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**Sustainable Industrial Policy –**
**Building on the Ecodesign Directive –**
**Energy-Using Product Group Analysis/2**

## Lot 6: Air-conditioning and ventilation systems

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# Draft Report Task 4

## Definition Base Cases Ventilation Systems for non residential and collective residential applications

*Prepared by VHK*

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# 1. Introduction

## 1.1 General

This is the draft report for Tasks 4 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.**

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.

Task 4 entails the assessment average EU product(s) that have to be defined as representative product "Base-cases" for the whole of the EU-27. On these Base-Cases most of the environmental and Life Cycle Cost analyses are built throughout the rest of the study. A Base-Case is a conscious abstraction of reality, necessary for practical reasons (budget, time). Having said that, the question if this abstraction leads to inadmissible conclusions for certain market segments will be addressed in the impact- and sensitivity analysis (tasks 6 and 7).

The description of the Base-Case is the synthesis of the results of Tasks 1 to 3 and the point-of-reference for tasks 5 (BAT, BNAT), 6 (improvement potential) and 7 (impact analysis).

Task 4 consists of the following subtasks

- Subtask 4.1. Product-specific inputs (Chapter 2 of this report)
- Subtask 4.2. Definition of Base Cases (Ch. 3)
- Subtask 4.3. Environmental Impact Assessment (Ch. 4)
- Subtask 4.4. Life Cycle Cost Assessment (Ch. 5)
- Subtask 4.5. Total impact EU-27 (Ch. 6)

Details of each subtask are given in the following paragraphs. Main information sources for the underlying report are the reports on Tasks 1, 2 and 3. For exhaust systems, also data from the preparatory study on industrial fans were used (Lot 10, DG TREN).

## 1.2 Subtasks

### 1.2.1 Subtask 4.1, Product-specific inputs

The following input data are required

1. Avg. EU product weight and Bill-of-Materials, distinguishing materials fractions (weight) at the level of the EuP EcoReport Unit Indicators as proposed in the MEEUP report. This includes packaging materials;
2. Primary scrap production during sheet metal manufacturing (avg. EU);[1]
3. Volume and weight of the packaged product avg. EU;
4. Annual resources consumption (energy, water) and direct emissions during product life according to the real-life situation ;
5. Selected EU scenario at end-of-life of materials flow [2] for:

Disposal (landfill, pyrolytic incineration);

Thermal Recycling (non-hazardous incineration optimised for energy recovery);

Re-use or Closed-loop Recycling.

### 1.2.2 Subtask 4.2, Definition of Base-Case

Define the Base-Cases in terms of their performance characteristics.

### 1.2.3 Subtask 4.3, Base-Case Environmental Impact Assessment.

The subtask entails that using the VHK EuP EcoReport indicate an environmental impact analysis should be performed, specifying:

6. Emission/resources categories as mentioned in the MEEUP Report;

for:

7. Raw Materials Use and Manufacturing;
8. Distribution;
9. Use;
10. End-of-Life Phase.

Distinguishing for the Use phase between the Standard Base-Case and the Real-life Base-Case.[3]

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[1] Necessary input into the EuP EcoReport

[2] At least for plastics and electronics, as defined in the EuP EcoReport. For metals and glass this may also be indicated if the recycling percentage is less than 95%.

[3] Making two analyses

Furthermore, if more than one type of resource is used in the Use phase, make a split-up between resources and their individual impacts.

### 1.2.4 Subtask 4.4, Base-Case Life Cycle Costs

Combining the results from tasks 1, 2 and 3 this subtask defines for all Base-Cases the Life Cycle Costs[4]

### 1.2.5 EU-27 Total Impact

Aggregate the Base-Case environmental impact data (subtask 4.3) and the Life Cycle Cost data (subtask 4.4) to EU-27 level, using stock and market data from task 2, indicating

11. The life cycle environmental impact and total LCC of the new products designed in 2010 (this relates to a period of 2010 up to 2010+product life);
12. The annual (2010) impact of production, use and (estimated) disposal of the product group, assuming post-RoHS and post-WEEE conditions.[5]

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[4], LCC = PP + PWF * OE, where LCC is Life Cycle Costs, PP is the purchase price, OE is the operating expense and PWF (Present Worth Factor) is PWF= $\{1 – 1/(1+ r)^{N}\}/r$ , in which N is the product life and r is the discount (interest-inflation) rate.

[5] “Business-as-Usual” scenario to be based on this assumption.

# 2. Product Specific Inputs BaseCases

This section describes the modelling of a base case that is the reference for the environmental and technical/ economical improvements to be established in task 5, 6 and 7. The base case is a theoretical approximation of the average product in stock or sold.

Anticipating subtask 4.2 and in line with Task 2, this chapter will make the assessment for five BaseCases: Central Exhaust units (CEXH), Central Heat Recovery Ventilation (CHRV) and 3 air handling units in 3 different capacities Small-Medium-Large (AHU-S, AHU-M, AHU-L)

## 2.1 Materials (BOMs)

The material composition is described by the Bill of Materials. The bills of materials are constructed on the basis of the data supplied in task 3, Chapter 9 (End of Life analysis) and supplementary data from the LOT10 Preparatory Study on Residential Ventilation. The table below gives the inputs that will be used for the environmental impact assessment, the Life Cycle Costs calculation and EU Totals.

**Table 4 - 1 BOMs of BaseCases**

| | Unit | **1.** Central exhaust unit (CEXH) | **2.** Central Heat Recovery Ventilation (CHRV) | **3.** Air Handling Unit Small (AHU-S) | **4.** Air Handling Unit Medium (AHU-M) | 5. Air Handling Unit Large (AHU-L) |
|---|---|---|---|---|---|---|
| Steel | *gr.* | 7.036 | 134.851 | 601.200 | 1.282.560 | 4.168.320 |
| Iron | *gr.* | 908 | 4.552 | | | |
| Aluminum | *gr.* | 661 | 11.949 | 64.800 | 138.240 | 449.280 |
| Copper | *gr.* | 1.652 | 5.121 | 59.250 | 126.400 | 410.800 |
| Brass | *gr.* | 0 | 0 | 2.400 | 5.120 | 16.640 |
| Techn. Plastics (NBR/PET) | *gr.* | 1.321 | 6.828 | 1.725 | 3.680 | 11.960 |
| Bulk plastics (LDPE/PP/PVC/ABS) | *gr.* | 7.432 | 32.148 | 9.450 | 20.160 | 65.520 |
| Electronics | *gr.* | 500 | 800 | 1.000 | 1.500 | 2.000 |
| Other | *gr.* | 491 | 3.752 | 10.175 | 22.340 | 75.480 |
| | | | | | | |
| **Total** | *gr.* | 20.000 | 200.000 | 750.000 | 1.600.000 | 5.200.000 |

## 2.2 Manufacturing phase

The inputs required to assess the environmental impacts for the manufacturing phase are generated automatically by the EcoReport. As metal scrap percentage we use the default 25%. Please note that for plastics the manufacturing impacts are included in the materials.

**Table 4 - 2. Manufacturing inputs for BaseCases**

| Row nr | Mat/process | Unit | **1.** Central exhaust unit (CEXH) | **2.** Central Heat Recovery Ventilation (CHRV) | **3.** Air Handling Unit Small (AHU-S) | **4.** Air Handling Unit Medium (AHU-M) | 5. Air Handling Unit Large (AHU-L) |
|---|---|---|---|---|---|---|---|
| 20 | OEM Plastics Manufacturing | *gr.* | 8.752 | 38.976 | 11.175 | 23.840 | 77.480 |
| 34 | Foundries Fe/Cu/Zn | *gr.* | 908 | 4.552 | 2.400 | 5.120 | 16.640 |
| 35 | Foundries Al/Mg | *gr.* | 661 | 11.949 | 64.800 | 138.240 | 449.280 |
| 36 | Sheet metal Manufacturing | *gr.* | 8.688 | 139.972 | 660.450 | 1.408.960 | 4.579.120 |
| 53 | PWB Manufacturing | *gr.* | 0 | 0 | 0 | 0 | 0 |
|  | Other materials | *gr.* | 991 | 4.552 | 11.175 | 23.840 | 77.480 |
| 37 | Sheet metal scrap | *gr.* | 2.172 | 34.993 | 165.113 | 352.240 | 1.144.780 |

## 2.3 Distribution phase

The EcoReport requires the product volume as an input for transportation and warehouse.

**Table 4 - 3. Distribution inputs for BaseCases**

| Row nr | Mat/process | *Unit* | **1.** Central exhaust unit (CEXH) | **2.** Central Heat Recovery Ventilation (CHRV) | **3.** Air Handling Unit Small (AHU-S) | **4.** Air Handling Unit Medium (AHU-M) | 5. Air Handling Unit Large (AHU-L) |
|---|---|---|---|---|---|---|---|
| 59 | Is it an ICT or Cons. Electr. Product< 15kg? |  | no | no | no | no | no |
| 60 | Is it an installed appliance? |  | yes | yes | yes | yes | yes |
| 63 | Volume of packaged final product | *$m^3$* | 1 | 1 | 1,5 | 4 | 20 |

## 2.4 Use phase

The environmental impacts in the use phase consist of

- Electricity consumption
- Space heating/cooling energy saved
- Energy use for maintenance, repairs and the energy content of the filters

The annual electricity consumption depends on the air flow rate (in m³/h or m³/s), the total pressure difference ΔP (both external and internal), the fan system efficiency (incl. motor and drive), auxiliary and stand-by electricity consumption.

The saving on space heating/cooling energy depends on the air flow rate and possibly the heat recovery. The saving is calculated with respect of a reference situation without whole building mechanical ventilation, which –in accordance with Task 3—still constitutes on average around 60% of current practice.

The average air flow rate, part of both impacts, is determined by the specific application, various leakage rates and the controls. Furthermore there is a relationship between air flow and the pressure drop ΔP in the unit and the system. Apart from that, the pressure drop depends on the friction losses in the unit and system. These losses depend on the aerodynamic design of the components (in the unit: fan in- and outlets, heat recovery system, filters; in the system: ducts, VAV-boxes, ATDs) and the face velocity (in m/s).

### 2.4.1 Electricity consumption

***Fan System Efficiency and Specific Fan Power***

In residential applications (EN 13141, see task 1 report) the total electricity consumption of the unit is included in the Specific Power Input SPI in W/(m³/h), where the flow rate is taken at **70%** of the maximum air flow rate (at 0 Pa) and an external pressure drop of 100 Pa. The SPI includes auxiliary energy inputs.

In non-residential applications (EN 13799, see task 1 report) the Specific Fan Power SFP in W/(m³/s) is used. It only takes into account the power consumption of the fan(s)[6], at a flow rate and external pressure drop that is **65%** of the maximum value (at 0 Pa and 0 m³/s respectively).

For the vast majority of non-residential units the auxiliary and stand-by electricity is negligible (<3%). For the calculation of the Base-Cases auxiliary and stand-by electricity consumption is thus not taken into account, published figures on the SFP and SPI will be considered equivalent. The exception is heat recovery units in the colder climate where defrosting electricity is part of the equation.

The value of the SFP for smaller units (CEXH and CHRV), is derived from FGK 2010 data, giving an SPI value of 0,3 W/(m³/h) for exhaust fans, based on 3-speed AC motors, equivalent to an SFP value of

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[6] Note that in EN 13799 the SFP may be expressed for individual fans, for the ventilation unit or for the building. In order to stay as close as possible to the residential standard, it is proposed to use SFP per unit.

1.080 W/(m³/s). For CHRV, similar to residential units but only larger, the SPI is estimated at 0,45 W/(m³/h,) equivalent to an SFP of 1.620 W/(m³/s).

As regards the Air Handling Units, the SFP-data for individual fans suggest that the average SFP[7] is around 1 W/ (m³/h) for an average AHU. But the figure incorporates the pressure drop for heating and cooling coils, which are outside the scope of strict ventilation. Thus in that case the SFP, without cooling/heating coils, can be estimated from the fan efficiency and is around 60% for the largest AHU (AHU-L) and slightly less for the AHU-M (59%) and AHU-S (56%)[8]. Especially with these smaller AHUs, e.g. used in ceiling voids, it is still quite common to find 3-speed AC motor solutions. Thus the SFP is estimated at 1.980 (AHU-S), 2.700 (AHU-M) and 3.240 (AHU-L) W/ (m³/s).

### ***Air flow rate (m³/h)***

The design flow rate is built from

a) The specific flow rate (in m³/h per m² or m³ building surface or volume), indicated in the building code or EN standard, to reach the desired minimum Indoor Air Quality at maximum occupancy/activity situations. Minimum IAQ and maximum occupancy/activity situations are also indicated in codes or standards.
b) the building floor area A (in m²) or volume V (in m³) per building, zone or room ('zone' defined as area with a certain activity/maximum occupancy rate);
c) surplus flow rate to account for ventilation effectiveness and leakage rate of the ducts.

Item c) is not always taken into account explicitly in building codes, guidelines, standards. In those cases it is taken into account implicitly. In order to accommodate possible correction, we will document this effect separately by the multiplier MISC.

MISC values were derived from residential systems (source FGK 2010) with some slight correction for leakage losses at the larger AHUs. Thus MISC is set at 1,33 (CEXH), 1,10 (CHRV), 1,10 (AHU-S), 1,15 (AHU-M) and 1,18 (AHU-L). [9]

The multiplication of items a), b) and c) will be denominated as the 'design flow rate' $q_{design}$.

The design air flow rate values (maximum flow rate at 65% $qv_{max}$ and 65% $\Delta p_{max}$) were chosen in accordance with estimated market averages, as indicated in the Task 3 report and further explained in the next chapter on the definition of BaseCases.

### ***Pressure drop (in Pa)***

The total pressure drop is the total of external and internal pressure drop of the unit. The former is a published catalogue figure (at least at design conditions), whereas the latter is derived from tabulated values according to EN 13799 and publications by Kaup 2009. The total pressure drop is used to determine realistic values for SFP and fan efficiency for ventilation units of various capacities.

*External pressure drop*

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[7] average for exhaust and supply fan

[8] Kaup 2009 reports an efficiency between 60 and 70%, but these are German units probably slightly above market average.

[9] Compare: In Lot 10 supplementary study by FGK 2010, the MISC factor is fsys:dw x fsys:rm x feff x fduct. For exhaust system with fans <125 W this results in 1,33 (is identical to MISC with CEXH here) and for CHRV with fans <125 W it results in 1,1 (is identical to MISC with CHRV here).

For the external pressure drop at design flow rate $q_{design}$ (in m³/h), the empirical formula from Dr. Kaup was used for units with design flow capacity >25.000 m³. For units with lower capacity, there are two formulas derived from catalogue data:

Design external pressure drop ΔPext (in Pa): if design flow rate $q_{design}$ <10.000 m³/h then

$\Delta Pext = 0,036 * q_{design} + 100$;

if $10.000 \leq q_{design} < 25.000$ m³/h then

$\Delta Pext = 0,0146 * q_{design} + 304$;

if $q_{design} \geq 25.000$ m³/h then

$\Delta Pext = 75 * \ln(q_{design}) - 190,5$ (equation Kaup, supply side, but subtract 100 for heat/cool coil)

The above equations are not prescriptive, but only intended to be descriptive of the current market situation.

*Internal pressure drop*

The internal pressure drop ΔPint (in Pa) is calculated from empirical equations for the pressure drop of the heat recovery unit ΔPintHR, as a function of the thermal efficiency $\eta_{th}$ and the design flow rate $q_{design}$ (in m³/h), and of the filter. An anchor point at 165 Pa and 10.000 m³/h was chosen. The coefficients were derived from work by Dr. Kaup (environmental Campus, University of Trier), based on design data of almost 14.000 AHU's sold in the period 2003-2009.

$\Delta PintHR = \{(0,0012\eta_{th}^3 - 0,16\eta_{th}^2 + 7,8*\eta_{th}) /165\} *\{22,6*\ln(q_{design})-42,8\}$

The F7 air filter pressure drop ΔPintfilter for the average filter ('normal' is 150 Pa) is calculated as

$\Delta Pintfilter = 0,9*\{22,5*\ln(q_{design})-42,8\}$

The pressure drop from air in- and outlet is set at

$\Delta PintIO = 0,3*\{22,6*\ln(q_{design})-42,8\}$

Heating and cooling coils are not part of the ventilation effort. The total internal pressure drop is the sum of the above:

$\Delta Pint = \{1,2 + (0,0012eta_{th}^3 - 0,16eta_{th}^2 + 7,8*eta_{th})/165\} *\{22,6*\ln(q_{design})-42,8\}$

Again, the above equations are not prescriptive, but only describe the current market situation.

The actual work performed by the fans, i.e. the power output $P_{vent}$, is given by

$P_{vent} = (q_{design}/3600) * (\Delta Pint + \Delta Pext) * Nfan$

Where qdesign is the design air flow in m³/h (the factor 1/3600 converts to m³/s) and Nfan is the number of fans in the unit.

***<u>Air flow control</u>***

The real-life air flow rate of a unit depends on the design flow rate and the control factor.

The air flow control factor depends on

a) on/off ('setback') control for non-occupancy periods;

b) the fan speed control in 'fan-on' mode, which in turn depends on the speed control options (single speed, 2 or 3 speed, continuous variable), the sensor types (occupancy, gas sensors, etc.), air distribution control (VAV boxes, ATDs), etc.;
c) the operation level of on/off and speed control, e.g. whole building, zone or room.

The BaseCase values for the on/off control ($CTRL_{on}$) are derived from the data and case studies given in the Task 3 report, Chapters 8 and 10.

Chapter 10, Table 3-23 indicates an annual fraction of 'on' hours of 42% for small/medium/large offices, 50-54% for retail outlets, 81-86% for care facilities (hospital and retirement home) and 100% for hotels. The on-off control is mostly at whole building level (offices, retail) or in care institutes in zones with separate technical ventilation.

Roughly weighted for the building types in the tertiary and public sector building stock (Chapter 8, table 3-16), the average is ca. 60% (0,6). This is the $CTRL_{on}$ value assumed for BaseCases of balanced ventilation units.

In the multi-family apartment buildings occupancy is almost 100% and therefore –and for safety reasons-- ventilation units are not assumed to be turned off. Multi-family apartment buildings predominantly use exhaust ventilation units and around 50% of all exhaust units in scope are used in this sector. Therefore for the BaseCase central exhaust system (CEXH) a $CTRL_{on}$ value of 80% (0,8) is used.

As regards the fan speed control $CTRL_{var}$, the case studies in Task 3, Chapter 10, do not assume any speed reduction from nominal speed. However, it may be assumed that at least half of the customers set the fan speed at medium position or at least a value that matches peak occupancy, i.e. 80% (0,8).

The average annual flow rate of an installation $q_a$ can thus be described as

$$q_a = q_{design} \times CTRL_{on} \times CTRL_{var}$$

The average annual electricity consumption

Apart from a small fixed part of stand-by power consumption (5%), the average annual electric power consumption $P_{el}$ is linear with $q_{design}$ and $CTRL_{on}$. Following the fan laws[10], the speed control factor $CTRL_{var}$ diminishes with the third power. This applies to 95% of the average annual power consumption $P_{ela}$.

$$P_{ela} = \{0,05 + 0,95 \times CTRL_{on} \times CTRL_{var}^3\} \times P_{eldesign}$$

Example 1 (e.g. CHRV, AHU): With $CTRL_{on}$ =0,6 and $CTRL_{var}$ =0,8 then $q_a$ = 0,48 $q_{design}$ and $P_{ela}$ = 0,34 $P_{eldesign.}$ In other words, in this example, the amount of equivalent full load hours for $P_{ela}$ is 2.980 h per year.

Example 2 (e.g. central exhaust CEXH): With $CTRL_{on}$ =0,8 and $CTRL_{var}$ =0,8 then $q_a$ = 0,64 $q_{design}$ and $P_{ela}$ = 0,43 $P_{eldesign.}$ In other words, in this example, the amount of equivalent full load hours for $P_{ela}$ is 3.766 h per year.

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[10] Fan laws: fan speed variation varies linearly with air flow, to the square with pressure drop and to the third power with electric power absorbed. At the same time the part load motor- and fan efficiency diminishes, especially for certain AC motor types, but at relatively high average flow rates of 0,8 $q_{design}$ of the BaseCase this effect is assumed negligible (or in part compensated by the 5% constant).

Compare: uses in BaseCases In the Ecodesign preparatory study for non-residential sector fans (Lot 11) Radgen uses equivalent full load hours of 2.000 h/a for BaseCase exhaust systems or 3.000 h/a for BaseCase balanced systems. Although these numbers are not identical to the examples above, they are at least in the same ballpark range.

### ***Electricity consumption (in kWh/a)***

The annual electricity consumption $AEC_E$ (in kWh electric/a) can now be found by the equation

$AEC_E = 8{,}76 * P_{eldesign} * \{ 0{,}05 + 0{,}95 \times CTRL_{on} \times CTRL_{var}^3 \}$

Where the factor 8,76 is a result of operating 8.760 h/a (whole year) and converting Wh in kWh.

To convert this value to primary fuel energy $AEC_F$ in kWh primary energy/a power generation and –distribution losses have to be taken into account using a multiplier 2,5 is used (40% efficiency, which in aggregate leads to a multiplier 2,5 * 8,76= 21,9):

$AEC_F = 21{,}9 * P_{eldesign} * \{ 0{,}05 + 0{,}95 \times CTRL_{on} \times CTRL_{var}^3 \}$

Published data for both fan system efficiency and SFP (per fan) were used as a basis for calculating the electric efficiency of the ventilation units with individual fans>125 W. The table below gives the typical (baseline) values for the SFP (per unit) sold in 2010:

**Table 4 - 4. Estimated electricity use non-residential ventilation units, sold 2010**

| Product --> | CEXH | CHRV | AHU-S | AHU-M | AHU-L |
|---|---|---|---|---|---|
| design flow rate $q_{design}$ (m³/h) | 1.500 | 2.250 | 4.000 | 10.000 | 35.000 |
| *---includes MISC factor* | *1,33* | *1,10* | *1,10* | *1,15* | *1,18* |
| *---effective flow rate* | *1.128* | *2.045* | *3.636* | *9.091* | *31.818* |
| Filter Yes (=1) or No (=0) | 0 | 1 | 1 | 1 | 1 |
| Avg. thermal efficiency $\eta_{th}$ in % | 0 | 80 | 44 | 44 | 44 |
| design ΔPext (in Pa) | 154 | 181 | 244 | 450 | 575 |
| design ΔPint (in Pa) | 37 | 329 | 292 | 334 | 391 |
| Number of fans per unit | 1 | 2 | 2 | 2 | 2 |
| Power output Pvent in W | 80 | 638 | 1.191 | 4.356 | 18.788 |
| SFP unit (in W/(m³/s)) | 1.080 | 1.620 | 1.980 | 2.700 | 3.420 |
| Design el. power $P_{eldesign}$ (in W) | 345 | 1.013 | 2.200 | 7.500 | 31.500 |
| *Design fan system efficiency* | *23%* | *63%* | *54%* | *58%* | *61%* |
| On/off control factor $CTRL_{on}$ | 0,8 | 0,6 | 0,6 | 0,6 | 0,6 |
| Speed control factor $CTRL_{var}$ | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 |
| Annual avg. el. power $P_{ela}$(in W) | 151 | 346 | 752 | 2.564 | 10.768 |
| Annual electricity/a ($kWh_e$/a) | 1.327 | 3.032 | 6.588 | 22.459 | 94.327 |

Please note, as is defined in the MEEUP report, the BaseCases refer to current **sales** and not to installed stock. Furthermore, the above represent real-life BaseCases; the standard BaseCases do not include MISC and CTRL factors.

Nonetheless, for the sake of estimating EU totals, the following table refers to stock averages. For the average units installed (stock) the yardstick is the average unit as sold around 8-10 years ago. The following characteristics for the stock area are assumed:

- A much lower market penetration of heat recovery: Less than 25% for AHUs. Market penetration of CHRV units was very low at the time, but those that did exist all had heat recovery;
- A lower thermal efficiency of heat recovery: based on a mix of cross flow plate heat exchangers, run around coils and rotary wheels in AHUs the efficiency is not estimated higher than 50%. Also for CHRV units, cross flow heat exchangers were quite popular at the time, although a few counter-flow types did exist. Here the HR efficiency is set at 60%;
- Combining the two previous points, the aggregated HR efficiency is assumed to be 60% for CHRV and 12,5% for AHUs;
- As regards the Specific Fan Power, the share of less-efficient AC motors was higher around 10 years ago. For AHUs Kaup reports that SFP improved by 3,2% between 2005 and 2009. Overall it is assumed in the stock the SFP is 8% higher than in the sales, due to motors and fans. For comparison: In Sweden 1995 the average SFP of 500 balanced ventilation systems found to be 3.000 W/(m³/s) and values in other countries were found to be higher or similar[11];
- As regards the internal pressure drop due to filters and heat exchangers some considerable progress has been made. For CHRVs presumably there is a 10% difference between stock and sales. For AHUs at least the same progress is expected, but on the other hand 10 years ago the market penetration of heat recovery units was much less (=less pressure drop) and thus for AHUs it is believed that no change occurred on this issue;
- In the field of controls we are probably on the verge of a larger market transformation, using more demand-side ventilation ($CO_2$ sensors, etc.). But thus far the difference between practice today and 10 years is believed not to be that great. The same control factors (based on a timer control and 3-speed AC motor) are thus also assumed for the stock. The same goes for the MISC factor, for which the same values will be assumed.

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[11] Nilsson, L.J., Air-handling energy efficiency and design practices, Energy & Buildings, Vol.22 (1995), pp. 1-13. In Schild, P.

**Table 4 - 5. Estimated electricity use non-residential ventilation units, stock 2010**

| Product --> | CEXH | CHRV | AHU-S | AHU-M | AHU-L |
|---|---|---|---|---|---|
| design flow rate $q_{design}$ (m³/h) | 1.500 | 2.250 | 4.000 | 10.000 | 35.000 |
| *---includes MISC factor* | *1,33* | *1,10* | *1,10* | *1,15* | *1,18* |
| *---effective flow rate* | *1.128* | *2.045* | *3.636* | *9.091* | *31.818* |
| Filter Yes (=1) or No (=0) | 0 | 1 | 1 | 1 | 1 |
| Avg. thermal efficiency $\eta_{th}$ in % | 0 | 60 | 12,5 | 12,5 | 12,5 |
| design ΔPext (in Pa) | 154 | 181 | 244 | 450 | 595 |
| design ΔPint (in Pa) | 40 | 306 | 241 | 275 | 322 |
| Number of fans per unit | 1 | 2 | 2 | 2 | 2 |
| Power output Pvent in W | 81 | 609 | 1.077 | 4.029 | 17.834 |
| SFP unit (in W/(m³/s)) | 900 | 1764 | 2124 | 2916 | 3492 |
| Design el. power $P_{eldesign}$ (in W) | 373 | 1.094 | 2.376 | 8.100 | 34.020 |
| *Design fan system efficiency* | *22%* | *56%* | *45%* | *50%* | *52%* |
| On/off control factor $CTRL_{on}$ | 0,8 | 0,6 | 0,6 | 0,6 | 0,6 |
| Speed control factor $CTRL_{var}$ | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 |
| Annual avg. el. power $P_{ela}$(in W) | 164 | 374 | 812 | 2.769 | 11.629 |
| Annual electricity/a ($kWh_e$/a) | 1.433 | 3.275 | 7.115 | 24.256 | 101.874 |

### 2.4.2 Saving on space heating fuel

*Reference for saving: Natural ventilation*

In principle, unless the efficiency and efficacy is extra-ordinarily bad, mechanical ventilation always saves space heating energy (hereafter ‘fuel’, although some may be electric) with respect of natural ventilation. The reason for this is that with mechanical ventilation the air flow is ‘controlled’, whereas with natural ventilation –meeting the same Indoor Air Quality requirements—the designer always depends on nature and has to *‘plan for the worst’*. This means that even if the wind comes from the most unfavourable direction and even if the surrounding buildings and other objects cause the most unfavourable partial pressure differences over the building, the natural ventilation system has to be able to meet the IAQ requirements. This implies that under ‘normal’ circumstances the ventilation and infiltration rate is much too high.

For residential applications, FGK 2010 indicates that at an effective ventilation rate requirement (excl. infiltration) $q_{eff}$ of 1,3 m³/h per m² dwelling surface, the average natural ventilation system (incl. passive stack) would provide 2,2 m³/h per m² [12]. For non-residential applications, with a bigger share of higher buildings, the situation is certainly worse. But for the sake of continuity/comparability with the residential units, a similar proportion of 2,2/1,3 = 1,7 will be assumed. Furthermore, in order not to overstate saving potential, it will be assumed that with natural ventilation no airing (open windows) will take place during non-occupancy hours. Natural stack ventilation (50% of ventilation load) is assumed to continue during non-occupancy hours and therefore an overall control factor $CTRL_{on}$ of 0,8 is assumed. So the effective natural ventilation load is set at 1,7 x 0,8 = 1,36 x $q_{eff}$

### Mechanical ventilation, heating energy loss

For mechanical ventilation units the starting point of the calculation is the ventilation requirement effective ventilation rate requirement (excl. infiltration) $q_{eff}$ .

The flow rate $q_{eff}$ is multiplied with the factors MISC (to arrive at $q_{design}$), $CTRL_{on}$, $CTRL_{var}$ and finally with ($1-\eta_{th}$), where $\eta_{th}$ is the sales weighted thermal efficiency of heat recovery. Values for $\eta_{th}$ are based on FGK 2010 for the CHRV (HR=80%). $\eta_{th}$ -values for AHUs are based on the study of Kaup 2009, who concludes that 70% of AHUs sold have heat recovery and that those that have heat recovery show an average efficiency of ca. 62%. As a conclusion for AHUs an $\eta_{th}$ of 44% (0,7*0,62) is used.

Subsequently the difference with natural ventilation is determined. This difference (in m³/h) is then multiplied with the number of hours of the heating season (e.g. *5.112 h/a for average climate*), the indoor/outdoor temperature difference in the heating season (e.g. *9,5 K in average climate*), specific heat of air per m³ (*0,000344 kWh/m³K*)[13] and the *factor 1,33* to find the annual saving on space heating energy in kWh/a. This factor of 1,33 reflects the efficiency of a good boiler of 75% (with at least also timer setback-control) in accordance with the latest MEPS of the Commission Ecodesign proposals.

In aggregate, the multiplier for the difference with natural ventilation is thus 5.112 x 9,5 x 0,000344 x 1,33 = 22,21 for the Average climate. For the Warmer climate (*heating season 4.392 h/a, ΔT =5 K*) the multiplier is 4.392 x 5 x 0,000344 x 1,33= 10,05. For the Colder climate (*heating season 6.552 h/a, ΔT =14,5 K* ) the multiplier is 6.552 x 14,5 x 0,000344 x 1,33 = 43,47.

### Defrost preheating

FGK 2010 indicates that for defrosting purposes the air entering the heat recovery heat exchanger should be preheated when the outdoor temperature drops below -4 °C. In the average climate this occurs during 168 hours per year (in the heating season of course). For the Colder climate this occurs during 1.003 hours per year. FGK assumes the preheating effort to be equivalent to a temperature rise ΔT= 2,4 K in the Average climate and ΔT= 5,2 K in the colder climate. Because the pre-heating is done with an electric resistance heater, a primary energy conversion factor 2,5 has to be applied to arrive at the primary energy requirement of pre-heating.

Finally, pre-heating is assumed to apply only for units with heat recovery. The HR market penetration $HR_{pen}$ for CHRV-units is assumed 100%. For AHUs it is 70%.

The equation for annual preheating primary energy requirement in the Average climate is

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[12] Average of 2,36 m³/h per m² for airing + infiltration and 2,09 m³/h per m² for passive stack + Infiltration. Note that 2,2 m³/h per m² roughly equals an air exchange rate (at internal floor height 3 m) of 0,7-0,75. This value is similar to the one found not only in standards, but also in literature as the air exchange rate for natural ventilation; e.g. Gierga et al. 1994 (Frauenhofer Institute. Energie-einsparpotential für den Gebaüdesektor in Badem Würtemberg) in Clausnitzer et al. Grundlagen der Einsatzmöglichkeiten und -hemnisse für die Einführung einer Lüftungsampel (Teilbericht 1), Juli 2003.

[13] Specific heat per kg air: 1 kJ/kg.K= 0,277 Wh/kg.K. Density air: 1,24 kg/m³. Specific heat per m³ air= 1,24 * 0,277 *0,001

168 h x 2,4 K x 0,000344 kWh/m³K x 2,5 W/W x $q_a$ m³/h = 0,35 $q_a$ kWh/a

The equation for annual preheating primary energy requirement in the colder climate is

1003 h x 5,2 K x 0,000344 kWh/m³K x 2,5 W/W x $q_a$ m³/h = 4,48 $q_a$ kWh/a

*Summary*

Annual heating saved Average climate (in kWh/a):

$AHS_A = 22{,}22 \cdot q_{eff} \cdot [1{,}36 - MISC \cdot CTRL_{on} \cdot CTRL_{var} \cdot (1-\eta_{th})] - HR_{pen} \cdot 0{,}35 \cdot q_a$

Annual heating saved Warmer climate:

$AHS_W = 10{,}05 \cdot q_{eff} \cdot [1{,}36 - MISC \cdot CTRL_{on} \cdot CTRL_{var} \cdot (1-\eta_{th})]$

Annual heating saved Colder climate

$AHS_C = 43{,}47 \cdot q_{eff} \cdot [1{,}36 - MISC \cdot CTRL_{on} \cdot CTRL_{var} \cdot (1-\eta_{th})] - HR_{pen} \cdot 4{,}48 \cdot q_a$

Note that the above AHS values are negative.

Furthermore, as mentioned in the section on electricity consumption:

$q_a = q_{design} \times CTRL_{on} \times CTRL_{var}$

with

$q_{design} = MISC \times q_{eff}$

This means that the right term of the AHS can be rewritten as $q_a \cdot (1-\eta_{th})$.

The calculation is climate-specific, so the appropriate 'climate' suffixes (A, W, C) have to be added to AHS.

**Waste heat from fan motor**

Throughout the calculations of the heating energy saving potential the possible contribution of fan-motor waste heat is not explicitly taken into account. In exhaust fans (CEXH) such a contribution does not take place. In balanced ventilation units (CHRV, AHU-S, AHU-M, AHU-L) this contribution is usually not specified separately if there is a heat recovery device, but it is implicitly included in the published thermal efficiency of the heat recovery system.[1] A separate credit would therefore overstate the overall efficiency. In case of balanced systems without heat recovery, the supply fan waste heat could make a small contribution, but only if the fan motor is placed in the air-stream (e.g. unlikely with belt-driven systems) and if the fan is specifically designed for this purpose. E.g. if placing the motor in the air stream has a noticeable impact on the aerodynamic efficiency, the overall effect may be negative. Given the high uncertainty of the possible contribution plus the possible perverse mechanism of giving a bonus to inefficient fan motors it is therefore decided not to take fan motor waste hat explicitly into account.

For the moment, the saving on space cooling ('air-conditioning') is not part of the cost calculation for mechanical ventilation unit. Savings are relatively small compared to savings on space heating and there are a number of methodological issues that are not clear:

First of all, there is the issue of the partitioning of savings between air-conditioning and mechanical ventilation. If the savings through e.g. free cooling and heat recovery are partitioned to ventilation systems, of course then they cannot again be claimed as a saving of the air conditioning side.

Second, whereas for savings on space heating the reference is clearly natural ventilation, for buildings with active space cooling the combination with natural ventilation is rare (although it happens, particularly with small cooling systems in shops or restaurants and of course dwellings) .

Also the sub-optimal situation with only a supply-side cooling fan and ‘natural exhaust’, which is quite common in the US, is rather an exception in Europe. Most air conditioning systems have a balanced ventilation system and thus this seems the most plausible reference for savings due to the less common heat recovery and the not always employed timer control through free (night) cooling.

Finally, as mentioned, the savings in the stock are relatively small, compared to space heating. Savings can apply to only 15-20% of the building stock that is equipped with space cooling. Free cooling during the night (running the ventilation at full power, bypassing the heat recovery unit, during ca. 8 hours at night) and heat recovery during the day (e.g. with 28 °C @ 80% RH outdoors, and a chiller set temperature of 22 °C (@100% RH → 24 °C 70% RH indoors[14]) may save up to 50-60% in the Warmer climates during the 3 summer months (2100 h). But in the Average climate (24-25 °C outdoors) the saving is perhaps only half and in a colder climate air conditioning there is no saving at all. So, compared to savings on space heating the saving on space cooling may give some 5% (Average climate) to 10% (Warmer climate) extra.

**Saving on space cooling**

For the reasons mentioned above, it is decided not give a credit for space cooling here. Possible contributions of free cooling (through by bypass of heat exchanger) and heat recovery will be taken into account in the Task reports on air-conditioning (air cooling) systems.

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[14] Note that for cooling, the relative humidity (RH) does play a role. For instance, when going from 28 °C@80% RH (quite common in e.g. Southern European cities) to 22 °C@100%RH just after the cooling coil, there is some 5 g/m³ that will condense in the heat recovery coil. At a specific condensing heat of 2.256 *kJ*/kg (= 627 Wh/kg) this means that 20-30% of heat recovery energy will be used (‘lost’ for temperate efficiency) in condensing.

**Table 4 - 6. Estimated space heating saving non-residential ventilation units, sold 2010**

| Product --> | Ref. natural vent. | CEXH | CHRV | AHU-S | AHU-M | AHU-L |
|---|---|---|---|---|---|---|
| design flow rate $q_{design}$ (m³/h) | X | 1.500 | 2.250 | 4.000 | 10.000 | 35.000 |
| *---includes MISC factor* | *1,7* | *1,33* | *1,10* | *1,10* | *1,15* | *1,18* |
| *---effective flow rate for IAQ* $q_{eff}$ | *X/1,7* | *1.128* | *2.045* | *3.636* | *8.695* | *29.661* |
| Filter Yes (=1) or No (=0) | 0 | 0 | 1 | 1 | 1 | 1 |
| Aggregate thermal efficiency $\eta_{th}$ in % | 0 | 0 | 0,8 | 0,44 | 0,44 | 0,44 |
| HR market penetration $HR_{pen}$ | 0 | 0 | 1 | 0,7 | 0,7 | 0,7 |
| On/off control factor $CTRL_{on}$ | 0,8 | 0,8 | 0,6 | 0,6 | 0,6 | 0,6 |
| Speed control factor $CTRL_{var}$ | 1 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 |
| Airflow annual average $q_a$ (m³/h)= $CTRL_{on}$ * $CTRL_{var}$*$q_{design}$ | 0,8*1*X | 960 | 1.080 | 1.920 | 4.800 | 16.800 |
| A. Reference natural ventilation, heating energy loss: (22,22 or 10,05 or 43,47) * 1,36 * $q_{eff}$ | | | | | | |
| Average climate (kWh/a) | | 34.087 | 61.798 | 109.877 | 262.786 | 896.332 |
| Warmer Climate (kWh/a) | | 15.418 | 27.951 | 49.697 | 118.857 | 405.407 |
| Colder climate (kWh/a) | | 66.686 | 120.899 | 214.957 | 514.101 | 1.753.535 |
| B. Mechanical ventilation, heat energy loss: (22,22 or 10,05 or 43,47)*$q_a$ *(1- $\eta_{th}$) | | | | | | |
| Average climate (kWh/a) | | 21.331 | 4.800 | 23.891 | 59.727 | 209.046 |
| Warmer Climate (kWh/a) | | 9.648 | 2.171 | 10.806 | 27.014 | 94.550 |
| Colder climate (kWh/a) | | 41.731 | 9.390 | 46.739 | 116.847 | 408.966 |
| C. Mechanical ventilation with HR, preheat primary energy: (0,35 or 0 or 4,48) * $q_a$ * $HR_{pen}$ | | | | | | |
| Average climate (kWh/a) | | 0 | 378 | 470 | 1.176 | 4.116 |
| Warmer Climate (kWh/a) | | 0 | 0 | 0 | 0 | 0 |
| Colder climate (kWh/a) | | 0 | 4.838 | 6.021 | 15.053 | 52.685 |
| Heating energy saved (A – B – C) | | | | | | |
| Average climate (kWh/a) | | 12.756 | 56.622 | 85.518 | 201.880 | 683.170 |
| Warmer Climate (kWh/a) | | 5.768 | 25.781 | 38.892 | 91.841 | 310.856 |
| Colder climate (kWh/a) | | 24.949 | 106.673 | 162.202 | 382.196 | 1.291.884 |
| *Average climate in %* | | *37,4%* | *91,6%* | *77,8%* | *76,8%* | *76,2%* |
| *Warmer Climate in %* | | *37,4%* | *92,2%* | *78,3%* | *77,3%* | *76,7%* |
| *Colder climate in %* | | *37,4%* | *88,2%* | *75,5%* | *74,3%* | *73,7%* |

For the average stock, with the assumptions mentioned in the previous paragraph on electricity consumption, the following table applies.

**Table 4 - 7. Estimated space heating saving non-residential ventilation units, stock 2010**

| Product --> | Ref. natural vent. | CEXH | CHRV | AHU-S | AHU-M | AHU-L |
|---|---|---|---|---|---|---|
| design flow rate $q_{design}$ (m³/h) | X | 1.500 | 2.250 | 4.000 | 10.000 | 35.000 |
| *---includes MISC factor* | *1,7* | *1,33* | *1,10* | *1,10* | *1,15* | *1,18* |
| *---effective flow rate for IAQ* $q_{eff}$ | *X/1,7* | *1.128* | *2.045* | *3.636* | *8.695* | *29.661* |
| Filter Yes (=1) or No (=0) | 0 | 0 | 1 | 1 | 1 | 1 |
| Aggregate thermal efficiency $\eta_{th}$ in % | 0 | 0 | 0,6 | 0,125 | 0,125 | 0,125 |
| HR market penetration $HR_{pen}$ | 0 | 0 | 1 | 0,25 | 0,25 | 0,25 |
| On/off control factor $CTRL_{on}$ | 0,8 | 0,8 | 0,6 | 0,6 | 0,6 | 0,6 |
| Speed control factor $CTRL_{var}$ | 1 | 0,8 | 0,8 | 0,8 | 0,8 | 0,8 |
| Airflow annual average $q_a$ (m³/h)= $CTRL_{on}$ * $CTRL_{var}$*$q_{design}$ | 0,8*1*X | 960 | 1.080 | 1.920 | 4.800 | 16.800 |
| Airflow seasonal total mln.m³/h (Avg. climate) | | 5 | 6 | 10 | 25 | 86 |
| A. <u>Reference natural ventilation, heating energy loss:</u> (22,22 or 10,05 or 43,47) * 1,36 * $q_{eff}$ | | | | | | |
| Average climate (kWh/a) | | 34.087 | 61.798 | 109.877 | 262.786 | 896.332 |
| Warmer Climate (kWh/a) | | 15.418 | 27.951 | 49.697 | 118.857 | 405.407 |
| Colder climate (kWh/a) | | 66.686 | 120.899 | 214.957 | 514.101 | 1.753.535 |
| B. <u>Mechanical ventilation, heat energy loss</u>: (22,22 or 10,05 or 43,47)*$q_a$ *(1- $\eta_{th}$) | | | | | | |
| Average climate (kWh/a) | | 21.331 | 9.599 | 37.330 | 93.324 | 326.634 |
| Warmer Climate (kWh/a) | | 9.648 | 4.342 | 16.884 | 42.210 | 147.735 |
| Colder climate (kWh/a) | | 41.731 | 18.779 | 73.030 | 182.574 | 639.009 |
| C. <u>Mechanical ventilation with HR, preheat primary energy: (0,35 or 0 or 4,48) * $q_a$ * $HR_{pen}$</u> | | | | | | |
| Average climate (kWh/a) | | 0 | 378 | 168 | 420 | 1.470 |
| Warmer Climate (kWh/a) | | 0 | 0 | 0 | 0 | 0 |
| Colder climate (kWh/a) | | 0 | 4.838 | 2.150 | 5.376 | 18.816 |
| <u>Heating energy saved (A – B – C)</u> | | | | | | |
| Average climate (kWh/a) | | 12.753 | 51.823 | 72.383 | 169.038 | 568.228 |
| Warmer Climate (kWh/a) | | 5.768 | 23.610 | 32.815 | 76.645 | 257.672 |
| Colder climate (kWh/a) | | 24.949 | 97.285 | 139.785 | 326.143 | 1.095.710 |
| *Average climate in %* | | *37,4%* | *83,9%* | *65,9%* | *64,3%* | *63,4%* |
| *Warmer Climate in %* | | *37,4%* | *84,5%* | *66,0%* | *64,5%* | *63,6%* |
| *Colder climate in %* | | *37,4%* | *80,5%* | *65,0%* | *63,4%* | *62,5%* |

### 2.4.4 Total energy balance

The table below gives the total energy balance per unit, based on the assumptions in the previous paragraphs, for the average units sold 2010.

**Table 4 - 8. Estimated energy balance ventilation units, sold 2010**

| Product --> | CEXH | CHRV | AHU-S | AHU-M | AHU-L |
|---|---|---|---|---|---|
| Fan electricity/a (kWh$_e$/a) | 1.327 | 3.032 | 6.588 | 22.459 | 94.327 |
| Fan primary energy (kWh/a) | 4.225 | 15.067 | 32.762 | 111.690 | 469.097 |
| Annual net heating energy saved: | | | | | |
| Average climate (kWh/a) | 12.756 | 56.622 | 85.518 | 201.880 | 683.170 |
| Warmer Climate (kWh/a) | 5.768 | 25.781 | 38.892 | 91.841 | 310.856 |
| Colder climate (kWh/a) | 24.949 | 106.673 | 162.202 | 382.196 | 1.291.884 |

**Table 4 - 9. Estimated energy balance ventilation units, stock 2010**

| Product --> | CEXH | CHRV | AHU-S | AHU-M | AHU-L |
|---|---|---|---|---|---|
| Fan electricity/a (kWh$_e$/a) | 1.433 | 3.275 | 7.115 | 24.256 | 101.874 |
| Fan primary energy (kWh/a) | 4.225 | 15.067 | 32.762 | 111.690 | 469.097 |
| Annual net heating energy saved: | | | | | |
| Average climate (kWh/a) | 12.753 | 51.823 | 72.383 | 169.038 | 568.228 |
| Warmer Climate (kWh/a) | 5.768 | 23.610 | 32.815 | 76.645 | 257.672 |
| Colder climate (kWh/a) | 24.949 | 97.285 | 139.785 | 326.143 | 1.095.710 |

### 2.4.5 Maintenance, incl. filters

The energy consumption related to maintenance is difficult to estimate. In general, for the ventilation units in the scope it may be assumed that regular maintenance is one of the tasks of in-house maintenance staff, ranging from a single concierge to a full maintenance staff. At this time there are no data on the energy consumption that should be partitioned for ventilation-unit maintenance and therefore –unless data come available during the course of this study, no energy consumption is assumed.

As regards repairs, also no data is available. For reasons of consistency with the domestic ventilation we assume for all the five basecases a total service travel distance of 100 km for 17 years of maintenance.

The energy content of the air filters (part of the ‘consumables’) in the MEEuP EcoReport, similarity with vacuum cleaner filters is assumed. The mass per filter was derived from catalogue data. The number of filter changes depends on the size of the filter, its ‘filter efficiency’ (capability to capture particles of a certain size, see Task 5 report), the air volume passing through the filter and the average pollution of the air. The numbers were derived from case descriptions. For all balanced types it was assumed that a mechanical EU7 bag filter was used. For exhaust units no filter is used. The table below gives an overview:

**Table 4 - 10 . Consumables: BaseCase filter material consumption**

| | CEXH* | CHRV | AHU-S | AHU-M | AHU-L |
|---|---|---|---|---|---|
| Filter mass kg/filter | n.a. | 1 | 2 | 5 | 6 |
| Filter change/year | n.a. | 1 | 1 | 2 | 6 |
| Annual filter material consumed in kg | 0 | 1 | 2 | 10 | 36 |
| Filter material over product life (17 years) in kg | 0 | 17 | 34 | 170 | 612 |

*= for country-specific analysis for regions where supply-systems (System B) still occurs (UK, Ireland), it should be noted that exhaust systems cannot be deemed to represent the total population of both systems B and C, as much as supply units do require EU7 filters.

## 2.5 End-of-Life phase

For the End-of-Life we assume the EcoReport default scenario:

**Table 4 - 11. Default EOL scenario**

| | |
|---|---|
| Landfill (not recovered) | 5% of total weight * [row 88] |
| Incinerated | (plastics & PWB fraction -(re-used + recycled)) * [row 91] |
| Cost of plastics recycling | (re-used + recycled fraction) * [row 92] |
| Plastics: Re-used (closed loop) | 1% of plastics fraction |
| Plastics: Materials recycling | 9 % of plastics fraction |
| Plastics: Thermal recycling | 90 % of plastics fraction |
| Electronics easy to assembly | YES: electronics fraction & manuf. [=row 98] * 20% |
| Metals & Misc. | 95% recycled (value already incorporated) |

As a consequence, the following inputs will be used for the EOL:

**Table 5.2.5-2 EOL Inputs BaseCases**

| Row nr | Mat/process | *Unit* | **1.** Central exhaust unit (CEXH) | **2.** Central Heat Recovery Ventilation (CHRV) | **3.** Air Handling Unit Small (AHU-S) | **4.** Air Handling Unit Medium (AHU-M) | 5. Air Handling Unit Large (AHU-L) |
|---|---|---|---|---|---|---|---|
| **Disposal** | | | | | | | |
| 88 | Landfill | *gr.* | 1000 | 10000 | 37500 | 80000 | 260000 |
| 91 | Incineration | *gr.* | 7877 | 35078 | 10058 | 21456 | 69732 |
| 92 | Plastic: Re-use & Recycling (cost-side) | *gr.* | 875 | 3898 | 1118 | 2384 | 7748 |
| **Re-use, Recycling Benefit** | | | | | | | |
| 4 | Plastics: Re-use, Closed Loop Recycling | *gr.* | 88 | 390 | 112 | 238 | 775 |
| 4 | Plastics: Materials Recycling | *gr.* | 788 | 3508 | 1006 | 2146 | 6973 |
| 72 | Plastics: Thermal Recycling | *gr.* | 7877 | 35078 | 10058 | 21456 | 69732 |
| 98 | Electronics: PWB Easy to Disassemble? | | Yes | Yes | Yes | Yes | Yes |
| | Metals & TV glass + Misc. | *gr.* | 10686 | 152974 | 701884 | 1497352 | 4866394 |

# 3. Definition of BaseCases

The following BaseCases are distinguished.

By type:
- Exhaust system (CEXH)
- Balanced Heat Recovery system, without option for additional cooling or heating (CHRV)
- Air Handling Units, i.e. with the option for air cooling/heating (AHU)

By size:
CHRV, $q_{design}$= 2.250 m³/h, $\Delta p_{ext}$ =181 Pa/fan;
AHU-S, $q_{design}$= 4.000 m³/h, $\Delta p_{ext}$ =244 Pa/fan;
AHU-M, $q_{design}$= 10.000 m³/h, $\Delta p_{ext}$ =450 Pa/fan;
AHU-M, $q_{design}$= 35.000 m³/h, $\Delta p_{ext}$ =575 Pa/fan;

By usage (for controls):

Table Case studies occupancy (extract from Tables 3-23 and 3-24, Task 3 report)

| | 1. Large office | 2. Medium-sized office | 3. Small office | 4. Hospital | 5. Retire-ment home | 6. Hotel | 7. Shop-ping mall | 8. Hyper-market |
|---|---|---|---|---|---|---|---|---|
| Floor area, in m² | 15.000 | 5.000 | 1.008 | 30.345 | 3.916 | 3.668 | 12.940 | 6.000 |
| Building volume, in m³ | 45.000 | 15.000 | 2.721 | 91.035 | 11.750 | 9.832 | 93.430 | 42.000 |
| No. of floors | 12 | 4 | 2 | 5 | 4 | 4 | 1 | 1 |
| ***Total design flow rate, in m³/h*** | ***45.750*** | ***15.100*** | ***2.730*** | ***179.535*** | ***8.340*** | ***17.475*** | ***146.870*** | ***28.075*** |
| Fraction occupied 'on' | 42% | 42% | 42% | 81% | 86% | 100% | 54% | 50% |
| Zone occupancy rate during 'on' | 53% | 53% | 53% | 41% | 63% | 34% | 23% | 15% |
| Zone peak occupancy rate | 80% | 80% | 80% | 80% | 80% | 80% | 80% | 80% |
| Avg. annual occupancy rate | 22% | 22% | 22% | 73% | 41% | 19% | 10% | 6% |

BaseCase $CTRL_{on}$: Overall building control as fraction 'on': average 0,6 (60%). Multi-family 0,8 (80%)
BaseCase $CTRL_{var}$: Building peak occupancy rate: 80% determines average fan speed setting.

A detailed description of the usage pattern can be found in the Task 3 report.

# 4. Environmental Impact BaseCases

EcoReports for all five BaseCases were calculated, using the inputs given in the previous chapters.

The table below summarizes the outcome for all non residential ventilation systems.

The environmental impact is related to the calculated ventilation capacity that can be served by the ventilation unit, based on the system specific reference airflow, when running at reference (= 70% of the maximum) airflow. The negative values for total energy (GER), Heat savings, Greenhouse gases and Volatile Organic Compounds can be explained simply because with mechanical ventilation the air flow is ‘controlled’, whereas with natural ventilation –meeting the same Indoor Air Quality requirements—the designer always depends on nature and has to ‘plan for the worst’ as can be see in task 2 Chapter 5.3.5 “Saving on space heating fuel”.

Main findings are:

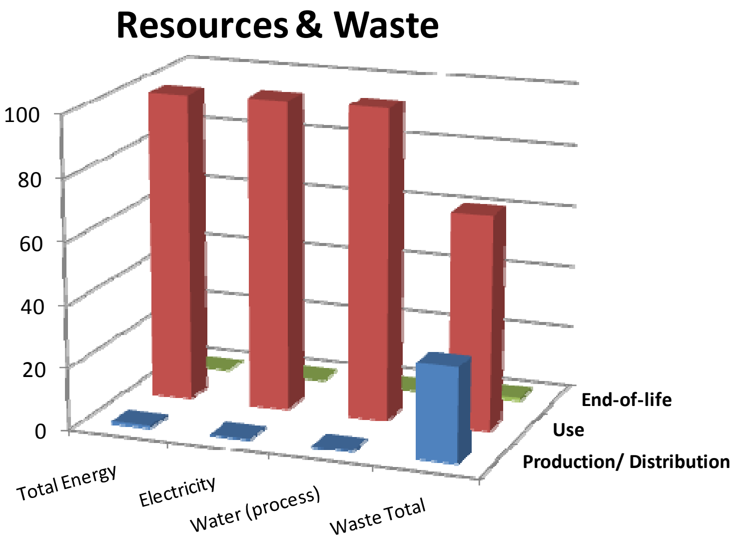
- 99 to 100,0% of all $CO_2$ emissions relate to the use phase
- 97 to 99% of all $SO_x$ emissions relate to the use phase
- 97 to 98 % of all VOC emissions relate to the use phase
- 36 – 55% of all PM emissions relate to the use phase.

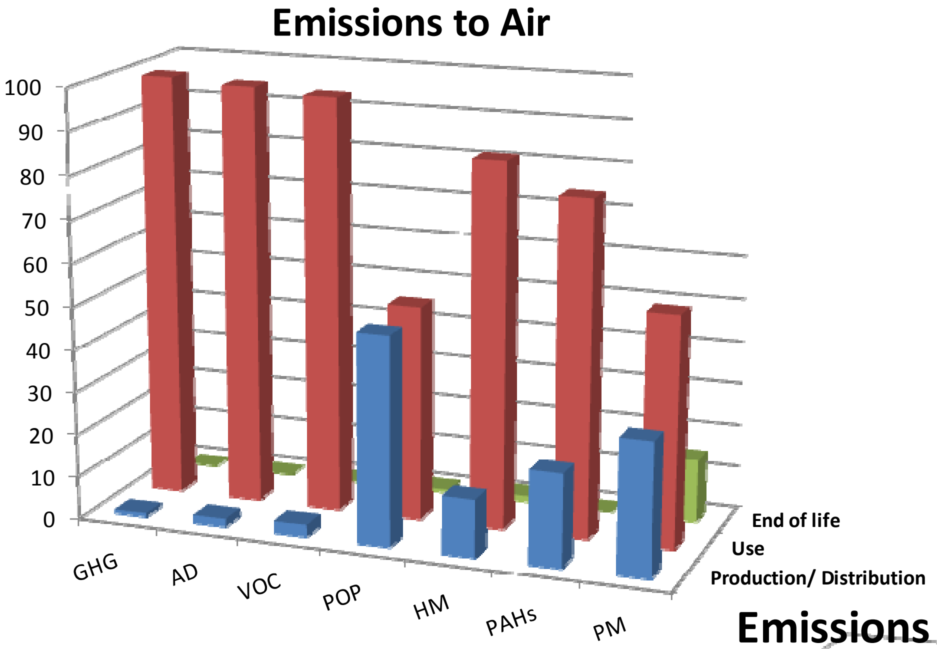
**Table 4 - 12**. **Environmental Impact *BaseCase Units* over lifetime for non residential ventilation systems per unit.**

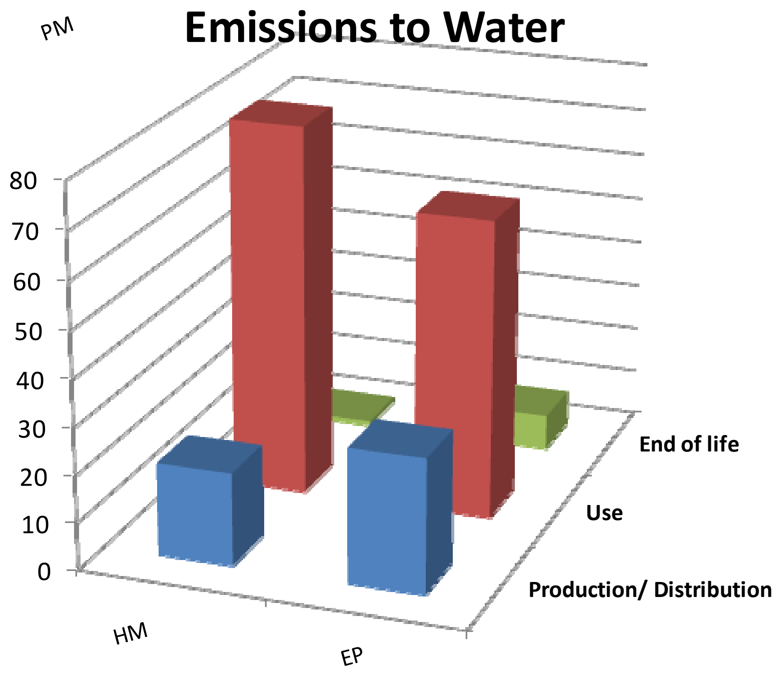
| | Unit | CEXH | CHRV | AHU-S | AHU-M | AHU-L |
|---|---|---|---|---|---|---|
| **Materials** | | | | | | |
| Total | kg | 20 | 196 | 740 | 1.578 | 5.125 |
| of which | | | | | | |
| Disposal | kg | 9 | 44 | 47 | 101 | 324 |
| Recycled | kg | 11 | 153 | 692 | 1.477 | 4.801 |
| **Other Resources & Waste** | | | | | | |
| Total Energy (GER)* | GJ | -599 | -3.172 | -4.413 | -9.981 | -32.143 |
| of which, electricity (in primary MJ)* | GJ | 237 | 545 | 1.185 | 4.029 | 16.904 |
| Heat Savings | GJ | -836 | -3.717 | -5.598 | -14.010 | -49.048 |
| Water (process) | m³ | 24 | 72 | 133 | 405 | 1.602 |
| Water (cooling) | m³ | 630 | 1.447 | 3.140 | 10.699 | 44.936 |
| Waste, non-haz./ landfill | kg | 305 | 950 | 3.060 | 8.271 | 31.300 |
| Waste, hazardous/ incinerated | kg | 14 | 48 | 38 | 115 | 460 |
| o **Emissions (Air)** | | | | | | |
| Greenhouse Gases in GWP100 | t $CO_2$ eq. | -36 | -182 | -257 | -597 | -1.969 |
| Ozone Depletion, emissions | mg R-11 eq. | | | | | 0 |
| Acidification, emissions | kg $SO_2$ eq. | 48 | 83 | 226 | 836 | 3.641 |
| Volatile Organic Compounds (VOC) | kg | 0 | -2 | -3 | -8 | -28 |
| Persistent Organic Pollutants (POP) | mg i-Teq | 2 | 8 | 28 | 71 | 254 |
| Heavy Metals | g Ni eq. | 4 | 12 | 30 | 89 | 355 |
| PAHs | g Ni eq. | 1 | 1 | 4 | 11 | 43 |
| Particulate Matter (PM, dust) | kg | 6 | 11 | 18 | 47 | 195 |
| o **Emissions (Water)** | | | | | | |
| Heavy Metals | g Hg/20 | 2 | 5 | 13 | 37 | 145 |
| Eutrophication | g $PO_4$ | 0 | 0 | 0 | 0 | 1 |
| Persistent Organic Pollutants (POP) | ng i-Teq | | | Negligible | | |

*=Energy use of the ventilation unit, including extra electricity consumption (ca. 10% of total electricity consumption) for the extra pressure drop caused by the pre-cooling/ pre-heating coils in AHUs. The energy consumption to cool/heat the coil(s) is excluded, because it is delivered by an external source (chiller/boiler), treated separately in the air conditioning part of the study.

**Fig. AHU-M. Environmental impacts as % of life cycle phases (example)**







# 5. Life Cycle Costs BaseCases

## 5.1 LCC Inputs: Prices and installation costs

The prices of the BaseCases are derived from task 2 chapter 5, paragraph 5.2 “Acquisition costs”. Based on the cost structure and market prices as presented in the Task 2 report, the costs for the five principal ventilation products in the scope is given below.

**Table 4 - 13. Prices and installation costs BaseCases per unit (2010)**

| Product --> | CEXH | CHRV | AHU-S | AHU-M | AHU-L |
|---|---|---|---|---|---|
| **<u>Features</u>** | | | | | |
| flow rate (m³/h) [5] | **1.500** | **2.250** | **4.000** | **10.000** | **35.000** |
| Ext. ΔP (in Pa) [6] | 154 | 181 | 244 | 460 | 670 |
| SPI (in W/(m³/h)) [7] | 0,30 | 0,45 | 0,55 | 0,90 | 1,00 |
| HRS market share[8] | 0% | 100% | 70% | 70% | 70% |
| HRS thermal efficiency [9] | 0% | 80% | 62% | 62% | 62% |
| Control factor CTRL [10] | 0,80 | 0,80 | 0,80 | 0,80 | 0,80 |
| Misc. factor MISC [11] | 1,33 | 1,10 | 1,10 | 1,10 | 1,10 |

**<u>PRICES in Euro 2010</u>**

| | CEXH | CHRV | AHU-S | AHU-M | AHU-L |
|---|---|---|---|---|---|
| labour | 45 | 500 | 680 | 1.200 | 2.000 |
| materials | 150 | 1.000 | 1.520 | 2.800 | 6.000 |
| overhead | 105 | 1.000 | 1.800 | 4.000 | 12.000 |
| *msp* | ***300*** | **2.500** | ***4.000*** | **8.000** | **20.000** |
| wholesale price | 390 | 3.250 | 4.800 | 8.800 | 21.000 |
| installer price [1] | 488 | 4.063 | 5.760 | 9.680 | 22.680 |
| builder price [2] | 634 | 5.281 | 7.488 | 12.584 | 29.484 |
| ducts, grills, ctrls [3] | 1.965 | 7.130 | 34.445 | 98.155 | 383.292 |
| inst. labour avg. [4] | 2.342 | 9.494 | 39.708 | 109.617 | 420.113 |

*[1]= end-customer unit price replacement (excl. VAT)*

*[2]= end-customer unit price new built/retrofit (excl. VAT)*

*[3]= not for replacements*

*[4]= "avg."= For CHRV the split up is 45/45/10 between new built/retrofit/replacement(in 2010); for CEXH and AHU the split up is 35/30/35 between new built/retrofit/replacement(in 2010).*

| *END PRICES* | | | | | |
|---|---|---|---|---|---|
| *Inst. labour new built* | *2.711* | *10.338* | *51.667* | *147.233* | *574.938* |
| *Inst. labour retrofit* | *3.792* | *12.477* | *62.001* | *176.679* | *689.926* |
| *inst. replacement(50% on ex installer price)* | *731* | *6.094* | *8.640* | *14.520* | *34.020* |

*[5] Design flow rate F (in m³/h)= 65% of flow rate at 0 Pa [EN 13799]*

*[6]Design external pressure drop h (in Pa), according to EN 13799 is measured at 65% of maximum (flow rate=0). Practical values above are estimated as follows: if design flow rate F<10.000 m$^3$/h then href= 0,036*F+100 ; if 10.000≤ F <25.000 m$^3$/h then href=0,0146*F+304; if F≥25.000 m$^3$/h then href=75*ln(F)-190,5 (equation Kaup, supply side, but subtract 100 for heat/cool coil)*

## 5.2 LCC Inputs: Maintenance, incl. filters

Maintenance costs consist of duct cleaning (assumed once every 10 years) and –most importantly— air filter costs. In the table below the maintenance costs for each of the five basecases are calculated per unit annual and the LCC unit running costs (17 years).

**Table 4 - 14. Maintenance costs per unit over lifetime**

Annual UNIT running costs SOLD 2010 (EUR/a):

| Product --> | CEXH | CHRV | AHU-S | AHU-M | AHU-L |
|---|---|---|---|---|---|
| Maintenance | 67 | 125 | 177 | 604 | 2.536 |

LCC UNIT running costs (17 yrs.) for SOLD 2010 (EUR/a)

| Product --> | CEXH | CHRV | AHU-S | AHU-M | AHU-L |
|---|---|---|---|---|---|
| Maintenance (15% el.) | 960 | 1.787 | 2.533 | 8.634 | 36.264 |

**EU-totals: Markets by Category**

The following builds on the previous paragraphs to show

- the appropriate Life Cycle Costs (LCC) per unit purchased today, with discounted running costs in the coming years, and
- the total EU-27 expenditure in 2010, being the sum of the running costs of the installed units (stock) and the acquisition costs. It is established per unit and –using the data from sales and stock per type—for the whole of the EU-27.

The calculation of the LCC poses some specific problems for this product and choices that have to be made regarding:

- the system boundaries and
- the time horizon.

As regards the system boundaries,

- The manufacturer of the units would probably like to take the acquisition costs and running costs of the whole unit, but not more than that, as a basis. However, already at the outset it was decided that this is not possible if –as is the case with many units—the unit fulfils more than one function.
- Thus the scope is already is restricted to just the ventilation function of the unit. This means that the specific fan power is measured without any heating or cooling coil or any (extra[15]) humidification/ dehumidification module. It is very much an objective of the underlying study to separate the strict ventilation function and the extra costs of the distribution side of (some) air conditioning.
- On the other hand, for a fair choice, the system-side of the ventilation function cannot be ignored. The very nature of the unit determines the amount of installation costs, which is very

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[15] Some dehumidification will take place in a heat recovery unit, like it or not, and then this is part of the ventilation function.

different between e.g. an exhaust unit and a central heat recovery unit, both in terms of labour costs and in terms of additional materials (grilles, ducts, etc.) required. Also in terms of running costs it is not fair to just look at the electricity consumption of the fan and not at the saving on space heating that is true for all mechanical ventilation and in particular for heat recovery ventilation.

To summarize, the study just looks at the ventilation function, but then at the whole system.

As regards the time horizon, there are also a number of options:

- From the societal perspective the LCC-calculation should be made over the life time of the installation, i.e. for a modern office this would be some 35 years. This covers the full technical write-off period for the duct-work and grilles. It would show that over this period the unit is not only purchased in year 1 but also replaced –as a whole or through consecutive 'repairs'- after around 17 years (at a different cost, see par. 5.2). And it presents the best case for recuperating any extra investment costs in energy efficiency.
- However, for no investor, financial institution, developer or even private company building his own premises 35 years is a realistic time horizon. Mortgages, fiscal write-offs and most certainly pay-back periods or return on investment for the installation of a building will look at a period of at the most 15 to 20 years. Hence, even though the ducting may only be at half of its technical life, a realistic approach would write off the whole investment in e.g. 17 years.

Thus it is proposed to make the LCC-calculation, including full installation costs, for a period of 17 years.

On this basis, the following LCC calculations were made, per unit type and for 3 climates (Average, Warmer, Colder), over a period of 17 years.

The applicable Present Worth Factor was calculated taking into account an annual price increase of 7,3 % (aggregated discount rate 4-7,3= -3,3%) and 2% for electricity as well as maintenance costs (aggregated discount rate 4-2= 2%). At a product life of 17 years this resulted in a PWF of 23,3 years for fuel costs and 14,3 years for electricity and maintenance costs.

## Table 4 - 15. Expenditure and LCC for products sold in 2010

| Product --> | CEXH | CHRV | AHU-S | AHU-M | AHU-L |
|---|---|---|---|---|---|
| Acquisition costs | | | | | |
| NEW BUILT | | | | | |
| unit msp | 300 | 2.500 | 4.000 | 8.000 | 20.000 |
| unit trade | 334 | 2.781 | 3.488 | 4.584 | 9.484 |
| ducts, grilles, ctrls | 1.331 | 1.848 | 26.957 | 85.571 | 353.808 |
| installer labour | 747 | 3.208 | 17.222 | 49.078 | 191.646 |
| | 2.711 | 10.338 | 51.667 | 147.233 | 574.938 |
| RETROFIT | | | | | |
| unit msp | 300 | 2.500 | 4.000 | 8.000 | 20.000 |
| unit trade | 334 | 2.781 | 3.488 | 4.584 | 9.484 |
| ducts, grilles, ctrls | 1.331 | 1.848 | 26.957 | 85.571 | 353.808 |
| installer labour | 1.827 | 5.347 | 27.556 | 78.524 | 306.634 |
| | 3.792 | 12.477 | 62.001 | 176.679 | 689.926 |

Annual UNIT running costs SOLD 2010 (EUR/a):

| Product --> | CEXH | CHRV | AHU-S | AHU-M | AHU-L |
|---|---|---|---|---|---|
| Costs electricity | 218 | 497 | 705 | 2.403 | 10.093 |
| Maintenance | 33 | 75 | 106 | 360 | 1.514 |
| Heating fuel, Avg. climate | -740 | -3.284 | -3.079 | -7.697 | -26.941 |
| Heating fuel, Warmer climate | -335 | -1.495 | -1.400 | -3.501 | -12.252 |
| Heating fuel, Colder climate | -1.447 | -6.187 | -5.839 | -14.600 | -51.099 |
| **Total Average climate** | **-490** | **-2.712** | **-2.268** | **-4.934** | **-15.334** |
| **Total Warmer climate** | **-84** | **-923** | **-589** | **-737** | **-645** |
| **Total Colder climate** | **-1.197** | **-5.615** | **-5.028** | **-11.836** | **-39.492** |

LCC UNIT running costs (17 yrs.) for SOLD 2010 (EUR/a)

| Product --> | CEXH | CHRV | AHU-S | AHU-M | AHU-L |
|---|---|---|---|---|---|
| Costs electricity | 3.112 | 7.111 | 10.080 | 34.364 | 144.330 |
| Maintenance (15% el.) | 467 | 1.067 | 1.512 | 5.155 | 21.650 |
| Heating fuel, Avg. climate | -17.239 | -76.517 | -71.731 | -179.352 | -627.718 |
| Heating fuel, Warmer climate | -7.797 | -34.839 | -32.622 | -81.566 | -285.476 |
| Heating fuel, Colder climate | -33.725 | -144.155 | -136.051 | -340.177 | -1.190.596 |
| NEW BUILT | | | | | |
| **LCC Average climate** | **-10.948** | **-58.002** | **-8.471** | **7.400** | **113.200** |
| **LCC Warmer climate** | **-1.507** | **-16.324** | **30.638** | **105.186** | **455.442** |
| **LCC Colder climate** | **-27.434** | **-125.640** | **-72.792** | **-153.426** | **-449.678** |
| RETROFIT | | | | | |
| **LCC Average climate** | **-9.868** | **-55.863** | **1.862** | **36.847** | **228.187** |
| **LCC Warmer climate** | **-426** | **-14.185** | **40.971** | **134.632** | **570.430** |
| **LCC Colder climate** | **-26.354** | **-123.501** | **-62.458** | **-123.979** | **-334.691** |

The table below gives the annual EU-expenditure. The prices for unit acquisition costs are taken from previous table 4-15 and not repeated here. The average saving on heating fuel is calculated using 66% average climate, 28% warmer climate and 6% colder climate.

**Table 4 - 16. Total expenditure 2010**

Annual UNIT running costs INSTALLED 2010 (EUR/a):

| Product --> | CEXH | CHRV | AHU-S | AHU-M | AHU-L |
|---|---|---|---|---|---|
| Costs electricity | 235 | 537 | 761 | 2.595 | 10.900 |
| Maintenance | 35 | 81 | 114 | 389 | 1.635 |
| Heating fuel, Avg. climate | -740 | -3.006 | -2.606 | -6.515 | -22.803 |
| Heating fuel, Warmer climate | -335 | -1.369 | -1.181 | -2.954 | -10.338 |
| Heating fuel, Colder climate | -1.447 | -5.642 | -5.032 | -12.582 | -44.036 |
| **Total Average climate** | **-490** | **-2.434** | **-1.795** | **-3.752** | **-11.196** |
| **Total Warmer climate** | **-84** | **-798** | **-371** | **-190** | **1.269** |
| **Total Colder climate** | **-1.197** | **-5.070** | **-4.221** | **-9.819** | **-32.429** |

Total expenditure EU-27 acquisition and running costs 2010

| Product --> | CEXH | CHRV | AHU-S | AHU-M | AHU-L | **Total** |
|---|---|---|---|---|---|---|
| Units sold 2010, # 000 [2] | 1.100 | 140 | 47 | 65 | 68 | |
| Units installed 2010, # 000 | 16.000 | 978 | 237 | 715 | 799 | |
| PER UNIT, in Euro | | | | | | |
| Manufacturer selling price | 300 | 2.500 | 4.000 | 8.000 | 20.000 | |
| Other acquisition [1] | 1.872 | 5.572 | 33.692 | 98.229 | 392.175 | |
| Electricity & maintenance | 235 | 537 | 761 | 2.595 | 10.900 | |
| Avg. heating fuel [3] | -669 | -2.706 | -2.352 | -5.882 | -20.587 | |
| TOTAL EU-27, 2010, in mln. Euro | | | | | | |
| Industry price | 330 | 350 | 188 | 520 | 1.360 | 2.748 |
| Trade & installation | 2.059 | 780 | 1.584 | 6.385 | 26.668 | 37.475 |
| Electricity & maintenance | 3.761 | 525 | 180 | 1.856 | 8.709 | 15.032 |
| Heating fuel saved | -10.701 | -2.646 | -558 | -4.206 | -16.449 | -34.559 |
| TOTAL | -4.552 | -991 | 1.394 | 4.555 | 20.289 | 20.696 |

# 6. EU-27 Total Impact

Based on the market data from the Task 2 report, the following table is put together:

**Table 4 - 17 Stock and segmentation mechanical ventilation *units***

**Ventilation equipment collective residential and non-residential estimated sales and stock 2008 [1] [2]**

| | **SALES 2008** | | | | | | | | | | **STOCK 2008** | | | **2008** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **TOTAL SALES** | | | | **REPLACEMENTS** | | | **NEW/1st TIME INST.** | | | **TOTAL STOCK** | | | **cap.** |
| **Ventilation collective residential and non-residential EU-27** | units<br># x 1000 | cap<br>1000 m$^3$/h | total*<br>Mm$^3$/h | % | units<br># x 1000 | total<br>Mm$^3$/h | % | units<br># x 1000 | total<br>Mm$^3$/h | % | units<br># x1000 | total<br>Mm$^3$/h | % | **stock**<br>m$^3$ % |
| **Mechanical ventilation** | | | | | | | | | | | | | | |
| AHU-L(>14500 m$^3$/h) | 68 | 35 | 2.380 | *46%* | 34 | 1.190 | *65%* | 34 | 1.190 | *35%* | 799 | 27.965 | *45%* | *20%* |
| AHU-M (5500-14500 m$^3$/h) | 65 | 10 | 650 | *13%* | 25 | 250 | *14%* | 40 | 400 | *12%* | 715 | 7.150 | *11%* | *5%* |
| AHU-S (2550-5500 m$^3$/h) | 47 | 4 | 188 | *4%* | 15 | 60 | *3%* | 32 | 128 | *4%* | 237 | 948 | *2%* | *1%* |
| CHRV (300-2250 m$^3$/h) | 140 | 2,3 | 315 | *6%* | 10 | 23 | *1%* | 130 | 293 | *9%* | 978 | 2.201 | *4%* | *2%* |
| Central Exhaust | 1.100 | 1,5 | 1.650 | *32%* | 200 | 300 | *16%* | 900 | 1.350 | *40%* | 16.000 | 24.000 | *39%* | *17%* |
| LHRV (fans <125W) | 30 | 0,1 | 3 | *0%* | 0 | 0 | *0%* | 30 | 3 | *0%* | 300 | 30 | *0%* | *0%* |
| local fans (<125 W) | 6.000 | 0,1 | 600 | *12%* | 3.000 | 300 | *16%* | 3000 | 300 | *9%* | 60.000 | 6.000 | *10%* | *n.a.* |
| **TOTAL MECH. (excl. loc.fans)** | *1.450* | | **5.186** | | *284* | **1.823** | | *1.166* | **3.364** | | *19.029* | **62.294** | | **45%** |
| **Natural ventilation** | | | | | | | | | | | | | | |
| | | | | | | **[built 1998]** | | | **[built 2008]** | | | | | |
| Natural (excl local fans) | | | | | | **2.200** | *55%* | | **2.045** | | | **75.000** | | 55% |
| **TOTAL ALL** | | | | | | ***4.023*** | | | ***5.409*** | | | ***137.294*** | | **100%** |

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[1] VHK on basis of misc. sources (see Annex). Note that the capacity ('cap') refers to the design air flow rate, not to the actual flow rate (see chapter 5 on control factor and misc. factor). For natural ventilation an estimated 'real' air change rate of 1,7 m$^3$/m$^3$ was assumed (relating to a ventilated building stock volume of 40 bln. m$^3$). The size distribution for AHU's and CHRV is based partly on Kaup 2009 and partly on a correction that 'mini' and 'compact' units are underrepresented in Kaup's figures (see graph below)

[2] Dedicated buildings are collective residential 16 bln. m$^3$ ventilated volume (37% mechanical ventilation), tertiary sector 29 bln. m$^3$ (60% mech. vent.), industry & agricultural 22 bln. m$^3$ (17% mech. vent); total 67 bln. m$^3$, of which 40% (27 bln. m$^3$) mechanically ventilated and 60% natural or natural with local fans (40 bln.). To this 4,2 mln. establishments with average 500 m$^3$ have to be added (0,645 bln. m$^3$), amongst which high share of bars and restaurants (high hourly air exchange rate of 2,5-4).
Small establishments are 3,5 mln. shops/bars/restaurants + 0,8 mln. professional dwellings (doctors, dentists, etc.). Assumed 50% chilled (90% in South, 30% rest EU)

Combining the sales and stock data from the previous table with the outcomes of Chapter 2 the following tables result.

**Table 4 - 18 . Estimated EU-27 energy balance non-residential ventilation units, sold 2010**

| Product --> | CEXH | CHRV | AHU-S | AHU-M | AHU-L | Total |
|---|---|---|---|---|---|---|
| Sales (000/a) | 1.100 | 140 | 47 | 65 | 68 | |
| Fan electricity/a (kWhe/a) | 1.327 | 3.032 | 6.588 | 22.459 | 94.327 | |
| Fan primary energy (kWh/a) | 4.225 | 15.067 | 32.762 | 111.690 | 469.097 | |
| <u>Annual net heating energy saved:</u> | | | | | | |
| Average climate (kWh/a) | 12.756 | 56.622 | 85.518 | 201.880 | 683.170 | |
| Warmer Climate (kWh/a) | 5.768 | 25.781 | 38.892 | 91.841 | 310.856 | |
| Colder climate (kWh/a) | 24.949 | 106.673 | 162.202 | 382.196 | 1.291.884 | |
| Fan electricity/a (TWhe/a) | 1 | 0 | 0 | 1 | 6 | ***10*** |
| SUBTOTAL fan primary energy (TWh/a) | ***5*** | ***2*** | ***2*** | ***7*** | ***32*** | ***47*** |
| SUBTOT.CO$_2$ (MtCO$_2$/a) @ 0,4 Mt/TWh | ***1*** | ***0*** | ***0*** | ***1*** | ***3*** | ***4*** |
| <u>Annual net heating energy saved:</u> | | | | | | |
| Average climate (TWh/a) 66% | 9 | 5 | 3 | 9 | 34 | 60 |
| Warmer Climate (TWh/a) 28% | 2 | 1 | 1 | 2 | 6 | 12 |
| Colder climate (TWh/a) 6% | 2 | 1 | 0 | 2 | 6 | 10 |
| SUBTOTAL primary heat saved (TWh/a) | ***13*** | ***7*** | ***4*** | ***13*** | ***46*** | ***82*** |
| SUBTOTAL primary heat saved (PJ/a) | ***46*** | ***26*** | ***13*** | ***45*** | ***165*** | ***295*** |
| SUBTOT.CO$_2$ (MtCO$_2$/a) @0,057 Mt/PJ) | ***3*** | ***1*** | ***1*** | ***3*** | ***9*** | ***17*** |
| TOTAL PRIMARY ENERGY (TWh/a) | **-8** | **-5** | **-2** | **-5** | **-14** | **-34** |
| TOTAL PRIMARY ENERGY (PJ/a) | **-29** | **-18** | **-7** | **-19** | **-50** | **-124** |
| TOTAL GWP100 in MtCO$_2$/a | **-2** | **-1** | **-1** | **-2** | **-7** | **-13** |

**Table 4 - 19. Estimated energy balance non-residential ventilation units, stock 2010**

| Product --> | CEXH | CHRV | AHU-S | AHU-M | AHU-L | Total |
|---|---|---|---|---|---|---|
| Stock (000/a) | 16.000 | 978 | 237 | 715 | 799 | 18.729 |
| Fan electricity/a (kWhe/a) | 1.433 | 3.275 | 7.115 | 24.256 | 101.874 | |
| Fan primary energy (kWh/a) | 4.225 | 15.067 | 32.762 | 111.690 | 469.097 | |
| Annual net heating energy saved: | | | | | | |
| Average climate (kWh/a) | 12.753 | 51.823 | 72.383 | 169.038 | 568.228 | |
| Warmer Climate (kWh/a) | 5.768 | 23.610 | 32.815 | 76.645 | 257.672 | |
| Colder climate (kWh/a) | 24.949 | 97.285 | 139.785 | 326.143 | 1.095.710 | |
| Fan electricity/a (TWhe/a) | 23 | 3 | 2 | 17 | 81 | ***127*** |
| SUBTOTAL fan primary energy (TWh/a) | ***68*** | ***15*** | ***8*** | ***80*** | ***375*** | ***545*** |
| SUBTOT.$CO_2$ (Mt$CO_2$/a) @ 0,4 Mt/TWh | ***9*** | ***1*** | ***1*** | ***7*** | ***33*** | ***51*** |
| Annual net heating energy saved: | | | | | | |
| Average climate (TWh/a) 66% | 135 | 33 | 11 | 85 | 334 | 599 |
| Warmer Climate (TWh/a) 28% | 26 | 6 | 2 | 16 | 64 | 115 |
| Colder climate (TWh/a) 6% | 24 | 6 | 2 | 15 | 59 | 105 |
| SUBTOTAL primary heat saved (TWh/a) | ***185*** | ***46*** | ***15*** | ***117*** | ***457*** | ***819*** |
| SUBTOTAL primary heat saved (PJ/a) | ***664*** | ***164*** | ***56*** | ***421*** | ***1.645*** | ***2.950*** |
| SUBTOT.$CO_2$ (Mt$CO_2$/a) @0,057 Mt/PJ) | ***38*** | ***9*** | ***3*** | ***24*** | ***94*** | ***168*** |
| TOTAL PRIMARY ENERGY (TWh/a) | **-117** | **-31** | **-8** | **-37** | **-82** | **-275** |
| TOTAL PRIMARY ENERGY (PJ/a) | **-421** | **-111** | **-28** | **-133** | **-296** | **-988** |
| TOTAL GWP100 in Mt$CO_2$/a | -29 | -8 | -3 | -17 | -61 | -118 |

The energy data from the table above are one of the inputs in the total environmental impact analysis.

The Table below shows the total environmental impact of the BaseCase units sold in 2008 over their lifetime, i.e. the period between 2008 and 2025.

**Table 4 - 20. EU Total Environmental Impact BaseCase units sold in 2008**

| | Unit | CEXH | CHRV | AHU-S | AHU-M | AHU-L | Total |
|---|---|---|---|---|---|---|---|
| **Materials** | | | | | | | |
| Total | kt | 21 | 27 | 35 | 103 | 348 | 535 |
| of which | | | | | | | |
| Disposal | kt | 10 | 6 | 2 | 7 | 22 | 47 |
| Recycled | kt | 12 | 21 | 33 | 96 | 326 | 488 |
| **Other Resources & Waste** | | | | | | | |
| Total Energy (GER) | PJ | -659 | -444 | -207 | -649 | -2186 | -4.145 |
| of which, electricity (in primary MJ) | PJ | 261 | 76 | 56 | 262 | 1150 | 1.804 |
| Heat Savings | PJ | -920 | -520 | -263 | -911 | -3335 | -5.949 |
| Water (process) | mln. m³ | 26 | 10 | 6 | 26 | 109 | 178 |
| Water (cooling) | mln. m³ | 693 | 203 | 148 | 695 | 3056 | 4.795 |
| Waste, non-haz./ landfill | kt | 336 | 133 | 144 | 538 | 2128 | 3.279 |
| Waste, hazardous/ incinerated | kt | 15 | 7 | 2 | 7 | 31 | 62 |
| o **Emissions (Air)** | | | | | | | |
| Greenhouse Gases in GWP100 | mt $CO_2$ eq. | -39 | -25 | -12 | -39 | -134 | -250 |
| Ozone Depletion, emissions | t R-11 eq. | | | Negligible | | | |
| Acidification, emissions | kt $SO_2$ eq. | 53 | 12 | 11 | 54 | 248 | 377 |
| Volatile Organic Compounds (VOC) | kt | -1 | 0 | 0 | -1 | -2 | -4 |
| Persistent Organic Pollutants (POP) | g i-Teq | 2 | 1 | 1 | 5 | 17 | 26 |
| Heavy Metals | ton Ni eq. | 5 | 2 | 1 | 6 | 24 | 38 |
| PAHs | ton Ni eq. | 1 | 0 | 0 | 1 | 3 | 5 |
| Particulate Matter (PM, dust) | kt | 7 | 2 | 1 | 3 | 13 | 26 |
| o **Emissions (Water)** | | | | | | | |
| Heavy Metals | ton Hg/20 | 2 | 1 | 1 | 2 | 10 | 16 |
| Eutrophication | kt $PO_4$ | 0 | 0 | 0 | 0 | 0 | 0 |
| Persistent Organic Pollutants (POP) | g i-Teq | | | Negligible | | | |

The Table on the next page gives the EU total environmental impact of the complete 2008 stock of mechanical ventilation units.

**Table 4 - 21 Total Environmental Impact of EU-Stock BaseCase ventilation systems in 2008**

| | Unit | CEXH | CHRV | AHU-S | AHU-M | AHU-L | Total |
|---|---|---|---|---|---|---|---|
| **Materials** | | | | | | | |
| Total | kt | 21 | 27 | 35 | 103 | 348 | 535 |
| of which | | | | | | | |
| Disposal | kt | 10 | 6 | 2 | 7 | 22 | 47 |
| Recycled | kt | 12 | 21 | 33 | 96 | 326 | 488 |
| **Other Resources & Waste** | | | | | | | |
| Total Energy (GER) | PJ | -507 | -181 | -60 | -418 | -1.504 | -2.669 |
| of which, electricity (in primary MJ) | PJ | 201 | 32 | 17 | 170 | 796 | 1.215 |
| Heat Savings | PJ | | | | | | 0 |
| Water (process) | mln. $m^3$ | 20 | 4 | 2 | 17 | 75 | 119 |
| Water (cooling) | mln. $m^3$ | 534 | 84 | 44 | 450 | 2.113 | 3.224 |
| Waste, non-haz./ landfill | kt | 267 | 81 | 98 | 430 | 1.715 | 2.591 |
| Waste, hazardous/ incinerated | kt | 14 | 6 | 1 | 5 | 23 | 49 |
| o **Emissions (Air)** | | | | | | | |
| Greenhouse Gases in GWP100 | mt $CO_2$ eq. | -30 | -10 | -3 | -25 | -92 | -161 |
| Ozone Depletion, emissions | t R-11 eq. | | | Negligible | | | |
| Acidification, emissions | kt $SO_2$ eq. | 41 | 5 | 4 | 36 | 173 | 259 |
| Volatile Organic Compounds (VOC) | kt | 0 | 0 | 0 | 0 | -1 | -2 |
| Persistent Organic Pollutants (POP) | g i-Teq | 2 | 1 | 1 | 4 | 15 | 22 |
| Heavy Metals | ton Ni eq. | 4 | 1 | 1 | 4 | 18 | 28 |
| PAHs | ton Ni eq. | 1 | 0 | 0 | 1 | 2 | 4 |
| Particulate Matter (PM, dust) | kt | 6 | 1 | 1 | 3 | 12 | 23 |
| o **Emissions (Water)** | | | | | | | |
| Heavy Metals | ton Hg/20 | 2 | 0 | 0 | 2 | 8 | 12 |
| Eutrophication | kt $PO_4$ | 0 | 0 | 0 | 0 | 0 | 0 |
| Persistent Organic Pollutants (POP) | g i-Teq | | | Negligible | | | |

The total EU energy consumption reduction due to heat recovery for non-residential ventilation is estimated at 3.201 PJ of primary energy per year, with a related emission reduction of 202 Mt $CO_2$ equivalent per annum.

# 7. Sensitivity analysis (preview)

## 7.1 Introduction

The sensitivity analysis is not part of the underlying Task 4 but should be treated in Tasks 6 and 7 of the study. It entails an analysis of e.g. the effect of energy price increases, introduction dates of measures, target levels, etc., but it also discusses how robust the underlying BaseCase data may be. For the benefit of the stakeholder consultation in the beginning of 2011 this part of the sensitivity analysis is already included here. It is a vital piece of information for the policy makers on how they should interpret the results of Task 4 and is therefore also a vital piece of information for other stakeholders to check in terms of plausibility and robustness. At a later stage of the study this part will be part of the Task 6 report and only a 'preview' will be presented here.

Basically, the authors have compared the outcomes of the BaseCase analyses with the analyses of related sources and has analysed the BaseCase results for consistency with ECCP estimates[16], Ecodesign preparatory studies on motors and industrial fans and the preliminary estimate presented in the Task 1 report of the underlying study.

## 7.2 Electricity consumption for ventilation

The underlying study estimates an electricity use of 127 TWh/a, equivalent to 457 PJ primary energy and to a GWP of 51 Mt $CO_2$ (at 0,4 Mt/TWh) for the ventilation products in scope.

The ECCP study does not give specific fan electricity figures, but instead gives the following figures for the 'Baseline 2010' where fan electricity consumption is included:

- Residential sector 'other' = 18 Mt (50% to multifamily dwellings);
- Tertiary sector 'other' (mostly fans) 16 Mt;
- Industrial sector 'other' 67 Mt (small part to fans).
- Air conditioning tertiary sector (partly to be partitioned to air handling units) 45 Mt;
- Relevant for a small part: Technical ventilation in industry/ primary sector: 47 Mt.

The total 193 Mt, so a figure of 51 Mt $CO_2$ for electricity consumption is plausible.

In the 2007 preparatory study on industrial/non-residential fans (Ecodesign, DG TREN, Lot 11) Peter Ragden estimates the electricity consumption of non-residential fans EU-25 is 190 TWh/a. This is in line with our 127 TWh/a, especially as also several process applications are included.

The preparatory study on Industrial Motors (Almeida et al.), DG TREN, 2008 gives figures of estimated fan electricity consumption in the EU-25. Corrected for EU-27 this comes down to a non-residential electricity consumption of 193,2 TWh/a, of which 124,3 industrial and 68,9 (24% of total) tertiary sector. Hence, this is again in line with 127 TWh.

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[16] European Climate Change Programme, EC DG ENV, Annex I. Summarised and extended version incorporated in Kemna et al., Methodology for Ecodesign of Energy-using Products (MEEUP), VHK for European Commission DG ENTR., Nov. 2005.

The Task 1 report, Chapter 4, makes a preliminary estimate of the electricity consumption in the scope, resulting in 50 TWh/a. This is significantly lower than the BaseCases, because the preliminary estimate uses a an 'ideal' amount of 2200 equivalent full load hours, not counting the hours outside the heating season. In reality, mechanical ventilation is found to work also outside the heating season and thus the preliminary estimate should be corrected upwards.

Conclusion: With respect of other studies our estimate for fan electricity consumption in the scope is robust within ±15%.

## 7.3 Space heating energy saved

Space heating energy saved (recovered ventilation losses): 2950 PJ/a or 168 Mt $CO_2$.

The ECCP study specifies for ventilation heat loss:

- Residential 'ventilation losses' 73 Mt (50% to multifamily dwellings);
- Tertiary sector 'ventilation losses' 45 Mt
- Industrial sector 'ventilation losses' 11 Mt

Total 129 Mt $CO_2$, so a saving on ventilation losses of 168 Mt $CO_2$ is not plausible (too high). Especially with regards to the industrial sector the ECCP estimate is too low. Furthermore, what is said about *'under-ventilation'* in the next paragraphs will also apply here.

Preparatory study Boilers, Lot 1 (Kemna et. Al., VHK), for DG TREN, 2007. For EU-25 total primary energy consumption 10.593 PJ/a. According to Lot 1 ventilation and infiltration make up ca. one-third (existing built) to half (new built) of the total (say 40%). Therefore ca. 4.200 PJ/a would be plausible as total ventilation loss in boiler-heated buildings. Of this, the individual dwellings (ca. 30% of total volume) are not in the scope of the underlying study. This leaves around 3.000 PJ/a for non-residential and apartment buildings. CH Boilers covers ca. 60% of EU space heating need; there is also a significant share of the building stock with district heating, 'dry' (air) heating system, local heaters etc. If this is taken into account, the total EU-27 ventilation and infiltration loss in the scope of the study is around 5.000 PJ. From this number, the infiltration share (ca. 20%) has to be subtracted, so the total ventilation loss in the scope of the study is ca. 4.000 PJ (equivalent to 231 Mt $CO_2$/a emissions).

The Task 1 report, Chapter 4, makes a preliminary estimate of ventilation losses in the scope. First, for all buildings, based on 0,8 $m^3/h.m^3$ air change rate and 110 billion $m^3$ of heated building volume (at 18 °C equivalent) the total ventilation heat loss was estimated at ca. 8.000 PJ. This includes infiltration (estimated at 0,15-0,2 $m^3/h.m^3$=20-25%) and individual dwellings (30% of total). Thus around 4.000 PJ is in the scope as ventilation losses. The saving by existing heat recovery was estimated at 8%.

Critique: The preliminary estimate did not take into account not only heat recovery systems save heating energy, but mechanical ventilation in general reduces air flow demand and thus saves heating energy. In Task 3 it is estimated that the mechanical systems (including exhaust systems) cover close to 40% of the total building stock (number of buildings, see Task 3). Assuming that mechanical ventilation systems on average (with and without heat recovery) save around 50%, it may be expected that 25% --or some 1.000 PJ—is saved. If allowance is made for the fact that bigger (high-rise) buildings are more likely to feature a mechanical ventilation system than smaller (low-rise) buildings, this total may go up to 1.500-2.000 PJ. In other words, without mechanical ventilation units the ventilation heat losses of the buildings in the scope would be 5.500-6.000 PJ instead of 4.000 PJ.

Hence, our statement that currently all mechanical ventilation systems are saving 2.500 PJ is – although still high—not completely implausible. The main reason why the estimate is too high may be that a significant share of buildings is in fact *'under-ventilated'* during occupancy hours. E.g. with mechanical exhaust systems, the grids that should ensure enough supply of natural air often cause cold drafts and other thermal discomfort (stratification: 'hot head, cold feet' syndrome). As a result they often remain closed, thus forcing the mechanical exhaust unit to extract the fresh air from infiltration openings, at much lower flow rates. This is good for energy efficiency but detrimental for a good Indoor Air Quality. This is confirmed by anecdotal evidence from the most critical applications, such as schools, where in the Netherlands $CO_2$-concentrations of over 1.800 ppm are measured, whereas in fact 1.200 ppm would correspond to the IDA-3 level (see Task 1 and Task 3 reports).

Also in fully naturally ventilated buildings *'under-ventilation'* during occupancy hours often occurs, because in a building design that originally took into account a certain infiltration contribution to the indoor air quality (besides airing and passive stacks), the infiltration openings were subsequently closed in the context of energy saving or increasing thermal comfort. For instance, in 2003 Clausnitzer et al.[17] looked into the barriers for introducing a *'ventilation traffic light'*, a triple gas sensor IAQ indicator that would tell people when to open their windows. The aim was to save energy, but in fact in a significant number of cases (dwellings, schools) the indicator had the opposite effect: The usual IAQ was below par and thus the indicator induced people to open their windows more and not less.

Note that the above situations occur during occupancy, it is not to say that the current building stock is under-ventilated as a whole. In fact, especially during low-occupancy or no occupancy hours most buildings are vastly over-ventilated. So the improved control situation with mechanical ventilation still has a large energy saving potential; it is just around 25-30% less than could be expected when comparing the same Indoor Air Quality during occupancy.

The authors propose to continue to make the BaseCase calculations on the basis of a healthy Indoor Air Quality performance (IDA-3 level), but –for policy makers—to add an ex-post 30% correction for the ***'rebound effect'*** of the increased indoor air quality.[18] In that sense, instead of 2950 PJ saving it is estimated that the current mechanical ventilation units have brought

a) a real primary energy heat energy saving of 2065 PJ/a,
b) equivalent to GWP-reduction of 120 Mt $CO_2$/a, and
c) an improvement of the indoor air quality of 30% during occupancy hours (to put a number on it: from 1.500 to 1.200 ppm during peak occupancy)

Taking into account the primary energy and $CO_2$ equivalent of electricity consumption, the net saving is 1.608 PJ/a and 69 Mt $CO_2$ eq./a. The 1.608 PJ is equivalent to 446 TWh primary energy and would be the equivalent of almost 180 $TWh_e$.

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[17] Clausnitzer et al. Grundlagen der Einsatzmöglichkeiten und -hemnisse für die Einführung einer Lüftungsampel (Teilbericht 1), Juli 2003.

[18] 'rebound effect' is not the correct term, because it has negative connotations and implies that –once the guilty feeling over squandering energy is lifted—people fulfill a latent, thus far considered irrational need e.g. to light their garden with energy-saving CFLs. In this case there is a real need, i.e. a healthy indoor climate that is fulfilled without a conscious change in consumer behaviour.

# 8. References

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# 9. List of tables