 6. Summary of Energy Consumption for Air Conditioning: Base Case, EU-27

The relative contribution of central air conditioning systems compared to the distribution of installed cooling capacity shown earlier is the result of the higher distribution losses (and energy needed to offset fan energy heat gains) associated with this type of systems. As can be seen, the energy associated with air movement in centralised systems is substantial.

Base Case and Theoretical Potential Savings

In the base case, the market penetration of air conditioning increases but no new energy saving measures are introduced. Existing policies such as energy labelling of room air conditioners and movable units are included in the base case.

From the modelling, we have estimated that universal application of the best available technology and practices in the three categories of energy-saving measures might, in theory, reduce consumption by up to 80%. The maximum realisable ten-year reductions approximately 10% of the base case.

Summary of Principal Results

The seven cases that generated the largest estimated energy savings over 10 years are illustrated below. In most cases there are energy savings related to both the cooling and air movement functions.
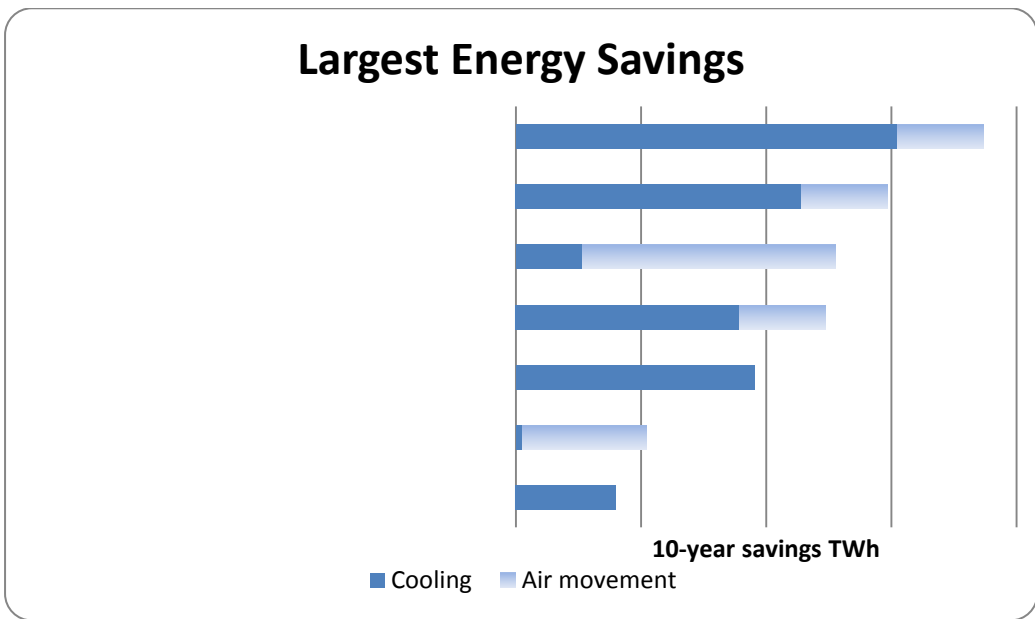

Largest Energy Savings

10-year savings TWh

■ Cooling ■ Air movement

Figure 7. Summary of the Cases showing the largest Realisable Savings

These high-potential cases impact on all three of the types of energy saving mechanism, but it is noticeable that all have some bearing on system efficiency and only one directly addresses operational practice. The number of "X"s indicates our subjective view of their relative impact on the different forms of saving. Thus improved specific fan power can have a major impact on system efficiency through the reduction of fan energy use but a much smaller impact on the cooling load placed on the system (through reduced heat pick-up from fans).

Case	Impacts on:		
	Cooling load	System efficiency	Operation
Minimum performance requirements integrating building and system characteristics	XXX	XXX	
Detailed energy audits of air conditioning systems	XX	XX	XXX
Reduced fresh air in spaces where smoking is now prohibited	XXX	XX	
Minimum energy performance requirements for complete systems		XXX	
Demanding minimum performance requirements for chillers		XXX	
Performance requirements for specific fan power and air leakage	X	XXX	
Demanding minimum performance requirements for room air conditioners and other packaged units		XXX	

Table 2. Relationship between Principal Cases and types of Energy Saving

As noted in the previous section, in many of the cases, the 10-year take-up for some savings is constrained by the likely refurbishment rate of existing buildings. In particular major changes to central air conditioning systems (apart from component replacements) and to the building fabric are unlikely except as part of major refurbishment. As a result further savings beyond the 10 years period can be expected for most of the high-impact cases. Few further savings beyond the 10 year period will occur for minimum performance requirements for room air conditioners (of which many existing products will be replaced within the ten-year period), nor for energy audits (we have assumed mandatory application and good take-up of recommendations). The effect is present, but to a lesser extent for minimum performance requirements applied to air conditioning chillers, which typically have operating lives of the order of 20 years, resulting in a significant number of older products still being in use after ten years.

Some measures occur within more than one case – though not necessarily with the same ambition levels – and there are also interactions between measures. The savings from each are therefore not simply additive.

Discussion of Principal Results

Minimum performance requirements integrating building and system characteristics

Scope

This case represents the application of minimum performance requirements to the combination of the building and its air conditioning systems and products, applied during initial design and major refurbishment. It also assumes that minimum performance requirements are applied to replacement air conditioning systems and products, albeit at a less demanding level than assumed in the case for product requirements alone. This combination permits designers to meet the performance requirement by trading off different forms of energy saving according to the specific needs and circumstances of each building. As a proxy for this flexibility, the modelling assumes a combination of moderately demanding performance requirements for systems and load reduction mechanisms.

Specific buildings could, of course, combine more demanding performance in some areas with less demanding performance in others.

Implementation Method

This case follows the principles of the EPBD minimum performance requirements for buildings. As it has to be applied at the level of individual buildings, practical implementation has to be by Member States – most conveniently using the framework of their existing building energy regulations or standards.

Implementation Issues

The savings estimates assume that every Member State has relatively demanding (but not extreme) ambition levels. This is far from certain, notwithstanding the cost-optimality requirements of the EPBD Recast.

As far as is known, only a few Member States building energy regulations apply minimum performance requirements to replacement air conditioning products and systems. The movement towards the introduction of such requirements for products, through the Ecodesign Directive will partially address this gap, though the levels of requirements for products that can be justified for single-market products that may be used in many different climates and applications might be problematical.

A more fundamental barrier is that few Member States' regulations contain detailed calculation methods for the seasonal energy consumption of air conditioning systems. In a survey by the EPBD Concerted Action [15], only 6 of the 15 respondents claimed to have such a calculation method. Where calculation procedures do exist, Member States have largely developed them in isolation from each other and there is a need for a recognised and practicable methodology. A practicable methodology needs to be compatible with the rather low data reliability for existing buildings and systems, balancing the complexity (or otherwise) of calculation against the uncertainty of the data. It should also, as far as possible be consistent and make use of experience with those methods that are already in use.

Recommendations to support implementation

- A consensus should be developed for a generally acceptable energy consumption calculation procedure, which should then be developed and tested.
- Member States should be required to implement an effective calculation procedure.
- In order to support the application of such calculations, energy labelling requirements for air conditioning products should make mandatory the public provision of the part-load data used to define the label.

Detailed energy audits of air conditioning systems

Scope

This case assumes the mandatory implementation "detailed energy audits". These are more detailed – and more costly - site investigations than the "inspection" that is required by the EPBD, In addition to more detailed physical inspection and testing of systems it includes an element of consumption monitoring and associated diagnosis. EPBD inspections have been shown to identify only a small proportion of potential energy savings, albeit these are usually easily-implemented low-cost measures. It is the only case offering substantial savings through improved energy management.

Implementation Method

Since this measure has to implemented at an individual building level, implementation has to be by Member States. A number of Member States already have active programmes of Energy Audits which offer a model for general implementation.

Implementation Issues

Energy audits are not cheap, can intrude on business operations and savings are not guaranteed. Implementation of the less costly, but less effective EPBD inspections has been slow and is widely seen as not being cost-effective. The most effective combination of measurement, analysis and physical inspection is uncertain. The use of remote monitoring as an adjunct to inspection or auditing is currently being investigated [16]. In order to achieve savings, identification of opportunities has to lead to actions, some of which may incur significant costs.

Recommendations to support implementation

- Review existing Member States' energy audit programmes and policies
- Investigate the use of electronic monitoring of air conditioning systems to improve the cost-effectiveness of inspections and audits

Reduced fresh air supply to spaces where smoking is now prohibited

Scope

The supply of outdoor air for many existing air conditioning systems was designed in the anticipation that occupants would be permitted to smoke. In many buildings smoking is now no longer permitted. There is scope for new systems to have lower ventilation energy requirements than older ones, and also for many existing systems to be modified to use lower outdoor air supply rates. This leads to reduced fan energy consumption and, to a lesser extent to reduced cooling demands to deal with hot outdoor air and to offset heat released by the fans.

Implementation Method

Since this measure has to implemented at an individual building level, implementation has to be by Member States. For new systems fresh air rates in design guidance should be reviewed. The energy saving opportunity should be brought to the attention of building operators and air conditioning system inspectors.

Implementation Issues

The savings for this case are rather uncertain since the number of air conditioning systems designed for spaces where smoking is permitted is uncertain and the extent to which Member states have banned smoking is poorly documented

Recommendations to support implementation

- Fresh air design rates and regulatory requirements should be reviewed in the light of smoking legislation and amended where appropriate.
- Air conditioning inspectors should be reminded of the potential for savings.

Minimum energy performance requirements for complete systems

Scope

This case assumes the mandatory application of minimum energy performance requirements for air conditioning systems: in practice central systems, since packaged units and movable air conditioners are series-produced self-contained products that can be subject to Ecodesign requirements. This would apply to new installations in new buildings, new installations in existing buildings and replacement systems.

Implementation Method

Central systems are, in essence, bespoke systems using more or less standard components. They are tailored to match the needs of individual buildings and implementation has to be by Member States. For new buildings and major refurbishments this can be through national building energy regulations and standards, but the scope of these does not necessarily include the installations of new systems in existing buildings.

Implementation Issues

Although this case offers the potential for substantial realisable savings, there are several implementation challenges. The absence of a suitable calculation methodology discussed above applies equally to this case. In addition, installations in existing buildings are commonly outside the remit of national building energy regulations and codes, and additional infrastructure to implement the measure (or an extension of the remit of national building energy regulations) would be needed. For example, either installers or contractors will need training, or they would be required to employ accredited specialists in order to demonstrate compliance. This is not impossible but would add an extra workload onto a structure that is already heavily loaded.

With the exception of new installations in existing buildings, the benefits can more easily be gained through the "*Minimum performance requirements integrating building and system characteristics*" case discussed earlier. Minimum performance requirements for air conditioning components such as chillers would capture a proportion of the savings potential of new systems in existing buildings and it seems debatable whether the advantages of this case justify the need for extra support infrastructure.

The EPBD Recast specifically calls for the introduction of minimum performance standards for technical building systems but does not specify how these are to b implemented.

Recommendations to support implementation

- Air conditioning system-level performance requirements should not be treated as priority issue, but the case for them should be reviewed from time to time.

Demanding minimum performance requirements for chillers

Scope

This case applies demanding minimum energy performance requirements to air conditioning chillers.

Implementation Method

Chillers are series-produced products and can be subject to Ecodesign requirements including minimum energy performance requirements.

Implementation Issues

A Preparatory Study [11] was released in 2012 (after the work summarised in this paper was completed) that makes the case for such requirements. The recommendations are currently being considered. A potentially difficult issue for European product performance requirements for air conditioning products is that the performance levels that can be justified vary, in principle between climates and applications. Demanding requirements – if they incur extra costs – may not be cost-effective for relatively mild climates and national requirements ma offer better value for money than a single Europe-wide requirement. The performance levels proposed by the Preparatory Study are cost-effective for most European climates, at least for the building type considered (although only very marginally so in milder climates).

Recommendations to support implementation

- Introduce mandatory energy labelling and MEPS for chillers
- Before introducing Europe-wide demanding levels of product minimum performance requirements, consideration should be given to implementing them via national building codes, accompanied by an over-riding but less demanding European minimum performance requirement.

Maximum specific fan power requirements and leakage requirements for air handling systems

Scope

A significant proportion of the energy used in air conditioning systems is for air movement. This case assumes the universal application of requirements to limit air leakage from ductwork and to limit fan energy use. The metric for the latter is "specific fan power" and is a characteristic of the air handling system as a whole. It is determined by a combination of ductwork design, air handling unit design, (including cooling coil design and filter specification) and fan and fan motor efficiency.

Implementation Method

A number of Member States have such requirements within their national building energy regulations and standards. This case makes such provision universal.

Implementation Issues

A Preparatory Study into the application of Ecodesign [12] requirements to ventilation products has recommended an alternative energy performance metric for air handling units. This metric relates to the product (the air handling unit) alone and characterises its performance under standardised operating conditions. It therefore ignores the important contribution to energy consumption made by other parts of the air handling system and, from the wider perspective of system performance is incomplete.

Recommendations to support implementation

- Minimum energy performance requirements for specific fan power should be introduced in those Member States that do not already have such requirements.
- Minimum energy performance requirements for ductwork and air handling unit leakage should be introduced in those Member States that do not already have such requirements.
- To assist Member States to introduce these requirements, model clauses and guidelines should be developed, based on the experience of those that already have them

Demanding minimum performance requirements for room air conditioners and other packaged units

Scope

This case considers the implementation of demanding minimum energy performance requirements for room air conditioners and other packaged air conditioning systems.

Implementation Method

From 2013 minimum energy performance requirements for room air conditioners of less than 12kW cooling capacity (the majority) have been implemented under the Ecodesign Directive [14]. The Requirements will be made more demanding in 2014.

Implementation Issues

The analysis supporting the current requirements was carried out some time ago and, notwithstanding some revisions, is less demanding than those assumed in this case. In the meantime, the range of high-performance products on the market has expanded substantially. In some countries, sales of high-efficiency units have also increased significantly. As in the case of chillers, universal requirements for demanding performance levels may not be cost-effective in some milder climates.

Recommendations to support implementation

- Evaluate the case for progressively making the minimum performance requirements more demanding.

Supplementary recommendations relating to the principal results are summarised in table 3 below.

Case	Recommendations and relevant Policy Instruments		
	EPBD	National Building Energy Codes *(may be implemented via EPBD)*	EcoDesign Directives
Minimum performance requirements integrating building and system characteristics	Develop agreed air conditioning system efficiency calculation procedure		Provision of part-load information
Detailed energy audits of cooling systems	Stronger implementation of current requirements	Explore use of automatic performance monitoring	
Supporting actions for energy audits	Report calculated system efficiency on EPC Report measured air conditioning energy consumption Expand use of measured energy ratings		
Reduced fresh air in spaces where smoking is now prohibited		Review of outdoor air requirements	
Minimum performance standards for air conditioning systems	Introduction of system MEPS		
Demanding minimum performance requirements for chillers			Introduction of MEPS
Performance requirements for specific fan power and air leakage		Wider introduction of requirements	
Demanding minimum performance requirements for room air conditioners and other packaged units			Review MEPS
Generic Recommendations		Consider combination of EU and national MEPS	
Recommendations for further work	Investigate effectiveness of information provision measures in business to business supply chains Investigate relationship between product price trends, energy performance and MEPS		

Table 3. Summary of recommendations (including supplementary recommendations)

A note on cost-effectiveness and ambition levels

The results discussed above relate to the cases which generate the largest 10-year "theoretically realisable" energy savings. In practice they represent relatively demanding levels of ambition embedded policy instruments that either already exist or seem to us to be feasible. Equivalent cases with lower levels of ambition were also examined but are not reported in this summary paper.

Deciding what is an appropriate level of ambition is clearly an important policy decision, but is no simple matter. While the general direction of travel of policy is reasonably clear, the pace of change and justifiable levels are not.

A rational choice of appropriate measures and ambition levels depends, amongst other considerations, on their expected cost-effectiveness. However, the concept and definition of "cost-effectiveness" are also less clear-cut than is often assumed. From a policy perspective, for example, cost effectiveness can be viewed from the perspective of the direct costs faced by building owners and operators, or from the costs and benefits to society as a whole. Regulatory intervention may be justified for measures that are cost effective for society but not from the end-user perspective. Broadly

speaking, the "demanding" performance levels referred to above reflect measures that are currently likely to be seen as cost effective by a only few building owners and operators in a limited number of building types and climates, but are – in our opinion - .plausibly likely to become cost-effective for society in general in the foreseeable future.

This section discusses a number of issues that surround (and often complicate) the definition of cost-effectiveness.

These two different perspectives are both important, but for different reasons. Ideally both need to be taken into consideration. Unhelpfully to the development of consistent policy, practice differs between different pan-European and National policy strands relating to energy use for air conditioning.

The two perspectives are:

- The perspective of society as a whole, including shadow prices for externalities (such as damage inflicted by climate change) excluding taxes and subsidies, using a (low) social discount rate.

- The perspective of end-users. This perspective includes taxes and subsidies, excludes non-priced impacts and uses commercial interest rates. Typically this only justifies lower performance levels than the societal perspective

Commonly both types of assessment are based on a hypothetical "typical" user and do not take account of different levels of impact on different parts of society. In the context of air conditioning, this could be users resident in different climates, for example.

From an economic perspective, in principle, all energy policy packages and measures should be designed to be cost-effective to society as a whole. However, policy measures that can be justified from this perspective may seem uneconomic from the perspective of some, or all, end-users. This situation is often used to justify the imposition of state regulation.

In practice, the cost effectiveness of product MEPS in Europe is generally assessed from that of an idealised end-user (who, somewhat inconsistently, is usually assumed to take a perspective that reflects the whole life of the measure and to apply a social discount rate). However, for building energy standards and regulations, the perspective differs between Member States. Roughly equal numbers of countries apply either a societal perspective or an end-user perspective, but a significant number consider both perspectives. Renewable energy policy generally takes a societal perspective.

For consistency of policy making it would be desirable to have an agreed set of conventions. The proposed EPBD methodology for cost-optimal building energy standards could be, in principle, a suitable basis for this but has become unnecessarily complex, yet still incomplete.

A common objective of policy design is that measures should be cost-effective or cost-optimal [2] . A policy is *cost effective* if its costs are less than the value of the resulting benefits. Cost effectiveness is sensitive to the assumed price and performance of the "base case" with which potential measures are compared. A policy is *cost-optimal* when the net benefits are maximised. This is a stronger requirement.

Many of the data needed for cost effectiveness calculations are inherently uncertain. This is most obviously the case for future prices (of, for example, energy) or of "shadow" prices (such a carbon damage price) for which there is no empirical evidence.

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[2] And improved energy efficiency should not be at the expense of other aspects of performance such as comfort or noise.

For product and system performance policy there is the extra complication of possible interaction between the introduction of minimum performance requirements and product prices. Engineering analysis for products in the USA [17] show ratios of between 0.5% and 1.5%, with the higher figures relating to higher performance equipment. Calculations in Preparatory studies for Ecodesign [11] show a similar range. Japanese product prices [18] suggest that a 1% improvement of efficiency is associated with a 5% increase in price, but that some of this results from non-efficiency factors. Equivalent figures at less demanding performance levels from China suggest a somewhat lower effect.

The impact on market prices may, however, be different since there may be compensating reductions in the cost of stocking and supply resulting from the higher volume of high-performance product sales (and the removal of low-performance products). Non-mandatory high-efficiency products may also command higher prices by being positioned as "premium" products with additional features such as self-cleaning filters.

An IEA report [18] not specifically dealing with air conditioning) concluded that "Although there appears to be no correlation between price and energy efficiency and the average price of appliances has been falling consistency, there is evidence that the most efficient products in some categories are more expensive than products which are less efficient." Some of this increase was thought likely to be due to the inclusion of non-energy-related features in "premium" products. However, "the commercially sensitive nature of pricing policies, together with the complexity of separating out pure efficiency costs from other appliance features, makes it difficult for an outside observer to understand how prices relate to costs of manufacture"

Thus while the idea that policy should be guided by some kind of assessment of the costs and benefits of that policy is generally accepted, *what* costs and to *whom* is the subject of continuing scientific, methodological and political discussion.

Concluding remarks

In this paper we have quantified the growing energy, economic and environmental challenge arising from growing demand for cooling. A significant technical potential for reducing the projected growth in the associated energy demand has been identified at the component, product, system, whole buildings, and operational level. A comprehensive menu of recommendations assembled on how existing and new policies can be mobilised, in an integrated manner, to help curb the projected rise in energy consumption from air conditioning.

Acknowledgement.

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