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Final Report Task 4

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

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Note that a complete list of acronyms and symbols is included in the Task 1 report

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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

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 Costs⁴

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

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 m^3/h or m^3/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

As mentioned in previous task reports, the data availability for non-residential ventilation products is poor, especially regarding the smaller capacity products. This means that the characteristics such as the fan systems efficiency and the fan power have to be estimated not only from direct data, but also on an extrapolation of known—and accepted—data in the residential sector. However, this poses some specific problems, because in the residential sector the data are based on different parameters.

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 $\text{W}/(\text{m}^3/\text{h})$, 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 $\text{W}/(\text{m}^3/\text{s})$ 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 m^3/s respectively).

Considering that for the vast majority of non-residential units the auxiliary and stand-by electricity is negligible (<3%) the published figures on the SFP and SPI will be considered equivalent for the

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.

smaller capacity units. 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 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 SFP⁷ 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% $q_{v_{\text{max}}}$ and 65% Δp_{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

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 $f_{\text{sys:dw}} \times f_{\text{sys:rm}} \times f_{\text{eff}} \times f_{\text{duct}}$. 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).

used to determine realistic values for SFP and fan efficiency for ventilation units of various capacities.

External pressure drop

For the external pressure drop at design flow rate q_{design} (in m^3/h), the empirical formula from Dr. Kaup was used for units with design flow capacity $>25.000 \text{ m}^3$. For units with lower capacity, there are two formulas derived from catalogue data:

Design external pressure drop ΔP_{ext} (in Pa): if design flow rate $q_{\text{design}} < 10.000 \text{ m}^3/\text{h}$ then

$$\Delta P_{\text{ext}} = 0.036 * q_{\text{design}} + 100;$$

if $10\,000 \leq q_{\text{design}} < 25\,000 \text{ m}^3/\text{h}$ then

$$\Delta P_{\text{ext}} = 0.0146 * q_{\text{design}} + 304;$$

if $q_{\text{design}} \geq 25\,000 \text{ m}^3/\text{h}$ then

$$\Delta P_{\text{ext}} = 75 * \ln(q_{\text{design}}) - 190.5 \text{ (equation Kaup, supply side, but subtract 100 for heat/cool coil)}$$

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

Internal pressure drop

The internal pressure drop ΔP_{int} (in Pa) is calculated from empirical equations for the pressure drop of the heat recovery unit ΔP_{intHR} , as a function of the thermal efficiency η_{th} and the design flow rate q_{design} (in m^3/h), and of the filter. An anchor point at 165 Pa and $10.000 \text{ m}^3/\text{h}$ 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.

$$\Delta P_{\text{intHR}} = \{(0.0012\eta_{\text{th}}^3 - 0.16\eta_{\text{th}}^2 + 7.8 * \eta_{\text{th}}) / 165\} * \{22.6 * \ln(q_{\text{design}}) - 42.8\}$$

The F7 air filter pressure drop $\Delta P_{\text{intfilter}}$ for the average filter ('normal' is 150 Pa) is calculated as

$$\Delta P_{\text{intfilter}} = 0.9 * \{22.5 * \ln(q_{\text{design}}) - 42.8\}$$

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

$$\Delta P_{\text{intIO}} = 0.3 * \{22.6 * \ln(q_{\text{design}}) - 42.8\}$$

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

$$\Delta P_{\text{int}} = \{1.2 + (0.0012\eta_{\text{th}}^3 - 0.16\eta_{\text{th}}^2 + 7.8 * \eta_{\text{th}}) / 165\} * \{22.6 * \ln(q_{\text{design}}) - 42.8\}$$

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_{ventr} is given by

$$P_{\text{vent}} = (q_{\text{design}} / 3600) * (\Delta P_{\text{int}} + \Delta P_{\text{ext}}) * N_{\text{fan}}$$

Where q_{design} is the design air flow in m^3/h (the factor $1/3600$ converts to m^3/s) and N_{fan} is the number of fans in the unit.

Air flow control

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% (0.80).

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

$$q_a = q_{\text{design}} \times \text{CTRL}_{\text{on}} \times \text{CTRL}_{\text{var}}$$

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 laws¹⁰, the speed control factor CTRL_{var} diminishes with the third power. This applies to 95% of the average annual power consumption P_{ela}.

$$P_{\text{ela}} = \{0.05 + 0.95 \times \text{CTRL}_{\text{on}} \times \text{CTRL}_{\text{var}}^3\} \times P_{\text{el design}}$$

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).

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.

Compare: uses in BaseCases In the Ecodesign preparatory study for non-residential sector fans (Lot 11) Radgen uses equivalent full load hours of 2000 h/a for BaseCase exhaust systems or 3000 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} (m ³ /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 η_{th} in %	0	80	44	44	44
design ΔP_{ext} (in Pa)	154	181	244	450	575
design ΔP_{int} (in Pa)	37	329	292	334	391
Number of fans per unit	1	2	2	2	2
Power output P_{vent} in W	80	638	1 191	4 356	18 788
SFP unit (in W/(m ³ /s))	1 080	1 620	1 980	2 700	3 420
Design el. power $P_{\text{el,design}}$ (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 3000 W/(m³/s) and values in other countries were found to be higher or similar¹¹;
- 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 (CO₂ 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.

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} (m ³ /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 η_{th} in %	0	60	12.5	12.5	12.5
design ΔP_{ext} (in Pa)	154	181	244	450	595
design ΔP_{int} (in Pa)	40	306	241	275	322
Number of fans per unit	1	2	2	2	2
Power output P_{vent} in W	81	609	1 077	4 029	17 834
SFP unit (in W/(m ³ /s))	900	1764	2124	2916	3492
Design el. power $P_{\text{el,design}}$ (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 space heating 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 $2.2 \text{ m}^3/\text{h}$ per m^2 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 $1.7 \times 0.8 = 1.36 \times q_{\text{eff}}$

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 $(1-\eta_{\text{th}})$, where η_{th} is the sales weighted thermal efficiency of heat recovery. Values for η_{th} are based on FGK 2010 for the CHRV (HR=80%). η_{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 η_{th} of 44% (0.7×0.62) is used.

Subsequently the difference with natural ventilation is determined. This difference (in m^3/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 m^3 ($0.000344 \text{ kWh}/\text{m}^3\text{K}$)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 $5.112 \times 9.5 \times 0.000344 \times 1.33 = 22.21$ for the Average climate. For the Warmer climate (*heating season 4.392 h/a, $\Delta T = 5 \text{ K}$*) the multiplier is $4.392 \times 5 \times 0.000344 \times 1.33 = 10.05$. For the Colder climate (*heating season 6.552 h/a, $\Delta T = 14.5 \text{ K}$*) the multiplier is $6.552 \times 14.5 \times 0.000344 \times 1.33 = 43.47$.

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 $-4 \text{ }^\circ\text{C}$. 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 $\Delta T = 2.4 \text{ K}$ in the Average climate and $\Delta T = 5.2 \text{ K}$ 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

¹² Average of $2.36 \text{ m}^3/\text{h}$ per m^2 for airing + infiltration and $2.09 \text{ m}^3/\text{h}$ per m^2 for passive stack + Infiltration. Note that $2.2 \text{ m}^3/\text{h}$ per m^2 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 (Fraunhofer Institute. Energie-einsparpotential für den Gebäudesektor in Baden Württemberg) in Clausnitzer et al. Grundlagen der Einsatzmöglichkeiten und -hemnisse für die Einführung einer Lüftungsampel (Teilbericht 1), Juli 2003.

¹³ Specific heat per kg air: $1 \text{ kJ}/\text{kg}\cdot\text{K} = 0.277 \text{ Wh}/\text{kg}\cdot\text{K}$. Density air: $1.24 \text{ kg}/\text{m}^3$. Specific heat per m^3 air = $1.24 \times 0.277 \times 0.001$

$$168 \text{ h} \times 2.4 \text{ K} \times 0.000344 \text{ kWh/m}^3\text{K} \times 2.5 \text{ W/W} \times q_a \text{ m}^3/\text{h} = 0.35 q_a \text{ kWh/a}$$

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

$$1003 \text{ h} \times 5.2 \text{ K} \times 0.000344 \text{ kWh/m}^3\text{K} \times 2.5 \text{ W/W} \times q_a \text{ m}^3/\text{h} = 4.48 q_a \text{ kWh/a}$$

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 heat 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 indoors¹⁴) 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.

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} (m ³ /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 η_{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 (m ³ /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- η_{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.

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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} (m ³ /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 η_{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 (m ³ /h)= $CTRL_{on} * CTRL_{var} * q_{design}$	0.8*1*X	960	1 080	1 920	4 800	16 800
Airflow seasonal total mln m ³ /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- η_{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:</u> (0.35 or 0 or 4.48) * q_a * HR_{pen}						
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
<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

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
<u>Annual net heating energy saved:</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

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 4-12. 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.	1 000	10 000	37 500	80 000	260 000
91	Incineration	gr.	7 877	35 078	10 058	21 456	69 732
92	Plastic: Re-use & Recycling (cost-side)	gr.	875	3 898	1 118	2 384	7 748
Re-use, Recycling Benefit							
4	Plastics: Re-use, Closed Loop Recycling	gr.	88	390	112	238	775
4	Plastics: Materials Recycling	gr.	788	3 508	1 006	2 146	6 973
72	Plastics: Thermal Recycling	gr.	7 877	35 078	10 058	21 456	69 732
98	Electronics: PWB Easy to Disassemble?		Yes	Yes	Yes	Yes	Yes
	Metals & TV glass + Misc.	gr.	10 686	152 974	701 884	1 497 352	4 866 394

3. Definition of BaseCases

The BaseCases are defined with characteristics that are average to their sales-classes as defined in Task 2. This coherence between Task 2 and Task 4 is necessary in order to be able to aggregate the BaseCase figures to the EU total level.

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, $q_{\text{design}} = 2.250 \text{ m}^3/\text{h}$, $\Delta p_{\text{ext}} = 181 \text{ Pa/fan}$;

AHU-S, $q_{\text{design}} = 4.000 \text{ m}^3/\text{h}$, $\Delta p_{\text{ext}} = 244 \text{ Pa/fan}$;

AHU-M, $q_{\text{design}} = 10.000 \text{ m}^3/\text{h}$, $\Delta p_{\text{ext}} = 450 \text{ Pa/fan}$;

AHU-L, $q_{\text{design}} = 35.000 \text{ m}^3/\text{h}$, $\Delta p_{\text{ext}} = 575 \text{ Pa/fan}$;

By usage (for controls):

Table 4-13. 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 m ²	15 000	5 000	1 008	30 345	3 916	3 668	12 940	6 000
Building volume, in m ³	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% of all CO₂ 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.

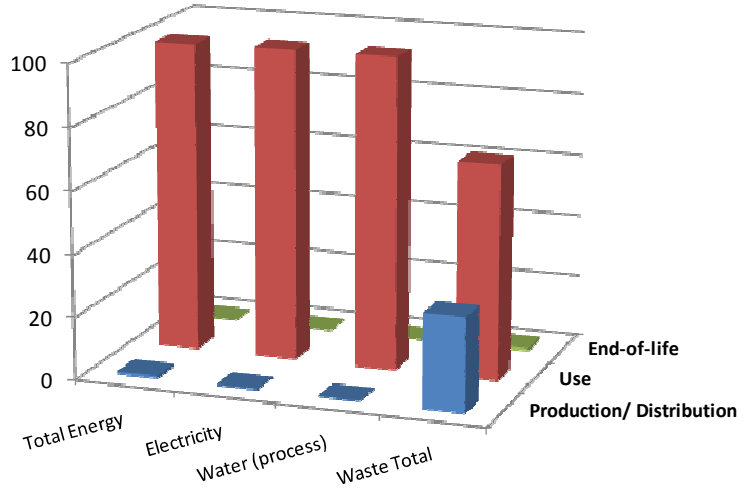
Table 4-14. Environmental Impact *BaseCase Units* over lifetime for non-residential ventilation systems per unit.

	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)	m ³	24	72	133	405	1 602	
Water (cooling)	m ³	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	
○ 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	
○ 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			

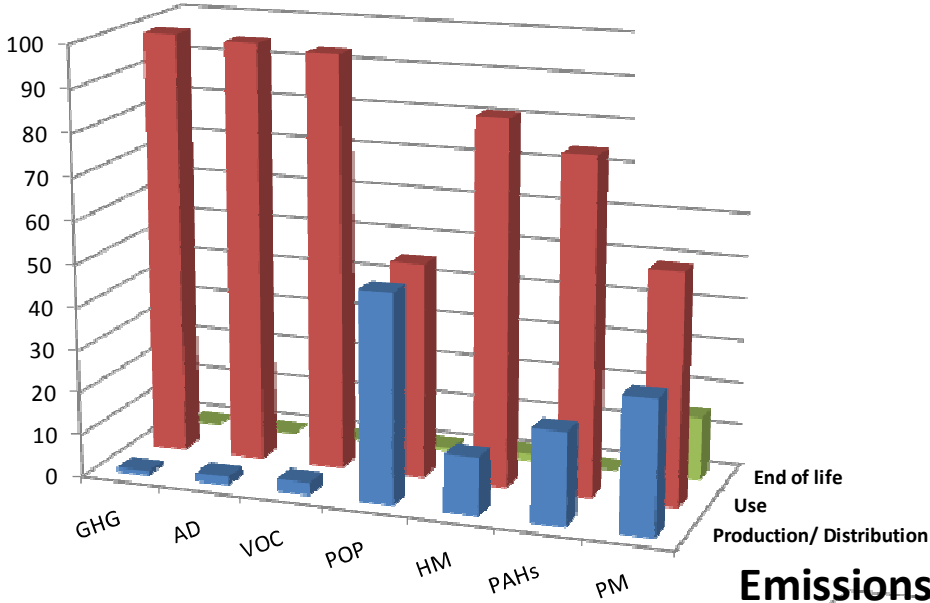
*=Energy use of the ventilation unit, including extra electricity consumption (ca. 10% of total electricity consumption) for the extra pressure drop caused by the pre-cooling/ pre-heating coils in AHUs. The energy consumption to cool/heat the coil(s) is excluded, because it is delivered by an external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

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

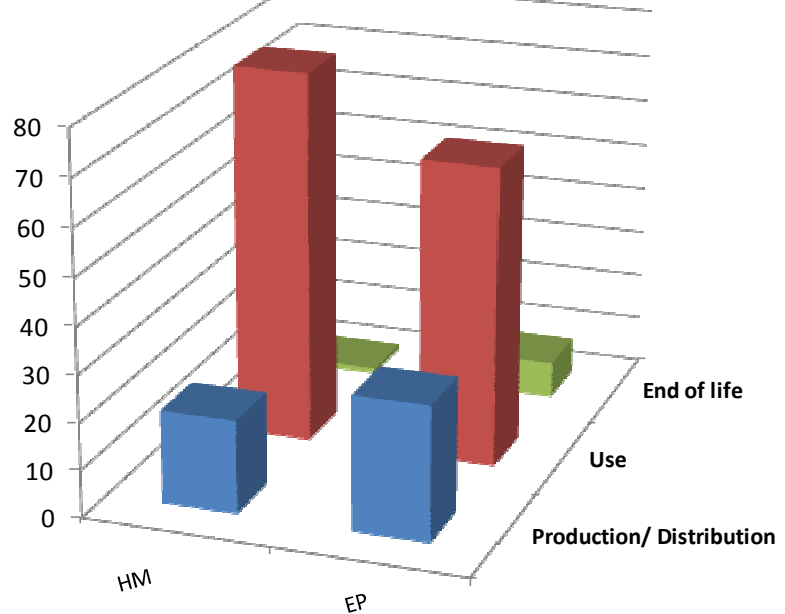
Resources & Waste



Emissions to Air



Emissions to Water



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. Note that the BaseCase represent a model; actual conditions in practice vary considerably depending on the exact application.

Table 4-15. Prices and installation costs BaseCases per unit (2010)

Product -->	CEXH	CHRV	AHU-S	AHU-M	AHU-L
Features					
flow rate (m ³ /h) [5]	1 500	2 250	4 000	10 000	35 000
Ext. ΔP (in Pa) [6]	154	181	244	460	670
SFP (in W/(m ³ /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
PRICES in Euro 2010					
	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
<i>msp</i>	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, ctrl's [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
<hr/>					
[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 m ³ /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 $F < 10\,000\text{ m}^3/\text{h}$ then $h_{ref} = 0.036 \cdot F + 100$; if $10\,000 \leq F < 25\,000\text{ m}^3/\text{h}$ then $h_{ref} = 0.0146 \cdot F + 304$; if $F \geq 25\,000\text{ m}^3/\text{h}$ then $h_{ref} = 75 \cdot \ln(F) - 190.5$ (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 4-16. 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 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 (extra¹⁵) 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

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.

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Table 4-17. Expenditure and LCC for products sold in 2010

Product -->	CEXH	CHRV	AHU-S	AHU-M	AHU-L
<u>Acquisition costs</u>					
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
<u>Annual UNIT running costs SOLD 2010 (EUR/a):</u>					
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
<u>LCC UNIT running costs (17 yrs.) for SOLD 2010 (EUR/a)</u>					
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

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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 4-18. 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 4-19 Stock and segmentation mechanical ventilation units

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

Ventilation collective residential and non-residential EU-27	SALES 2008									STOCK 2008			2008 cap. stock
	TOTAL SALES				REPLACEMENTS			NEW/1st TIME INST.		TOTAL STOCK			
	units	cap	total*		units	total		units	total		units	total	
	# x 1000	m ³ /h	Mm ³ /h	%	# x 1000	Mm ³ /h	%	# x 1000	Mm ³ /h	%	# x1000	Mm ³ /h	%

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%	3 000	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

Natural (excl local fans)								[built 1998]						[built 2008]				
								2 200	55%					2 045			75 000	55%
TOTAL ALL								4 023						5 409			137 294	100%

[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 m³/m³ was assumed (relating to a ventilated building stock volume of 40 bln. m³). 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. m³ ventilated volume (37% mechanical ventilation), tertiary sector 29 bln. m³ (60% mech. vent.), industry & agricultural 22 bln. m³ (17% mech. vent); total 67 bln. m³, of which 40% (27 bln. m³) mechanically ventilated and 60% natural or natural with local fans (40 bln.). To this 4.2 mln. establishments with average 500 m³ have to be added (0.645 bln. m³), 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 4-20 . 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	

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

Fan electricity/a (TWh/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

Annual net heating energy saved:

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 4-21. 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 (kWh/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	
<u>Annual net heating energy saved:</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	
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 (MtCO ₂ /a) @ 0.4 Mt/TWh	9	1	1	7	33	51
<u>Annual net heating energy saved:</u>						
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 (MtCO 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 MtCO 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 4-22. 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. m ³	26	10	6	26	109	178
Water (cooling)	mln. m ³	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
○ 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
○ 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 4-23 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
of which							
Disposal	kt		10	6	2	7	22
Recycled	kt		12	21	33	96	326
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
○ Emissions (Air)							
Greenhouse Gases in GWP100	mt CO ₂ eq.	-30	-10		-3	-25	-92
Ozone Depletion, emissions	t R-11 eq.				Negligible		
Acidification, emissions	kt SO ₂ eq.	41	5		4	36	173
Volatile Organic Compounds (VOC)	kt	0	0		0	0	-1
Persistent Organic Pollutants (POP)	g i-Teq	2	1		1	4	15
Heavy Metals	ton Ni eq.	4	1		1	4	18
PAHs	ton Ni eq.	1	0		0	1	2
Particulate Matter (PM, dust)	kt	6	1		1	3	12
○ Emissions (Water)							
Heavy Metals	ton Hg/20	2	0		0	2	8
Eutrophication	kt PO ₄	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 CO₂ 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 estimates¹⁶, 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 CO₂ (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 CO₂ 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.

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 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 $\pm 15\%$.

7.3 Space heating energy saved

Space heating energy saved (recovered ventilation losses): 2950 PJ/a or 168 Mt CO₂.

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 CO₂, so a saving on ventilation losses of 168 Mt CO₂ 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. 4200 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 3000 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. 4000 PJ (equivalent to 231 Mt CO₂/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 m³/h.m³ air change rate and 110 billion m³ 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 m³/h.m³=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 1000 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 1500-2000 PJ. In other words, without mechanical ventilation

units the ventilation heat losses of the buildings in the scope would be 5500-6000 PJ instead of 4000 PJ.

Hence, our statement that currently all mechanical ventilation systems are saving 2500 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 CO₂-concentrations of over 1800 ppm are measured, whereas in fact 1200 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 CO₂/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 CO₂ equivalent of electricity consumption, the net saving is 1608 PJ/a and 69 Mt CO₂ eq./a. The 1608 PJ is equivalent to 446 TWh primary energy and would be the equivalent of almost 180 TWh_e.

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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