

# **Study on Energy Use by Air- Conditioning: Annex F: Calculated air conditioning energy savings arising from a range of possible policy interventions**

**BRE Client Report for the Department of Energy &  
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## Annex F: Calculated air conditioning energy savings arising from a range of possible policy interventions

This Annex presents UK results from a modelling exercise; “Study to assess barriers and opportunities to improving energy efficiency in cooling appliances/systems” which was carried out in 2012 by BRE and was funded by CLASP. It also identifies relevant policy interventions for the UK

- 1.1 In 2012 the Collaborative Labeling and Appliance Standards Program (CLASP) commissioned BRE to carry out an international study on the barriers to improving the energy efficiency of cooling appliances and systems and on policy and other opportunities for overcoming those barriers. A report on the study was published in 2012.<sup>A</sup> This Annex presents UK results from that study which have relevance to the current DECC project.
- 1.2 The study established current and theoretically possible energy consumption levels in air conditioning systems. It identified and quantified the potential impact of a range of potential energy performance improvement measures and policy instruments put together as packages of energy efficiency measures to reduce energy consumption over a ten year period, relative to a business as usual case.
- 1.3 The study took account of practical constraints and identified the “realisable savings” that would accrue taking into account the replacement rate of air conditioning systems and components, refurbishment rates of buildings and rates of market growth.
- 1.4 This study used a purpose-built model, which takes into account inter alia climate, system type, system and product efficiency, product and system replacement rates, building type, and difference of cooling demand between existing and new buildings. The results of a number of existing studies were also reanalysed to develop some of the modelling data and to refine some of the modelling results.
- 1.5 In particular, the analysis took account of:

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- available sales data for air conditioning systems
- energy efficiency levels and distribution of efficiency levels for equipment and systems
  - in the current market,
  - after the possible introduction of policy instruments,
  - of the best available technology
- current estimates of the annual growth rate of the air conditioner market over the next 10 years
- operating characteristics of each category of cooling equipment

1.6 The model was used to estimate the potential annual energy savings that would hypothetically result by implementing the measures described for every installation of a new system or product in each of the Energy Performance Improvement Cases, compared to the current 'no change' situation (by suddenly replacing the current stock of equipment by only those pieces of equipment that would be included in the particular case being studied). The model estimates the savings in terms of annual energy consumption for each specific case and projected the energy savings over the next 10 years.

1.7 The study estimated the current situation in terms of energy consumption (the base case) and then went on to identify the savings potential arising from implementing a range of energy efficiency measures.

1.8 Initially the technical savings potential was estimated based on the application of the best available technologies (BAT). This was achieved by comparing the energy consumption of a hypothetical situation where all the opportunities in current buildings to switch cooling equipment to the BAT were implemented, and then compared against the energy consumption of cooling equipment currently in use in the same buildings (base case). This estimate provides a ceiling for each type of equipment.

1.9 Following on from this, a series of (realistic) examples of energy performance improvement cases were also applied to the model. This included the introduction of more stringent MEPS (Minimum Energy Performance Standards), reductions of cooling load by improvements in the building shell, more effective use and control of existing systems and others. This allowed the study to compare the magnitude of the potential savings with a variety of options ranging from improved system design and operation to higher product performance levels (technology-based savings potential) and thus provide a more detailed understanding of how product policies might potentially interact with other initiatives aimed at reducing the energy consumption of cooling systems.

- 1.10 The model was used to estimate the market potential savings for each of the cases developed to represent the various initiatives. For product (and system component) level cases, e.g., equipment MEPS, the market potential savings were calculated using the sales figures for new and replacement air conditioning products, and the difference in average consumption between equipment currently in the market and the new mix of equipment that would exist after the initiative described in the case study was fully implemented. Calculations were based on the cumulative savings for the next 10 years. For system and building level cases the potential savings that could be achieved in the existing stock of air conditioning products were also assessed.
- 1.11 Detailed economic studies were not undertaken to determine which Energy Performance Improvement Cases that would be sufficiently attractive economically for consumers to implement were not undertaken. However, an indication of how cost effective each particular case was likely to be was provided.
- 1.12 The study then went on to identify barriers to reducing the energy consumption of cooling appliances and systems, and the potential for energy savings from better design of cooling systems and from technical and other changes to the products/devices and their use.
- 1.13 The study was carried out before the introduction of eco-design requirements for air conditioning and draws on the Eco-design Preparatory studies which explored the projected market for products, the technical potential for energy efficiency and lifetime environmental impacts for various types of products.
- 1.14 Two Eco-design Preparatory Studies are of relevance for air conditioning products, Lot 10 which covered room air conditioning units with a cooling capacity of  $>12\text{kW}^{\text{B}}$  and Lot 6 covered Air Conditioners with a cooling capacity  $>12\text{kW}$ , chillers, terminal units and heat rejection units.<sup>C</sup>
- 1.14.1 Requirements for room air conditioners  $<12\text{KW}$  cooling capacity were introduced in March 2012 which set minimum energy performance standards (MEPS) for cooling from 2013 which increased in 2014<sup>D</sup>. The performance levels set vary depending on the system type, its cooling capacity and the global warming potential (GWP) of the refrigerant used. This was included in the modelling as the energy efficiency improvement case “RAC proposed MEPS”, where RAC = Room Air Conditioner.
- 1.14.2 Eco-design requirements for air conditioning systems with a cooling capacity  $>12\text{KW}$  which were covered in the Lot 6 Preparatory study were subsequently grouped with Lot 21 products (central heating products using hot air to distribute heat (other than CHP). A draft for eco-design requirements for

these products was published in 2015<sup>E</sup> which identifies minimum seasonal efficiencies for cooling energy efficiency and for useful energy efficiencies to come into force from 2018 along with improved performance values to apply from 2021. The minimum performance values vary (considerably) depending on the system type, size and the GWP of the refrigerant. Because the study was carried out before the draft performance levels were proposed, the modelled energy performance improvement cases presented here do not correspond directly with those modelled for central systems, but the moderate chiller MEPS fall within the range of the proposed 2018 values and the demanding chiller MEPS falls within the range of the values proposed for 2021.

## 2. Modelling energy consumption in UK air conditioning systems

There were two main elements to the modelling procedure, a stock model, which provides information on the number of systems in UK buildings, replacement rates and anticipated growth rates, and an energy model which calculates the energy use for different system types with different cooling demands.

### 2.1 Stock Model

2.1.1 The stocks of air conditioning systems in Europe were taken from the market analyses carried out for the Lot 6 Eco Design Preparatory Study<sup>1</sup>. This study used a modified form of the Bass market diffusion model<sup>F</sup> calibrated to market research sales data to provide information on the existing stock of air conditioning systems and also the anticipated number of new installations in future years arising from new buildings, replacement systems in existing buildings and retrofit systems in existing buildings.

2.1.2 There are considerable levels of uncertainty associated with this market data. The primary sources for the information used in the Lot 10 and Lot 6 studies are country specific market studies carried out by the Building Services Research and Information Association (BSRIA)<sup>2</sup>.

2.1.3 Information from the Lot 10 Eco Design preparatory study on cooling loads associated with the different building types is equally applicable to centralised cooling systems. Six different buildings types were used in the model to represent cooling demands across different building types. New build office, new build retail, new build residential, existing office, existing retail and existing residential. The full time equivalent cooling attributed to each of these building types is shown in Table F1.

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<sup>1</sup> These results were subsequently incorporated into the Lot 21 Preparatory Study which also includes air heating products and high temperature chillers as well as cooling products.

<sup>2</sup> These inevitably involve a degree of uncertainty and rely on extrapolation.

Cooling load	New build			Existing		
	residential	office	retail	residential	office	retail
FTEH	79	285	300	63	200	256

**Table F1: Full time equivalent hours cooling load from Lot 10 Eco-Design**

## 2.2 Energy Model

2.2.1 The energy model used to calculate potential savings for central air condition systems uses the algorithm which is used to calculate the HVAC system performance within SBEM, which forms part of the UK's National Calculation Methodology<sup>G</sup>. This model is capable of modelling the energy performance of a range of different system types and of taking account of the efficiency of various system components and different cooling demands. As well as energy consumption in use the model also takes account of standby energy use and energy use in "off" mode.

2.2.2 The model considers ten types of air conditioning system. These are described in Table F2.

<b>Central plant systems</b>	
Split Systems <12Kw	Single Splits <12kW with a single outdoor and single indoor unit cooling a single space
Split Systems >12Kw	This category comprises both single splits systems and multisplit systems. Multisplit systems are similar to single split systems except that there are multiple indoor units which serve separate rooms or zones. These are individually connected to a single outdoor unit via refrigeration pipework. The system can usually operate in cooling only mode or in heat pump mode for heating.
VRF	VRF (Variable Refrigerant Flow) multisplit systems are a more sophisticated version of the multisplit system. These systems supply heating and cooling and can have 2-pipe refrigerant pipework, or 3-pipe refrigerant pipework that enables heat to be transferred from a room that requires cooling to another within the same building that requires heating. A variable speed compressor allows the system capacity to be varied to accurately match the building heating and cooling loads.
Rooftops	These are packaged units where both sides of the refrigeration cycle are housed in a single unit which is located on the outside of the building (often on top of the roof) together with an air handling unit which supplies the conditioned air to the building via ducts.
All Air Constant Volume (CAV)	These systems provide a constant volume air supply at a single temperature. Cooling of the air is normally provided by a chilled water or direct expansion (DX) cooling coil in an air-handling unit (AHU) which distributes the cooled air to rooms via ductwork. The air-handling unit is usually able to vary the proportion of fresh to recirculated air to meet the ventilation requirements of the building and to minimise cooling requirements. Some systems also include terminal reheat coils to allow different air supply temperatures in different rooms or zones.
All Air Variable Air volume (VAV)	As above but different cooling requirements of individual rooms or zones can be accommodated by varying the volume of air supplied to each room or zone. The AHU fan speed is varied to match the overall supply air flow rate and therefore significant fan energy savings are possible when the overall cooling requirement is low.
Water based fan coil unit (FCU)	Chilled water (and sometimes also hot water) is circulated around the building to supply terminal units in the rooms where a fan blows room air over a cooling coil. Most fan coil systems are also supplied with conditioned fresh air from a central AHU. The room air and ducted fresh air are mixed at the inlet to the FCU.
Water based induction	Similar to the above except that a minimum quantity of conditioned fresh air from an AHU is injected through nozzles to induce a flow of room air over a chilled water coil before the mixed air flow is supplied to the room.
Heat Pump Loop	This system is based on a constant temperature water loop circulated around the building with self-contained heat pumps providing either heating and cooling of individual rooms or zones by transferring heat from or to the water loop. These systems are sometimes referred to by their historical trade name "Versatemp". Some versions are also fed with ducted conditioned fresh air from an AHU which is mixed with room air at the inlet to the unit. The water loop is kept cool by a central chiller, cooling tower or dry air coolers.
Chilled Ceiling/Passive chilled beam/other construction embedded cooling	High temperature chilled water is circulated through embedded cooling pipes, passive coils or cooled ceiling panels to provide cooling by conduction and natural convection.
Active chilled beam	As with passive chilled beams, high temperature chilled water is circulated within cooling coils but room air flow is induced through the coils by a minimum quantity of conditioned fresh air supplied from a central AHU and injected through nozzles but at a lower pressure than with induction units.

**Table F2: Description of various types of central air conditioners**

2.2.3 A feature of air conditioning systems with air distribution systems is that the same fans and ventilation systems are often used to meet both cooling and ventilation demands. The model used for this study calculates both the fan energy use for each of these functions.

2.2.4 For air conditioning systems the energy consumption will depend on both the efficiency of the products and components that comprise the system and their configuration.



### 3. Base Case Definition

3.1 The Base Case represents the 2010 situation and includes energy savings measures that were already in effect at that time. It therefore includes voluntary labelling of chillers and air handling units and national regulations on duct leakage. The Base Case also takes account of typical building construction and prevalent building codes via the typical annual cooling demand (FTELH cooling as kW/m<sup>2</sup>) for six representative building types. Because Eco Design Requirements are specified separately for single split systems with a cooling capacity of 12 kW or less, these are considered separately to that of other larger (central) systems in the study.

3.1.2 Table F3 shows the breakdown of the sales and stock of air conditioning systems for the base case.

GW Cooling Capacity	Split systems > 12kW	Split systems > 12kW	VRF	Roof top	All air constant volume	All air VAV	Water based fan coil	Water based Induction	Heat pump loop	Active chilled beam	Chilled Ceilings and Passive Chilled Beams with Displacement Ventilation
Existing Buildings	13.	9.8	2.7	2.4	4.7	5.8	18.4	2.3	0.4	0.1	0.8
New installations	1.7	0.6	0.4	0.2	0.2	0.2	0.6	0.1	0.0	0.0	0.02

**Table F3: Showing the UK breakdown of the 2010 stock and annual (2010) sales by system type**

3.1.2 Table F4 shows the peak cooling demand, duct leakage rates and specific fan power values for the base case for systems with air distribution

Peak cooling demand	Duct leakage		Specific Fan power	
	kW/m <sup>2</sup>	% existing	% new	W/l/s existing
0.069	20%	7%	3.0	2.5

**Table F4: Peak cooling demand, duct leakage and specific fan power for new and existing (2010 and earlier) buildings**

3.1.4 The current kW installed in 2010 by system was taken to be the starting point in determining the total consumption for the base case. The total electricity consumption was determined by considering a range of factors which impact on the electricity used by the installed systems. These factors are summarised in Table F5.

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Separation of air and water sub-systems		
Air	% of load handed by air sub-system	Allows separation of load handled by air and water sub-systems
Water	% of load handed by water /liquid sub-system	Allows separation of load handled by air and water sub-systems
Air and water cooling space demand (energy required to meet demand for coolth for a given space)		
Air and water	Peak cooling demand	% of total installed kW assumed to be used at peak cooling demand this accounts for oversizing of plant resulting in it not being used to full capacity
	Equivalent full load cooling hours	Hours in use based on occupancy/operational hours, typical internal gains, thermal performance of the building envelope and climate
	Terminal auxiliary power parameter	kW/kW cooling * peak cooling demand
	Terminal auxiliary pickup factor	Takes account of additional heat generated by distribution fan which also needs to be cooled
	Local latent load	Takes account of loss due to some of the cooling condensing on the cooling coils in the room
	Allowance for imperfect local control	Estimate of losses due to imperfect control
	Extra cooling load from mixing reheat	Estimate of losses due to mixing of reheated air requiring additional cooling
Extra load from imperfect zoning	Estimate of losses due to provision of more cooling than required	
Air cooling demand on chiller (demand for coolth for a given space plus additional energy demands placed on chiller)		
Air	Air cooling space demand	Calculated as described above
	Duct leakage	Takes account of duct leakage resulting in proportion of cold air not reaching desired location
	Duct heat pickup	Losses occurring in the transportation of coolth through the duct work for air-based parts of systems
	Central latent load	Takes account of loss due to some of the cooling condensing in the AHU
	Fan energy use allocated to cooling	This determines the amount of energy consumption for cooling only by removing the ventilation part of the system so that only the cooling part remains and ensures like is compared with like across the systems
	Fan energy pickup factor	Takes account of that fact that some heat from the running of the fan ends up in the ducts
Water heating demand on chiller (demand for coolth for a given space plus additional energy demands placed on chiller)		
Water	Water cooling space demand	Calculated as described above
	Pipe heat pickup	Losses occurring in the transportation of coolth through the pipe work for water/liquid-based parts of systems
	Cooling pump energy	Energy consumed by cooling pumps
	Cooling pump pickup factor	Takes account of losses due to heat generated by the pumps in water/liquid-based systems
Other elements included in the model		
All systems	SEER	Takes account of the Seasonal Energy Efficiency Ratio of the chiller applied to total cooling (chiller) consumption, standby and off chiller energy use
Fans	Fan energy use allocated to cooling	This determines the amount of energy consumption for cooling only by removing the ventilation part of the system so that only the cooling part remains and ensures like is compared with like across the systems
Pumps	Cooling pump energy	Energy consumed by cooling pumps
Chiller standby	Current stock standby energy	% of current stock (kW installed) which is associated with standby
	Standby hours	Hours in standby mode
	Current stock	kW installed - current stock
Chiller off mode	Current stock off mode energy	% of current stock (kW installed) which is associated with off mode
	Off hours	Hours in off mode
	Current stock	kW installed - current stock
Terminal	Terminal auxiliary energy use	Energy use at terminal auxiliary
	Cooling only run hours	Hours system is in active cooling mode

**Table F5: Factors that impact on the electricity consumption of installed systems**

3.1.5 The base case, SEER values for both existing and new self-contained cooling units and for chillers used in the central system modelling are shown in Table F6.

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SEER	existing installations	new installations
Split systems <12kW	4.25	4.7
Split systems >12kW	3.88	4.29
VRF	4.66	4.66
All air constant volume	3.46	3.75
All air VAV	3.46	3.75
Water based fan coil	3.46	3.75
Water based induction	3.46	3.75
Heat pump loop	4.03	4.03
Active chilled beam	3.46	3.75
Chilled Ceilings and Passive Chilled Beams with Displacement Ventilation	3.46	3.75

**Table F6 Base case SEER values for air conditioning products**

## 4 Using the model to determine potential energy savings

4.1 The effect of applying a wide variety of energy performance improvement measures to cooling systems is explored by substituting alternative values into the energy use calculation described above. The parameters in the model that are varied in order to model the energy saving cases are summarised below:

- **Chiller seasonal energy efficiency ratio (SEER)**, which is the average energy efficiency and takes into account the seasonal load pattern
- **Full Time Equivalent Load Hours Cooling (FTELH)**. Reduction in cooling demand compared to the base case.

### **And where relevant**

- **Terminal Efficiency**. Determined as a percentage change in efficiency compared to the base case which is defined in terms of kW/KW<sub>cooling</sub>
- **Pump Efficiency**. Determined as a percentage change in efficiency compared to the base case which is defined in terms of kW/KW<sub>cooling</sub>
- **AHU Efficiency** measured in terms of the Specific Fan Power (SFP)<sup>3</sup>
- **Duct Leakage** measured as a percentage air leakage from AHU/ductwork.

4.2 In order to provide policy makers with an indication of the scale of savings that the policy measures might be able to address the potential for savings that could be achieved in both existing and future cooling system installations was explored. In some instance e.g., those that require product or component replacement, they are likely to be applicable to new installations, whilst measures that impact on controls or reduced FTELH for cooling can potentially be applied to both current and future installations.

4.3 The expected growth in air conditioning in the UK is taken into account and the annual potential energy savings for new installations are calculated for the next 10 years. The growth in air conditioning systems in Europe is taken from the market analyses carried out for the Lot 6 study for central systems and the Lot 10 study for moveables and RACs. The process used a modified form of the Bass market diffusion model calibrated to market research sales data and is described in the Preparatory Study reports.

4.3 The same FTELH were assumed for future years in the Energy performance improvement cases as the growth in demand for cooling is already incorporated in the projected sales data. However, if the average temperature in the cooling season were to increase this would result in an increase in the annual average full load equivalent hours. Although this is not expected to happen on the timescales of a decade or so, which is the focus of this study, it would be possible to use the model to explore the effect of increasing external temperatures on cooling energy consumption This could also be used to explore

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<sup>3</sup> This takes account of the effect of filters and other aspects of AHU efficiency. Despite its name, SFP is actually a system characteristic.

the extent to which this would impact on the most efficient system mix as the efficiency ranking of system types varies with FTELH.

## 5 Selection of energy performance improvement cases

5.1 The assessment of the potential for reducing the energy consumption of air conditioning equipment in Europe requires looking at the current level of consumption in existing buildings as well as in new buildings that will be coming into service in the future. Whilst it may not be feasible to replace cooling systems in existing buildings with more efficient types until they are totally refurbished, it is useful to determine the potential savings in cooling energy through the application of three types of measures that:

1. Reduce cooling demands (by improvements in the building shell characteristics and internal gains from people and equipment)
2. Improve the average efficiency of air-conditioning systems (installed plant)
3. Improve the quality of operation and management of air conditioning systems (via improvements in operation and maintenance)

5.2 Since the vast majority of cooling consumption in Europe is attributed to existing buildings (new buildings represent a small percentage of the total stock), any model used to estimate the impact of measures to reduce cooling energy consumption must consider options that are feasible in existing buildings as well as for new buildings. Although some of these options are likely to be easier to implement in new buildings.

5.3 This section describes in detail the energy performance improvement cases chosen for this study. It discusses the rationale for the choice of cases and identifies the data sources and assumptions used, as well as presenting the data inputs used in the modelling.

5.4 The energy saving opportunities, or intervention points, for cooling systems were identified at four different levels:

- Product and component energy performance
- System energy performance, which incorporates component energy performance
- Building energy performance, which relates to building design
- Operational energy performance, i.e., how effectively the system is controlled to meet cooling

5.5 The energy performance improvement cases defined here address product, systems and building level energy performance measures and consider the potential savings for a selection of different policy components:

- Labelling and information
- Minimum Energy Performance Standards
- Financial incentives, and

- Improved building design, including fabric measures, such as solar shading, and more energy efficient lighting and appliances

5.6 A variety of energy performance improvement cases were defined for covering these policy components. These provided an assessment of the potential savings from within system improvements. In addition, a separate analysis considered the potential savings that could be achieved from system switching.

5.7 The maximum savings that would be achieved by implementing the current best available technology (BAT) in all feasible instances, regardless of cost considerations, was modelled to establish a limiting yardstick. Whilst current BAT technology is unlikely to be cost effective, even at the societal level, it is not unreasonable to assume that current BAT might be nearly cost effective in a few instances; it would be unlikely to be on the market in the first place if this was not the case. Furthermore, for cooling products the cost of current BAT technology is liable to decrease rather than increase so it may become cost effective in more instances in the future. Therefore it is reasonable to assume that current BAT technology has the potential to become cost effective (at least at the societal level) in the future.

5.8 In addition to BAT, the savings that would arise from applying the following policy levers at each of the three intervention points (product, system or building) were considered:

- Labelling and information – which encourages decision makers to choose more efficient options.
- Financial incentives – which would boost the uptake of higher efficiency options.
- Minimum Energy Performance Standards (MEPS), which would cut out the least efficient options.

Generally at least two different savings levels were considered:

- Light: This is representative of policies that would be defined as “backstop” requirement or only slightly above. These are likely to be cost effective from the end user perspective in almost all applications.
- Moderate or demanding: This relates to a more substantial level of savings that might be expected to be cost effective from the societal perspective, and typically has the objective of forcing the pace of technical development.

5.9 In many cases additional savings levels were also modelled, particularly for product MEPS, in order to provide a better understanding of the sensitivity of potential savings to regulatory performance requirements.

5.10 As well as modelling the effect of energy performance improvements that might be achieved for each system sub-type (individual system level), the energy savings that could be achieved by switching to more efficient system types were considered. For the system switching analysis two cases were considered, one of which examined the effect of replacing a system by a typical example of the most efficient system sub-type. The second case considered the

extreme case of replacement with the most efficient system sub-type with BAT (Best Available Technology) levels of performance.

- 5.11 The energy performance improvement cases for the individual system analysis take account of the point at which a potential policy intervention could be made, e.g., for products this would generally be related to sales, whereas for systems and buildings it may also relate to the existing stock. Accordingly the cases have been applied to new installations only, for product level interventions and to both new and existing installations for system and building level energy saving options.
- 5.12 The energy performance improvement cases considered both products, which will be the components which comprise the system, the system as a whole and the building.
- 5.13 Each of the specific cases that were explicitly modelled for this study for each of the three main system types are referenced by a unique alphanumeric code which is referred to throughout this report and termed “case number”.

## 6 Description of energy performance improvement cases selected

- 6.1 Product level cases were modelled for new installations only as existing systems are not likely to be affected by product level policies and replacement systems are included under new installations. Building and system level cases are modelled for both new and existing systems. Building envelope saving measures could potentially be applied to all buildings so these measures were applied to both new and existing installations and will result in a reduction in the hours that the cooling system is required to operate. They may also reduce the number of systems installed and perhaps the choice of system type, but these effects were not modelled.
- 6.2 Table F7 outlines the energy performance improvement cases modelled for larger (central) systems are designated by C case codes, whilst those for small single splits <12kW designated by RAC (Room Air Conditioning unit) case codes).

Case code	Description	Installations
C0	Central (Base case) voluntary labelling and existing building regulations	All
C1	Central (Product (Chillers and Packaged Units)) labelling	New
C2	Central (Product (Chillers and Packaged Units)) labelling + financial incentives	New
C3	Central (Product (Chillers and Packaged Units)) MEPS 1 + labelling	New
C4	Central (Product (Chillers and Packaged Units)) MEPS 2 + labelling	New
C5	Central (Product (Chillers and Packaged Units)) MEPS 3 + labelling	New
C6	Central (Product (Chillers and Packaged Units)) MEPS 1 + labelling + financial incentives	New

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Case code	Description	Installations
C7	Central (Product (Chillers and Packaged Units)) MEPS 2 + labelling + financial incentives	New
C8	Central (Product (Chillers and Packaged Units)) MEPS 3 + labelling + financial incentives	New
C9	Central (Product (Chillers and Packaged Units)) BAT	New
C10	Central (Product (AHU)) labelling	New
C11	Central (Product (AHU)) labelling + financial incentives	New
C12	Central (Product (AHU)) MEPS 1 + labelling	New
C13	Central (Product (AHU)) MEPS 1 + labelling + financial incentives	New
C14	Central (Product (AHU)) BAT	New
C15	Central (Product (Fan coil terminal units)) MEPS 1 + labelling	New
C16	Central (Product (Fan coil terminal units)) MEPS 1 + labelling + financial incentives	New
C17	Central (Product (Fan coil terminal units)) BAT	New
C18	Central (Product (Pump)) MEPS 1 + labelling	New
C19	Central (Product (Pump)) MEPS 1 + labelling + financial incentives	New
C20	Central (Product (Pump)) BAT	New
C21	Central (System (air leakage)) MEPS	All
C22	Central (System (air leakage)) BAT	All
C23	Central (System (AHU)) reduce fresh air flow rate	All
C24	Central (System (rigorous A/C inspection))	All
C25	Central (System (All components)) MEPS	All
C26	Central (System (All components)) BAT	All
C27	Central (Building Envelope) achievable envelope savings	All
C28	Central (Building Envelope) BAT envelope savings	All
CX	Central Systems Switching	New
RAC0	RAC (Base case) labelling + existing building regulations	All
RAC1	RAC (Product) proposed MEPS	New
RAC2	RAC (Product) MEPS 1	New
RAC3	RAC (Product) MEPS 2	New
RAC4	RAC (Product) MEPS 3	New
RAC5	RAC (Product) MEPS 4	New



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Case code	Description	Installations
RAC6	RAC (Product) proposed MEPS <sup>4</sup> + financial incentives	New
RAC7	RAC (Product) MEPS 1 + financial incentives	New
RAC8	RAC (Product) MEPS 2 + financial incentives	New
RAC9	RAC (Product) MEPS 3 + financial incentives	New
RAC10	RAC (Product) MEPS 4 + financial incentives	New
RAC11	RAC (Product) BAT	New
RAC12	RAC (Building Envelope) achievable envelope savings	All
RAC13	RAC (Building Envelope) BAT envelope savings	All

**Table F7: Energy performance improvement cases for central systems and small single splits <12kW**

MEPS = Minimum Energy Performance Standards, BAT = Best Available Technology

6.3 The performance levels associated with the cases are shown in Tables F8-F13.

Case no.	New/ Existing Installations	Central Systems SEER (Chillers and Packaged Units)					
		Split systems	VRF	Roof top	Heat pump loop	Chillers	Passive chilled beam
C0-C9	Existing	3.88	4.66	3.33	4.03	3.46	3.46
C0	New	4.29	4.66	3.33	4.03	3.75	3.75
C1	New	4.33	4.66	3.36	4.05	3.77	3.77
C2	New	4.37	4.66	3.40	4.99	3.79	3.79
C3	New	4.50	4.66	3.53	4.35	3.86	3.86
C4	New	4.84	4.84	4.03	4.39	3.97	3.97
C5	New	5.42	5.42	5.13	4.59	5.90	5.90
C6	New	4.54	4.66	3.56	5.05	3.87	3.87
C7	New	4.86	4.86	4.03	5.35	3.98	3.98
C8	New	5.42	5.42	5.13	5.59	5.90	5.90
C9	New	5.42	5.42	5.13	5.59	5.90	5.90

**Table F8: SEERs for energy performance improvement cases which involve improved energy performance levels for chillers and packaged units for central systems**

<sup>4</sup> Proposed MEPS refers to performance levels proposed at the time the study was undertaken.

Study on Energy Use by Air-Conditioning: Annex F: Calculated air conditioning energy savings arising from a range of possible policy interventions

Case no.	Description	existing all years	new	New from 1 year on	New from 2 year on	New from 3 years on
RAC0	Labelling + existing building regulations	4.25	4.7	4.7	4.7	4.7
RAC1	proposed MEPS	4.25	4.7	4.7	5.12	5.32
RAC2	MEPS 1	4.25	4.7	5.12	5.12	5.12
RAC3	MEPS 2	4.25	4.7	5.32	5.32	5.32
RAC4	MEPS 3	4.25	4.7	5.59	5.59	5.59
RAC5	MEPS 4	4.25	4.7	5.98	5.98	5.98
RAC6	MEPS + financial incentives	4.25	4.7	4.7	5.16	5.35
RAC7	MEPS 1 + financial incentives	4.25	4.7	5.16	5.16	5.16
RAC8	MEPS 2 + financial incentives	4.25	4.7	5.35	5.35	5.35
RAC9	MEPS 3 + financial incentives	4.25	4.7	5.59	5.59	5.59
RAC10	MEPS 4 + financial incentives	4.25	4.7	5.98	5.98	5.98
RAC11	BAT	4.25	4.7	6.5	6.5	6.5

**Table F9: SEERs for Energy Performance Improvement Cases which involve improved energy performance levels for chillers and packaged units for central systems**

MEPS = Minimum Energy Performance Standards, BAT = Best Available Technology

Study on Energy Use by Air-Conditioning: Annex F: Calculated air conditioning energy savings arising from a range of possible policy interventions

Case Code.	New/ Existing Installations	Central Systems SEER (Chillers and Packaged Units)						AHU	Duct Loss	Pump	Terminal	Reduction in FTELH	Reduction in fan operating hours
		Split systems	VRF	Roof top	Heat pump loop	Chillers	Passive chilled beam	SFP (W/Us)	AHU	Pump (% Improvement)	Terminal (% Improvement)	FTEH	
C21	All								5%				
C22	All								3%				
C23	All						1.25					40	
C24	All	+5%	+5%	+5%	+5%	+5%	+5%					20	10%
C25	New	4.50	4.66	3.53	4.35	3.86	3.86	2.20		20%	28%		
C26	New	5.42	5.42	5.13	5.59	5.90	5.90	1.25		40%	82%		
C27	All											25	
C28	All											191	

**Table F10: Seasonal Energy Efficiency Ratios, Specific Fan Power, Duct losses, improved pump and terminal efficiencies and reduced for Energy Performance Improvement Cases which involve improved energy performance levels for chillers, packaged units, fans, pumps and terminal units, reduced duct leakage rates, and/or reduced cooling loads**

Study on Energy Use by Air-Conditioning: Annex F: Calculated air conditioning energy savings arising from a range of possible policy interventions

Case Code	New/ Existing Installations	AHU
		SFP (W/l/s)
C10	New	2.95
C11	New	2.25
C12	New	2.20
C13	New	2.20
C14	New	1.25

**Table F11: Specific Fan Power for Energy Performance Improvement Cases which involve improved energy performance levels for fans**

Case Code	New/ Existing Installations	Terminal
		% improvement
C15	New	28%
C16	New	33%
C17	New	82%

**Table F12: Percentage energy efficiency improvements for Energy Performance Improvement Cases which involve improved energy performance levels for terminal units**

Case Code	New/ Existing Installations	Pumps
		% improvement
C18	New	20%
C19	New	25%
C20	New	40%

**Table F13: Percentage energy efficiency improvements for Energy Performance Improvement Cases which involve improved energy performance levels for pumps**

6.4 The Energy Performance Improvement Cases identified above are based on like-for-like replacement of systems and system components. The study also explored the potential savings that could be achieved through switching to more efficient system types. This is designated by an energy performance case code CX.

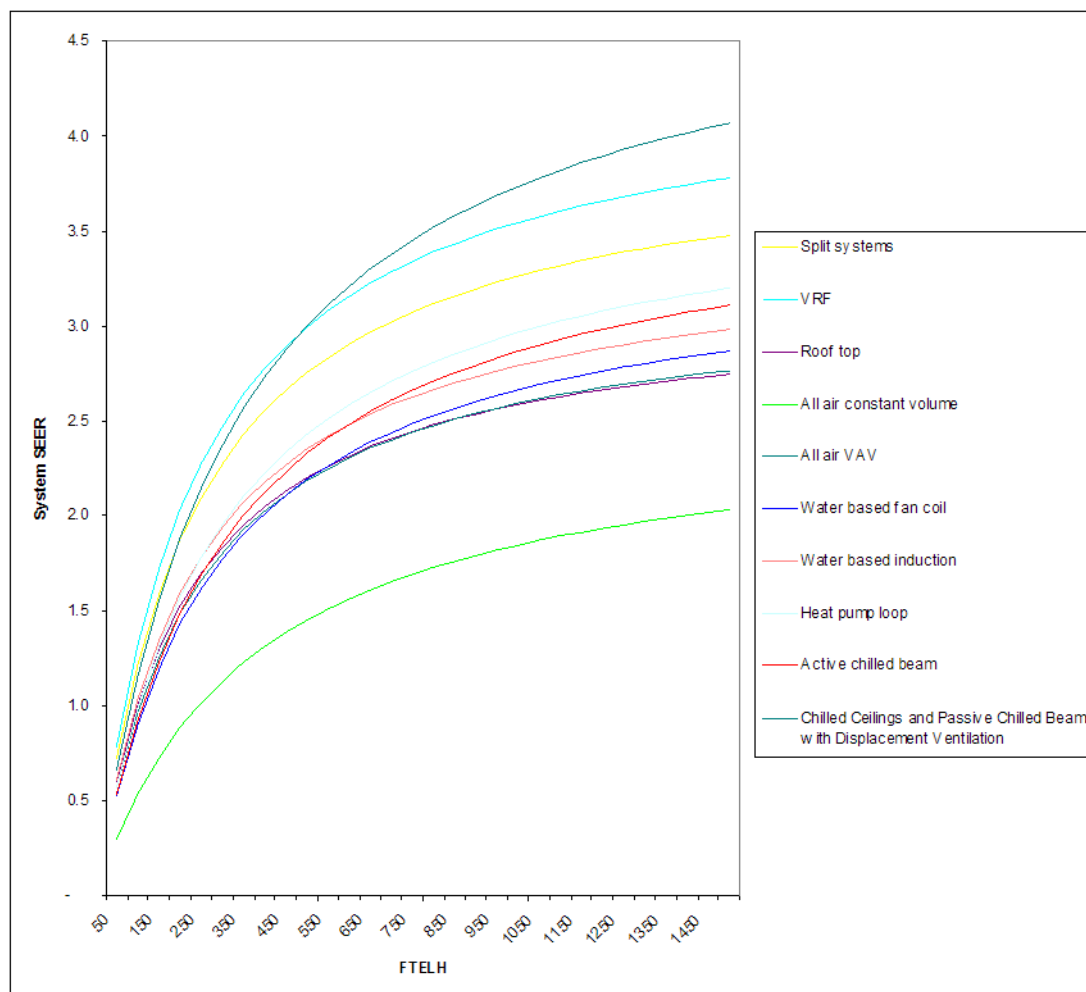
6.5 The analysis took account of how the efficiencies of different system types vary with the usage hours (EFLH) for different building types<sup>5</sup> and also the feasibility of changing to a particular system type. The most efficient system type for UK applications tends to be split systems <12KW, however, these are not suitable for cooling larger spaces because they require appropriate access to the external building envelope and are unable to provide a ventilation function.

6.6 However, the overall efficiency for a particular system type will depend not only on the SEER of the self-contained unit or chiller, but also the efficiency of

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<sup>5</sup> For this study three building types were used to represent the building stock offices, retail and residential.

the other energy using components and the various factors that affect their performance, again, plus any standby or off mode energy consumption. This overall system SEER is calculated from the kW cooling installed divided by the total system energy use calculated using the models. These overall system values will therefore be lower than their respective product or chiller SEER and will vary significantly with cooling demand. The system SEER for new installations of the ten different central system types over a range of cooling hours is shown in Figure F1.



**Figure F1: Showing how the system efficiency for central systems varies with FTELH cooling**

6.7 These results indicate that central air system are typically the least efficient system type, which arises because the fans in the AHU will be running at full load for the cooling system run hours. It is clear that amongst the other system types, in particular chilled ceilings and passive chilled beams with displacement ventilation, VRF and split system would appear to be the more efficient choices in most instances. However, there will be considerable variation in the actual performance in a particular application so the appropriate choice of system is far from obvious. Furthermore, technical constraints, such as having the necessary space to install a system will be important, as will economic considerations.

6.8 Whilst some types are clearly more efficient than others it needs to be remembered that not all systems are appropriate for specific applications, and

although two systems may provide a similar level of cooling they may not provide equivalent levels of comfort. For example direct expansion system (e.g. split systems, VRF) and chilled ceilings do not provide humidity control. Similarly there may be other advantages associated with certain systems which cannot be directly accounted for in the modelling e.g., the ability of heat pump loops and VRF systems to move heat around between different spaces to minimise heating energy use.

- 6.9 Therefore, identification of the best performing system is not as straightforward as it might appear at first sight.
- 6.10 To model the energy savings potential associated with switching between each system type the overall system efficiency was calculated for a range of different cooling hours for new systems of typical efficiency. This was then used to rank the system types in order of efficiency for different EFLHs
- 6.11 The appropriate energy efficiency ranking was then applied to each of the six modelled building types (new and existing offices, retail and residential) based on their EFLHs. The most efficient mix of system types was then determined by applying the appropriate percentage of possible system mix for each building type to the efficiency ranking until 100% is reached.
- 6.12 Applying the percentage of possible system types for offices to this hierarchy gives the most efficient mix of system types that could be installed in new offices. The resultant energy savings from switching to the most efficient system mix are calculated from the energy consumption for the current system mix of system types and that for the most efficient system mix.
- 6.13 The additional potential energy savings that would be achieved from switching to the most efficient mix of the most efficient versions of each system type (i.e. one made up of BAT components) was calculated in a similar way.

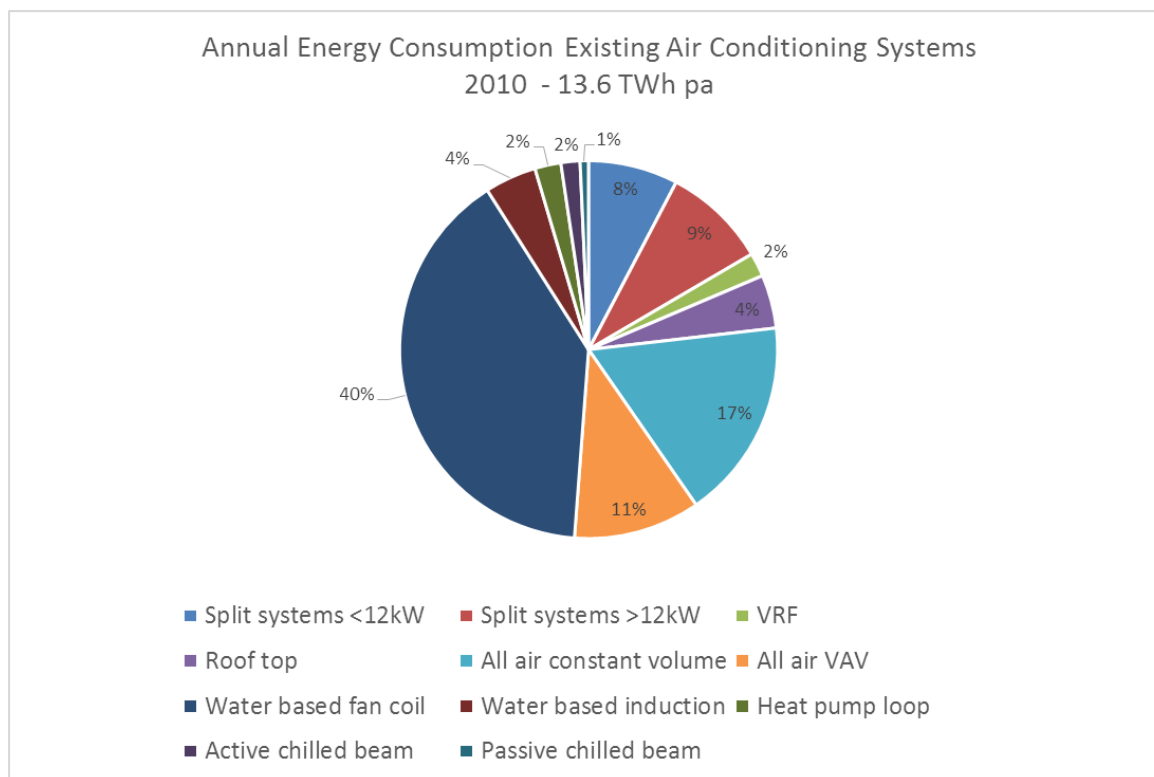
## 7 Modelling results

This section presents the UK results for the Base Case and the potential savings associated with the energy performance improvement cases outlined earlier in this Annex.

### 7.1 Base Case Results

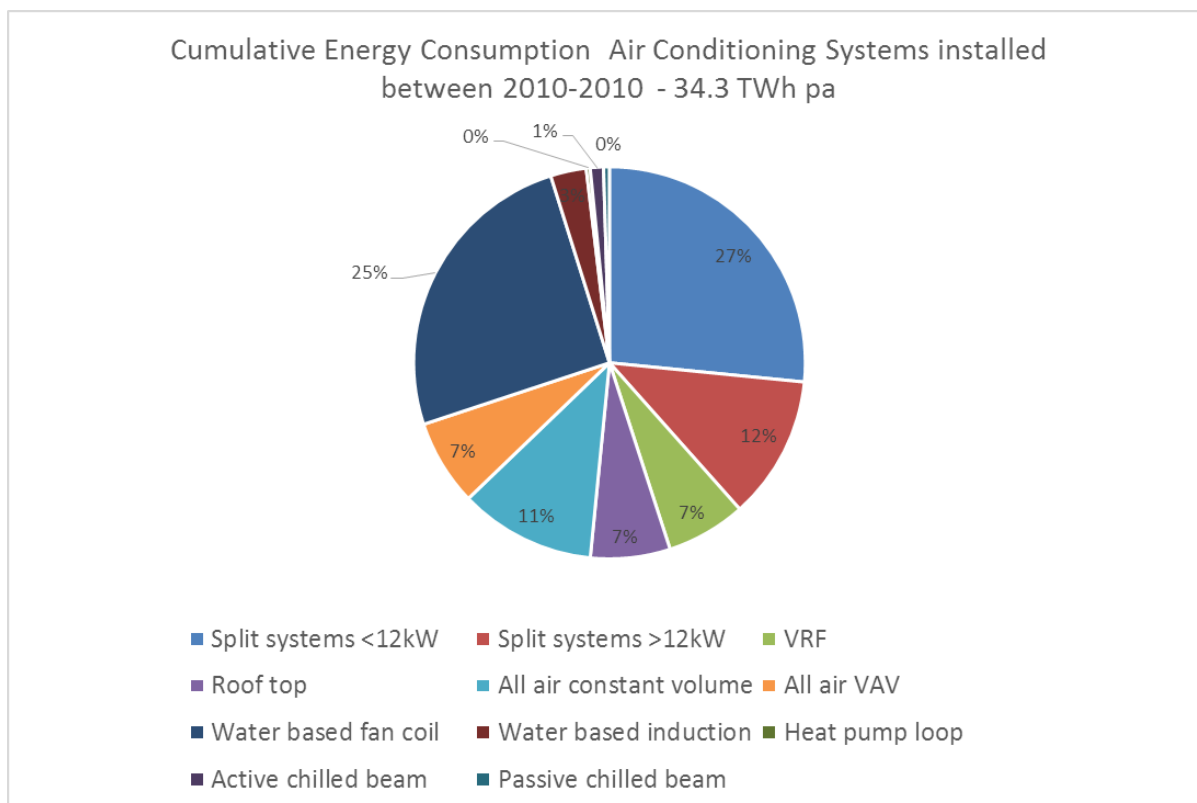
- 7.1.2 Figure F2 show the modelled energy consumption for the base case the 2010 stock of air conditioning systems. This shows that split systems (including vrf and roof top units) account for around a quarter of energy use, whilst all air systems and water based systems account for 38% and 44 % of

air conditioning energy consumption, respectively, with heat pump loop and chilled beams accounting for the remainder.



**Figure F2: Base case energy consumption broken down by system type**

7.1.3 F3 shows that the cumulative energy consumption for anticipated new installations, which includes replacement and retrofit systems as well as new build installations is almost twice as high as the annual consumption in 2010 at 34.3 TWh. In contrast to the existing stock split systems (including vrf and rooftop units) account for around 50% of total energy use reflecting the projected increase in market share for these system types over the period.



**Figure F3: Base case energy consumption for new installations broken down by system type**

## 7.2 Modelled Energy Performance Improvement Cases: New Installations

7.2.1 The uptake rate for new installations that is used in the model is based on projected sales of products quantified in terms of kW cooling. For central systems sales of packaged units and chillers do not necessarily relate to system installations. This is because most central systems comprise a variety of standard and bespoke components and these components have different lifetimes and are often replaced independently. Where central systems are installed in new buildings and retrofit applications in existing buildings, the one to one relationships between chiller sales and system installation is retained. However, where these sales relate to the replacement of failed units in existing buildings, this relationship does not hold and it is appropriate to make adjustments to the savings generated directly from the modelling in instances when they relate to components other than chillers.

7.2.2 For the energy performance improvement cases that relate to product or component standards, the modelled savings for new installations provide a good indication of the level of savings that standard related policies are likely to achieve. In practice failures in measurement standards and metric and compliance may lead to the savings not being fully realised.

7.2.3 For energy performance improvement cases that relate to system and building measures, the levels of uncertainty associated with the results are likely to be higher than those for product standards. Here there will be an even greater variation in performance across the stock (compared to product and component measures) arising from the additional variation of system and building related variables.



- 7.2.4 The modelling is based on an assessment of energy use and savings on an annual basis and for simplicity the model assumes that all installations take place on January 1. In reality systems are likely to be installed more evenly over the course of 12 months, so the actual savings that accrue in the first year will be around half of the reported savings. The results presented in this section for new installations are summarised to show the cumulative savings over 10 years, from 2010 (the baseline year) to 2019.
- 7.2.5 The results from Energy Performance Improvement Cases for the existing building stock indicate the potential savings that exist across the currently installed stock of cooling systems. The extent to which these savings could be realised in practice will be dependent on the policy implementation route, in particular the roll out rate, the extent to which the policy accesses the savings assumed in the energy performance improvement case and the compliance rate. For example, if the energy performance improvement case presented here for A/C system inspection were to be required for all existing buildings on sale or rent (e.g., where an EPC is required under the EPBD), then the savings achievable would relate to the proportion of the existing stock that is sold or rented each year, how effective the policy is expected to be in realising the savings identified and the extent to which the policy is complied with. The modelled savings presented in this section indicate the annual savings potential for the estimated current installed stock.
- 7.2.6 Tables F14 to F22 show the energy consumption, energy savings and % reduction in energy use arising from implementing the energy performance improvement cases described earlier in this Annex for the 2010 stock, new installations in 2010 and cumulative values for new installations between 2010 and 2019.
- 7.2.7 For small single split systems <12kW (Room Air Conditioning units) although this shows a very large potential for reducing cooling energy consumption by improving the thermal performance of the building envelope by reducing solar gain, insulation and thermal mass, the savings that are likely to be achievable in practice are much smaller.

Energy Performance Improvement Case	Description	TWh	TWh savings	% saving
RAC0	Base Case	1.05		
RAC12	Achievable envelope savings	0.95	0.10	9%
RAC13	BAT Envelope savings	0.36	0.69	65%

**Table F14: Annual energy consumption, energy savings and % savings of the existing (2010) stock of air conditioning systems with energy performance improvement cases applied for small split systems <12kW**

Energy Performance Improvement Case	Description	TWh	TWh savings	% saving
RAC0	Base Case	9.10	-	-
RAC1	Proposed MEPS	8.69	0.41	4%
RAC2	MEPS1	8.09	1.01	11%
RAC3	MEPS2	7.56	1.54	17%
RAC4	MEPS3	6.93	2.17	24%
RAC5	MEPS4	6.15	2.95	32%
RAC6	Proposed MEPS+FI	8.65	0.46	5%
RAC7	MEPS1+FI	7.98	1.12	12%
RAC8	MEPS2+FI	7.48	1.62	18%
RAC9	MEPS3+FI	6.93	2.17	24%
RAC10	MEPS4+FI	6.15	2.95	32%
RAC11	BAT	5.33	3.77	41%
RAC12	Achievable envelope savings	8.47	0.64	7%
RAC13	BAT Envelope savings	4.48	4.62	51%

**Table F15: Cumulative energy consumption, energy savings and % savings from implementing energy performance improvement cases to new installations 2010 -2019 for small split systems <12kW**

MEPS = Minimum Energy Performance Standards, BAT = Best Available Technology

7.2.8 For new installations the modelling studies show that product MEPS could save between 4% and 32% of energy consumption whilst installation of BAT products would achieve a 41% energy saving for small split systems. The addition of financial incentives is not expected to provide significant increase in the savings potential over MEPS alone. The envelope savings are identified are only slightly smaller than that for the existing stock because although the potential envelope savings will be lower for new build, replacement and retrofit systems in existing buildings will account for a large proportion all new installations.

Study on Energy Use by Air-Conditioning: Annex F: Calculated air conditioning energy savings arising from a range of possible policy interventions

Case Code	Energy Performance Improvement	Larger split incl. vrf	Roof top	All Air Systems	Water Based Systems	Heat Pump Loop	Chilled Beams	Total
C21	MEPS AHU air leakage	1.49	0.58	3.44	5.62	0.30	0.31	11.74
C22	BAT AHU air leakage	1.49	0.57	3.39	5.56	0.30	0.30	11.62
C23	Reduce Flow rates	1.10	0.37	2.04	3.61	0.23	0.23	7.57
C24	BAT AC inspection	0.91	0.41	2.57	3.92	0.19	0.23	8.23
C27	Achievable Reduction in cooling load	1.24	0.53	3.29	5.12	0.25	0.29	10.73
C28	BAT Reduction in cooling load	0.17	0.09	0.59	0.87	0.04	0.10	1.86

**Table F16: Annual energy consumption of the existing (2010) stock of air conditioning systems with policy cases applied (TWh pa)**

Case Code	Energy Performance Improvement	Larger split incl. vrf	Roof top	All Air Systems	Water Based Systems	Heat Pump Loop	Chilled Beams	Total
C21	MEPS AHU air leakage	-	0.05	0.38	0.41	-	0.02	0.85
C22	BAT AHU air leakage	-	0.05	0.43	0.47	-	0.02	0.97
C23	Reduce Flow rates	0.39	0.26	1.78	2.42	0.08	0.10	5.02
C24	BAT AC inspection	0.58	0.21	1.25	2.11	0.11	0.09	4.36
C27	Achievable Reduction in cooling load	0.25	0.09	0.53	0.91	0.05	0.04	1.86
C28	BAT Reduction in cooling load	1.32	0.53	3.23	5.16	0.27	0.22	10.73

**Table F17: Annual energy savings from implementing Energy Performance Improvement Cases for the existing (2010) stock of larger air conditioning systems (TWh)**

Study on Energy Use by Air-Conditioning: Annex F: Calculated air conditioning energy savings arising from a range of possible policy interventions

Case Code	Energy Performance Improvement	Larger split incl. vrf	Roof top	All Air Systems	Water Based Systems	Heat Pump Loop	Chilled Beams	Total
C21	MEPS AHU air leakage		7%	10%	7%		5%	7%
C22	BAT AHU air leakage		8%	11%	8%		5%	8%
C23	Reduce Flow rates	26%	41%	47%	40%	26%	30%	40%
C24	BAT AC inspection	39%	34%	33%	35%	38%	28%	35%
C27	Achievable Reduction in cooling load	17%	14%	14%	15%	16%	11%	15%
C28	BAT Reduction in cooling load	88%	85%	85%	86%	88%	68%	85%

**Table F18: Percentage energy savings from implementing Energy Performance Improvement Cases in the existing (2010) stock of larger air conditioning systems**

Study on Energy Use by Air-Conditioning: Annex F: Calculated air conditioning energy savings arising from a range of possible policy interventions

Energy Performance Improvement Case Code	Split systems >12kW	VRF	Roof top	All air constant volume	All air VAV	Water based fan coil	Water based induction	Heat pump loop	Active chilled beam	Passive chilled beam	Total
C1	3.99	2.25	2.22	3.86	2.43	8.64	1.01	0.11	0.37	0.17	25.06
C2	3.91	2.25	2.18	3.86	2.43	8.64	1.01	0.07	0.37	0.17	24.91
C3	3.69	2.25	2.06	3.86	2.43	8.64	1.01	0.10	0.37	0.17	24.58
C4	3.19	2.09	1.68	3.76	2.36	8.42	0.98	0.09	0.36	0.16	23.11
C5	2.54	1.67	1.18	2.23	1.30	4.74	0.55	0.09	0.21	0.11	14.61
C6	3.63	2.25	2.03	3.86	2.43	8.64	1.01	0.07	0.37	0.17	24.47
C7	3.17	2.07	1.68	3.75	2.35	8.38	0.98	0.07	0.36	0.16	22.98
C8	2.54	1.67	1.18	2.23	1.30	4.74	0.55	0.06	0.21	0.11	14.59
C9	2.54	1.67	1.18	2.23	1.30	4.74	0.55	0.06	0.21	0.11	14.59
C10	4.06	2.25	2.24	3.82	2.42	8.59	1.00	0.11	0.37	0.17	25.04
C11	4.06	2.25	2.23	3.78	2.40	8.54	1.00	0.11	0.37	0.17	24.91
C12	4.06	2.25	2.05	3.25	2.22	7.87	0.92	0.11	0.34	0.17	23.25
C13	4.06	2.25	2.04	3.21	2.21	7.82	0.91	0.11	0.34	0.17	23.12
C14	4.06	2.25	1.78	2.45	1.94	6.84	0.79	0.11	0.29	0.17	20.69
C15	4.06	2.25	2.25	3.86	2.43	8.51	1.01	0.11	0.37	0.17	25.03
C16	4.06	2.25	2.25	3.86	2.43	8.49	1.01	0.11	0.37	0.17	25.00
C17	4.06	2.25	2.25	3.86	2.43	8.26	1.01	0.10	0.36	0.17	24.76
C18	4.06	2.25	2.25	3.86	2.43	8.64	1.01	0.11	0.37	0.17	25.16
C19	4.06	2.25	2.25	3.86	2.43	8.64	1.01	0.11	0.37	0.17	25.16
C20	4.06	2.25	2.25	3.86	2.43	8.64	1.01	0.11	0.37	0.17	25.16
C21	4.06	2.25	2.23	3.79	2.40	8.56	1.00	0.11	0.37	0.17	24.94
C22	4.06	2.25	2.21	3.73	2.36	8.47	0.99	0.11	0.37	0.17	24.72
C23	3.71	2.06	1.67	2.33	1.83	6.47	0.74	0.10	0.28	0.15	19.35
C24	4.06	2.25	2.25	3.86	2.43	8.64	1.01	0.11	0.37	0.17	25.16
C25	4.06	2.25	2.03	3.20	2.19	7.67	0.91	0.11	0.33	0.17	22.93
C26	2.54	1.67	0.85	1.28	0.95	3.23	0.39	0.05	0.14	0.11	11.23
C27	3.85	2.13	2.19	3.78	2.36	8.42	0.98	0.11	0.37	0.16	24.34
C28	2.55	1.41	1.78	3.34	1.93	7.05	0.81	0.07	0.31	0.12	19.37

**Table F19: Cumulative Energy Consumption with Energy Performance Improvement Cases for New Installations of Larger Air Conditioning Systems 2010-2019**

Study on Energy Use by Air-Conditioning: Annex F: Calculated air conditioning energy savings arising from a range of possible policy interventions

Energy Performance Improvement Case Code	Split systems>12 kW	VRF	Roof top	All air constant volume	All air VAV	Water based fan coil	Water based induction	Heat pump loop	Active chilled beam	Passive chilled beam	Total
C1	0.07	-	0.03	-	-	-	-	0.00	-	-	0.11
C2	0.15	-	0.07	-	-	-	-	0.04	-	-	0.26
C3	0.37	-	0.19	-	-	-	-	0.01	-	-	0.58
C4	0.87	0.16	0.57	0.09	0.07	0.23	0.03	0.02	0.01	0.00	2.05
C5	1.52	0.59	1.07	1.62	1.13	3.91	0.46	0.02	0.17	0.06	10.55
C6	0.44	-	0.22	-	-	-	-	0.04	-	-	0.69
C7	0.90	0.18	0.57	0.11	0.08	0.26	0.03	0.05	0.01	0.00	2.18
C8	1.52	0.59	1.07	1.62	1.13	3.91	0.46	0.05	0.17	0.06	10.58
C9	1.52	0.59	1.07	1.62	1.13	3.91	0.46	0.05	0.17	0.06	10.58
C10	-	-	0.01	0.04	0.01	0.05	0.01	-	0.00	-	0.13
C11	-	-	0.03	0.08	0.03	0.10	0.01	-	0.00	-	0.26
C12	-	-	0.20	0.60	0.21	0.77	0.10	-	0.03	-	1.92
C13	-	-	0.22	0.64	0.22	0.82	0.10	-	0.04	-	2.04
C14	-	-	0.47	1.40	0.49	1.80	0.22	-	0.08	-	4.47
C15	-	-	-	-	-	0.13	-	0.00	0.01	-	0.14
C16	-	-	-	-	-	0.15	-	0.00	0.01	-	0.16
C17	-	-	-	-	-	0.38	-	0.01	0.02	-	0.41
C18	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00
C19	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00
C20	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.01
C21	-	-	0.02	0.06	0.03	0.09	0.01	-	0.00	-	0.22
C22	-	-	0.05	0.12	0.07	0.17	0.02	-	0.01	-	0.44
C23	0.35	0.19	0.59	1.52	0.60	2.17	0.27	0.01	0.09	0.01	5.81
C24	-	-	-	-	-	-	-	-	-	-	-
C25	-	-	0.22	0.65	0.24	0.98	0.10	0.00	0.04	-	2.24
C26	1.52	0.59	1.40	2.57	1.48	5.41	0.62	0.06	0.23	0.06	13.94
C27	0.22	0.12	0.07	0.07	0.07	0.23	0.03	0.01	0.01	0.01	0.83
C28	1.51	0.84	0.48	0.51	0.50	1.60	0.20	0.04	0.06	0.05	5.79
CX	2.29	1.10	1.41	-	-	-	-	0.07	0.19	0.07	5.12

**Table F20: Cumulative Energy Savings from implementing Energy Performance Improvement Cases for New Installations of Larger Air Conditioning Systems 2010-2019 (TWh)**

Study on Energy Use by Air-Conditioning: Annex F: Calculated air conditioning energy savings arising from a range of possible policy interventions

Energy Performance Improvement Case Code	Split systems	VRF	Roof top	All air constant volume	All air VAV	Water based fan coil	Water based induction	Heat pump loop	Active chilled beam	Passive chilled beam	Total
C1	2%		1%					1%			0%
C2	4%		3%					33%			1%
C3	9%		9%					13%			2%
C4	21%	7%	25%	2%	3%	3%	3%	15%	3%	2%	8%
C5	37%	26%	48%	42%	46%	45%	46%	22%	45%	34%	42%
C6	11%		10%					35%			3%
C7	22%	8%	25%	3%	3%	3%	3%	41%	3%	2%	9%
C8	37%	26%	48%	42%	46%	45%	46%	46%	45%	34%	42%
C9	37%	26%	48%	42%	46%	45%	46%	46%	45%	34%	42%
C10			1%	1%	1%	1%	1%		1%		1%
C11			1%	2%	1%	1%	1%		1%		1%
C12			9%	16%	9%	9%	9%		9%		8%
C13			10%	17%	9%	10%	10%		10%		8%
C14			21%	36%	20%	21%	22%		21%		18%
C15						1%		3%	2%		1%
C16						2%		3%	2%		1%
C17						4%		8%	5%		2%
C18						0%	0%	0%	0%	0%	0%
C19						0%	0%	0%	0%	0%	0%
C20						0%	0%	0%	0%	0%	0%
C21			1%	2%	1%	1%	1%		1%		1%
C22			2%	3%	3%	2%	2%		2%		2%
C23	9%	9%	26%	39%	25%	25%	27%	8%	25%	7%	23%
C24											
C25			10%	17%	10%	11%	10%	3%	12%		9%
C26	37%	26%	62%	67%	61%	63%	61%	52%	63%	34%	55%
C27	5%	5%	3%	2%	3%	3%	3%	5%	2%	4%	3%
C28	37%	37%	21%	13%	21%	18%	19%	33%	17%	31%	23%
CX	56%	49%	63%					59%	52%	40%	20%

**Table F21: Cumulative Percentage Energy Savings from Implementing Energy Performance Improvement Cases for New Installations of Larger Air Conditioning Systems 2010-2019**

## 8 Ventilation Energy Savings

8.1 In addition to achieving a reduction in energy use for, some of the energy performance improvement cases explored also lead to a reduction in fan energy use. This applies to systems where cooling is distributed by air and these systems generally provide a ventilation function in addition to distributing cooling. In the UK the energy use associated with the ventilation function in these systems is often significantly higher than the air movement required for cooling. According the savings associated with a reductions in fan energy use can be very significant.

8.2 Table F22 to F24 show the modelled fan energy consumption and energy savings associated with relevant energy performance improvement cases for the existing stock and for new installations from 2010-2019.

Energy Performance Improvement Cases	Description	Existing Stock (2010)		New Installations 2010-2019	
		Ventilation	Cooling	Ventilation	Cooling
C0	Base Case	10.64	5.09	15.60	5.39
C12	MEPS1AHU	9.31	4.46	15.31	5.29
C14	MEPS2+FI AHU	9.13	4.37	15.02	5.19
C21	MEPS AHU air leakage	10.64	5.09	15.31	5.29
C23	Reduce Flow rates	3.22	2.11	5.98	2.77
C24	BAT AC inspection	6.49	3.67	15.60	5.39
C26	BAT Components	10.64	5.09	4.38	1.76
C27	Achievable load	9.43	4.50	15.60	5.39
C28	BAT Reduction in cooling load	2.19	0.96	15.60	5.39
CX	System switching	10.64	5.09	12.31	5.06

**Table F22: Fan Energy Consumption for the existing stock (TWh pa), and for new installations (Cumulative TWh), after implementing Energy Performance Improvement Cases in Larger Air Conditioning Systems**



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Energy Performance Improvement Cases	Description	Existing Stock (2010)		New Installations 2010-2019	
		Ventilation	Cooling	Ventilation	Cooling
C0	Base Case	-	-	-	-
C12	MEPS1AHU	1.33	0.64	0.29	0.10
C14	MEPS2+FI AHU	1.51	0.72	0.58	0.20
C21	MEPS AHU air leakage	-	-	0.29	0.10
C23	Reduce Flow rates	7.42	2.98	9.62	2.63
C24	BAT AC inspection	4.15	1.42	-	-
C26	BAT Components	-	-	11.22	3.64
C27	Achievable load	1.22	0.60	-	-
C28	BAT Reduction in cooling load	8.45	4.14	-	-
CX	System switching	-	-	3.29	0.34

**Table F23: Fan Energy Savings for the existing stock (TWh pa), and for new installations (Cumulative TWh), after implementing Energy Performance Improvement Cases in Larger Air Conditioning Systems**

Energy Performance Improvement Cases	Description	Existing Stock (2010)		New Installations 2010-2019	
		Ventilation	Cooling	Ventilation	Cooling
C0	Base Case				
C12	MEPS1AHU	13%	13%	2%	2%
C14	MEPS2+FI AHU	14%	14%	4%	4%
C21	MEPS AHU air leakage			2%	2%
C23	Reduce Flow rates	70%	59%	62%	49%
C24	BAT AC inspection	39%	28%		
C26	BAT Components			72%	67%
C27	Achievable load	11%	12%		
C28	BAT Reduction in cooling load	79%	81%		
CX	System switching			21%	6%

**Table F24: Percentage Fan Energy Savings for the existing stock, and for new installations, after implementing Energy Performance Improvement Cases in Larger Air Conditioning Systems**

The calculated energy consumption for the 2010 stock of air conditioning systems (the base case) are higher than estimates for the same year in the DECC publication “Energy Consumption in the UK” (ECUK)<sup>6</sup>

The base case for this study estimated total energy use for the cooling function to be 13.6 TWh, with 5.1 TWh of fan energy use for distributing cooling (in air systems), plus and an additional 10.6 TWh for providing a ventilation function in systems with air distribution. This gives a total of 18.7 TWh for the cooling function and 10.6 TWh for ventilation and a total of 29.3 TWh for cooling and ventilation combined

In comparison for 2010 Table 5.15 of ECUK gives total electricity use for cooling and ventilation as 9.0 TWh. In contrast Table 5.21 give electricity use for central and packaged HVAC air conditioning systems are 12.3 TWh and 8.0 TWh, respectively, giving a total of 20.3 TWh for all HVAC systems.

These differences serves to highlight the level of uncertainty associated with energy use for air conditioning in the UK.

<sup>6</sup> Energy Consumption in the UK, July 2015,

<https://www.gov.uk/government/collections/energy-consumption-in-the-uk>

## 9 Policy Instruments

- 9.1 The study also identified possible policy instruments that could potentially achieve a significant level of energy savings based on the modelled energy performance improvement cases. These are identified as follows:
- 9.1.1 **Moderate product Minimum Energy Performance Standards for moveable units, RACs, Chillers, AHUs and Ductwork (Moderate product MEPs):** These apply to all new installations and are set at a level that would probably be cost effective from an end-user perspective.
- 9.1.2 **Demanding product Minimum Energy Performance Standards for moveable units, RACs, Chillers, AHUs and Ductwork (Demanding products MEPs):** These apply to all new installations and are set at a level that is expected to be cost effective from the societal perspective.
- 9.1.3 **Reduced fresh air rates (Reduced fresh air):** These apply to all new and existing installations of central systems there is. The policy component would be expected to be cost effective from the societal perspective and, in many cases also from an end-user perspective.
- 9.1.4 **Moderate system Minimum Energy Performance Standards (Moderate system MEPs):** These apply to all new installations of central systems and are set at a level that would be cost effective from an end-user perspective in most instances.
- 9.1.5 **Load Reduction:** This relates to improvements to the building envelope and applies to all new and existing installations. It is set at a level that could realistically be achieved cost effectively at the UK level from a societal perspective.
- 9.1.6 **Inspection:** This relates to improvements to the way in which central cooling systems are operated in response to an inspection. These savings relate to controls and behavioural improvements<sup>7</sup> that could realistically be achieved cost effectively at the UK level from a societal perspective.<sup>8</sup>
- 9.1.7 **Detailed Audit:** This relates to improved operation (as outlined in inspection above) plus the implementation of recommendations for component upgrade identified during a more thorough inspection process, possibly linked to operational benchmarking. The level of component upgrade relates to the moderate system MEPS outlined above. The savings identified equate to a level that is potentially cost effective at the UK level from a societal perspective.<sup>9</sup>

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<sup>7</sup> Modelling operational savings is complex and beyond the scope of the modelling carried out for this study. Therefore the potential savings used here were taken from other existing studies.

<sup>8</sup> In many instances the measures will be cost-effective for an individual end-user, but the cost of universal inspection including systems which are operated efficiently casts doubt on whether universal inspection is cost-effective for end-users overall.

<sup>9</sup> The question again is whether the cost of auditing reasonably efficient systems is offset by the benefits of improvements to a minority of them. The development of improved methods of automatic energy reporting and analysis may hold the key to this.

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9.1.8 **Moderate Minimum Energy Performance Standards Building plus system (Moderate Building MEPS):** This relates to MEPS being applied at the building level where the level of savings is defined by the combined effect of moderate system level MEPS in addition to load reduction measures applied to the building envelope. The savings identified therefore equate to a level that could realistically be achieved cost effectively at the UK level from a societal perspective.

9.2 Table F25 maps the within system energy performance improvement cases according to the policy components and implementation levels that they relate to (e.g., light, moderate or BAT). The table also indicates the extent to which these policy components are expected to be cost effective.

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<b>Policy Component</b>	<b>Energy Performance Improvement Case</b>	<b>Installation</b>	<b>Cost Effective</b>
<b>Base case</b>	C0	All	almost always
<b>Labelling and Information</b>	C1 (Chiller)	New	almost always
	C10 (AHU)		almost always
<b>Labelling and information + financial incentives</b>	C2 (Chiller)	New	almost always
	C11 (AHU)		almost always
<b>Light Product Minimum Energy Performance Standards</b>	C3/C4 (Chiller)	New	almost always
	RAC1/2/3 (System)	New	
<b>Moderate Product Minimum Energy Performance Standards</b>	C5 (Chiller) RAC4/5 (System)	New	on average
	C12 (AHU)		
	C18 (Pumps)		
	C15 (Terminal)		
<b>Light Product Minimum Energy Performance Standards + financial incentives</b>	C6/C7 (Chiller)	New	almost always
	RAC6/7/8 (System)		
<b>Moderate Product Minimum Energy Performance Standards S + financial incentives</b>	RAC9/10 (System)	New	on average
	C8 (Chiller)		
	C13 (AHU)		
	C19 (Pumps)		
	C16 (Terminal)		
<b>Best Available Technology product</b>	RAC11 (System)	New	potentially
	C9 (Chiller)		
	C14 (AHU)		
	C20 (Pumps)		
	C17 (Terminal)		

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Policy Component	Energy Performance Improvement Case	Installation	Cost Effective
<b>Moderate System Minimum Energy Performance Standards and Labelling</b>	C21 (Ductwork Leakage)	All	on average
	C23 (System Performance)	All	
	C24 (System Performance)	All	
	C25 (System Performance)	New	
<b>BAT System Minimum Energy Performance Standards and labelling</b>	C22 (Ductwork Leakage)	All	potentially
	C26(System Performance)	New	
<b>Moderate Building Minimum Energy Performance Standards</b>	C27/RAC12	All	on average
<b>Best Available Technology Building Performance</b>	C28/RAC13	All	unlikely

**Table F25: Summary of within system energy performance improvement cases indicating installations addressed and potential cost effectiveness**

9.3 For some Modelled Cases, there are significant potential energy savings associated with the ventilation function. The combined cooling and ventilation potential energy savings for the energy performance improvement cases with the biggest potential impacts are shown in table F26 and presented graphically in Figure F4.

Study on Energy Use by Air-Conditioning: Annex F: Calculated air conditioning energy savings arising from a range of possible policy interventions

<b>Energy Saving Measures</b>	<b>Installations</b>	<b>Realisable Savings (Cooling)</b>	<b>Additional Savings (Ventilation)</b>
Moderate RAC Minimum Energy Performance Standards	New	2.8	-
Demanding RAC Minimum Energy Performance Standards	New	4.6	-
Moderate Chiller Minimum Energy Performance Standards	New	1.0	-
Demanding Chiller Minimum Energy Performance Standards	New	3.0	-
Demanding AHU Minimum Energy Performance Standards	New	0.6	-
Ductwork Minimum Energy Performance Standards	All	10.5	-
Reduced Fresh Air	All	1.8	5.2
Moderate System Minimum Energy Performance Standards	New	0.1	0.4
Load Reduction	All	1.1	8.5
Inspection	All	3.7	3.7
Detailed Audit	All	7.8	2.4
Moderate Building Minimum Energy Performance Standards	All	1.3	4.2

**Table F26: Estimated Cumulative Realisable Energy Savings from Selected Energy Saving Measures over 10 years (2010 - 2019) in TWh**

Inspection assumes savings will be made through improvements to controls and behaviour change, detailed audit encompasses controls, behaviour change and component replacement, including system switching, whilst moderate building MEPS is a combination of load reduction and system level MEPS.

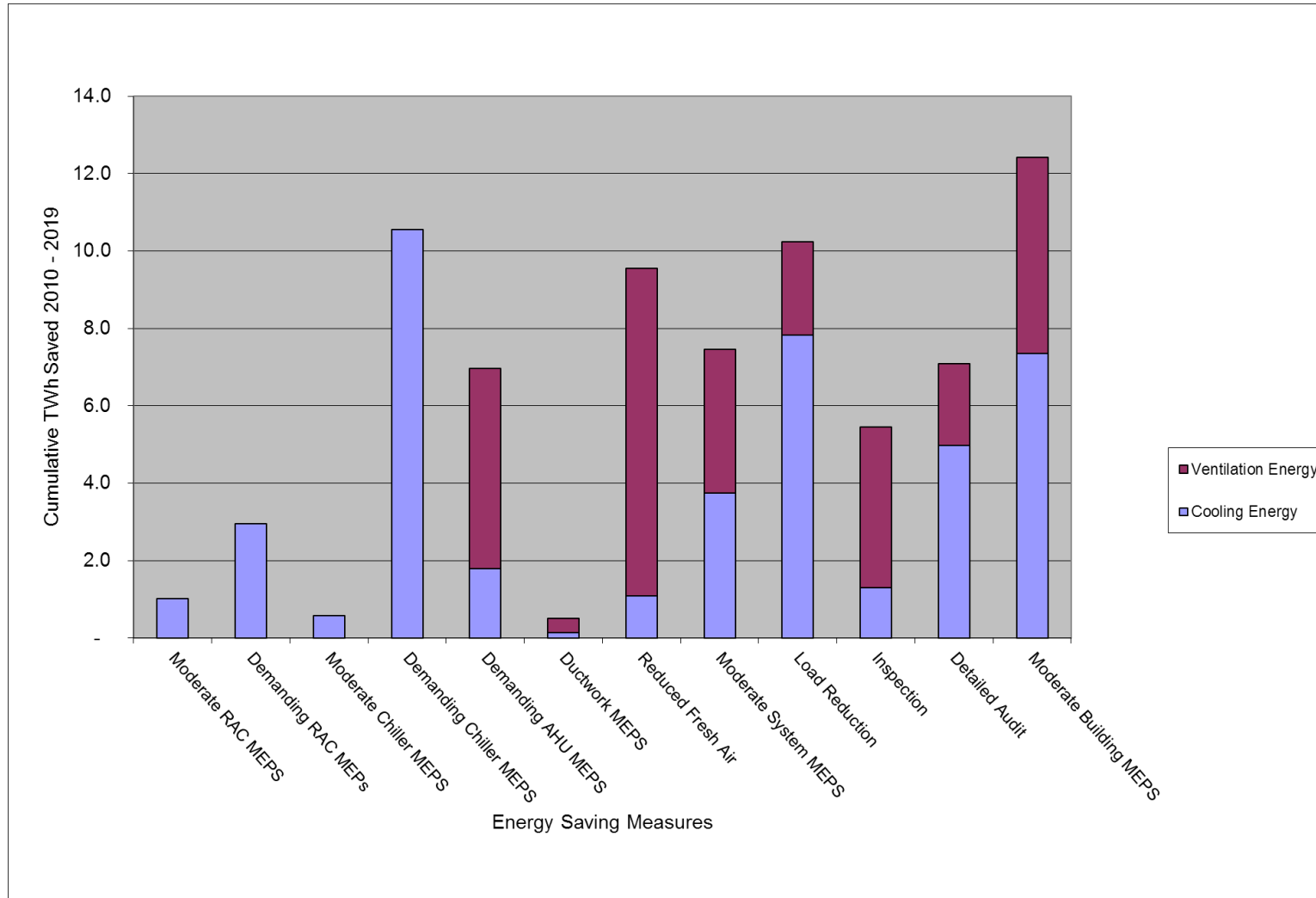


Figure F4: Estimated potential energy savings from implementing a range of policy instruments – Cumulative TWh savings 2010-2019



- 9.4 The modelling process takes account of the important constraint on rates of implementation imposed by product replacement rates. However, for some policy instruments, there are other constraints, typically where the implementation rate is restricted by rates of major building or system refurbishment or replacement.
- 9.5 For policy instruments other than Minimum Energy Performance Standards (or those triggered by Minimum Energy Performance Standards), the impact is not dependent on product replacement rates but rather on voluntary actions by owners and users. In these cases (for building envelope measures, for example), the Modelled Cases (other than BAT) reflect relatively low-cost measures that are most likely to be taken. The actual take-up rates are dependent on the economics of the upgrade for the individual owners, market conditions, incentives available, rate of growth of the market, equipment useful life, etc.
- 9.6 Where possible policy instruments combine the impact of more than one energy performance improvement case in such a way that one measure reduces the scope of potential savings from another measure e.g., inspection where savings are achieved through a combination of controls and behaviour change the following formula was used to adjust the savings: % saving for a & b =  $1 - ((1 - \% \text{ saving a}) * (1 - \% \text{ savings b}))$ .
- 9.7 Savings in 2019 would be expected to account for at least 18%<sup>10</sup> of the total savings between 2010 and 2019.

## 10. References

<sup>A</sup> Study to assess barriers and opportunities to improving energy efficiency in cooling appliances/systems, Christine Pout, Roger Hitchin and David Butler, BRE, March 2012  
[https://www.bre.co.uk/filelibrary/pdf/rpts/Realisable\\_energy\\_savings\\_in\\_European\\_air-conditioning.pdf](https://www.bre.co.uk/filelibrary/pdf/rpts/Realisable_energy_savings_in_European_air-conditioning.pdf)

<sup>B</sup> Eco-design Lot 10: Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation) Contract TREN/D1/40-2005/LOT10/S07.56606, Service contract to DGTREN, 2008

<sup>C</sup> Sustainable Industrial Policy – Building on the Ecodesign Directive – Energy-Using Product Group Analysis/2 Lot 6: Air-conditioning and ventilation systems Contract No. ENTR/B1/35-2009/LOT6/ SI2.549494, July 2012

<sup>D</sup> COMMISSION REGULATION (EU) No 206/2012, Implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to eco design requirements for air conditioners and comfort fans. Official Journal of the European Union, March 2012

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<sup>10</sup> This would be the case if sales within the period were flat. As the sales trend is increasing, savings in 2019 are likely to account for more than 18% of the total savings over the period.

<sup>E</sup> Implementing Directive 2009/125/EC of the European Parliament and of the Council establishing a framework for the setting of ecodesign requirements for energy-related products, with regard to ecodesign requirements for air heating products, cooling products and high temperature chillers.

<sup>F</sup> Bass, Frank, "A new product growth model for consumer durables" Management Science 15 (5) 215-227, 1969

<sup>G</sup> Hitchin, E. R HVAC System Efficiencies for EPBD Calculations. In: CLIMA 2007, Wellbeing Indoors, Helsinki 200 additional information at <http://www.ncm.bre.co.uk>

<sup>H</sup> Energy Consumption in the UK, July 2015, <https://www.gov.uk/government/collections/energy-consumption-in-the-uk>