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Final Report Task 6

Design Options

Prepared by VHK

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Main contractor: ARMINES, France

Project leader: Philippe RIVIERE

PARTICIPANTS

Jérôme ADNOT, Olivier GRESLOU, Philippe RIVIERE, Joseph SPADARO
AMINES, France

René KEMNA, Rob VAN HOLSTEIJN, Martijn VAN ELBURG, William LI, Roy van den BOORN
VHK, The Netherlands

Roger HITCHIN, Christine POUT
BRE, UK

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Introduction

This is the draft report for Task 6 on the Ventilation Systems, as part of the preparatory study on Air Conditioning and Ventilation Systems in the context of the Ecodesign Directive: **'ENTR Lot 6 – Air Conditioning and Ventilation Systems'.** The product scope is ventilation systems with individual fan power larger than 125 W. This implies systems that are commonly used in non-residential and collective residential applications.

This study is being carried out for the European Commission (DG ENTR). The consortium responsible for the study is Armines (lead contractor), BRE and VHK. Subcontractor for the underlying report is VHK.

Subtasks

In accordance with the Terms of Reference for this contract Task 6 consists of:

subtask 6.1	Identification of design options
subtask 6.2	Assessment of target values/design options with Least Life Cycle Costs (LLCC) and Best Available Technology (BAT). This entails
	assessment of environmental impact per design option;
	assessment of costs per design option;
	ranking of options by LCC, estimating side-effects (e.g. 'rebound'-effects), ranking accumulative options, determining LLCC and BAT
subtask 6.3	Analysis of possible long term targets, based on Best Not yet Available Technology (BNAT).
Subtask 6.4	Sensitivity analysis of the main parameters
Subtask 6.5	System improvement

Task 6 is performed in accordance with the various subtasks in the MEEuP methodology 2005, but is also in line with the new MEErP methodology 2011.

The numbering of the chapters 1 to 5 in the underlying report follows the numbering of subtasks.

Inputs from previous tasks, continuity in subsequent tasks

<u>**Inputs**</u> for Task 6 are supplied by the preceding 5 Tasks:

- Task 1 supplies measurement methods (standards) and related existing legislation, e.g. the Ecodesign Fan and Motor regulations;
- Task 2 gives extensive data on prices and cost rates that are necessary for Life Cycle Cost (LCC)calculations, as well as EU sales and stock data that help to aggregate the outcomes per product to EU level;
- Task 3 describes typical loads, i.e. the ventilation demand, also as a function of sector, building type and occupancy;
- Task 4 defines the Base Case, i.e. the starting point for the LCC and impact calculation of the design options. It also defines the characteristics of the 5 product sub-categories: Central

exhaust systems (CEXH), central balanced heat recovery ventilation (CHRV) as well as small, medium and large air handling units (AHU-S, AHU-M, AHU-L)

- Task 5 provides a technical analysis of existing ventilation systems, which will be used as the technical reference report for the design options that are modelled in Task 6.

In principle, Task 6 does not include information retrieval from other sources than the preceeding Task Reports

Outputs of Task 6 provide the following input for Task 7:

- Least Life Cycle Costs (LLCC) levels per product subcategory, typically to be used as (minimum) targets for Ecodesign measures if this instrument is appropriate;
- LLCC, BAT and BNAT levels, typically to be used –if this instrument is appropriate— in Energy Labelling as lower class limits for 'C', 'A' and 'A+' classes;
- Levels of uncertainty of the assessments above following the sensitivity analysis;
- Possible contribution of other instruments, outside Ecodesign and Energy Label, that could contribute in promoting products with a lower environmental impact (e.g. EPBD, procurement, Ecolabel, MS support schemes, etc.)

The outputs of Task 6 strictly look at the technical-economic parameters, which are important inputs for the policy analysis in Task 7. These parameters are not the only ones taken into account in final decision making. Task 7 will study other parameters in as much as they are relevant for market- and/or legislative failure in achieving environmentally friendly and resource-efficient products.

Definitions and basics

Base Cases

The general scope are ventilation units with a rated power >125 W per individual fan. Within that scope five Base Cases are distinguished and one reference situation, i.e. natural ventilation. The Base Cases are

- Central Exhaust ventilation (CEXH)
- Central Heat Recovery Ventilation (CHRV)
- Air Handling Units in sizes Small, Medium and Large (AHU-S, AHU-M, AHU-L)

The purpose of the Base Cases, as defined in the previous Tasks, is to present the policy makers with insight of what is technically and economically feasible, following the stipulations of Annex II of the Ecodesign Directive.

Base Cases and the Design Options are an abstraction of a much more complex reality, where there is an almost infinite number of capacities, types and configurations. Especially because data availability in this sector is poor, the findings should be regarded as indicative.

Life Cycle Costs and Payback Period

The analysis uses the definition of Life Cycle Costs (LCC) as given in MEErP 2011. With respect of the MEEuP 2005, the definition is extended, amongst others, with the notion of ‘escalation rate’ e. The escalation rate is the real (above inflation) growth rate of the price components, e.g. the energy costs. Whereas in the previous methodology it could be assumed that all price components show the growth rate of the inflation (escalation rate=0), the latest figures show that in particular energy prices show a nominal annual growth rate of around 6%, which results –at an inflation rate of around 2%-- in an escalation rate of 4% for the electricity and fossil fuel prices that are used in the underlying report.

The basic LCC formula is:

LCC = PP + PWF * OE + EoL,

where

LCC is Life Cycle Costs to end-users in €,

PP is the purchase price (including installation costs) in €,

OE is the annual operating expense in €,

EoL is End-of-life costs (disposal cost, recycling charge) or benefit (resale) in €,

PWF (Present Worth Factor) is

$$\mathbf{PWF = 1 - \left(\frac{1+e}{1+d}\right) \cdot \left[1 - \left(\frac{1+e}{1+d}\right)^{N}\right]} \qquad (d \neq e)$$

in which

N is the product service life in years,

d is the discount rate in % (by definition 4%[1]),

e is the aggregated annual growth rate of the operating expense (a.k.a. ‘escalation rate’, in €) .

If *d=e* then ***PWF= N and*** the LCC formula can be simplified to

LCC= PP + N*OE + EoL

The value of *EoL* for ventilation products is assumed to be negligible.[2] Furthermore, for the sake of simplification, the running costs are calculated in Task 6 without the maintenance costs and without the costs of possible auxiliaries such as filters.

The fact that the escalation rate of the running costs more or less equals the discount rate also means that the discounted payback period equals the simple payback period (SPP). This is the time period it takes for an investor to recuperate the extra investment in purchase price *dPP* through the reduction in annual operating expense *dOE*.

The equation for comparing two alternatives ‘A’ and ‘B’ is then

[1] In accordance with the European Commission Impact Assessment Guidelines 2009.

[2] Meaning that, given the fact that the units consist largely of metals representing a value for recycling, there will be no net disposal costs.

$\boldsymbol{SPP_{AB}} = \boldsymbol{dPP_{AB}} / \boldsymbol{dOE_{AB}}$ (in years)

where

$\boldsymbol{SPP_{AB}}$ is the Simple Payback Period of a higher acquisition cost of a product B over product A (in years)

$\boldsymbol{dPP_{AB}}$ is the extra Purchase Price of product B over A (in €)

$\boldsymbol{dOE_{AB}}$ is the saving in annual Operating Expense of Product B over A (in €/year)

This formula can only be used to judge the payback period for products that roughly have the same product service life. This is assumed to be the case for the ventilation units.

Product Life

For the ventilation units a product service life of 17 years is assumed.

However, the ventilation units do present a special case in this respect, especially if a design option does not only involve changes in the ventilation unit itself, but also in the installation (ductwork, grills, etc.). The service life of the installation components is usually as long as the building, i.e. in the area of 50 years, or rather 3 times the product life of the (major components of the) ventilation unit.

In theory, for new installations it would mean that the passive installation components like ducts and grills--including the related labour—should be written off over a 50 year period. For retrofit situations such a decision would typically be made at the time of the first replacement of (major components of) the ventilation unit and thus the write-off is over 34 years.

In practice, and this may well be construed as a 'market failure' (see Task 7), most builders have a much shorter time scope and typically would like to recuperate their investments within a 20 year period for non-residential applications. This is close to the 17 year time period and for reasons of simplification a generic write-off period ('product life') of 17 years will be assumed for both the active ventilation unit and the passive (ducts, grills, labour) installation. This subject will be revisited in Task 7, because it obviously has a negative impact on what is perceived to be 'economical' and for whom.

Energy rates

Task 6 assumes the energy rates mentioned in the MEErP 2011 for January 2011. For ventilation of smaller premises, e.g. < 1000 m² floor area, an electricity tariff of € 0.18/kWh is assumed. This applies for the CEXH, CHRV and AHU-S units. For the larger AHU-M unit a tariff of € 0.14/kWh is taken and the running costs of the largest unit, AHU-L, will be calculated at an 'industrial rate' of € 0.10/kWh excluding VAT.

Similarly, the tariffs for space heating fuel, assumed to be natural gas, are set at € 0.052/kWh for smaller units € 0.042 for AHU-M and an industrial tariff of € 0.032 for AHU-L.

This differentiation of tariffs renders the calculation closer to reality and points at what again could be construed as a 'market failure', i.e. that energy tariffs are lower –and thus payback periods of energy saving investments are higher—for buildings with higher total energy use. This subject will be revisited in Task 7.

Note that this choice for a differentiation of energy tariffs in Task 6 can also be deceiving. For instance, a large building will generally have several ventilation units or even several different ventilation systems for different parts of the building. Thus also the smaller CEXH, CHRV and AHU-S units may be, and usually are, part of that configuration and thus the lower energy-tariffs apply also to smaller units. This subject will be part of the sensitivity analysis (Subtask 6.4), which will look at how robust the targets are in view of these variations.

Subtask 6.4 will also look at regional variations both in energy tariffs as wells in purchase & labour costs. MEErP 2011 shows that electricity tariffs can be 50% lower (Bulgaria) or 50% higher (Denmark) than the EU average. Gas and oil prices, cutting out the extremes, are closer to the EU average but may still vary ± 20% depending on the country.

As mentioned in Task 2, the purchase price and labour cost estimates are averages. Prices may be double (e.g. Northern Europe) or half (e.g. Eastern Europe), depending on the country. Countries with more or less an EU-average price are the Netherlands, France and the UK.

Design option levels

Design options may be defined at different aggregation levels:

- At system level, i.e. the improvement of mechanical ventilation solutions versus the most commonly used ventilation practice, i.e. natural ventilation.
- At category level, i.e. the improvement of one category of mechanical ventilation versus another. More specifically this is relevant for a comparison between exhaust ventilation CEXH versus the other, balanced ventilation, categories.
- Within a category, investigating the design options of improved fan system energy, lower internal pressure drop, more efficient heat recovery, etc..

It is debatable whether all these levels are relevant for the regulatory possibilities offered by the Ecodesign directive and/or whether a wider policy mix would be required. This is a subject to be discussed in Task 7. Task 6 attempts to supply the necessary inputs for such a discussion.

Chapters 6.2 and 6.3 will deal with the two lowest aggregation levels: They will discuss within every category and –where appropriate—extend the analysis to replacement options by products from another category.

Chapter 6.5 (*System Options*) will deal with the economics of replacing natural ventilation by any of the mechanical ventilation options, both as a Base Case and in the Least Life Cycle cost version. This Chapter will also briefly touch upon options for system components such as ductwork.

1. Identification of design options

1.1 Central exhausts units (CEXH)

The Central exhaust unit (CEXHs) Base Case characteristics are modelled after the active mechanical ventilation component of a *Type C* ventilation system. This is a common type in offices and apartment buildings. It typically entails a 'rooftop' or 'boxed' ventilation unit connected to a vertical duct, which is connected to inlets in kitchen/bathroom of apartments or the central hallways in offices, schools, etc..[3]

The fresh air supply is realized through grills in the windows and/or –especially in older—natural infiltration openings around windows and doors.

This Base Case is intended to represent a common archetype. There are a range of other single fan ventilation units with fans >125 W on the market, e.g.

- Central supply (ducted) ventilation units for Type B overpressure ventilation systems, whereby the grills in windows serve `as an air outlet. These units distinguish themselves from Type C through different external pressure and the presence of filters.
- Exhaust or ventilation (ducted) units that are part of a –more or less-- balanced ventilation system where the air in- and outlet occur at different locations of the building shell. These units either have no heat recovery or –more seldom—heat recovery through run-around coils.
- Local (unducted) exhaust ventilation units, typically with lower operating hours, for the extraction of humidity and/or toxic substances. These units
- Rooftop (unducted) injection ventilation units for the ventilation of industrial halls and large warehouses.

It remains to be seen, i.e. in Task 7, whether and to what extend all these types could or should be covered in policy measures.

As with all product subcategories, CEXHs are described in subtask 1.1 (Chapter 2 of Task 1 report on *'Product classification and definition'*) and subtask 3.1 (Chapter 2 of Task 3 on *'User requirements'*) . Price, installation costs and various trade margins are given in Task 2, Chapter 5 *('Expenditure Base Data'*) and in the Annexes. Environmental impacts were first calculated in Task 4 (*Definition Base Cases*), showing that the use of energy resources in the use phase, relating both to the direct electricity use and the indirect impact on space heating, is the dominant factor.

Table 1 summarizes the main characteristics from previous Task reports. Note that, as an extension to Task 4, also the space cooling costs arising from ventilation losses have been added. For this calculation the method of the ENTR Lot 6, Task 1, Air Conditioning by Armines was used.[4]

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[3] Rooftop ventilation units are not to be confused with 'Rooftop AC units' that are described in the air-conditioning part of DG ENTR Lot 6.

[4] : The ENTR Lot 6, Air Conditioning Task 1 report (page 203) derives the average space cooling load from sensible heat difference including solar gain during the cooling season (11 oC in Warmer Climate, 4 in Average Climate), the operating hours (2000 h/year in Warmer Climate, 1200 in Average Climate), the latent load is 20% (→ sensible load * 1,2). The infiltration + ventilation rate is 1 m³/m³ (ventilation only 0.8 m³/m³) and the specific sensible heat is 0,000344 kWh/m³.K. E.g. for the CEXH Base Case, with a design flow rate of 1500 m³/h this means that the ventilation cooling losses during the cooling season are
960 m³/h x 2000 h x 11 K x 0.000344 kWh/m³.K x 1.2 = 8718 kWh/year= 8.7 MWh/yr. For the electricity consumption to meet this cooling load it is assumed that system losses (auxiliary heat supplementary load, distribution losses, suboptimal control, etc.) are 25% of the load, the aggregate Seasonal Energy Efficiency Ratio SEER for cooling is 2 and additional

Table 6-1. Key figures CEXH Base Case (Sold 2010)

Parameters	**CEXH**
performance data	
design/ effective/ average flow rate [000m³/h]	1.5/ 1.13/ 0.96
pressure drop external/internal/total [Pa]	154/ 37/ 191
specific fan power [kW/(m³/s)]	1.08
individual rated fan power [kW]	0.345
fans system efficiency [-]	23%
heat recovery thermal efficiency [-]	0%
misc factor	1.33
control factor on-off/variable/total	0.8/ 0.8/ 0.64
consumption data	
electricity consumption AHU [MWh/a]	1.33
electricity rate EUR/kWh	0.18
electricity costs AHU [000 EUR /a]	0.2
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	22/ 10/ 45
fossil fuel (ca. gas) rate[EUR/kWh]	0.052
space heating cost Avg/Warm/Cold climate [000 EUR/a]	1.1/ 0.5/ 2.3
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	1.9/ 8.7
space cooling extra costs [000 EUR/a]	0.2/ 1.0
total extra energy cost Avg/Warm/Cold [000 EUR/a]	1.6/ 1.7/ 2.6
investment data	
product end price [000 EUR]	0.634
Installation materials** [000 EUR]	2
install. labour new/ retrofit/ replace/ avg*** [000 EUR]	3/ 4/ 1/ 3
total new/ retrofit/ replace/ avg*** [000 EUR]	5/ 6/ 1/ 5

The technical analysis in Task 5 discusses relevant design options as regards

- Fan systems (motor, drive, fan),
- Housing aerodynamics and filters, whereby the latter are relevant only for Type B systems, i.e. supply ventilation,
- Heat Recovery,
- Controls.

From these four main subjects in Task 5, the following specific design options for CEXHs are derived:

Design option 1. Improved fan systems

Improvement

The CEXH Base Case has a design fan efficiency of 23% and nominal (design) power of 373 W. This is based on a CEXH with a 3-speed AC motor and suboptimal --e.g. radial or forward curved-- impeller. The configuration is an average: There are products on the market with fan efficiencies as low as 18% or less, but also efficiencies of 28% or more.

electricity consumption not taken into account in the SEER value (e.g. extra exhaust fan operation) is 25% of the electricity consumption. E.g. in a warmer Climate this is 1.25 x 1.25 x 8718/2.5= 5448 kWh. At € 0.18/kWh → € 980/yr

From 1.1.2013 (Tier 1) such a solution would no longer be allowed under the Fan Regulation[5], which stipulates a minimum fan efficiency of around 28% for this type of fan with ducted inlet. From 1.1.2015 the minimum efficiency should be 35%. In other words, this level of efficiency does not require additional regulation. This will be marked as **Design Option 1a**.

However, given the number of running hours and the favorable payback period, the efficiency level could be further raised to that of a *backward curved fan with housing*. By 1.1.2015 such a fan, of this nominal power, should reach a minimum efficiency of 47-48%. This is marked as **Design Option 1b**. The general formula for the minimum efficiency of fans with P <= 10 kW would then be 4.56*ln(P) – 10.5 + 62 %, with P being the nominal power in kW.

Fans with P > 10 kW would then have to meet a minimum efficiency 4.56*ln(P) – 10.5 + 52 %. This means, for instance, that a 32 kW fan would have to meet a minimum efficiency of 64%.

For supply fans (ventilation system Type B) there is a ducted outlet and the minimum efficiency values in the Fan Regulation are slightly different.

In analogy with Task 5, Annex V, it is estimated that the improved fan system (AC to DC including SMPS) will result in a 20% increase of the unit price.

There are no extra installation or maintenance costs for this option.

Design option 2. Internal pressure drop

The technical analysis of Task 5 highlights the importance of reducing the internal pressure drop in a ventilation system. In exhaust systems, usually not equipped with heat exchangers, filters, cooling or heating coils, the internal pressure drop depends primarily on carefully designed housing and in- and outlets. In this sense, the 40 Pa internal pressure drop for the CEXH Base Case is relatively high and probably some 20-25% (say 10 Pa) could be gained, practically without extra production costs and only new R&D and tooling.[6]

The total pressure drop, internal and external, for the BaseCase is set at 194 Pa, so a 10 Pa drop results in a 5% electricity reduction. The costs are set symbolically at a small amount, representative of a higher R&D effort and possibly a slightly higher write-off on tooling.

Design option 3: Heat recovery

In the Task 5 technical analysis the heat recovery options primarily focused on balanced systems (CHRV and AHUs), but also exhaust systems are placed on the market with an integrated facility for heat recovery. These are systems with already a built-in heat exchanger for a runaround heat recovery solution or exhaust ventilation systems where the exhaust air is used in combination with heat pumps for space and/or water heating.

Design Option 3a Integrated run-around coil

The exhaust systems with integrated runaround coils are –as yet-- relatively rare. These are e.g. exhaust units for laboratory, hospital or similar applications where every possibility of cross-contamination between ingoing and outgoing air must be excluded. In that case the exhaust ducts and supply ducts are completely separated. At the warm outlet-air a heat exchanger coil absorbs the

[5] COMMISSION REGULATION (EU) No 327/2011 of 30 March 2011 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for fans driven by motors with an electric input power between 125 W and 500 kW, OJ 6.4.2011, L90/8

[6] For supply systems (ventilation system Type B), which are not included in the analysis because of their small market share, the internal pressure drop is higher e.g. because they are connected to ductwork at the outlet and usually equipped with a filter.

heat of the warm inlet-air. This coil is connected to a pumped, liquid-filled circuit and another coil at the air inlet. This other coil at the inlet gives off the absorbed heat to the cold inlet air. Typical thermal efficiency of such a construction is reported between 50 and 65%. This is lower than the thermal efficiency of a counter-flow or rotary heat exchanger, but still much better solution than having no heat recovery at all.

The cost of such a solution is considerably higher than that of a simple rooftop exhaust fan. Roughly the component prices are a factor 3 higher (extra supply ventilation + costs of two coils and circulation pump) and also the installation costs are probably a factor 3 higher in new buildings and a factor 4 if such a solution is applied in a renovation situation, i.e. where the supply duct has to be realized afterwards. For the final calculation in Chapter 2 the prices of a downsized CHRV plus extra product- and installation costs are taken as a yardstick.

Note that this solution does not require inlet grilles (e.g. in windows), which will save around € 1500 in component and installation costs. Also the addition of a mechanically vented supply duct gives better control over the indoor air quality (IAQ) because the air volume no longer depends on the pressure differences over the building shell[7]. This is taken into account through the MISC factor (see Task 4 report), which decreases from 1,33 (CEXH Base Case) to 1,1 for a balanced system. This enables a 17% downsizing of the fan flow capacity for the same IAQ performance as the CEXH Base Case, which favourably influence monetary costs and savings.

The savings are a balance. The decreased ventilation heat losses result, using 75% efficiency as a multiplier, in considerable space heating fuel cost savings. On the other hand, fan electricity will more than double, because not only are there 2 fans instead of one but they will also have to work harder against the pressure drop from heat exchanger and filter(s). Furthermore, the circulation pump between the coils will also result in more electricity use.

In an Average Climate (reference Strasbourg, France) it can be expected to be just about economical, especially when space cooling benefits are taken into account. In a Colder Climate (reference Helsinki, Finland) the annual energy savings on space heating are around twice as high and the monetary savings may even be higher, depending on the space heating energy source.

An added bonus of using heat recovery is the higher level of comfort, because the cold inlet air is now pre-heated by the heat recovery coil. The higher level of comfort may also lead to people respecting the minimum standards for healthy indoor air quality, which is very often not the case with system C in the winter, and thus ventilating more in winter. This possible effect may be seen as a *'rebound effect'* , if this is indeed the term to use for a healthier indoor air quality.

For the Warmer Climate and also most parts of the Average Climate zone it is relevant that heat recovery also saves on cooling energy during the summer, if full air conditioning is installed. As mentioned in Task Report 4, this saving will be treated with the Air Conditioning part of the Lot 6 study.

Apart from the summary calculations in Chapter 2, the detailed tables in Annex I give more details on the performance and economics in the 3 reference climates as well as in new, retrofit and replacement situations.

[7] It assumed that the CEXH exhaust unit is part of a ventilation system C, where the air inlet is through openings in the façade (grills in windows, extra infiltration with doors, etc.). In order to guarantee a minimum Indoor Air Quality, even under the worst outdoor pressure conditions, the system C capacity must be considerably higher than with a system D, i.e. where both the inlet and outlet air are under control through mechanical ventilation.

Design Option 3b: Balanced ventilation units with heat recovery

The run-around coil solution has the advantage of free design of the air-ducts, which can be especially relevant in retrofit situations, situations where avoiding cross-contamination is paramount (laboratories, hospitals) and new buildings with a lay-out that would make run-around coils a more economical solution than balanced ventilation solutions.

But apart from that, it has most of the characteristics of an integrated balanced ventilation unit with heat recovery. The main differences are that a balanced system (CHRV) is a more integrated product with thus lower component and installation costs and that the typical rotary or counter-flow heat exchangers a higher thermal efficiency than a run-around coil (e.g. 80% instead of 60%). It is estimated that component and installation costs could be 20% lower and energy savings 25% higher (c.p.). As a result, payback times will be lower.

Design option 3c: Integrated ventilation heat pump

Relatively popular in Northern Europe is the option to combine the exhaust unit with a heat pump, i.e. an air-to-water heat pump that is contributing to space heating and/or water heating. The big advantage of this heat recovery option is that it does not require the installation of a separate supply duct.

The energy saving was calculated for a ventilation air heat pump with COP 4.5 and some auxiliary energy. The effective average flow rate of the CEXH Base Case is 960 m³/h and the exhaust air is cooled from 20 to 2 °C (temperature difference 18 K). During the 5000 h heating season the energy that is thus extracted from the exhaust air is

960 x 5000 x 18 x 0,000344= 29 722 kWh

where 0,000344 is the specific heat of air in kWh/m³.K. At a gas boiler efficiency of 75% this yields a saving of 39 630 kWh and € 2060 on space heating.

At a COP of 4,5 [8] the electricity consumption of the ventilation heat pump is 5 944 kWh/year. With a primary energy factor of 2.5 for power generation and distribution this is equivalent to 14 860 kWh primary energy and thus the net energy saving is 14 862 kWh.

The extra acquisition costs of the 6 kW heat pump and hydronic circuit are estimated at around € 10 000, including the installation.

In this situation a gas-fired boiler is assumed as a back-up[9]. However, in a configuration where an electric heat pump is anyway the preferred option (e.g. when the building is not connected to the gas grid or an efficient district heating) the economics of also –besides outside air-- using the ventilation exhaust air changes dramatically. The extra costs to mix the two air streams would be significantly lower (only some extra ductwork and mixing chamber), which would easily be recuperated within a short payback period. The ventilation air would just be a second source to the outside air source heat pump that boosts the COP.

Design option 4: Controls

The CEXH Base Case is equipped with a whole building timer control ($CTRL_{on}$=0.8) and high-low speed control ($CTRL_{var}$=0.8). The overall control factor is 0.64. This is common practice in modern office buildings. Given the fact that many exhaust fans are still operating continuously, either in

[8] Note that this is a ventilation heat pump, i.e. it uses 20 oC exhaust temperature throughout the heating season and it feeds into the space heating circuit, with a considerably higher COP (Coefficient of Performance) than a 'normal' air-to-water heat pump that uses outdoor air. COP would be higher if it feeds into a low-temperature space heating circuit and lower if it is used for sanitary hot water heating.

[9] Note that, for a space with this capacity of CEXH, the design heat demand is up to 50 kW in an average climate. So at outdoor temperatures lower than 2-3 oC the gas-fired boiler would have to contribute.

collective residential applications or older commercial properties, it is optimistic to assume this as a Base Case, but it makes sure that the saving potential of controls is certainly not overstated.

Design Option 4a: Central sensor

By adding a central CO2 and relative humidity (RH) sensor instead of the timer control the actual periods of building occupancy can be assessed more accurately ($CTRL_{on}$=0.7, overall control 0.56), yielding a saving on both electricity and ventilation heat losses. The cost of adding the sensors is around € 300.

Design Option 4b: Central sensor with variable speed drive

With a continuous variable speed drive, instead of a high-low speed control, the saving could be higher because the flow could be tuned more accurately to the demand. The $CTRL_{var}$ value could be 0.7. This option needs to be combined with option 1b and this is also where most of the price increase comes from. Extra costs mainly relate to the more sophisticated central controls.

This is demand control at the level of the whole building or the part of the building serviced by the exhaust unit, as opposed to the next solution.

Design Option 4c: Local VAV boxes and sensors.

When using VAV-boxes[10] and CO2/ RH sensors the demand control could take place at the level of individual zones (or apartments in a high-rise building). An example of such an integrated product with zone demand control through a plenum box, placed on the market as a whole, is given in the Task 5 report (Chapter 5.2). The manufacturer claims an 80% saving with respect of the most unfavourable solution, i.e. an exhaust unit running at full capacity (1500 m³/h in case of the CEXH Base Case). As the CEXH Base Case already boosts timer control and high-low speed control this is already a better starting point and savings will be 40-50% with respect of the best central sensor solution.

The price increase for the VAV boxes and is estimated at around € 1000 for a residential setting (max. 250 m³/h). In an apartment building the costs would be around € 3000 - € 4000 for 8 VAV boxes with wireless (RF) transmitters, including installation costs.

1.2 Central Heat Recovery Ventilation (CHRV)

The CHRV Base Case characteristics are modelled for a Type D ventilation system found in small offices, shops and other commercial and public premises. The ventilation unit contains filters (EU7 type) , a heat recovery unit, 2 fans, timer-control and a manual 3-speed (AC motor) control. External pressure performance is characteristic for a relatively moderate duct lay-out, e.g. for a ceiling mount unit or a unit that is an oversized version of a residential unit.

As with the CEXH Base Case, main characteristics are defined in previous task reports. Purchase price and price increases for design options were estimated on the basis of information in the Task 2 report.

Table 1 summarizes the key figures from previous Task reports. Note that, as an extension to Task 4, also the space cooling costs arising from ventilation losses have been added.

[10] VAV=Variable Air Volume. Used as a general denomination for all types of control valves for air flow.

Table 6-2. Key figures CHRV Base Case (Sold 2010)

Parameters	CHRV
performance data	
design/ effective/ average flow rate [000m³/h]	2.25/ 2.0/ 1.1
pressure drop external/internal/total [Pa]	160/ 140/ 300
specific fan power [kW/(m³/s)]	1.72
individual rated fan power [kW]	0.536
fans system efficiency [-]	35%
heat recovery thermal efficiency [-]	80%
misc factor	1.10
control factor on-off/variable/total	0.6/ 0.8/ 0.48
consumption data	
electricity consumption AHU [MWh/a]	3.21
electricity rate EUR/kWh	0.18
electricity costs AHU [000 EUR /a]	0.6
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	5/ 2/ 13
fossil fuel (ca. gas) rate[EUR/kWh]	0.042
space heating cost Avg/Warm/Cold climate [000 EUR/a]	0.3/ 0.1/ 0.7
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	0.4/ 2.0
space cooling extra costs [000 EUR/a]	0.0/ 0.2
total extra energy cost Avg/Warm/Cold [000 EUR/a]	0.9/ 0.9/ 1.2
investment data	
product end price [000 EUR]	5.281
Installation materials** [000 EUR]	7.10
install. labour new/ retrofit/ replace/ avg*** [000 EUR]	10/ 12/ 6/ 11
total new/ retrofit/ replace/ avg*** [000 EUR]	23/ 25/ 11/ 22

For CHRV units the design options can be defined along the same lines as for CEXH.

Design option 1. Improved fan systems

The CHRV Base Case has a design fan systems efficiency of 35%, typical of an AC motor with direct drive forward curved impeller[11]. This is typical of low-cost ceiling-mount models, where space is at a premium and forward curved fans are chosen because they are more silent than backward curved fans, i.e. they require less silencing measures. In centralized standing models EC or DC motors with direct drive backward curved impellers are more common; AC motors may still occur in imported and legacy products.

The obvious option is to raise the efficiency to a level of the backward curved fans minimum requirements as formulated in the Fan Regulation. This is similar to what is proposed for CEXH.

Design option 2: Reduce internal pressure loss

The CHRV Base Case features an internal pressure drop of 140 Pa. The internal pressure drop is caused by the heat recovery heat exchanger, the filter and the housing aerodynamics. An overall factor that is relevant for the internal pressure drop is the face velocity ('face' being the frontal filter surface) . Compared to the larger AHU units face velocity in CHRV units is relatively low. Even in

[11] Note that it is assumed –in contrast to CEXH-- that current CHRV units will be able to meet the minimum requirements for forward curved fans in the Fan Regulation and thus there is no benefit from the Fan Regulation.

applications where space is at a premium, like the small commercial heat recovery units placed in a plenum, the face velocity is rarely higher than 1.2-1.3 m/s and often below 1 m/s. This is much better than the highest face velocity class in standards and the Eurovent classification (V1, < 1.6 m/s) so it appears that in this area there is little to be gained.

Also in the area of the pressure drop over the heat exchangers, by far the most important contributor to the overall internal pressure drop, the value of 140 Pa at a thermal efficiency of heat recovery of 80% is not bad. When allowing ca. 40-50 Pa pressure drop for filter and casing, it means a pressure drop of around 90-100 Pa for the heat exchanger. Compared to the best EN 13503 classification for a heat exchanger with 75% thermal efficiency (class 'H1') this is very low (280 Pa per flow). Also the EN 13799 mentions that for H1 devices a pressure drop of 300 Pa is normal, with around 200 Pa as the lowest value and 400 Pa as the highest. On the other hand, for residential CHRV units these low internal pressure drops at a high thermal efficiency are perfectly normal.

A probable explanation is that the commercial EN standards are valid for units with face velocity of 2.5 m/s or higher. As it is assumed that the internal pressure drops quadratic with the airspeed [12], a face velocity of 1 m/s yields an internal pressure drop that is over 70-80% lower than that at 2.5 m/s.

Requirements for CHRV (e.g. units up to 5 000 m³/h) could be set at EN 13503 default settings, including an EU 7 filter[13] , but with a correction for face velocity. The Base Case already answers these requirements so there is limited extra calculated gain.

Design option 3. Heat recovery.

The CHRV Base Case features a counter-flow heat exchanger with thermal efficiency of 80%. Currently manufacturers would claim a thermal efficiency of 90-95%, but often this includes excessive fan motor waste heat and does not take into account internal leakages in the heat exchanger. These factors could artificially boost the thermal efficiency by up to 10-15% and thus the assumed thermal efficiency for this Base Case is set at 80%.

When setting minimum thermal efficiency requirements it is thus important also to make sure that the fan motor is not oversized, i.e. that there are stringent fan system efficiency requirements (Design option 1), and that leakage rates answer state-of-the-art requirements. There are several test methods and classifications for this, especially in the residential standards, but ultimately they all say that the internal leakage (in the heat exchanger, between ducts), the external leakage (to the outside) and filter bypass leakage should all be lower than 2% at the appropriate pressure. The current status of products on the market is estimated at 5%. For the external recirculation rate (a.k.a. 'mixing rate', i.e. short-circuit between air-inlet and air outlet) the best classification also features 2%, but it is estimated that the current situation in many countries is much worse (e.g. 10%). For instance, in many countries concentric solutions (i.e. air in- and outlet only 10-20 cm apart) are still allowed and quite commonly applied.

If all these conditions are met, which is not easy, it may be possible to raise the actual requirement to 90% thermal efficiency. It is estimated that effectively fighting the leakages will raise the unit price by around 5-10%, i.e. proportional to the thermal efficiency gain in percentage points.

[12] Note that the relationship between face velocity and pressure drop does not depend on one single aerodynamics formula, but there are also other effects, e.g. at equal filter efficacy and thermal efficiency the filters and heat exchangers can also save on the third dimension, i.e. the depth, which again leads to a reduction in pressure drop. The US EPA even states that the correlation is quadratic, but in order not to overstate the saving potential only a linear dependence is assumed in the underlying Task 6.

[13] Note that the testing should be done with the EU 7 filter model (EN 799) that the manufacturer proposes. EU 7 filters are recommended in the standards for general application, but are not mandatory.

Design option 4. Controls

In terms of control technology the situation with CHRV is similar to that of CEXH units. Because many CHRV are in fact upgraded residential units, the integration of CPU and specific controls is quite normal, i.e. the units and controls are placed on the market as an integrated package.

This is in contrast with traditional AHU-manufacturers (see next section) for whom the CHRV is in fact a downsized ('micro') air handling unit with typically a modular approach towards controls, , even if the base unit feature an integrated balanced heat recovery ventilation . In practice it means that there is a basic fan speed control (e.g. with a steering voltage up to 24 V and or through a digital bus) but all the rest is optional.

This dichotomy makes it difficult to judge whether design options would be within the realm of Ecodesign or not. This is a political/legal decision, to be discussed in Task 7. From the technical point of view setting minimum requirements makes sense, but it must be remembered that –in contrast to the situation with CEXH—the saving effect of controls is more limited because it overlaps with the heat recovery effect.

Design option 4a: Central sensor

For instance, where the addition of a central CO2 and RH sensor for a CEXH unit would save € 184/yr on the space heating bill, for a CHRV unit of the same size with 80% thermal heat recovery efficiency the saving would only be € 37/yr. To this the electricity saving of 2 x € 18/yr should be added, but at a cost of around € 300 for the sensors the payback time would be still economical, but less than with CEXH.

Design option 4b: Central sensor and vsd

With a continuous variable speed drive the savings go up by another 10-15% on the control side. If it is combined with an EC or DC motor in design option 1 the extra cost over just a central sensor would be negligible.

Design option 4c: Local VAV Boxes and sensors.

Likewise, the addition of VAV-boxes and local CO2 sensors per zone would not save € 740 on space heating but –for a CHRV unit with the same capacity-- € 148. The electricity saving would be 2 x € 129, bringing the total saving to € 406.

1.3 Air Handling Units (AHU)

Task 4 distinguishes three types of Air Handling Units. The table below summarizes the main characteristics. Please note that, as mentioned in the Introduction chapter, electricity and gas rates were adapted to real-life industrial and semi-industrial rates for the two largest AHUs.

Table 6-3. Key figures AHU Base Cases (Sold 2010)

Parameters	AHU-S	AHU-M	AHU-L
performance data			
design/ effective/ average flow rate [000m³/h]	4.0/ 3.64/ 1.92	10.0/ 8.7/ 4.8	35.0/ 29.7/ 16.8
pressure drop external/internal/total [Pa]	244/ 292/ 536	450/ 334/ 784	575/ 391/ 966
specific fan power [kW/(m³/s)]	1.98	2.7	3.42
individual rated fan power [kW]	1.1	3.75	15.75
fans system efficiency [-]	54%	58%	61%
heat recovery thermal efficiency [-]	44%	44%	44%
misc factor	1.10	1.15	1.18
control factor on-off/variable/total	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48
*consumption data**			
electricity consumption AHU [MWh/a]	6.59	22.46	94.33
electricity rate EUR/kWh	0.18	0.14	0.10
electricity costs AHU [000 EUR /a]	1.2	3.1	9.4
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	24/ 11/ 53	61/ 27/ 132	213/ 95/ 462
fossil fuel (ca. gas) rate[EUR/kWh]	0.052	0.042	0.032
space heat extra cost Avg/Warm/Cold climate* [000 EUR/a]	1.3/ 0.6/ 2.7	2.6/ 1.1/ 5.5	6.8/ 3.0/ 14.8
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	2.1/ 9.8	5.3/ 24.4	18.6/ 85.4
space cooling extra costs [000 EUR/a]	0.2/ 1.1	0.5/ 2.1	1.2/ 5.3
total extra energy cost Avg/Warm/Cold * [000 EUR/a]	2.7/ 2.8/ 3.9	6.2/ 6.4/ 8.7	17.4/ 17.8/ 24.2
investment data			
product end price [000 EUR]	7.5	12.6	29.5
Installation materials*** [000 EUR]	34.4	98.2	282.3
install. labour new/ retrofit/ replace/ avg**** [000 EUR]	52/ 62/ 9/ 52	147/ 177/ 9/ 147	575/ 690/ 34/ 573
total new/ retrofit/ replace/ avg**** [000 EUR]	94/ 104/ 17/ 91	258/ 288/ 28/ 249	887/ 1002/ 64/ 856

As has been established in the stakeholder meeting 30.9.2011 the common denominator of these AHUs is that they are characterized by a modular approach. As opposed to the previous categories this means at least that certain design options like controls are not part of the products as they are placed on the market. For that reason they are not discussed here.

Design option 1. Improved fan systems

For fan system efficiency there are several possible yardsticks that were discussed in preceding task reports. One metric is the Specific Fan Power SFP, in accordance with EN 13799 classification. Another metric is given by the latest edition of EN 13053. And finally, it was discussed that – whatever the actual metric chosen for ventilation systems—it should be in line with minimum fan efficiency according to the Ecodesign Fan Regulation No. 327/2010.

As regards the latter, the graph below gives the Tier 1 (2013) and Tier 2 (2015) of minimum static fan efficiency for backward curved fans with housing and in the same graph the classes P1 to P4 are given in accordance with EN 13053. The latter follows the formula

$$Pmref = (\_pstat / 450)^{0.925} \bullet (qv + 0.08)^{0.95}$$

The classes P1, P2, P3, P4 etc. have as lower class limits 0.85Pmref, 0.9 Pmref, 0.95 Pmref, Pmref etc..

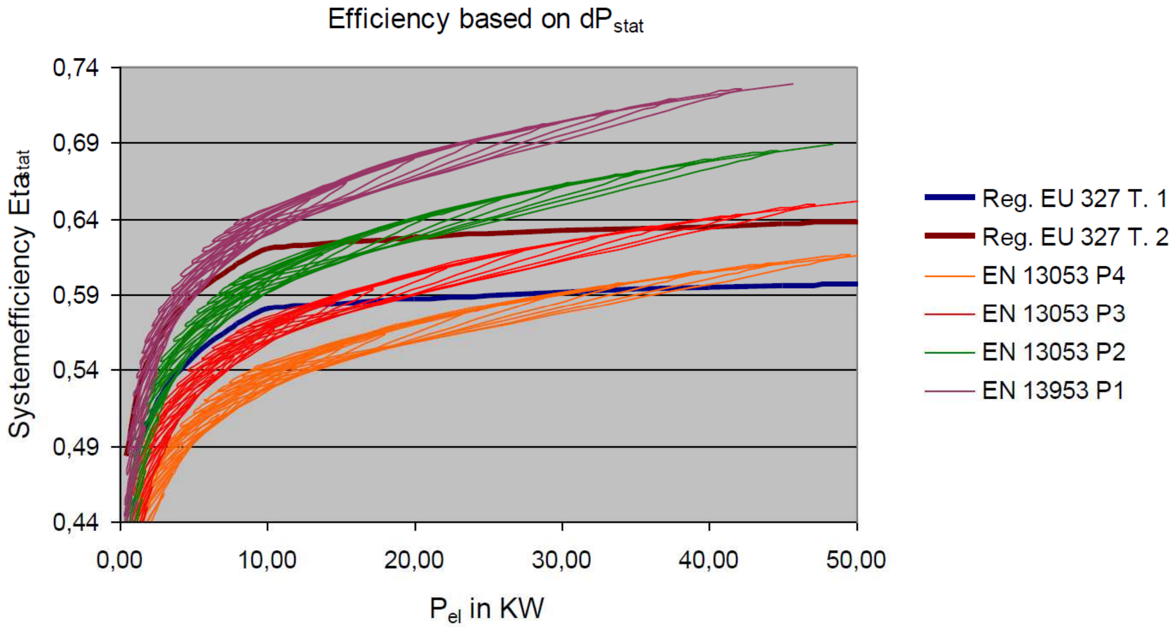

Figure 6-1. Comparison between EN 13053 classification and Tiers 1 and 2 of the Ecodesign Fan Regulation No. 327/2011.(source: JIEG, 2012)

The graph shows that for individual fan power up to 5 kW the ambition level of the fan regulation for <u>fan efficiency</u> is comparable to that of <u>fan system efficiency</u> in classes P2 (compare to Tier 1) and P1 (compare Tier 2). At higher fan power the classes P1 and P2 are more ambitious than the Fan Regulation.

A comparison with SFP classes is difficult, because SFP –in W/(m³/s)—only looks at the air flow and is missing the (internal and external) pressure component. For instance, as can be seen from the table 1, the SFP of 3.42 for the AHU-L means a fan system efficiency of 61%, whereas the SFP of 1.98 for the AHU-S means a fan system efficiency of 54%.

For a population of AHUs sold in Germany over the period 2003-2009, that the average (supply) fan efficiency is 69.2%. The BAT values for fan efficiency are around 83-84%. As system efficiency (including heat recovery and filters), the values are in the range of 65-70% for the units above 15-20 000 m³ and for smaller units the system efficiency is in the range of 50-60%.

As design option, it is therefore proposed a fan system efficiency of 58% for AHU-S, 63% for AHU-M and 68% for AHU-L. This is more or less in line with EN 13053 class P1. In Task 2 Annex IV it was assessed that for a 31 000 m³/h AHU a 15% efficiency improvement would be realized at an expense of € 4 600, which is more or less 15% of the end price. Thus the design option of 5 %-point improvement leads to a 5% higher price.

<u>Design option 2: Reduce internal pressure loss</u>

The internal pressure losses are the sum of pressure drop over the heat recovery heat exchanger, the filter box and the housing with an overall influence of face velocity.

Typically for AHUs the face velocity is 2.5 m/s (EN 13053 class V5). Reducing the face velocity by using a larger housing, or using a housing originally designed for a larger capacity but with smaller fans, creates an extra cost. There is a cost increase of the housing proportional to the surface increase, but on the other hand there is a relative saving in the filters, heat exchanger and coils because –as the face surface increases, the 'depth' can decrease. Furthermore, as internal pressure drop is lower, also the fan capacity can be substantially lower. On the other hand, the occupied surface area is larger and handling is more difficult. Therefore it is assumed that the overall product cost increase will be proportional to the face velocity decrease. E.g. a 25% decrease in face velocity will lead to a cost increase of the product costs of 25%.

US EPA calculates that a reduction in face velocity will reduce the power demand by the square of the velocity reduction, including the effect of the 'depth' reduction of the heat exchanger and filter E.g. for a 25% reduction in face velocity (Class V3) the power demand decreases by 44% ($1 – 0.75^2$), according to US EPA.[14] In cases where the external pressure drop is zero or small this may be the case, but for the calculations in the next chapter it is assumed that face velocity saving is quadratic with the internal pressure drop only.

<u>Design Option 2a: Face velocity V3</u>

Option 2a is a reduction of face velocity of 2.5 m/s with 25% to 1.875 m/s or rather face velocity class V3. This will lead to a 44% decrease in internal pressure drop. Given that the internal pressure drop makes up 47% of the total internal plus external pressure drop of the Base Case, the electricity saving will be around 20% (0.44 x 0.47). Product costs will increase by 25%.

<u>Design Option 2b: Face velocity V1</u>

At a 40% reduction in face velocity (to 1.5 m/s, Class V1) a 64% reduction in internal pressure drop is expected. Following the same principles as above, the electricity savings will be around 30%. Product costs will increase by 40%.

<u>Design Option 2c: Filter 'A' class</u>

Apart from the reduction of the face velocity, the pressure drop of the individual components plays a role. For instance EN 13503 prescribes a maximum final pressure drop of 200 Pa for F5-F7 filters. EN 13799 mentions as an <u>average</u> pressure drop a 'normal' value of 150 Pa for F7 air filters (low 100 Pa, high 250 Pa).

The filter energy efficiency classification Eurovent 4/11 [15]proposes to rate filters as a function of a fixed flow rate q_v=0.944 m³/s, operating time t=6000h and fan efficiency η=0.5 as well as a measured average pressure drop Δp in Pa. The equation for the energy W in kWh/a is thus

$W = qv * \Delta p * t / (\eta * 1000)$

or –summarizing the constants—

$W = 11.328 * \Delta p$

The pressure drop is determined while feeding an amount of test dust during the standard EN 799 filter test. For F-type filters this is 100 g of test dust. The classification shows the lower class limits for W starting with 1200 kWh for 'A' class and then increasing with class widths of 250 kWh up to a lower class width of 2400 kWh for 'F' class. One could also say the lower class width for 'A' is 106 Pa and then increasing with class widths of 22 Pa. The lower class width for 'C' is 150 Pa, which is typical for the Base Cases.

[14] US EPA, Low pressure drop HVAC design for laboratories, Feb. 2005.
[15] Eurovent COM_11013, Chapter 3 on Filters, 2011.

The obvious design option is to bring the Base Case to ‘A’ class filter level, i.e. 106 Pa. This would save between 4 -7.5% on electricity consumption for the AHUs if the filter modules of the AHU would be equipped with and dimensioned for ‘A’ class F7 filters.[16]

Other: Lower pressure drop heat exchanger

A major contributor to the internal pressure drop is the heat exchanger for the heat recovery. In EN 13053 this is linked to the thermal efficiency. At a Base Case thermal efficiency of 44% one could expect a pressure drop of around 125 Pa (lower limit of class H5). This is more or less what is assumed in the Base Cases. Perhaps the pressure drop could be lowered to 100 Pa (saving 20%), which is deemed realistic in EN 13799, but overall there is a risk that setting too strict specific requirements on maximum pressure drop over the heat exchanger will be detrimental to thermal efficiency. Hence for AHUs it seems prudent to use the EN 13053 definition of ‘energy efficiency’ , i.e. including a certain pressure drop, but preferably with some refinement as regards the role of the lower face velocity in smaller units.

Finally there is the housing with fan in- and outlet. Typical pressure drop is 40-50 Pa in the BaseCase and –depending on size—this may be reduced. This effect will be also taken into account with design option 2c.

Design option 3. Heat recovery.

The thermal efficiency of the heat exchanger of all Base Cases is set at 44%, reflecting not only the relatively larger share of more inefficient (cross-flow) heat exchangers but also the fact that a substantial part of the balanced AHUs (estimate 30%) is still sold without a heat exchanger.

Equipping the AHU Base Cases with a state-of-the-art rotary or counter-flow heat exchanger would raise the thermal efficiency to 75%, thus increasing the space heating saving by 42%. The internal pressure drop at current face velocity would increase by 155 Pa (from 125 Pa to 280 Pa, according to EN 13053), increasing the electricity consumption by 29%/20%/16% for small/medium/large AHUs. The resulting net saving is a balance between the positive space heating savings and the extra electricity costs. The extra costs are estimated at around 30% of the product price.

[16] Note that this doesn’t mean that the end user is obliged to use F7 filters. Such a decision is outside the scope of Ecodesign.

2. Economics of design options

2.1 Central exhaust units (CEXH)

The CEXH Base Case consumes 1 331 kWh/yr in electricity and causes space heating energy for ventilation losses of 21 331 kWh/yr. The total direct and indirect primary energy consumption is 24 659 kWh/yr. The Life Cycle Costs are € 31 997. Acquisition costs including installation and installation materials are € 5 429, of which € 634 for the unit.

Table 1 summarizes the single design options for CEXH in terms of energy savings and costs. The second part of Table 1 shows the effects of accumulative options, ranked by payback time. The graph shows the LCC versus the savings of accumulative options.

The Least Life Cycle Cost (LLCC) is accumulative option nr. 4, the combination of better (48%) fan efficiency and smart central controls. Payback period is 1.1 year, at a Life Cycle Cost saving of € 6 798 (20%), a primary energy saving of around 7 317 kWh/yr (30%) and an extra investment of € 459. The average elasticity between Base Case and this LLCC point is around € 0.06/kWh primary energy saved per year.

The Best Available Technology (BAT) point is accumulative design option nr. 9, the ventilation heat pump. Payback period is 12.7 years, at a Life Cycle Cost saving of € 3 979 (12%), a primary energy saving of around 23 587 kWh/yr (96%) and an extra investment of € 11 700. The average elasticity between Base Case and LLCC point is around € 0.32/ kWh primary energy saved per year.

With respect of the LLCC point the BAT saves 16 270 kWh/yr at an extra investment of € 11 241. The average elasticity between LLCC and BAT point is around € 0.69/kWh primary energy saved per year.

Table 6-4. CEXH Design Options, improvements versus Base Case

CEXH **Single Design Options** *('saved'= per year; LCC over 17 yrs)*		**kWh elec saved**	**kWh heat saved**	**kWh primary saved**	**€ price increase**	**€ elec saved**	**€ heat saved**	**years payback**	**€ LCC gain**
1a	Fan system efficiency 35%	456	0	1141	76	82	0	0.9	1320
1b	Fan system efficiency 48%	693	0	1733	159	125	0	1.3	1963
2	int dP minus 10 Pa	70	0	174	5	13	0	0.4	208
3a	run-around coil	-1344	14962	11601	12368	-242	778	23.1	-3256
3b	CHRV	-1101	16726	13973	9568	-198	870	14.2	1848
3c	ventilation heat pump	-6085	38801	23587	11700	-1095	2018	12.7	3979
4a	Central sensor	147	2666	3035	300	27	139	1.8	2508
1+4b	Central sensor + vsd	927	5000	7317	459	167	260	1.1	6798
1+4c	Local VAV boxes and sensors	1050	7333	9957	3959	189	381	6.9	5736

SORTED SINGLE & ACCUMULATIVE

1	**Base Case**			**0**				0.0	**0**
2	**Option 2**	70	0	174	5	13	0	0.4	208
3	**Option 1a**	456	0	1141	76	82	0	0.9	1320
4	**Option 1b+4b (LLCC)**	927	5000	7317	459	167	260	1.1	6798
5	**Option 1b**	693	0	1733	159	125	0	1.3	1963
6	**Option 4a**	147	2666	3035	300	27	139	1.8	2508
7	**Option 1b+4c**	1050	7333	9957	3959	189	381	6.9	5736
8	**Option 1b+2+3b**	776	16726	18666	10443	140	870	10.3	6717
9	**Option 3c (BAT)**	-6085	38801	23587	11700	-1095	2018	12.7	3979
10	**Option 1b+2+3a+4b**	979	16455	18903	13593	176	856	13.2	3950
11	**Option 3b**	-1101	16726	13973	9568	-198	870	14.2	1848
12	**Option 1b+2+3a**	776	15156	17096	13293	140	788	14.3	2479
13	**Option 1b+2+3a+4c**	1035	16277	18865	16793	186	846	16.3	763
14	**Option 3a**	-1344	14962	11601	12368	-242	778	23.1	-3256

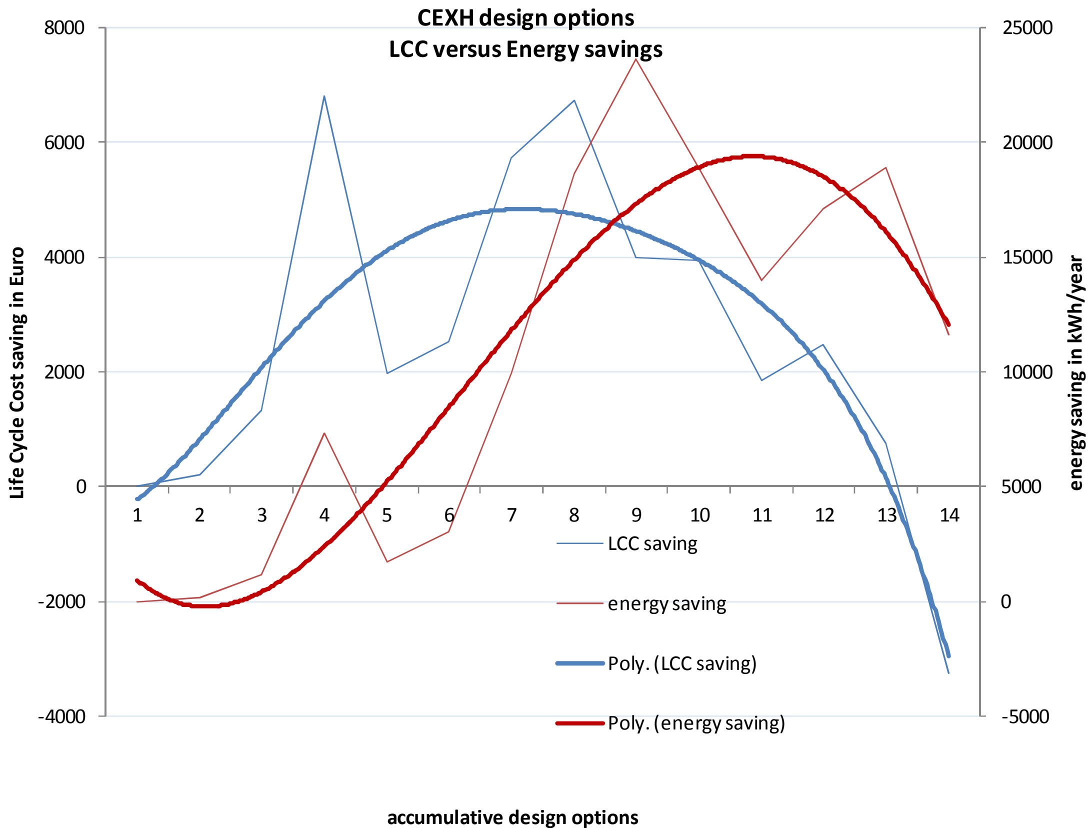

Figure 6-2. CEXH design options LCC versus Energy savings

2.2 Central Heat Recovery Ventilation (CHRV)

The CHRV Base Case consumes 3 209 kWh/yr in electricity and causes space heating energy for ventilation losses of around 5 064 kWh/yr. The total direct and indirect primary energy consumption is 13 087 kWh/yr. The Life Cycle Costs are € 37 609. Acquisition costs including installation and installation materials are € 22 500, of which € 5 281 for the unit.

Table 3 summarizes the single design options for CHRV in terms of energy savings and costs. The second part of the table shows the effects of accumulative options, ranked by payback time. The graph shows the LCC versus the savings of accumulative options.

The Least Life Cycle Cost (LLCC) point is represented by design option nr. 4, a combination of improved fan efficiency, slightly lower internal pressure drop, a little better heat recovery and a central control sensor. This saves a total of 6 497 kWh/yr primary energy (50% of Base Case), composed of 1 500 kWh/yr electricity and 2 733 kWh/yr in space heating. Payback period is 3.7 years. LCC savings are € 5 504 (15%) and require an extra investment of € 1 515. The average elasticity between Base Case and LLCC point is around € 0.23/ kWh primary energy.

Table 2. CHRV Design Options, improvements versus Base Case

		electri-city saved	heating/ cooling saved	total primary energy saving	price inc.	saving electric at 0.18/kWh	saving space heat at 0.052/kWh	simple payback period	LCC effect (17 yrs)
SINGLE OPTIONS		kWh/yr	kWh/yr	kWh/yr	EURO/yr	EURO/yr	EURO/yr	years	EURO
1	Fan system efficiency	869	0	2172	687	156	0	4.4	1972
2	Face velocity 0.9 m/s + int dP -20 Pa	458	0	1144	647	82	0	7.9	754
3	Thermal efficiency 90% (from 80%)	-267	2400	1731	528	-48	125	6.9	775
4a	Central sensor	457	863	2004	300	82	45	2.4	1860
1+4b	Central sensor + vsd	904	647	2908	300	163	34	1.5	3039
1+4c	Local VAV boxes and sensors	2070	1942	7118	3800	373	101	8.0	4252
SORTED SINGLE & ACCUMULATIVE									
1	**Base Case**			**0**				**0**	**0**
2	**Option 1+4b**	904	647	2908	300	163	34	1.5	3039
3	**Option 4a**	457	863	2004	300	82	45	2.4	1860
4	**Option 1+2+3+4b**	1500	2747	6497	1515	270	143	3.7	5504
5	**Option 1+2+3+4a**	1168	2863	5784	1515	210	149	4.2	4591
6	**Option 1**	869	0	2172	687	156	0	4.4	1972
7	**Option 1+2+3**	830	2400	4475	1215	149	125	4.4	3446
8	**Option 1+3**	674	2400	4085	1215	121	125	4.9	2969
9	**Option 1+2**	1203	0	3007	1333	216	0	6.2	2347
10	**Option 2+3**	241	2400	3003	1056	43	125	6.3	1803
11	**Option 3**	-267	2400	1731	528	-48	125	6.9	775
12	**Option 2**	458	0	1144	647	82	0	7.9	754
13	**Option 1+4c**	2070	1942	7118	3800	373	101	8.0	4252
14	**Option 1+2+3+4c**	2365	3441	9353	5015	426	179	8.3	5264

Table 2. CHRV Design Options, improvements versus Base Case

		electri-city saved	heating/ cooling saved	total primary energy saving	price inc.	saving electric at 0.18/kWh	saving space heat at 0.052/kWh	simple payback period	LCC effect (17 yrs)
SINGLE OPTIONS		kWh/yr	kWh/yr	kWh/yr	EURO/yr	EURO/yr	EURO/yr	years	EURO
1	Fan system efficiency	869	0	2172	687	156	0	4.4	-1972
2	Face velocity 0.9 m/s + int dP -20 Pa	458	0	1144	647	82	0	7.9	-754
3	Thermal efficiency 90% (from 80%)	-267	2400	1731	528	-48	125	6.9	-775
4a	Central sensor	457	844	1985	300	82	44	2.4	-1843
1+4b	Central sensor + vsd	904	633	2893	300	163	33	1.5	-3026
1+4c	Local VAV boxes and sensors	2070	1899	7075	3800	373	99	8.1	4214
SORTED SINGLE & ACCUMULATIVE									
1	**Base Case**			**0**				**0**	**0**
2	**Option 1+4b**	904	633	2893	300	163	33	1.5	3026
3	**Option 4a**	457	844	1985	300	82	44	2.4	1843
4	**Option 1+2+3+4b**	1500	2733	6483	1515	270	142	3.7	5492
5	**Option 1+2+3+4a**	1168	2844	5765	1515	210	148	4.2	4575
6	**Option 1**	869	0	2172	687	156	0	4.4	1972
7	**Option 1+2+3**	830	2400	4475	1215	149	125	4.4	3446
8	**Option 1+3**	674	2400	4085	1215	121	125	4.9	2969
9	**Option 1+2**	1203	0	3007	1333	216	0	6.2	2347
10	**Option 2+3**	241	2400	3003	1056	43	125	6.3	1803
11	**Option 3**	-267	2400	1731	528	-48	125	6.9	775
12	**Option 2**	458	0	1144	647	82	0	7.9	754
13	**Option 1+4c**	2070	1899	7075	3800	373	99	8.1	4214
14	**Option 1+2+3+4c**	2365	3399	9311	5015	426	177	8.3	5226

The Best Available Technology (BAT) point is represented by accumulative design option nr. 14, identical to the LLCC but with local sensors and local valve control. This saves a total of 9 353 kWh/yr primary energy (71% of Base Case), composed of 2 365 kWh/yr electricity and 3 441 kWh/yr in space heating. Payback period is 8.3 years. LCC savings are € 5 226 and require an extra investment of € 5 015. The average elasticity between LLCC and BAT point is around € 1.23/ kWh primary energy, based on a difference of 2 856 kWh more saving and a € 3 500 higher investment.

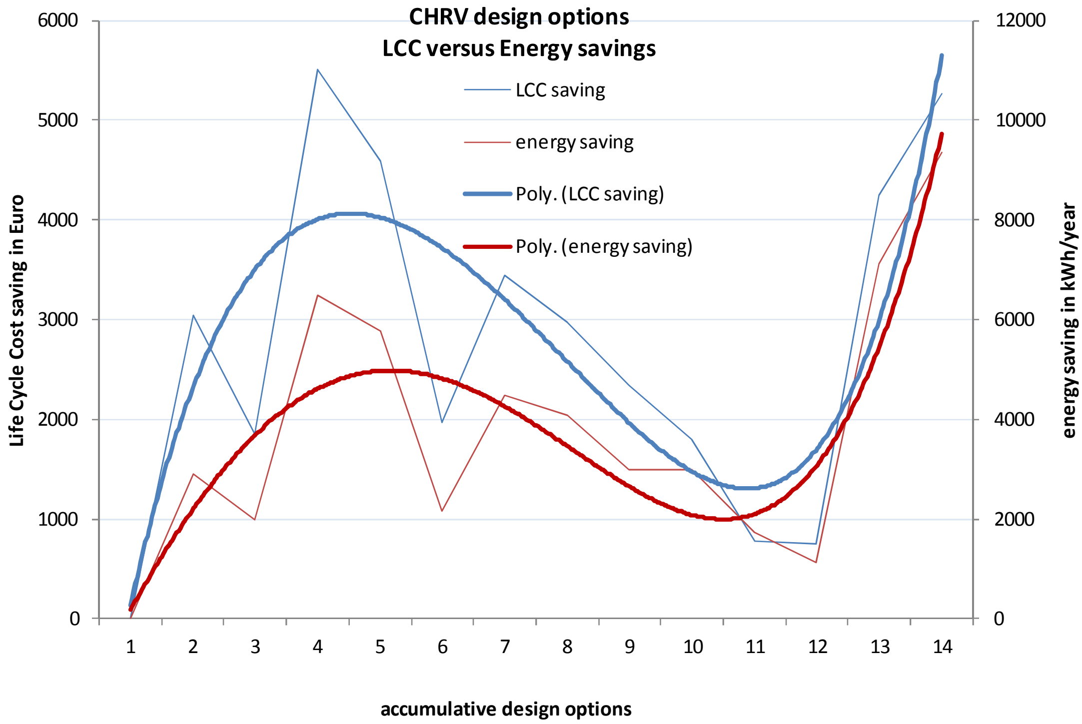

Figure 6-3. CHRV design options LCC versus Energy savings

2.3 Air Handling Units (AHU)

2.3.1 AHU-S

The AHU-S Base Case consumes 6 605 kWh/yr in electricity and causes space heating energy for ventilation losses of around 24 361 kWh/yr. The total direct and indirect primary energy consumption is 40 874 kWh/yr. The Life Cycle Costs are € 136 482. Acquisition costs including installation and installation materials are € 91 000, of which € 7 500 for the unit.

The first part of Table 3 summarizes the single design options for AHU-S in terms of energy savings and costs. The second part also shows the effects of accumulative options, ranked by payback time. The graph shows the LCC versus the savings of accumulative options and helps to identify the LLCC and BAT options.

The design option with the most LCC-saving and most energy saving is accumulative option nr. 3, i.e. the combination of better fan efficiency, lower the face velocity to class V1 and improved heat recovery. The LCC saving is € 12 062 (9% vs. Base Case) and the primary energy annual energy saving is 18 124 kWh/yr (37% saving). The extra purchase price is € 5 625. Payback is within 5.4 years.

The average elasticity between Base Case and LLCC point is around € 0.31/ kWh primary energy (5625/18124).

Table 6-5. AHU-S Design Options, improvements versus Base Case

	electri-city saved	heating/ cooling saved	Total primary energy saving	price inc.	saving electric	saving space heat	simple payback period	LCC effect (17 yrs)
SINGLE OPTIONS	kWh/yr	kWh/yr	kWh/yr	EURO/yr	EURO/yr	EURO/yr	years	EURO
1 Fan system efficiency	456	0	1139	300	82	0	3.7	1094
2a Face velocity 1.875 m/s (class V3)	1574	0	3936	1875	283	0	6.6	2942
2b Face velocity 1.5 m/s (class V1)	2303	0	5757	3000	415	0	7.2	4047
2c Filter F7 'A' class (150 --> 100 Pa)	616	0	1540	750	111	0	6.8	1135
3 Thermal efficiency 75% (from 44%)	-1910	13225	8450	2325	-344	688	6.8	3521
SORTED SINGLE & ACCUMULATIVE								
1 **option 1**	456	0	1139	300	82	0	3.7	1094
2 **option 1+2a+3**	921	13225	15528	4500	166	688	5.3	10009
3 **option 1+2b+3**	1959	13225	18124	5625	353	688	5.4	12062
4 **option 1+2c**	1029	0	2573	1050	185	0	5.7	2099
5 **option 1+3**	-1323	13225	9918	2625	-238	688	5.8	5018
6 **option 1+2b+2c+3**	2166	13225	18640	6375	390	688	5.9	11944
7 **option 1+2c+3**	-749	13225	11352	3375	-135	688	6.1	6024
8 **option 1+2a**	1921	0	4803	2175	346	0	6.3	3704
9 **option 2a**	1574	0	3936	1875	283	0	6.6	2942
10 **option 3**	-1910	13225	8450	2325	-344	688	6.8	3521
11 **option 2c**	616	0	1540	750	111	0	6.8	1135
12 **option 1+2b**	2600	0	6499	3300	468	0	7.1	4655
13 **option 2b**	2303	0	5757	3000	415	0	7.2	4047

The Best Available Technology (BAT) is represented by the design option nr. 6, which is the extension of the LLCC option with some extra saving on the internal pressure drop of filters and other internal components. The saving is 18 640 kWh/yr (38%), at an extra investment of € 6 375, an LCC saving of € 11 944 (11%) and a payback of 5.9 years in Average Climate conditions.

With respect of the LLCC point the primary energy saving is only marginally better than that of option nr. 3 and thus it is assumed for modelling that the latter represents both the LLCC and BAT point .

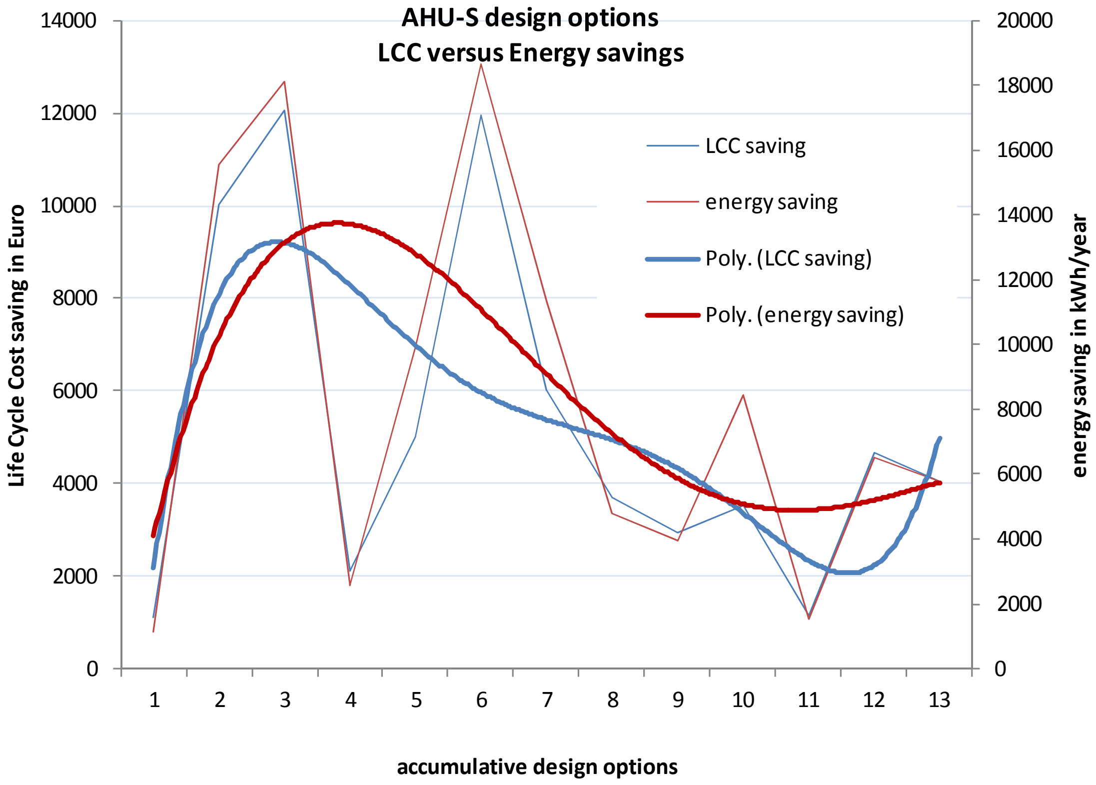

Figure 6-4. AHU-S design options LCC versus Energy savings

2.3.2 AHU-M

The AHU-M Base Case consumes 22 487 kWh/yr in electricity and causes space heating energy for ventilation losses of around 60 903 kWh/yr. The total direct and indirect primary energy consumption is 117 120 kWh/yr. The Life Cycle Costs are € 352 608. Acquisition costs including installation and installation materials are € 247 680, of which € 12 600 for the unit.

The first part of Table 4 summarizes the single design options for AHU-S in terms of energy savings and costs. The second part also shows the effects of accumulative options, ranked by payback time. The graph shows the LCC versus the savings of accumulative options and helps to identify the LLCC and BAT options.

As with the AHU-S differences between LLCC and BAT point are minimal and are assumed to be represented by accumulative option nr. 4, i.e. the combination of better fan efficiency, lower the face velocity to class V1 and improved heat recovery. The LCC saving is € 28 206 (8% vs. Base Case) and the primary energy annual energy saving is 47 953 kWh/yr (41% saving). The extra purchase price is € 9 576. Payback is within 4.3 years.

The average elasticity between Base Case and LLCC point is around € 0.20/ kWh primary energy (9 576/47 953)

Table 6-6. AHU-M Design Options, improvements versus Base Case

	electri-city saved	heating/ cooling saved	Total primary energy saving	price inc.	saving electric at 0.14/kWh	saving space heat at 0.042/kWh	payback period	LCC effect (17 yrs)
SINGLE OPTIONS	kWh/yr	kWh/yr	kWh/yr	EURO/yr	EURO/yr	EURO/yr	years	EURO
1 Fan system efficiency	1785	0	4462	630	250	0	2.5	3618
2a Face velocity 1.875 m/s (class V3)	4191	0	10478	3150	587	0	5.4	6825
2b Face velocity 1.5 m/s (class V1)	6131	0	15328	5040	858	0	5.9	9553
2c Filter F7 'A' class (150 --> 100 Pa)	1434	0	3585	1260	201	0	6.3	2153
3 Thermal efficiency 75% (from 44%)	-4446	33063	21949	3906	-622	1389	5.1	9120
SORTED SINGLE & ACCUMULATIVE								
1 **option 1**	1785	0	4462	630	250	0	2.5	3618
2 **option 1+2a+3**	3341	33063	41416	7686	468	1389	4.1	23873
3 **option 1+3**	-2308	33063	27293	4536	-323	1389	4.3	13577
4 **option 1+2b+3**	5956	33063	47953	9576	834	1389	4.3	28206
5 **option 1+2c**	3105	0	7763	1890	435	0	4.3	5500
6 **option 1+2c+3**	-988	33063	30593	5796	-138	1389	4.6	15460
7 **option 1+2b+2c+3**	6431	33063	49141	10836	900	1389	4.7	28078
8 **option 1+2a**	5643	0	14109	3780	790	0	4.8	9651
9 **option 3**	-4446	33063	21949	3906	-622	1389	5.1	9120
10 **option 2a**	4191	0	10478	3150	587	0	5.4	6825
11 **option 1+2b**	7429	0	18574	5670	1040	0	5.5	12012
12 **option 2b**	6131	0	15328	5040	858	0	5.9	9553
13 **option 2c**	1434	0	3585	1260	201	0	6.3	2153

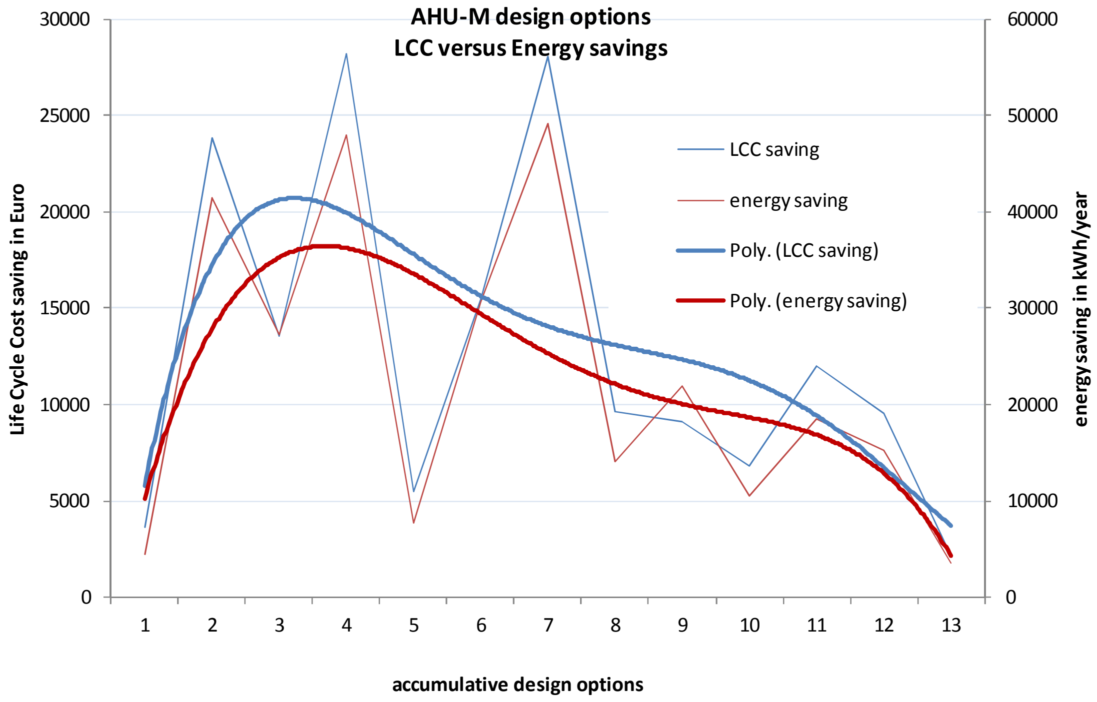

Figure 6-5. AHU-M design options LCC versus Energy savings

2.3.3 AHU-L

The AHU-L Base Case consumes 92 208 kWh/yr in electricity and causes space heating energy for ventilation losses of around 213 162 kWh/yr. The total direct and indirect primary energy consumption is 443 682 kWh/yr. The Life Cycle Costs are € 1 128 741. Acquisition costs including installation and installation materials are € 856 000, of which € 29 500 for the unit.

The first part of Table 5 summarizes the single design options for AHU-L in terms of energy savings and costs. The second part also shows the effects of accumulative options, ranked by payback time. The graph shows the LCC versus the savings of accumulative options and helps to identify the LLCC and BAT options.

As with AHU-M, the LLCC and BAT point are the same. The design option with the most LCC-saving and most energy saving is accumulative option nr. 5, i.e. the combination of better fan efficiency, lower the face velocity to class V1 and improved heat recovery. The LCC saving is € 84 973 (8 % vs. Base Case) and the primary energy annual energy saving is 181 075 kWh/yr (41% saving). The extra purchase price is € 22 420. Payback is within 3.5 years.

The average elasticity between Base Case and LLCC point is around € 0.12/ kWh primary energy (22 420/181 075)

Table 6-7. AHU-L Design Options, improvements versus Base Case

	electri-city saved	heating/ cooling saved	Total primary energy saving	price inc.	saving electric at 0.10/kWh	saving space heat at 0.032/kWh	simple payback period	LCC effect (17 yrs)
SINGLE OPTIONS	kWh/yr	kWh/yr	kWh/yr	EURO/yr	EURO/yr	EURO/yr	years	EURO
1 Fan system efficiency	9492	0	23730	1475	949	0	1.6	14661
2a Face velocity 1.875 m/s (class V3)	16329	0	40821	7375	1633	0	4.5	20384
2b Face velocity 1.5 m/s (class V1)	23886	0	59716	11800	2389	0	4.9	28807
2c Filter F7 'A' class (150 --> 100 Pa)	4773	0	11932	2950	477	0	6.2	5164
3 Thermal efficiency 75% (from 44%)	-14795	115722	78733	9145	-1480	3703	4.1	28656
SORTED SINGLE & ACCUMULATIVE								
1 **option 1**	9492	0	23730	1475	949	0	1.6	14661
2 **option 1+3**	-3780	115722	106271	10620	-378	3703	3.2	45906
3 **option 1+2c**	13773	0	34434	4425	1377	0	3.2	18990
4 **option 1+2a+3**	16674	115722	157407	17995	1667	3703	3.4	73304
5 **option 1+2b+3**	26141	115722	181075	22420	2614	3703	3.5	84973
6 **option 1+2c+3**	501	115722	116975	13570	50	3703	3.6	50235
7 **option 1+2a**	24140	0	60349	8850	2414	0	3.7	32187
8 **option 1+2b+2c+3**	27683	115722	184929	25370	2768	3703	3.9	84643
9 **option 3**	-14795	115722	78733	9145	-1480	3703	4.1	28656
10 **option 1+2b**	30919	0	77299	13275	3092	0	4.3	39288
11 **option 2a**	16329	0	40821	7375	1633	0	4.5	20384
12 **option 2b**	23886	0	59716	11800	2389	0	4.9	28807
13 **option 2c**	4773	0	11932	2950	477	0	6.2	5164

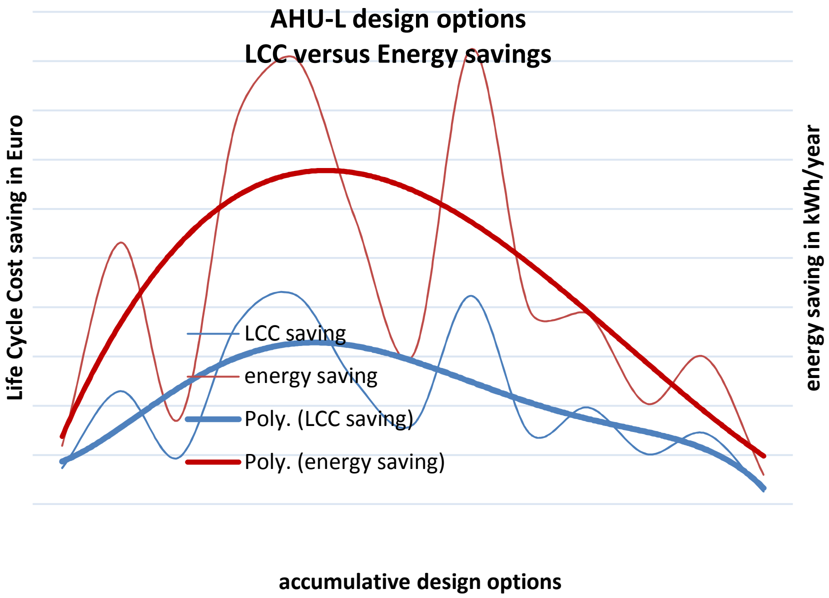

Figure 6-6. AHU-L design options LCC versus Energy savings

2.4 Summary

Table 6-8. Summary LLCC and BAT Design Options (Avg. climate, average installation)

Base Case, vs. zero vent. loss	CEXH	CHRV	AHU-S	AHU-M	AHU-L
electricity (kWh/yr & €/yr)	1 331 / € 240	3209/€ 578	6605/€ 1189	22487/€ 3148	92208/€ 9221
heating fuel vent.loss (kWh/yr & €/yr)	21 331/€ 1109	5064/€ 263	24361/€ 1267	60903/€ 2558	213162/€ 6821
primary energy (kWh/yr)	24 659	13 087	40 874	117 120	443 682
energy costs (€/yr)	€ 1 349	€ 841	€ 2 456	€ 5 706	€ 16 042
acquisition cost incl. installation (€)	€ 5 429	€ 22 500	€ 91 000	€ 247 680	€ 856 220
of which unit price (€)	€ 634	€ 5 281	€ 7 500	€ 12 600	€ 29 500
Life Cycle Costs (€ & %)	€ 31 997	€ 37 609	€ 136 482	€ 352 608	€ 1 128 741

Option LLCC, saving vs. Base Case	CEXH 1b+4b	CHRV 1+2+3+4b	AHU-S 1+2b+3	AHU-M 1+2b+3	AHU-L 1+2b+3
electricity saved (kWh/yr & €/yr)	927 / € 167	1 500 / € 270	1 959/€ 353	5 956/€ 834	26 141/€ 2614
heating fuel saved (kWh/yr & €/yr)	5 000 / € 260	2 747/€ 143	13 225/€ 688	33063/€ 1 389	115 722/€ 3 703
primary energy saved (kWh/yr & %)	7 317 (30%)	6 497 (50%)	18 124 (44%)	47 953 (41%)	181 075 (41%)
energy costs saved (€/yr & %)	€ 417 (31%)	€ 413 (49%)	€ 1 041 (42%)	€ 2 223 (39%)	€ 6 317 (40%)
purchase price increase (€)	€ 459	€ 1 515	€ 5 625	€ 9 576	€ 22 420
Payback (years)	1.1	3.7	5.4	4.3	3.5
Life Cycle Costs saved (€ & %)	€ 6 798 (20%)	€ 5 506 (15%)	€ 12 062 (9%)	€ 28 206 (8%)	€ 84 973 (10%)
price elasticity BC-->LLCC (€/kWh prim.)	€ 0.06/ kWh	€ 0.23/ kWh	€ 0.31/ kWh	€ 0.20/ kWh	€ 0.12/ kWh

Option BAT, saving vs. Base Case	3c	1+2+3+4c	1+2b+3	1+2b+3	1+2b+3
electricity saved (kWh/yr & €/yr)	-6 085 / € -1095	2 365 / € 426			
heating fuel saved (kWh/yr & €/yr)	38801 / € 2018	3 441 / € 179			
primary energy saved (kWh/yr & %)	23 587 (96%)	9 353 (71%)			
energy costs saved (€/yr & %)	€ 923 (68%)	€ 605 (68%)		as above	
purchase price increase (€)	€ 11 700	€ 5 015			
Payback (years)	12.7	8.3			
Life Cycle Costs saved (€ & %)	€ 3 979 (12%)	€ 5270 (14%)			
price elasticity LLCC-->BAT(€/kWh prim.)	€ 0.69/ kWh	€ 1.23/ kWh			

The base case heating ventilation losses are calculated against a fictitious zero ventilation situation. In reality the Base Case is always saving against the reference natural ventilation, but using those numbers would probably be confusing in this table.

Note that the percentages in brackets relate to savings versus the Base Case numbers on top of the table.

3. Best Not yet Available Technology options

3.1 Technology options

Task 5 principally foresees an evolutionary pathway for ventilation technology and mentions as latest trends :

- Increase number of ventilation units per building system;
- Downsize single ventilation system, smart balance between large and small units;
- Increase fan impeller diameter;
- Structurally decrease fan speed, at nominal design air flow;
- Minimal ductwork, optimal use of atriums, staircases, halls, double façade, full air-tight building shell, remaining ductwork with very large face sections;
- ‘hybrid’ solutions, probably also more slow-moving axial fans;
- Renovation: through the wall solutions, integration with façade renewal;
- Local VSD ventilation solutions to replace local VAV-box;
- Low speed it can be expected that the current trends will continue: Ventilation and air conditioning (space cooling and/or heating) will be more and more separate systems.

Some of these trends are already visible from the latest market data. For instance, the latest RLT-data show that the average capacity of units on the German market has decreased by 6%. [17]

At the moment it is too early to create exact benchmarks from the above trends, in part because many of them are not taking place at product-level but at the level of the whole building system. The future improvements, beyond BAT level, may well add up to another 10-20% savings.

3.2 Regulatory options

Some of the best not yet available improvement options are related to standards for the non-residential sector. Relevant information can be found in Task 1 (Standards) and 3 (Usage).

Task 1 shows the recommended ventilation rates for different types of non-residential buildings, according to EN 15251:2007. For modern “low-polluting” single offices the ventilation rate for emissions from the building (carpets, furniture, etc.) is set just as high as for fighting emissions from occupancy, i.e. at 0.4 $l/s/m^2$. This is 1.44 $m^3/h/m^2$ or –at a ceiling height of 3 m—0.48 m^3/m^3.

This means that, even if the non-residential building is completely empty, the ventilation rate in a non-residential building always has to run at least at 50% of its capacity. In other words, if the recommendations in EN 15251 and similar national standards are followed, even the smartest control can only save at the most 50%.

In comparison, the non-occupancy ventilation rate in modern residential buildings, using similar space and materials conditions, is set at less than half of that, i.e. at 0.15-0.2 m^3/m^3. The occupancy-dependent rate is around 0.5-0.6 m^3/m^3. This means that in an unoccupied building smart controls can reduce the ventilation rate to only 20-30% of its normal capacity. Smart sensors and controls can thus have a 70-80% saving both on electricity and on space heating.

[17] Kaup, C., *RLT-Geräte: Energiebedarf und Einsparpotenzial in Europa*, TGA Fachplaner 02.2012.

This difference in base ventilation does not make sense. There is no rational reason to assume that the potentially polluting materials (carpets, furniture) in an office are worse than in a residential dwelling. It must therefore be assumed that, whereas the residential standards have been updated under pressure of the much more dynamic EPBD and national building regulations for residential buildings, the standards for non-residential buildings are lagging behind and base their recommendations on legacy insights.

As will be elaborated in Task 7, this topic should be investigated and could deliver a considerable saving when combined with smart controls.

4. Sensitivity Analysis

As mentioned in the Introductory chapter, the sensitivity analysis will investigate if the LLCC targets are still economical at variations of energy rates, purchase prices and climatic conditions.

4.1 Energy and product prices

Energy prices vary regionally and they vary through the tariff system of the utilities. MEErP 2011 shows that electricity tariffs can be 50% lower (Bulgaria) or 50% higher (Denmark) than the EU average. Gas and oil prices, cutting out the extremes, are closer to the EU average but may still vary ± 20% depending on the country.

In parallel to this, electricity and gas rates show a difference of around 40% between small and big users. This has a negative impact on payback times in energy saving measures for large buildings.

As mentioned in Task 2, the purchase price and labour cost estimates are averages. Prices may be double (e.g. Northern Europe) or half (e.g. Eastern Europe), depending on the country. Fortunately the Member States with low labour costs are also the ones with the lowest energy tariffs, so there is no or hardly any accumulative effect. Countries with more or less an EU-average price are the Netherlands, France and the UK.

The sensitivity analysis can be relatively simple, because in fact a 50% reduction in energy rates or a doubling of purchase costs have the same effect: They double the payback period.

Given the fact that the payback periods of LLCC targets are all well below 10 years and the assumed product stock life is 17 years this means that all LLCC solutions are still ‘economical’, i.e. the extra investment can be recuperated through lower energy costs well within the product life (see Table 6.8).

As an example, in the least favourable case of the AHU-S the table 6-8 shows a payback period of 5.4 years for the LLCC option, based on a purchase price increase (production cost increase + trade margins) of € 5 625 and an annual saving of energy costs of € 1041 per year. When doubling the purchase price, to € 11.250, the payback time becomes 10.8 years (11250/1041). This is still well below the 17 year product life. Alternatively, if the energy saving is reduced by 50%, to € 520/year, the payback time also becomes 10.8 years (5625/520). This is again still well below the 17 year product life.

4.2 Climate conditions

The LLCC targets were determined for the reference Average Climate, as is used also in other preparatory studies e.g. for room air conditioners and boilers. The Average Climate is based on the outdoor temperature profile of Strasbourg (FR). In the Chapter 2 calculations the savings on space cooling were excluded.

In order to test the robustness of the targets also the payback periods of the LLCC targets were determined for the Warmer Climate, based on the outdoor temperature profile of Athens (GR), and the Colder Climate, based on the outdoor temperature profile of Helsinki (FIN).

The results are given in the table below for the LLCC in each of the five categories. This time also the savings on space cooling were taken into account.

As could be expected, the payback periods for the Colder climate are much shorter than those for the Average Climate. However, and probably contrary to some expectations, the payback times for the Warmer Climate are hardly longer than those for the Average Climate. The reason is the contribution of e.g. heat recovery options to savings in space cooling, which are in the same order of magnitude as those for space heating.

Table 6-9. Economic comparison of LLCC options under Average/ Warmer / Colder climate conditions

Option LLCC	CEXH 1b+4b	CHRV 1+2+3+4b	AHU-S 1+2b+3	AHU-M 1+2b+3	AHU-L 1+2b+3
electricity saving ventilation unit [kWh/a]	927	1500	1959	5956	26141
electricity saving space cooling [kWh/a]	279/ 1277/ 0	150/ 690/ 0	737/ 3378/ 0	1843/ 8446/ 0	6450/ 29561/ 0
space heating fuel saving [kWh/a]	7317/ 4579/ 12098	2747/ 1221/ 5886	13225/ 5982/ 25873	47953/ 29844/ 79573	115722/ 52340/ 226392
price increase [EUR]	458.5	1515	5625	9576	22420
saving electricity (ex cooling) [EUR/a]	167	270	353	834	2614
saving electricity cooling [EUR/a]	50/ 230/ 0	27/ 124/ 0	133/ 608/ 0	258/ 1182/ 0	645/ 2956/ 0
saving fuel space heating [EUR/a]	347/ 157/ 678	143/ 63/ 306	688/ 311/ 1345	1389/ 628/ 2716	3703/ 1675/ 7245
payback period [years]*	1/ 0.9/ 0.7	3.4/ 3.3/ 2.6	4.8/ 4.4/ 3.3	3.9/ 3.6/ 2.7	3.2/ 3.1/ 2.3

**=Note that payback periods for the average climate in this table are slightly lower than in Chapter 2 because space cooling is included*

Calculated values for all design options can be found in Annex I.

Please note that especially the calculation of the merits of heat recovery for space cooling are based on a rough calculation and may be too optimistic (see Task 7 report, comments AL-KO).

5. System options

5.1 Mechanical versus natural ventilation

All five product categories are part of mechanical ventilation systems, but overall the most popular systems are still natural ventilation solutions, i.e. ventilation through infiltration and the opening of windows.

In a new or renovated buildings that answer the building codes, natural ventilation is not an option. The reason is not only the excessive heating loss but also the fact that a healthy indoor climate for the inhabitants can no longer be guaranteed. As a rule-of-thumb: If more than one-third of the windows is replaced by modern windows, mechanical ventilation is a necessity.

A second reason is comfort, especially with heat recovery ventilation. In many instances inhabitants do not tolerate the cold draughts from natural ventilation. A first reaction is to fight the drafts, which gives more comfort, saves energy but also creates an unhealthy living environment. Ventilation systems with preheated air from heat recovery are a good solution.

Last but not least, mechanical ventilation is also believed to be economically attractive. After anti-draught measures, roof- and floor insulation it is seen as one of the best investments. On average the ventilation heat losses determine 35-38% of the heating boiler load, but especially in modern well-insulated dwellings the ventilation heat losses can make up more than half of the heat losses.

The tables in Annex II compare natural ventilation (at assumed zero cost) to the five Base Case solutions and to the five LLCC target values. The assumptions for natural ventilation losses are explained in Task 4 and –as is mentioned there—probably too optimistic for the current natural ventilation practice.

Still, the calculations show that even at these optimistic values for natural ventilation, the payback periods for most categories are in the range of the standard product service life of 17 years. The exceptions are the larger air handling units where the discounted energy prices are used. On the other hand, as mentioned in the introductory chapter, the period of 17 years was mainly assumed to reflect current short time thinking; if installation labour and components such as grilles and ducts were discounted over the actual product life of 35-50 years the payback would be much more favourable.

5.2 Ducts and other system components

Eurovent argues that in Northern Europe 5% and in Middle and Southern Europe 15% of the air in ventilation systems is lost due to leakage of the ductwork.[18] Eurovent estimates that more than 25 TWh of electricity use for ventilation systems (including ventilation for central air cooling or heating) is involved and that high-quality, leak-free ducts can make a significant difference. An important basis for their assessments is an AIVC study for the European Commission. [19]

More in general, leak-free, low-friction, easy-to-clean, properly sized, effectively positioned and shaped systems and system components can make a considerable contribution in lowering the

[18] Eurovent Committee on Ductwork, pers. comm. 'Ductwork arguments', 2011.

[19] Carrié, F.R., Andersson, J., Wouters, P. (ed), *Improving ductwork,…, a status report on ductwork airtightness in various countries with recommendations for future designs and regulations*, International Energy Agency (IEA)-Air Infiltration and Ventilation Centre (AIVC) for European Commission in the framework of ECB and ESP as well as the SAVE programme (SAVE-DUCT project), DG TREN, 1999.

required flow rate and the external pressure drop. As such they constitute an important opportunity for energy saving. Furthermore, they can contribute in improving the Indoor Air Quality.

Ducts and other system components are not included in the scope of the underlying study but they can be included in horizontal measures or other pieces of legislation (Energy Performance of Buildings, Green Public Procurement, MS building codes, etc.) that are addressing the design of installations in buildings. This subject will be revisited in the policy analysis of Task 7.

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References

Armines, ENTR Lot 6 Air Conditioning, *Draft Report Task 1, Product Definition, Standards and Legislation,* 2011.

Carrié, F.R., Andersson, J., Wouters, P. (ed.), *Improving ductwork,..., a status report on ductwork airtightness in various countries with recommendations for future designs and regulations*, International Energy Agency (IEA) - Air Infiltration and Ventilation Centre (AIVC) for European Commission in the framework of ECB and ESP as well as the SAVE programme (SAVE-DUCT project), DG TREN, 1999.

COMMISSION REGULATION (EU) No 327/2011 of 30 March 2011 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to *ecodesign requirements for fans driven by motors with an electric input power between 125 W and 500 kW*, OJ 6.4.2011, L90/8.

EN 13503:2006 (new draft Jan. 2010) *Ventilation for buildings — Air handling units — Rating and performance for units, components and sections*. 2006(2010)

EN 13799: 2007, *Ventilation for non-residential buildings; Performance requirements for ventilation and room-conditioning systems*. May 2007

EN 15251: 2007, *Indoor environmental input parameters for design and assessment of energy performance of buildings, addressing indoor air quality, thermal environment, lighting and acoustics*. June 2007.

European Commission, *Impact Assessment Guidelines (IAG)*, 2009.

Eurovent COM_11013, Chapter 3 on Filters, 2011.

Eurovent Committee on Ductwork, *'100829 Ductwork arguments'*, pers. comm., 29 Aug. 2010.

JIEG, joint industry expert group Eurovent, EVIA, EPEE, pers. comm. Feb. 2012.

Kaup, C., *RLT-Geräte: Energiebedarf und Einsparpotenzial in Europa*, TGA Fachplaner 02.2012.

Kaup, C., *Erweiterung der Studie zur Energieeffizienz von raumlufttechnischen Geraten*, HLH, 1/2012 (Springer Verlag).

Kemna, R. et al., *Methodology for Ecodesign of Energy-related Products (MEErP 2011), Methodology Report Part 1: Methods*, VHK for European Commission DG ENTR, Nov. 2011. (www.meerp.eu)

Kemna, R. et al., *Methodology for Ecodesign of Energy-using Products (MEEuP 2005), Methodology Report*, VHK for European Commission DG ENTR, Nov. 2005.

VHK, ENTR Lot 6 Ventilation, *Draft Report Task 1, Product Definition, Standards and Legislation*, 2 May 2011.

VHK, ENTR Lot 6 Ventilation, *Draft Report Task 2, Market*, 2 May 2011.

VHK, ENTR Lot 6 Ventilation, *Draft Report Task 3*, *Usage,* 2 May 2011.

VHK, ENTR Lot 6 Ventilation, *Draft Report Task 4, Base Cases*, 2 May 2011.

VHK, ENTR Lot 6 Ventilation, *Draft Report Task 5, Technical analysis*, 2 May 2011

US EPA, *Low pressure drop HVAC design for laboratories*, Feb. 2005.

ANNEX I: Design Options Tables

Annex Table 1a. Design Options CEXH							
Parameters	**Base Case**	**Option 1a**	**Option 1b**	**Option 2**	**Option 3a**	**Option 3b**	**Option 3c**
performance data							
design/ effective/ average flow rate [000m3/h]	1.5/ 1.1/ 1.0	1.5/ 1.1/ 1.0	1.5/ 1.1/ 1.0	1.5/ 1.13/ 0.96	1.2/ 1.1/ 0.8	1.2/ 1.1/ 0.8	1.5/ 1.13/ 0.96
pressure drop external/internal/total [Pa]	154/ 37/ 191	154/ 37/ 191	154/ 37/ 191	154/ 27/ 181	154/ 57/ 211	154/ 57/ 211	154/ 57/ 211
specific fan power [kW/(m3/s)]	1.66	1.09	0.80	1.57	1.83	1.83	9.25
individual rated fan power [kW]	0.35	0.23	0.17	0.33	0.32	0.32	1.93
fans system efficiency [-]	23%	35%	48%	23%	23%	23%	5%
heat recovery thermal efficiency [-]	0%	0%	0%	0%	65%	75%	183%
misc factor	1.33	1.33	1.33	1.33	1.10	1.10	1.33
control factor on-off/variable/total	0.8/ 0.8/ 0.64	0.8/ 0.8/ 0.64	0.8/ 0.8/ 0.64	0.8/ 0.8/ 0.64	0.8/ 0.8/ 0.64	0.8/ 0.8/ 0.64	0.8/ 0.8/ 0.64
*consumption data**							
electricity consumption AHU [MWh/a]	1.33	0.87	0.64	1.26	2.68	2.43	7.42
electricity rate EUR/kWh	0.18	0.18	0.18	0.18	0.18	0.18	0.18
electricity costs AHU [000 EUR /a]	0.24	0.16	0.11	0.23	0.48	0.44	1.33
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	21/ 10/ 42	21/ 10/ 42	21/ 10/ 42	21/ 10/ 42	6/ 3/ 15	5/ 2/ 11	-17/ -8/ -32
fossil fuel (ca. gas) rate[EUR/kWh]	0.052	0.052	0.052	0.052	0.052	0.052	0.052
space heat extra cost Avg/Warm/Cold climate* [000 EUR/a]	1.1/ 0.5/ 2.2	1.1/ 0.5/ 2.2	1.1/ 0.5/ 2.2	1.1/ 0.5/ 2.2	0.3/ 0.1/ 0.8	0.2/ 0.1/ 0.6	-0.9/ -0.4/ -1.6
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	1.9/ 8.7	1.9/ 8.7	1.9/ 8.7	1.9/ 8.7	0.6/ 2.5	0.4/ 1.8	-1.6/ -7.2
space cooling extra costs [000 EUR/a]	0.2/ 1.0	0.2/ 1.0	0.2/ 1.0	0.2/ 1.0	0.1/ 0.3	0.0/ 0.2	-0.2/ -0.8
total extra energy cost Avg/Warm/Cold * [000 EUR/a]	1.6/ 1.7/ 2.4	1.5/ 1.6/ 2.3	1.4/ 1.6/ 2.3	1.6/ 1.7/ 2.4	0.9/ 0.9/ 1.2	0.7/ 0.7/ 1.0	0.2/ 0.1/ -0.3
investment data							
product end price [000 EUR]	0.634	0.710	0.793	0.639	4.521	3.521	8.634
Installation materials*** [000 EUR]	2.000	2.000	2.000	2.000	5.733	4.733	4.000
install. labour new/ retrofit/ replace/ avg**** [000 EUR]	3/ 4/ 1/ 3	3/ 4/ 1/ 3	3/ 4/ 1/ 3	3/ 4/ 1/ 3	8/ 9/ 4/ 8	7/ 8/ 4/ 7	5/ 6/ 2/ 5
total new/ retrofit/ replace/ avg**** [000 EUR]	5/ 6/ 1/ 5	5/ 7/ 1/ 6	5/ 7/ 1/ 6	5/ 6/ 1/ 5	18/ 20/ 9/ 18	15/ 17/ 8/ 15	17/ 18/ 10/ 17
LCC							
LCC avg install in A/W/C climate	32/ 35/ 46	31/ 33/ 45	30/ 33/ 44	32/ 34/ 46	33/ 33/ 39	27/ 28/ 32	21/ 19/ 12
LCC decrease	0/ 0/ 0	1/ 1/ 1	2/ 2/ 2	0/ 0/ 0	-1/ 1/ 8	5/ 7/ 14	11/ 16/ 35
Saving data							
electricity saving ventilation unit [kWh/a]	0	456	693	70	-1344	-1101	-6085
electricity saving space cooling [kWh/yr]	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	845/ 3872/ 0	943/ 4322/ 0	2176/ 9972/ 0
space heating fuel saving [kWh/a]	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	14962/ 6855/ 27161	16726/ 7653/ 30613	38801/ 17656/ 73358
primary energy saving (ex cooling) [kWh/a]	0/ 0/ 0	1141/ 1141/ 1141	1733/ 1733/ 1733	174/ 174/ 174	11601/ 3494/ 23800	13973/ 4900/ 27860	23587/ 2442/ 58144
price increase [EUR]	0	76.08	158.5	4.755	12368.33333	9568.333333	11700
saving electricity (ex cooling) [EUR/a]	0	82	125	13	-242	-198	-1095
saving electricity cooling [EUR/a]	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	152/ 697/ 0	170/ 778/ 0	392/ 1795/ 0
saving fuel space heating [EUR/a]	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	778/ 356/ 1412	870/ 398/ 1592	2018/ 918/ 3815
payback period [years]	0.0/ 0.0/ 0.0	0.9/ 0.9/ 0.9	1.3/ 1.3/ 1.3	0.4/ 0.4/ 0.4	18.0/ 15.2/ 10.6	11.4/ 9.8/ 6.9	8.9/ 7.2/ 4.3

Annex Table 1b. Design Options CEXH							
Parameters	**Option 4a**	**Option 1b+4b**	**Option 1b+4c**	**Option 1b+2+3a**	**Option 1b+2+3b**	**Option 1b+2+3a+4b**	**Option 1b+2+3a+4c**
performance data							
design/ effective/ average flow rate [000m3/h]	1.5/ 1.1/ 0.8	1.5/ 1.1/ 0.7	1.5/ 1.13/ 0.63	1.2/ 1.1/ 0.8	1.2/ 1.1/ 0.8	1.2/ 1.13/ 0.61	1.5/ 1.1/ 0.6
pressure drop external/internal/total [Pa]	154/ 37/ 191	154/ 37/ 191	154/ 37/ 191	154/ 47/ 201	154/ 47/ 201	154/ 47/ 201	154/ 47/ 201
specific fan power [kW/(m3/s)]	1.66	0.80	0.80	0.84	0.84	0.84	0.84
individual rated fan power [kW]	0.35	0.17	0.17	0.14	0.14	0.14	0.17
fans system efficiency [-]	23%	48%	48%	48%	48%	48%	48%
heat recovery thermal efficiency [-]	0%	0%	0%	65%	75%	65%	65%
misc factor	1.33	1.33	1.33	1.10	1.10	1.10	1.33
control factor on-off/variable/total	0.7/ 0.8/ 0.56	0.7/ 0.7/ 0.49	0.7/ 0.6/ 0.42	0.8/ 0.8/ 0.64	0.8/ 0.8/ 0.64	0.7/ 0.7/ 0.49	0.7/ 0.6/ 0.42
*consumption data**							
electricity consumption AHU [MWh/a]	1.18	0.40	0.28	0.56	0.56	0.35	0.30
electricity rate EUR/kWh	0.18	0.18	0.18	0.18	0.18	0.18	0.18
electricity costs AHU [000 EUR /a]	0.21	0.07	0.05	0.10	0.10	0.06	0.05
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	19/ 8/ 37	16/ 7/ 32	14/ 6/ 27	6/ 3/ 12	5/ 2/ 11	5/ 2/ 11	5/ 2/ 12
fossil fuel (ca. gas) rate[EUR/kWh]	0.052	0.052	0.052	0.052	0.052	0.052	0.052
space heat extra cost Avg/Warm/Cold climate* [000 EUR/a]	1.0/ 0.4/ 1.9	0.8/ 0.4/ 1.7	0.7/ 0.3/ 1.4	0.3/ 0.1/ 0.6	0.2/ 0.1/ 0.6	0.3/ 0.1/ 0.6	0.3/ 0.1/ 0.6
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	1.7/ 7.6	1.5/ 6.7	1.2/ 5.7	0.6/ 2.5	0.4/ 1.8	0.4/ 1.9	0.4/ 2.0
space cooling extra costs [000 EUR/a]	0.2/ 0.9	0.2/ 0.8	0.1/ 0.6	0.1/ 0.3	0.0/ 0.2	0.0/ 0.2	0.0/ 0.2
total extra energy cost Avg/Warm/Cold * [000 EUR/a]	1.4/ 1.5/ 2.1	1.1/ 1.2/ 1.7	0.9/ 1.0/ 1.5	0.5/ 0.5/ 0.7	0.4/ 0.4/ 0.7	0.4/ 0.4/ 0.6	0.4/ 0.4/ 0.7
investment data							
product end price [000 EUR]	0.934	1.093	4.593	5.446	4.396	5.746	8.946
Installation materials*** [000 EUR]	2.000	2.000	2.000	5.733	4.733	5.733	5.733
install. labour new/ retrofit/ replace/ avg**** [000 EUR]	3/ 4/ 1/ 3	3/ 4/ 1/ 3	3/ 4/ 1/ 3	8/ 9/ 4/ 8	7/ 8/ 4/ 7	8/ 9/ 4/ 8	8/ 9/ 4/ 8
total new/ retrofit/ replace/ avg**** [000 EUR]	6/ 7/ 2/ 6	6/ 7/ 2/ 6	9/ 10/ 5/ 9	19/ 20/ 10/ 19	16/ 17/ 8/ 16	19/ 21/ 10/ 19	23/ 24/ 13/ 22
LCC							
LCC avg install in A/W/C climate	29/ 31/ 42	24/ 26/ 35	25/ 27/ 34	27/ 28/ 31	22/ 23/ 27	25/ 26/ 30	28/ 29/ 33
LCC decrease	3/ 3/ 5	8/ 8/ 11	7/ 8/ 12	5/ 7/ 15	10/ 12/ 19	7/ 9/ 16	4/ 6/ 13
Saving data							
electricity saving ventilation unit [kWh/a]	147	927	1050	776	776	979	1035
electricity saving space cooling [kWh/yr]	149/ 681/ 0	279/ 1277/ 0	409/ 1873/ 0	845/ 3872/ 0	943/ 4322/ 0	925/ 4241/ 0	916/ 4197/ 0
space heating fuel saving [kWh/a]	2666/ 1206/ 5216	5000/ 2261/ 9781	7333/ 3317/ 14345	15156/ 6855/ 29651	16726/ 7653/ 30613	16455/ 7510/ 30576	16277/ 7432/ 30170
primary energy saving (ex cooling) [kWh/a]	3035/ 1575/ 5585	7317/ 4579/ 12099	9957/ 5941/ 16970	17096/ 8795/ 31591	18666/ 9593/ 32552	18903/ 9958/ 33025	18865/ 10020/ 32758
price increase [EUR]	300	458.5	3958.5	13293.33333	10443.33333	13593.33333	16793.33333
saving electricity (ex cooling) [EUR/a]	27	167	189	140	140	176	186
saving electricity cooling [EUR/a]	27/ 123/ 0	50/ 230/ 0	74/ 337/ 0	152/ 697/ 0	170/ 778/ 0	167/ 763/ 0	165/ 756/ 0
saving fuel space heating [EUR/a]	139/ 63/ 271	260/ 118/ 509	381/ 172/ 746	788/ 356/ 1542	870/ 398/ 1592	856/ 391/ 1590	846/ 386/ 1569
payback period [years]	1.6/ 1.4/ 1.0	1.0/ 0.9/ 0.7	6.1/ 5.7/ 4.2	12.3/ 11.1/ 7.9	8.9/ 7.9/ 6.0	11.3/ 10.2/ 7.7	14.0/ 12.6/ 9.6

Annex Table 2a. Design Options CHRV							
Parameters	**Base Case**	**Option 1**	**Option 2**	**Option 3**	**Option 4a**	**Option 1+4b**	**Option 1+4c**
performance data		AA	AE	AI	AM	AQ	AU
design/ effective/ average flow rate [000m3/h]	2.3/ 1.9/ 1.1	2.3/ 1.9/ 1.1	2.3/ 1.9/ 1.1	2.3/ 1.91/ 1.08	2.3/ 1.9/ 0.9	2.3/ 1.9/ 0.9	2.3/ 1.91/ 0.68
pressure drop external/internal/total [Pa]	160/ 140/ 300	160/ 140/ 300	160/ 97/ 257	160/ 165/ 325	160/ 140/ 300	160/ 140/ 300	160/ 140/ 300
specific fan power [kW/(m3/s)]	1.71	1.25	1.47	1.86	1.71	1.71	1.71
individual rated fan power [kW]	0.54	0.39	0.46	0.58	0.54	0.54	0.54
fans system efficiency [-]	35%	48%	35%	35%	35%	35%	35%
heat recovery thermal efficiency [-]	80%	80%	80%	90%	80%	80%	80%
misc factor	1.18	1.18	1.18	1.18	1.18	1.18	1.18
control factor on-off/variable/total	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.5/ 0.8/ 0.40	0.6/ 0.7/ 0.42	0.6/ 0.5/ 0.30
*consumption data**							
electricity consumption AHU [MWh/a]	3.21	2.34	2.75	3.48	2.75	2.30	1.14
electricity rate EUR/kWh	0.18	0.18	0.18	0.18	0.18	0.18	0.18
electricity costs AHU [000 EUR /a]	0.58	0.42	0.50	0.63	0.50	0.41	0.20
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	5/ 2/ 14	5/ 2/ 14	5/ 2/ 14	3/ 1/ 10	4/ 2/ 12	5/ 2/ 12	3/ 1/ 9
fossil fuel (ca. gas) rate[EUR/kWh]	0.052	0.052	0.052	0.052	0.052	0.052	0.052
space heat extra cost Avg/Warm/Cold climate* [000 EUR/a]	0.3/ 0.1/ 0.7	0.3/ 0.1/ 0.7	0.3/ 0.1/ 0.7	0.1/ 0.1/ 0.5	0.2/ 0.1/ 0.6	0.2/ 0.1/ 0.6	0.2/ 0.1/ 0.5
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	0.4/ 2.0	0.4/ 2.0	0.4/ 2.0	0.2/ 1.0	0.4/ 1.6	0.4/ 1.7	0.3/ 1.2
space cooling extra costs [000 EUR/a]	0.0/ 0.2	0.0/ 0.2	0.0/ 0.2	0.0/ 0.1	0.0/ 0.2	0.0/ 0.2	0.0/ 0.1
total extra energy cost Avg/Warm/Cold * [000 EUR/a]	0.9/ 0.9/ 1.3	0.7/ 0.8/ 1.2	0.8/ 0.8/ 1.2	0.8/ 0.8/ 1.1	0.8/ 0.8/ 1.1	0.7/ 0.7/ 1.1	0.4/ 0.4/ 0.7
investment data							
product end price [000 EUR]	5.281	5.968	5.928	5.809	5.581	5.581	9.081
Installation materials*** [000 EUR]	7.1	7.1	7.1	7.1	7.1	7.1	7.1
install. labour new/ retrofit/ replace/ avg**** [000 EUR]	10/ 12/ 6/ 11	10/ 12/ 6/ 11	10/ 12/ 6/ 11	10/ 12/ 6/ 11	10/ 12/ 6/ 11	10/ 12/ 6/ 11	10/ 12/ 6/ 11
total new/ retrofit/ replace/ avg**** [000 EUR]	23/ 25/ 11/ 22	23/ 25/ 12/ 23	23/ 25/ 12/ 23	23/ 25/ 12/ 23	23/ 25/ 12/ 23	23/ 25/ 12/ 23	26/ 29/ 15/ 26
LCC							
LCC avg install in A/W/C climate	38/ 38/ 45	36/ 36/ 43	24/ 24/ 24	24/ 24/ 24	24/ 24/ 24	23/ 24/ 24	27/ 27/ 27
LCC decrease	0/ 0/ 0	2/ 2/ 2	14/ 14/ 21	14/ 14/ 21	14/ 14/ 21	14/ 14/ 21	11/ 11/ 18
Saving data							
electricity saving ventilation unit [kWh/a]	0	869	458	-267	457	904	2070
electricity saving space cooling [kWh/yr]	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	134/ 613/ 0	45/ 204/ 0	33/ 153/ 0	100/ 460/ 0
space heating fuel saving [kWh/a]	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	2400/ 1085/ 4695	863/ 362/ 2371	647/ 271/ 1778	1942/ 814/ 5335
primary energy saving (ex cooling) [kWh/a]	0/ 0/ 0	2172/ 2172/ 2172	1144/ 1144/ 1144	1731/ 417/ 4026	2004/ 1503/ 3513	2908/ 2532/ 4039	7118/ 5990/ 10511
price increase [EUR]	0	686.53	646.9225	528.1	300	300	3800
saving electricity (ex cooling) [EUR/a]	0	156	82	-48	82	163	373
saving electricity cooling [EUR/a]	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	24/ 110/ 0	8/ 37/ 0	6/ 28/ 0	18/ 83/ 0
saving fuel space heating [EUR/a]	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	125/ 56/ 244	45/ 19/ 123	34/ 14/ 92	101/ 42/ 277
payback period [years]	0.0/ 0.0/ 0.0	4.4/ 4.4/ 4.4	7.9/ 7.9/ 7.9	5.2/ 4.5/ 2.7	2.2/ 2.2/ 1.5	1.5/ 1.5/ 1.2	7.7/ 7.6/ 5.8

Annex Table 2b. Design Options CHRV							
Parameters	**Option 1+2**	**Option 1+3**	**Option 2+3**	**Option 1+2+3**	**Option 1+2+3+4a**	**Option 1+2+3+4b**	**Option 1+2+3+4c**
performance data	AY	BC	BG	BK	BO	BS	
design/ effective/ average flow rate [000m3/h]	2.3/ 1.9/ 1.1	2.3/ 1.9/ 1.1	2.3/ 1.91/ 1.08	2.3/ 1.9/ 1.1	2.3/ 1.9/ 0.9	2.3/ 1.91/ 0.95	2.3/ 1.9/ 0.7
pressure drop external/internal/total [Pa]	160/ 97/ 257	160/ 165/ 325	160/ 117/ 277	160/ 145/ 305	160/ 145/ 305	160/ 145/ 305	160/ 145/ 305
specific fan power [kW/(m3/s)]	1.07	1.35	1.59	1.27	1.27	1.27	1.27
individual rated fan power [kW]	0.33	0.42	0.50	0.40	0.40	0.40	0.40
fans system efficiency [-]	48%	48%	35%	48%	48%	48%	48%
heat recovery thermal efficiency [-]	80%	90%	90%	90%	90%	90%	90%
misc factor	1.18	1.18	1.18	1.18	1.18	1.18	1.18
control factor on-off/variable/total	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.5/ 0.8/ 0.40	0.6/ 0.7/ 0.42	0.6/ 0.5/ 0.30
*consumption data**							
electricity consumption AHU [MWh/a]	2.01	2.53	2.97	2.38	2.04	1.71	0.84
electricity rate EUR/kWh	0.18	0.18	0.18	0.18	0.18	0.18	0.18
electricity costs AHU [000 EUR /a]	0.36	0.46	0.53	0.43	0.37	0.31	0.15
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	5/ 2/ 14	3/ 1/ 10	3/ 1/ 10	3/ 1/ 10	2/ 1/ 8	2/ 1/ 8	2/ 1/ 6
fossil fuel (ca. gas) rate[EUR/kWh]	0.052	0.052	0.052	0.052	0.052	0.052	0.052
space heat extra cost Avg/Warm/Cold climate* [000 EUR/a]	0.3/ 0.1/ 0.7	0.1/ 0.1/ 0.5	0.1/ 0.1/ 0.5	0.1/ 0.1/ 0.5	0.1/ 0.0/ 0.4	0.1/ 0.0/ 0.4	0.1/ 0.0/ 0.3
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	0.4/ 2.0	0.2/ 1.0	0.2/ 1.0	0.2/ 1.0	0.2/ 0.8	0.2/ 0.9	0.1/ 0.6
space cooling extra costs [000 EUR/a]	0.0/ 0.2	0.0/ 0.1	0.0/ 0.1	0.0/ 0.1	0.0/ 0.1	0.0/ 0.1	0.0/ 0.1
total extra energy cost Avg/Warm/Cold * [000 EUR/a]	0.7/ 0.7/ 1.1	0.6/ 0.6/ 1.0	0.7/ 0.7/ 1.0	0.6/ 0.6/ 0.9	0.5/ 0.5/ 0.8	0.5/ 0.5/ 0.7	0.3/ 0.3/ 0.5
investment data							
product end price [000 EUR]	6.614	6.496	6.337	6.496	6.796	6.796	10.296
Installation materials*** [000 EUR]	7.1	7.1	7.1	7.1	7.1	7.1	7.1
install. labour new/ retrofit/ replace/ avg**** [000 EUR]	10/ 12/ 6/ 11	10/ 12/ 6/ 11	10/ 12/ 6/ 11	10/ 12/ 6/ 11	10/ 12/ 6/ 11	10/ 12/ 6/ 11	10/ 12/ 6/ 11
total new/ retrofit/ replace/ avg**** [000 EUR]	24/ 26/ 13/ 24	24/ 26/ 13/ 24	24/ 26/ 12/ 24	24/ 26/ 13/ 24	24/ 26/ 13/ 24	24/ 26/ 13/ 24	28/ 30/ 16/ 28
LCC							
LCC avg install in A/W/C climate	25/ 25/ 25	24/ 24/ 25	24/ 24/ 25	24/ 24/ 25	25/ 25/ 25	24/ 24/ 25	28/ 28/ 28
LCC decrease	13/ 13/ 20	13/ 14/ 20	13/ 14/ 20	13/ 14/ 20	13/ 13/ 20	13/ 14/ 20	10/ 10/ 17
Saving data							
electricity saving ventilation unit [kWh/a]	1203	674	241	830	1168	1500	2365
electricity saving space cooling [kWh/yr]	0/ 0/ 0	134/ 613/ 0	134/ 613/ 0	134/ 613/ 0	156/ 715/ 0	150/ 690/ 0	184/ 843/ 0
space heating fuel saving [kWh/a]	0/ 0/ 0	2400/ 1085/ 4695	2400/ 1085/ 4695	2400/ 1085/ 4695	2863/ 1266/ 6284	2747/ 1221/ 5886	3441/ 1492/ 8270
primary energy saving (ex cooling) [kWh/a]	3007/ 3007/ 3007	4085/ 2770/ 6380	3003/ 1688/ 5298	4475/ 3160/ 6770	5784/ 4187/ 9205	6497/ 4972/ 9637	9353/ 7404/ 14182
price increase [EUR]	1333.4525	1214.63	1056.2	1214.63	1514.63	1514.63	5014.63
saving electricity (ex cooling) [EUR/a]	216	121	43	149	210	270	426
saving electricity cooling [EUR/a]	0/ 0/ 0	24/ 110/ 0	24/ 110/ 0	24/ 110/ 0	28/ 129/ 0	27/ 124/ 0	33/ 152/ 0
saving fuel space heating [EUR/a]	0/ 0/ 0	125/ 56/ 244	125/ 56/ 244	125/ 56/ 244	149/ 66/ 327	143/ 63/ 306	179/ 78/ 430
payback period [years]	6/ 6/ 6	4.5/ 4.2/ 3.3	5.5/ 5.0/ 3.7	4.1/ 3.8/ 3.1	3.9/ 3.7/ 2.8	3.4/ 3.3/ 2.6	7.9/ 7.7/ 5.9

Annex Table 3a. Design Options AHU-S

Parameters	**Base Case**	**Option 1**	**Option 2a**	**Option 2b**	**Option 2c**	**Option 3**	**Options 1+2a**
performance data	S	W	AA	AE	AI	AM	AQ
design/ effective/ average flow rate [000m3/h]	4.0/ 3.6/ 1.9	4.0/ 3.6/ 1.9	4.0/ 3.6/ 1.9	4.0/ 3.64/ 1.92	4.0/ 3.6/ 1.9	4.0/ 3.6/ 1.9	4.0/ 3.64/ 1.92
pressure drop external/internal/total [Pa]	244/ 292/ 536	244/ 292/ 536	244/ 164/ 408	244/ 105/ 349	244/ 242/ 486	244/ 447/ 691	244/ 164/ 408
specific fan power [kW/(m3/s)]	1.99	1.85	1.51	1.29	1.80	2.56	1.41
individual rated fan power [kW]	1.10	1.03	0.84	0.72	1.00	1.42	0.78
fans system efficiency [-]	54%	58%	54%	54%	54%	54%	58%
heat recovery thermal efficiency [-]	44%	44%	44%	44%	44%	75%	44%
misc factor	1.10	1.10	1.10	1.10	1.10	1.10	1.10
control factor on-off/variable/total	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48
*consumption data**							
electricity consumption AHU [MWh/a]	6.61	6.15	5.03	4.30	5.99	8.52	4.68
electricity rate EUR/kWh	0.18	0.18	0.18	0.18	0.18	0.18	0.18
electricity costs AHU [000 EUR /a]	1.19	1.11	0.91	0.77	1.08	1.53	0.84
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	24/ 11/ 53	24/ 11/ 53	24/ 11/ 53	24/ 11/ 53	24/ 11/ 53	11/ 5/ 27	24/ 11/ 53
fossil fuel (ca. gas) rate[EUR/kWh]	0.052	0.052	0.052	0.052	0.052	0.052	0.052
space heat extra cost Avg/Warm/Cold climate* [000 EUR/a]	1.3/ 0.6/ 2.7	1.3/ 0.6/ 2.7	1.3/ 0.6/ 2.7	1.3/ 0.6/ 2.7	1.3/ 0.6/ 2.7	0.6/ 0.3/ 1.4	1.3/ 0.6/ 2.7
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	2.1/ 9.8	2.1/ 9.8	2.1/ 9.8	2.1/ 9.8	2.1/ 9.8	1.0/ 4.4	2.1/ 9.8
space cooling extra costs [000 EUR/a]	0.2/ 1.1	0.2/ 1.1	0.2/ 1.1	0.2/ 1.1	0.2/ 1.1	0.1/ 0.5	0.2/ 1.1
total extra energy cost Avg/Warm/Cold * [000 EUR/a]	2.7/ 2.8/ 3.9	2.6/ 2.8/ 3.9	2.4/ 2.6/ 3.6	2.3/ 2.4/ 3.5	2.6/ 2.7/ 3.8	2.2/ 2.3/ 2.9	2.3/ 2.5/ 3.6
investment data							
product end price [000 EUR]	7.5	7.8	9.375	10.5	8.25	9.825	9.675
Installation materials*** [000 EUR]	34.4	34.4	34.4	34.4	34.4	34.4	34.4
install. labour new/ retrofit/ replace/ avg**** [000 EUR]	52/ 62/ 9/ 52	52/ 62/ 9/ 52	52/ 62/ 9/ 52	52/ 62/ 9/ 52	52/ 62/ 9/ 52	52/ 62/ 9/ 52	52/ 62/ 9/ 52
total new/ retrofit/ replace/ avg**** [000 EUR]	94/ 104/ 17/	94/ 104/ 17/ 91	96/ 106/ 18/ 93	97/ 107/ 20/ 94	95/ 105/ 17/ 91	96/ 106/ 19/ 93	96/ 106/ 19/ 93
LCC							
LCC avg install in A/W/C climate	136/ 139/ 158	135/ 138/ 156	134/ 136/ 155	132/ 135/ 153	135/ 138/ 156	131/ 132/ 143	133/ 135/ 154
LCC decrease	0/ 0/ 0	1/ 1/ 1	3/ 3/ 3	4/ 4/ 4	1/ 1/ 1	6/ 7/ 15	4/ 4/ 4
Saving data							
electricity saving ventilation unit kWh/yr	0	456	1574	2303	616	-1910	1921
electricity saving space cooling kWh/yr	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	737/ 3378/ 0	0/ 0/ 0
fuel saving	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	13225/ 5982/	0/ 0/ 0
primary energy saving (ex cooling)	0/ 0/ 0	1139/ 1139/ 1139	3936/ 3936/ 3936	5757/ 5757/ 5757	1540/ 1540/ 1540	8450/ 1207/ 21098	4803/ 4803/ 4803
price increase	0	300	1875	3000	750	2325	2175
saving electricity (ex cooling)	0	82	283	415	111	-344	346
electricity cooling	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	133/ 608/ 0	0/ 0/ 0
saving fuel (ex cooling, except warm)	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	688/ 311/ 1345	0/ 0/ 0
payback period	0.0/ 0.0/ 0.0	3.7/ 3.7/ 3.7	6.6/ 6.6/ 6.6	7.2/ 7.2/ 7.2	6.8/ 6.8/ 6.8	4.9/ 4.0/ 2.3	6.3/ 6.3/ 6.3

Annex Table 3b. Design Options AHU-S							
Parameters	**Options 1+2b**	**Options 1+2c**	**Options 1+3**	**Options 1+2a+3**	**Options 1+2b+3**	**Options 1+2c+3**	**Opt.1+2b+2c+3**
performance data							
design/ effective/ average flow rate [000m3/h]	4.0/ 3.6/ 1.9	4.0/ 3.6/ 1.9	4.0/ 3.64/ 1.92	4.0/ 3.6/ 1.9	4.0/ 3.6/ 1.9	4.0/ 3.64/ 1.92	4.0/ 3.6/ 1.9
pressure drop external/internal/total [Pa]	244/ 105/ 349	244/ 242/ 486	244/ 447/ 691	244/ 251/ 495	244/ 161/ 405	244/ 397/ 641	244/ 143/ 387
specific fan power [kW/(m3/s)]	1.20	1.68	2.38	1.71	1.40	2.21	1.33
individual rated fan power [kW]	0.67	0.93	1.32	0.95	0.78	1.23	0.74
fans system efficiency [-]	58%	58%	58%	58%	58%	58%	58%
heat recovery thermal efficiency [-]	44%	44%	75%	75%	75%	75%	75%
misc factor	1.10	1.10	1.10	1.10	1.10	1.10	1.10
control factor on-off/variable/total	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48
*consumption data**							
electricity consumption AHU [MWh/a]	4.01	5.58	7.93	5.68	4.65	7.35	4.44
electricity rate EUR/kWh	0.18	0.18	0.18	0.18	0.18	0.18	0.18
electricity costs AHU [000 EUR /a]	0.72	1.00	1.43	1.02	0.84	1.32	0.80
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	24/ 11/ 53	24/ 11/ 53	11/ 5/ 27	11/ 5/ 27	11/ 5/ 27	11/ 5/ 27	11/ 5/ 27
fossil fuel (ca. gas) rate[EUR/kWh]	0.052	0.052	0.052	0.052	0.052	0.052	0.052
space heat extra cost Avg/Warm/Cold climate* [000 EUR/a]	1.3/ 0.6/ 2.7	1.3/ 0.6/ 2.7	0.6/ 0.3/ 1.4	0.6/ 0.3/ 1.4	0.6/ 0.3/ 1.4	0.6/ 0.3/ 1.4	0.6/ 0.3/ 1.4
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	2.1/ 9.8	2.1/ 9.8	1.0/ 4.4	1.0/ 4.4	1.0/ 4.4	1.0/ 4.4	1.0/ 4.4
space cooling extra costs [000 EUR/a]	0.2/ 1.1	0.2/ 1.1	0.1/ 0.5	0.1/ 0.5	0.1/ 0.5	0.1/ 0.5	0.1/ 0.5
total extra energy cost Avg/Warm/Cold * [000 EUR/a]	2.2/ 2.4/ 3.5	2.5/ 2.7/ 3.7	2.1/ 2.2/ 2.8	1.7/ 1.8/ 2.4	1.5/ 1.6/ 2.2	2.0/ 2.1/ 2.7	1.5/ 1.5/ 2.2
investment data							
product end price [000 EUR]	10.8	8.55	10.125	12	13.125	10.875	13.875
Installation materials*** [000 EUR]	34.4	34.4	34.4	34.4	34.4	34.4	34.4
install. labour new/ retrofit/ replace/ avg**** [000 EUR]	52/ 62/ 9/ 52	52/ 62/ 9/ 52	52/ 62/ 9/ 52	52/ 62/ 9/ 52	52/ 62/ 9/ 52	52/ 62/ 9/ 52	52/ 62/ 9/ 52
total new/ retrofit/ replace/ avg**** [000 EUR]	97/ 107/ 20/ 94	95/ 105/ 18/ 92	97/ 107/ 19/ 93	98/ 108/ 21/ 95	100/ 110/ 22/ 96	97/ 107/ 20/ 94	100/ 110/ 23/ 97
LCC							
LCC avg install in A/W/C climate	132/ 134/ 153	134/ 137/ 155	129/ 130/ 141	124/ 125/ 136	122/ 123/ 134	128/ 129/ 140	122/ 123/ 134
LCC decrease	5/ 5/ 5	2/ 2/ 2	7/ 9/ 16	12/ 14/ 21	14/ 16/ 23	8/ 10/ 17	14/ 16/ 23
Saving data							
electricity saving ventilation unit kWh/yr	2600	1029	-1323	921	1959	-749	2166
electricity saving space cooling kWh/yr	0/ 0/ 0	0/ 0/ 0	737/ 3378/ 0	737/ 3378/ 0	737/ 3378/ 0	737/ 3378/ 0	737/ 3378/ 0
fuel saving	0/ 0/ 0	0/ 0/ 0	13225/ 5982/ 25873	13225/ 5982/ 25873	13225/ 5982/ 25873	13225/ 5982/ 25873	13225/ 5982/ 25873
primary energy saving (ex cooling)	6499/ 6499/ 6499	2573/ 2573/ 2573	9918/ 2675/ 22566	15528/ 8284/ 28176	18124/ 10880/ 30772	11352/ 4109/ 24000	18640/ 11397/ 31288
price increase	3300	1050	2625	4500	5625	3375	6375
saving electricity (ex cooling)	468	185	-238	166	353	-135	390
electricity cooling	0/ 0/ 0	0/ 0/ 0	133/ 608/ 0	133/ 608/ 0	133/ 608/ 0	133/ 608/ 0	133/ 608/ 0
saving fuel (ex cooling, except warm)	0/ 0/ 0	0/ 0/ 0	688/ 311/ 1345	688/ 311/ 1345	688/ 311/ 1345	688/ 311/ 1345	688/ 311/ 1345
payback period	7/ 7/ 7	5.7/ 5.7/ 5.7	4.5/ 3.9/ 2.4	4.6/ 4.1/ 3.0	4.8/ 4.4/ 3.3	4.9/ 4.3/ 2.8	5.3/ 4.9/ 3.7

Annex Table 4a. Design Options AHU-M

Parameters	Base Case	Option 1	Option 2a	Option 2b	Option 2c	Option 3	Options 1+2a
performance data							
design/ effective/ average flow rate [000m3/h]	10.0/ 8.7/ 4.8	10.0/ 8.7/ 4.8	10.0/ 8.7/ 4.8	10.0/ 8.70/ 4.80	10.0/ 8.7/ 4.8	10.0/ 8.7/ 4.8	10.0/ 8.70/ 4.80
pressure drop external/internal/total [Pa]	450/ 334/ 784	450/ 334/ 784	450/ 188/ 638	450/ 120/ 570	450/ 284/ 734	450/ 489/ 939	450/ 188/ 638
specific fan power [kW/(m3/s)]	2.70	2.49	2.20	1.97	2.53	3.24	2.03
individual rated fan power [kW]	3.75	3.46	3.05	2.73	3.52	4.50	2.81
fans system efficiency [-]	58%	63%	58%	58%	58%	58%	63%
heat recovery thermal efficiency [-]	44%	44%	44%	44%	44%	75%	44%
misc factor	1.15	1.15	1.15	1.15	1.15	1.15	1.15
control factor on-off/variable/total	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48
*consumption data**							
electricity consumption AHU [MWh/a]	22.49	20.70	18.30	16.36	21.05	26.93	16.84
electricity rate EUR/kWh	0.14	0.14	0.14	0.14	0.14	0.14	0.14
electricity costs AHU [000 EUR /a]	3.15	2.90	2.56	2.29	2.95	3.77	2.36
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	61/ 27/ 132	61/ 27/ 132	61/ 27/ 132	61/ 27/ 132	61/ 27/ 132	28/ 12/ 67	61/ 27/ 132
fossil fuel (ca. gas) rate[EUR/kWh]	0.042	0.042	0.042	0.042	0.042	0.042	0.042
space heat extra cost Avg/Warm/Cold climate* [000 EUR/a]	2.6/ 1.1/ 5.5	2.6/ 1.1/ 5.5	2.6/ 1.1/ 5.5	2.6/ 1.1/ 5.5	2.6/ 1.1/ 5.5	1.2/ 0.5/ 2.8	2.6/ 1.1/ 5.5
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	5.3/ 24.4	5.3/ 24.4	5.3/ 24.4	5.3/ 24.4	5.3/ 24.4	2.4/ 10.9	5.3/ 24.4
space cooling extra costs [000 EUR/a]	0.5/ 2.1	0.5/ 2.1	0.5/ 2.1	0.5/ 2.1	0.5/ 2.1	0.2/ 1.0	0.5/ 2.1
total extra energy cost Avg/Warm/Cold * [000 EUR/a]	6.2/ 6.4/ 8.7	5.9/ 6.2/ 8.4	5.6/ 5.8/ 8.1	5.3/ 5.6/ 7.8	6.0/ 6.2/ 8.5	5.1/ 5.2/ 6.6	5.4/ 5.6/ 7.9
investment data							
product end price [000 EUR]	12.6	13.23	15.75	17.64	13.86	16.506	16.38
Installation materials*** [000 EUR]	98.2	98.2	98.2	98.2	98.2	98.2	98.2
install. labour new/ retrofit/ replace/ avg**** [000 EUR]	147/ 177/ 9/ 147	147/ 177/ 9/ 147	147/ 177/ 9/ 147	147/ 177/ 9/ 147	147/ 177/ 9/ 147	147/ 177/ 9/ 147	147/ 177/ 9/ 147
total new/ retrofit/ replace/ avg**** [000 EUR]	258/ 288/ 22/ 248	258/ 288/ 22/ 248	261/ 291/ 25/ 251	263/ 293/ 27/ 253	259/ 289/ 23/ 249	262/ 292/ 26/ 252	262/ 292/ 25/ 251
LCC							
LCC avg install in A/W/C climate	353/ 357/ 395	349/ 353/ 392	346/ 350/ 389	343/ 347/ 386	350/ 355/ 393	339/ 341/ 364	343/ 347/ 386
LCC decrease	0/ 0/ 0	4/ 4/ 4	7/ 7/ 7	10/ 10/ 10	2/ 2/ 2	14/ 16/ 32	10/ 10/ 10
Saving data							
electricity saving ventilation unit [kWh/a]	0	1785	4191	6131	1434	-4446	5643
electricity saving space cooling [kWh/yr]	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	1843/ 8446/ 0	0/ 0/ 0
space heating fuel saving [kWh/a]	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	33063/ 14954/ 64683	0/ 0/ 0
primary energy saving (ex cooling) [kWh/a]	0/ 0/ 0	4462/ 4462/ 4462	10478/ 10478/ 10478	15328/ 15328/ 15328	3585/ 3585/ 3585	21949/ 3840/ 53569	14109/ 14109/ 14109
price increase [EUR]	0	630	3150	5040	1260	3906	3780
saving electricity (ex cooling) [EUR/a]	0	250	587	858	201	-622	790
saving electricity cooling [EUR/a]	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	258/ 1182/ 0	0/ 0/ 0
saving fuel space heating [EUR/a]	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	1389/ 628/ 2717	0/ 0/ 0
payback period [years]	0.0/ 0.0/ 0.0	2.5/ 2.5/ 2.5	5.4/ 5.4/ 5.4	5.9/ 5.9/ 5.9	6.3/ 6.3/ 6.3	3.8/ 3.3/ 1.9	4.8/ 4.8/ 4.8

Annex Table 4b. Design Options AHU-M

Parameters	Options 1+2b	Options 1+2c	Options 1+3	Options 1+2a+3	Options 1+2b+3	Options 1+2c+3	Options 1+2b+2c+3
performance data	AU	AY	BC	BG	BK	BO	BS
design/ effective/ average flow rate [000m3/h]	10.0/ 8.7/ 4.8	10.0/ 8.7/ 4.8	10.0/ 8.70/ 4.80	10.0/ 8.7/ 4.8	10.0/ 8.7/ 4.8	10.0/ 8.70/ 4.80	10.0/ 8.7/ 4.8
pressure drop external/internal/total [Pa]	450/ 120/ 570	450/ 284/ 734	450/ 489/ 939	450/ 275/ 725	450/ 176/ 626	450/ 439/ 889	450/ 158/ 608
specific fan power [kW/(m3/s)]	1.81	2.33	2.98	2.30	1.99	2.82	1.93
individual rated fan power [kW]	2.51	3.24	4.14	3.20	2.76	3.92	2.68
fans system efficiency [-]	63%	63%	63%	63%	63%	63%	63%
heat recovery thermal efficiency [-]	44%	44%	75%	75%	75%	75%	75%
misc factor	1.15	1.15	1.15	1.15	1.15	1.15	1.15
control factor on-off/variable/total	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48
*consumption data**							
electricity consumption AHU [MWh/a]	15.06	19.38	24.80	19.15	16.53	23.48	16.06
electricity rate EUR/kWh	0.14	0.14	0.14	0.14	0.14	0.14	0.14
electricity costs AHU [000 EUR /a]	2.11	2.71	3.47	2.68	2.31	3.29	2.25
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	61/ 27/ 132	61/ 27/ 132	28/ 12/ 67	28/ 12/ 67	28/ 12/ 67	28/ 12/ 67	28/ 12/ 67
fossil fuel (ca. gas) rate[EUR/kWh]	0.042	0.042	0.042	0.042	0.042	0.042	0.042
space heat extra cost Avg/Warm/Cold climate* [000 EUR/a]	2.6/ 1.1/ 5.5	2.6/ 1.1/ 5.5	1.2/ 0.5/ 2.8	1.2/ 0.5/ 2.8	1.2/ 0.5/ 2.8	1.2/ 0.5/ 2.8	1.2/ 0.5/ 2.8
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	5.3/ 24.4	5.3/ 24.4	2.4/ 10.9	2.4/ 10.9	2.4/ 10.9	2.4/ 10.9	2.4/ 10.9
space cooling extra costs [000 EUR/a]	0.5/ 2.1	0.5/ 2.1	0.2/ 1.0	0.2/ 1.0	0.2/ 1.0	0.2/ 1.0	0.2/ 1.0
total extra energy cost Avg/Warm/Cold * [000 EUR/a]	5.1/ 5.4/ 7.6	5.7/ 6.0/ 8.3	4.8/ 4.9/ 6.3	4.1/ 4.1/ 5.5	3.7/ 3.8/ 5.1	4.7/ 4.7/ 6.1	3.6/ 3.7/ 5.1
investment data							
product end price [000 EUR]	18.27	14.49	17.136	20.286	22.176	18.396	23.436
Installation materials*** [000 EUR]	98.2	98.2	98.2	98.2	98.2	98.2	98.2
install. labour new/ retrofit/ replace/ avg**** [000 EUR]	147/ 177/ 9/ 147	147/ 177/ 9/ 147	147/ 177/ 9/ 147	147/ 177/ 9/ 147	147/ 177/ 9/ 147	147/ 177/ 9/ 147	147/ 177/ 9/ 147
total new/ retrofit/ replace/ avg**** [000 EUR]	263/ 293/ 27/ 253	260/ 290/ 23/ 250	262/ 292/ 26/ 252	265/ 295/ 29/ 255	267/ 297/ 31/ 257	264/ 294/ 27/ 253	269/ 299/ 32/ 259
LCC							
LCC avg install in A/W/C climate	341/ 345/ 383	347/ 351/ 390	335/ 336/ 359	324/ 326/ 349	320/ 321/ 345	333/ 334/ 357	320/ 322/ 345
LCC decrease	12/ 12/ 12	6/ 6/ 6	18/ 21/ 36	28/ 31/ 46	33/ 35/ 51	20/ 23/ 38	32/ 35/ 51
Saving data							
electricity saving ventilation unit [kWh/a]	7429	3105	-2308	3341	5956	-988	6431
electricity saving space cooling [kWh/yr]	0/ 0/ 0	0/ 0/ 0	1843/ 8446/ 0	1843/ 8446/ 0	1843/ 8446/ 0	1843/ 8446/ 0	1843/ 8446/ 0
space heating fuel saving [kWh/a]	0/ 0/ 0	0/ 0/ 0	33063/ 14954/ 64683	33063/ 14954/ 64683	33063/ 14954/ 64683	33063/ 14954/ 64683	33063/ 14954/ 64683
primary energy saving (ex cooling) [kWh/a]	18574/ 18574/ 18574	7763/ 7763/ 7763	27293/ 9184/ 58913	41416/ 23307/ 73036	47953/ 29844/ 79573	30593/ 12484/ 62213	49141/ 31033/ 80761
price increase [EUR]	5670	1890	4536	7686	9576	5796	10836
saving electricity (ex cooling) [EUR/a]	1040	435	-323	468	834	-138	900
saving electricity cooling [EUR/a]	0/ 0/ 0	0/ 0/ 0	258/ 1182/ 0	258/ 1182/ 0	258/ 1182/ 0	258/ 1182/ 0	258/ 1182/ 0
saving fuel space heating [EUR/a]	0/ 0/ 0	0/ 0/ 0	1389/ 628/ 2717	1389/ 628/ 2717	1389/ 628/ 2717	1389/ 628/ 2717	1389/ 628/ 2717
payback period [years]	5/ 5/ 5	4.3/ 4.3/ 4.3	3.4/ 3.0/ 1.9	3.6/ 3.4/ 2.4	3.9/ 3.6/ 2.7	3.8/ 3.5/ 2.2	4.3/ 4.0/ 3.0

Annex Table 5a. Design Options AHU-L							
Parameters	**Base Case**	**Option 1**	**Option 2a**	**Option 2b**	**Option 2c**	**Option 3**	**Options 1+2a**
performance data							
design/ effective/ average flow rate [000m3/h]	35.0/ 29.7/ 16.8	35.0/ 29.7/ 16.8	35.0/ 29.7/ 16.8	35.0/ 29.66/ 16.80	35.0/ 29.7/ 16.8	35.0/ 29.7/ 16.8	35.0/ 29.66/ 16.80
pressure drop external/internal/total [Pa]	575/ 391/ 966	575/ 391/ 966	575/ 220/ 795	575/ 141/ 716	575/ 341/ 916	575/ 546/ 1121	575/ 220/ 795
specific fan power [kW/(m3/s)]	3.17	2.84	2.61	2.35	3.00	3.68	2.34
individual rated fan power [kW]	15.40	13.81	12.67	11.41	14.60	17.87	11.37
fans system efficiency [-]	61%	68%	61%	61%	61%	61%	68%
heat recovery thermal efficiency [-]	44%	44%	44%	44%	44%	75%	44%
misc factor	1.18	1.18	1.18	1.18	1.18	1.18	1.18
control factor on-off/variable/total	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48
*consumption data**							
electricity consumption AHU [MWh/a]	92.21	82.72	75.88	68.32	87.44	107.00	68.07
electricity rate EUR/kWh	0.10	0.10	0.10	0.10	0.10	0.10	0.10
electricity costs AHU [000 EUR /a]	9.22	8.27	7.59	6.83	8.74	10.70	6.81
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	213/ 95/ 462	213/ 95/ 462	213/ 95/ 462	213/ 95/ 462	213/ 95/ 462	97/ 42/ 235	213/ 95/ 462
fossil fuel (ca. gas) rate[EUR/kWh]	0.032	0.032	0.032	0.032	0.032	0.032	0.032
space heat extra cost Avg/Warm/Cold climate* [000 EUR/a]	6.8/ 3.0/ 14.8	6.8/ 3.0/ 14.8	6.8/ 3.0/ 14.8	6.8/ 3.0/ 14.8	6.8/ 3.0/ 14.8	3.1/ 1.4/ 7.5	6.8/ 3.0/ 14.8
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	18.6/ 85.4	18.6/ 85.4	18.6/ 85.4	18.6/ 85.4	18.6/ 85.4	8.3/ 38.1	18.6/ 85.4
space cooling extra costs [000 EUR/a]	1.2/ 5.3	1.2/ 5.3	1.2/ 5.3	1.2/ 5.3	1.2/ 5.3	0.5/ 2.4	1.2/ 5.3
total extra energy cost Avg/Warm/Cold * [000 EUR/a]	17.2/ 17.6/ 24.0	16.3/ 16.6/ 23.0	15.6/ 16.0/ 22.4	14.8/ 15.2/ 21.6	16.7/ 17.1/ 23.5	14.3/ 14.4/ 18.2	14.8/ 15.2/ 21.6
investment data							
product end price [000 EUR]	29.5	30.975	36.875	41.3	32.45	38.645	38.35
Installation materials*** [000 EUR]	282.3	282.3	282.3	282.3	282.3	282.3	282.3
install. labour new/ retrofit/ replace/ avg**** [000 EUR]	575/ 690/ 34/ 573	575/ 690/ 34/ 573	575/ 690/ 34/ 573	575/ 690/ 34/ 573	575/ 690/ 34/ 573	575/ 690/ 34/ 573	575/ 690/ 34/ 573
total new/ retrofit/ replace/ avg**** [000 EUR]	887/ 1002/ 64/	888/ 1003/ 65/ 858	894/ 1009/ 71/ 864	899/ 1014/ 75/ 868	890/ 1005/ 66/ 859	896/ 1011/ 73/ 865	896/ 1011/ 72/ 865
LCC							
LCC avg install in A/W/C climate	1149/ 1155/ 1264	1134/ 1141/ 1249	1128/ 1135/ 1244	1120/ 1126/ 1235	1144/ 1150/ 1259	1109/ 1111/ 1175	1117/ 1123/ 1232
LCC decrease	0/ 0/ 0	15/ 15/ 15	20/ 20/ 20	29/ 29/ 29	5/ 5/ 5	40/ 44/ 89	32/ 32/ 32
Saving data							
electricity saving ventilation unit [kWh/a]	0	9492	16329	23886	4773	-14795	24140
electricity saving space cooling [kWh/yr]	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	6450/ 29561/ 0	0/ 0/ 0
space heating fuel saving [kWh/a]	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	115722/ 52340/	0/ 0/ 0
primary energy saving (ex cooling) [kWh/a]	0/ 0/ 0	23730/ 23730/ 23730	40821/ 40821/ 40821	59716/ 59716/ 59716	11932/ 11932/ 11932	78733/ 15352/	60349/ 60349/ 60349
price increase [EUR]	0	1475	7375	11800	2950	9145	8850
saving electricity (ex cooling) [EUR/a]	0	949	1633	2389	477	-1480	2414
saving electricity cooling [EUR/a]	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	645/ 2956/ 0	0/ 0/ 0
saving fuel space heating [EUR/a]	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	0/ 0/ 0	3703/ 1675/ 7245	0/ 0/ 0
payback period [years]	0.0/ 0.0/ 0.0	1.6/ 1.6/ 1.6	4.5/ 4.5/ 4.5	4.9/ 4.9/ 4.9	6.2/ 6.2/ 6.2	3.2/ 2.9/ 1.6	3.7/ 3.7/ 3.7

Annex Table 5b. Design Options AHU-L

Parameters	Options 1+2b	Options 1+2c	Options 1+3	Options 1+2a+3	Options 1+2b+3	Options 1+2c+3	Options 1+2b+2c+3
performance data							
design/ effective/ average flow rate [000m3/h]	35.0/ 29.7/ 16.8	35.0/ 29.7/ 16.8	35.0/ 29.66/ 16.80	35.0/ 29.7/ 16.8	35.0/ 29.7/ 16.8	35.0/ 29.66/ 16.80	35.0/ 29.7/ 16.8
pressure drop external/internal/total [Pa]	575/ 141/ 716	575/ 341/ 916	575/ 546/ 1121	575/ 307/ 882	575/ 197/ 772	575/ 496/ 1071	575/ 179/ 754
specific fan power [kW/(m3/s)]	2.11	2.69	3.30	2.59	2.27	3.15	2.22
individual rated fan power [kW]	10.23	13.10	16.03	12.61	11.03	15.31	10.77
fans system efficiency [-]	68%	68%	68%	68%	68%	68%	68%
heat recovery thermal efficiency [-]	44%	44%	75%	75%	75%	75%	75%
misc factor	1.18	1.18	1.18	1.18	1.18	1.18	1.18
control factor on-off/variable/total	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48
*consumption data**							
electricity consumption AHU [MWh/a]	61.29	78.43	95.99	75.53	66.07	91.71	64.53
electricity rate EUR/kWh	0.10	0.10	0.10	0.10	0.10	0.10	0.10
electricity costs AHU [000 EUR /a]	6.13	7.84	9.60	7.55	6.61	9.17	6.45
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	213/ 95/ 462	213/ 95/ 462	97/ 42/ 235	97/ 42/ 235	97/ 42/ 235	97/ 42/ 235	97/ 42/ 235
fossil fuel (ca. gas) rate[EUR/kWh]	0.032	0.032	0.032	0.032	0.032	0.032	0.032
space heat extra cost Avg/Warm/Cold clim.* [000 EUR/a]	6.8/ 3.0/ 14.8	6.8/ 3.0/ 14.8	3.1/ 1.4/ 7.5	3.1/ 1.4/ 7.5	3.1/ 1.4/ 7.5	3.1/ 1.4/ 7.5	3.1/ 1.4/ 7.5
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	18.6/ 85.4	18.6/ 85.4	8.3/ 38.1	8.3/ 38.1	8.3/ 38.1	8.3/ 38.1	8.3/ 38.1
space cooling extra costs [000 EUR/a]	1.2/ 5.3	1.2/ 5.3	0.5/ 2.4	0.5/ 2.4	0.5/ 2.4	0.5/ 2.4	0.5/ 2.4
total extra energy cost Avg/Warm/Cold * [000 EUR/a]	14.1/ 14.5/ 20.9	15.8/ 16.2/ 22.6	13.2/ 13.3/ 17.1	11.2/ 11.3/ 15.1	10.2/ 10.3/ 14.1	12.8/ 12.9/ 16.7	10.1/ 10.2/ 14.0
investment data							
product end price [000 EUR]	42.775	33.925	40.12	47.495	51.92	43.07	54.87
Installation materials*** [000 EUR]	282.3	282.3	282.3	282.3	282.3	282.3	282.3
install. labour new/ retrofit/ replace/ avg**** [000 EUR]	575/ 690/ 34/ 573	575/ 690/ 34/ 573	575/ 690/ 34/ 573	575/ 690/ 34/ 573	575/ 690/ 34/ 573	575/ 690/ 34/ 573	575/ 690/ 34/ 573
total new/ retrofit/ replace/ avg**** [000 EUR]	900/ 1015/ 77/ 869	891/ 1006/ 68/ 861	897/ 1012/ 74/ 867	905/ 1020/ 81/ 874	909/ 1024/ 86/ 879	900/ 1015/ 77/ 870	912/ 1027/ 89/ 882
LCC							
LCC avg install in A/W/C climate	1109/ 1116/ 1225	1130/ 1136/ 1245	1092/ 1094/ 1158	1064/ 1066/ 1131	1053/ 1054/ 1119	1088/ 1089/ 1154	1053/ 1055/ 1119
LCC decrease	39/ 39/ 39	19/ 19/ 19	57/ 62/ 106	84/ 89/ 134	96/ 101/ 145	61/ 66/ 110	96/ 100/ 145
Saving data							
electricity saving ventilation unit [kWh/a]	30919	13773	-3780	16674	26141	501	27683
electricity saving space cooling [kWh/yr]	0/ 0/ 0	0/ 0/ 0	6450/ 29561/ 0	6450/ 29561/ 0	6450/ 29561/ 0	6450/ 29561/ 0	6450/ 29561/ 0
space heating fuel saving [kWh/a]	0/ 0/ 0	0/ 0/ 0	115722/ 52340/ 226392	115722/ 52340/ 226392	115722/ 52340/ 226392	115722/ 52340/ 226392	115722/ 52340/ 226392
primary energy saving (ex cooling) [kWh/a]	77299/ 77299/ 77299	34434/ 34434/ 34434	106271/ 42890/ 216941	157407/ 94025/ 268077	181075/ 117694/ 291745	116975/ 53593/ 227645	184929/ 121547/ 295599
price increase [EUR]	13275	4425	10620	17995	22420	13570	25370
saving electricity (ex cooling) [EUR/a]	3092	1377	-378	1667	2614	50	2768
saving electricity cooling [EUR/a]	0/ 0/ 0	0/ 0/ 0	645/ 2956/ 0	645/ 2956/ 0	645/ 2956/ 0	645/ 2956/ 0	645/ 2956/ 0
saving fuel space heating [EUR/a]	0/ 0/ 0	0/ 0/ 0	3703/ 1675/ 7245	3703/ 1675/ 7245	3703/ 1675/ 7245	3703/ 1675/ 7245	3703/ 1675/ 7245
payback period [years]	4/ 4/ 4	3.2/ 3.2/ 3.2	2.7/ 2.5/ 1.5	3.0/ 2.9/ 2.0	3.2/ 3.1/ 2.3	3.1/ 2.9/ 1.9	3.6/ 3.4/ 2.5

ANNEX II: Mechanical vs. natural ventilation tables

Annex Table 6. CEXH and CHRV Base Cases vs. natural ventilation		
Parameters	**CEXH**	**CHRV**
performance data		
design/ effective/ average flow rate [000m3/h]	1.5/ 1.13/ 0.96	2.25/ 2.0/ 1.1
pressure drop external/internal/total [Pa]	154/ 37/ 191	160/ 140/ 300
specific fan power [kW/(m3/s)]	1.08	1.72
individual rated fan power [kW]	0.345	0.536
fans system efficiency [-]	23%	35%
heat recovery thermal efficiency [-]	0%	80%
misc factor	1.33	1.10
control factor on-off/variable/total	0.8/ 0.8/ 0.64	0.6/ 0.8/ 0.48
consumption data		
electricity consumption AHU [MWh/a]	1.33	3.21
electricity rate EUR/kWh	0.18	0.18
electricity costs AHU [000 EUR /a]	0.2	0.6
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	21/ 10/ 42	5/ 2/ 14
fossil fuel (ca. gas) rate[EUR/kWh]	0.052	0.042
space heating cost Avg/Warm/Cold climate [000 EUR/a]	1.1/ 0.5/ 2.2	0.3/ 0.1/ 0.7
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	1.9/ 8.7	0.4/ 2.0
space cooling extra costs [000 EUR/a]	0.2/ 1.0	0.0/ 0.2
total extra energy cost Avg/Warm/Cold [000 EUR/a]	1.6/ 1.7/ 2.4	0.9/ 0.9/ 1.3
investment data		
product end price [000 EUR]	0.634	5.281
Installation materials** [000 EUR]	2.00	7.10
install. labour new/ retrofit/ replace/ avg*** [000 EUR]	3/ 4/ 1/ 3	10/ 12/ 6/ 11
total new/ retrofit/ replace/ avg*** [000 EUR]	5/ 6/ 1/ 5	23/ 25/ 11/ 22
equivalent (in IAQ) natural ventilation		
ventilation heat loss Avg/Warm/Cold climate [MWh/a]	34/ 15/ 67	62/ 28/ 121
extra heat energy cost Avg/Warm/Cold climate [000 EUR/a]	1.8/ 0.8/ 3.5	3.2/ 1.5/ 6.3
ventilation cooling loss Avg/Warm climate [MWh/a]	3.0/ 13.9	5.5/ 25.3
extra space cooling costs Avg/Warm climate [000 EUR/a]	0.3/ 1.6	0.6/ 2.8
total energy cost Avg/Warm/Cold climate [000 EUR/a]	2.1/ 2.4/ 3.5	3.8/ 4.3/ 6.3
saving versus natural ventilation (reference)		
primary energy saving total [MWh/yr]	12/ 15/ 22	61/ 76/ 99
net energy cost saved (incl. electr.) A/W/C [000 EUR/a]	0.6/ 0.6/ 1.1	2.9/ 3.4/ 5.0
simple payback period avg install in A/W/C climate [years]	9.8/ 8.4/ 5.1	7.7/ 6.6/ 4.5

Please note that, as opposed to a similar Base Case calculation in Task 4 Table 4-6, in Annex Tables 6 to 9 the primary energy saving, saving of net energy costs and the payback period are calculated including the electricity for ventilation and the saving from space cooling.

Annex Table 7. AHU Base Cases versus natural ventilation			
Parameters	**AHU-S**	**AHU-M**	**AHU-L**
performance data			
design/ effective/ average flow rate [000m3/h]	4.0/ 3.64/ 1.92	10.0/ 8.7/ 4.8	35.0/ 29.7/ 16.8
pressure drop external/internal/total [Pa]	244/ 292/ 536	450/ 334/ 784	575/ 391/ 966
specific fan power [kW/(m3/s)]	1.98	2.7	3.42
individual rated fan power [kW]	1.1	3.75	15.75
fans system efficiency [-]	54%	58%	61%
heat recovery thermal efficiency [-]	44%	44%	44%
misc factor	1.10	1.15	1.18
control factor on-off/variable/total	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48
*consumption data**			
electricity consumption AHU [MWh/a]	3.29	22.46	94.33
electricity rate EUR/kWh	0.18	0.14	0.10
electricity costs AHU [000 EUR /a]	0.6	3.1	9.4
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	24/ 11/ 53	61/ 27/ 132	213/ 95/ 462
fossil fuel (ca. gas) rate[EUR/kWh]	0.052	0.042	0.032
space heat extra cost Avg/Warm/Cold climate* [000 EUR/a]	1.3/ 0.6/ 2.7	2.6/ 1.1/ 5.5	6.8/ 3.0/ 14.8
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	2.1/ 9.8	5.3/ 24.4	18.6/ 85.4
space cooling extra costs [000 EUR/a]	0.2/ 1.1	0.5/ 2.1	1.2/ 5.3
total extra energy cost Avg/Warm/Cold * [000 EUR/a]	2.1/ 2.3/ 3.3	6.2/ 6.4/ 8.7	17.4/ 17.8/ 24.2
investment data			
product end price [000 EUR]	7.5	12.6	29.5
Installation materials*** [000 EUR]	34.4	98.2	282.3
install. labour new/ retrofit/ replace/ avg**** [000 EUR]	52/ 62/ 9/ 52	147/ 177/ 9/ 147	575/ 690/ 34/ 573
total new/ retrofit/ replace/ avg**** [000 EUR]	94/ 104/ 17/ 91	258/ 288/ 22/ 248	887/ 1002/ 64/ 856
equivalent (in IAQ) natural ventilation			
ventilation heat loss Avg/Warm/Cold climate [MWh/a]	110/ 50/ 215	263/ 119/ 514	896/ 405/ 1754
extra heat energy cost Avg/Warm/Cold climate [000 EUR/a]	5.7/ 2.6/ 11.2	11.0/ 5.0/ 21.6	28.7/ 13.0/ 56.1
ventilation cooling loss Avg/Warm climate [MWh/a]	9.8/ 44.9	23.4/ 107.4	79.9/ 366.3
extra space cooling costs Avg/Warm climate [000 EUR/a]	1.1/ 5.1	2.1/ 9.4	5.0/ 22.9
total energy cost Avg/Warm/Cold climate [000 EUR/a]	6.8/ 7.6/ 11.2	13.1/ 14.4/ 21.6	33.7/ 35.9/ 56.1
saving versus natural ventilation (reference)			
primary energy saving total [MWh/yr]	98/ 94/ 162	230/ 222/ 382	779/ 750/ 1292
net energy cost saved (incl. electr.) A/W/C [000 EUR/a]	4.7/ 5.4/ 7.8	6.9/ 8.0/ 12.9	16.3/ 18.1/ 31.9
simple payback period avg install in A/W/C climate [years]	19/ 17/ 12	36/ 31/ 19	53/ 47/ 27

Annex Table 8. CEXH and CHRV LLCC versus natural ventilation		
Parameters	**CEXH LLCC**	**CHRV LLCC**
performance data	*Option 1b+4b*	*Option 1+2+3+4b*
design/ effective/ average flow rate [000m3/h]	1.5/ 1.13/ 0.74	2.25/ 2.0/ 0.9
pressure drop external/internal/total [Pa]	154/ 37/ 191	160/ 145/ 305
specific fan power [kW/(m3/s)]	0.795833333	1.270833333
individual rated fan power [kW]	0.165798611	0.397135417
fans system efficiency [-]	48%	48%
heat recovery thermal efficiency [-]	0%	90%
misc factor	1.33	1.10
control factor on-off/variable/total	0.7/ 0.7/ 0.49	0.6/ 0.7/ 0.42
consumption data		
electricity consumption AHU [MWh/a]	0.40	1.71
electricity rate EUR/kWh	0.18	0.18
electricity costs AHU [000 EUR /a]	0.1	0.3
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	16/ 7/ 32	2/ 1/ 7
fossil fuel (ca. gas) rate[EUR/kWh]	0.052	0.042
space heating cost Avg/Warm/Cold climate [000 EUR/a]	0.8/ 0.4/ 1.7	0.1/ 0.0/ 0.4
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	1.5/ 6.7	0.2/ 0.9
space cooling extra costs [000 EUR/a]	0.2/ 0.8	0.0/ 0.1
total extra energy cost Avg/Warm/Cold [000 EUR/a]	1.1/ 1.2/ 1.7	0.4/ 0.5/ 0.7
investment data		
product end price [000 EUR]	1.093	6.796
Installation materials** [000 EUR]	2.00	7.10
install. labour new/ retrofit/ replace/ avg*** [000 EUR]	3/ 4/ 1/ 3	10/ 12/ 6/ 11
total new/ retrofit/ replace/ avg*** [000 EUR]	6/ 7/ 2/ 6	24/ 26/ 13/ 24
equivalent (in IAQ) natural ventilation		
ventilation heat loss Avg/Warm/Cold climate [MWh/a]	34/ 15/ 67	62/ 28/ 121
extra heat energy cost Avg/Warm/Cold climate [000 EUR/a]	1.8/ 0.8/ 3.5	3.2/ 1.5/ 6.3
ventilation cooling loss Avg/Warm climate [MWh/a]	3.0/ 13.9	5.5/ 25.3
extra space cooling costs Avg/Warm climate [000 EUR/a]	0.3/ 1.6	0.6/ 2.8
total energy cost Avg/Warm/Cold climate [000 EUR/a]	2.1/ 2.4/ 3.5	3.8/ 4.3/ 6.3
saving versus natural ventilation (reference)		
primary energy saving total [MWh/yr]	21/ 25/ 34	69/ 84/ 110
net energy cost saved (incl. electr.) A/W/C [000 EUR/a]	1.0/ 1.2/ 1.7	3.4/ 3.8/ 5.6
simple payback period avg install in A/W/C climate [years]	5.7/ 5.1/ 3.4	7.1/ 6.2/ 4.3

Annex Table 9. AHU LLCC versus natural ventilation			
Parameters	**AHU-S LLCC**	**AHU-M LLCC**	**AHU-L LLCC**
performance data	*Option 1+2b+3*	*Option 1+2b+3*	*Option 1+2b+3*
design/ effective/ average flow rate [000m3/h]	4.0/ 3.64/ 1.92	10.0/ 8.7/ 4.8	35.0/ 29.7/ 16.8
pressure drop external/internal/total [Pa]	244/ 161/ 405	450/ 176/ 626	575/ 197/ 772
specific fan power [kW/(m3/s)]	1.40	1.99	2.27
individual rated fan power [kW]	0.78	2.76	11.03
fans system efficiency [-]	58%	63%	68%
heat recovery thermal efficiency [-]	75%	75%	75%
misc factor	1.10	1.15	1.18
control factor on-off/variable/total	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48	0.6/ 0.8/ 0.48
*consumption data**			
electricity consumption AHU [MWh/a]	2.32	16.53	66.07
electricity rate EUR/kWh	0.18	0.14	0.10
electricity costs AHU [000 EUR /a]	0.4	2.3	6.6
ventilation heat loss Avg/Warm/Cold climate**[MWh/a]	11/ 5/ 27	28/ 12/ 67	97/ 42/ 235
fossil fuel (ca. gas) rate[EUR/kWh]	0.052	0.042	0.032
space heat extra cost Avg/Warm/Cold climate* [000 EUR/a]	0.6/ 0.3/ 1.4	1.4/ 0.6/ 3.5	5.1/ 2.2/ 12.2
ventilation cooling loss Avg/Warm/Cold climate [MWh/a]	1.0/ 4.4	2.4/ 10.9	8.3/ 38.1
space cooling extra costs [000 EUR/a]	0.1/ 0.5	0.2/ 1.0	0.5/ 2.4
total extra energy cost Avg/Warm/Cold * [000 EUR/a]	1.1/ 1.2/ 1.8	4.0/ 3.9/ 5.8	12.2/ 11.2/ 18.8
investment data			
product end price [000 EUR]	13.125	22.176	51.92
Installation materials*** [000 EUR]	34.4	98.2	282.3
install. labour new/ retrofit/ replace/ avg**** [000 EUR]	52/ 62/ 9/ 52	147/ 177/ 9/ 147	575/ 690/ 34/ 573
total new/ retrofit/ replace/ avg**** [000 EUR]	100/ 110/ 22/ 96	267/ 297/ 31/ 257	909/ 1024/ 86/ 879
equivalent (in IAQ) natural ventilation			
ventilation heat loss Avg/Warm/Cold climate [MWh/a]	110/ 50/ 215	263/ 119/ 514	896/ 405/ 1754
extra heat energy cost Avg/Warm/Cold climate [000 EUR/a]	5.7/ 2.6/ 11.2	13.7/ 6.2/ 26.7	46.6/ 21.1/ 91.2
ventilation cooling loss Avg/Warm climate [MWh/a]	9.8/ 44.9	23.4/ 107.4	79.9/ 366.3
extra space cooling costs Avg/Warm climate [000 EUR/a]	1.1/ 5.1	2.1/ 9.4	5.0/ 22.9
total energy cost Avg/Warm/Cold climate [000 EUR/a]	6.8/ 7.6/ 11.2	15.7/ 15.6/ 26.7	51.6/ 44.0/ 91.2
saving versus natural ventilation (reference)			
primary energy saving total [MWh/yr]	113/ 108/ 188	268/ 258/ 447	911/ 876/ 1518
net energy cost saved (incl. electr.) A/W/C [000 EUR/a]	5.7/ 6.5/ 9.4	11.7/ 11.7/ 20.9	39.4/ 32.8/ 72.3
payback period excl. cool, avg install, A/W/C climate [years]	17/ 15/ 10	22/ 22/ 12	22/ 27/ 12