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Strategic Planning Towards Carbon Neutrality in Tourism Accommodation Sector

CARBONTOUR

DELIVERABLE 1.2: Identification and evaluation of CO_2 equivalent emission sources from the accommodation facilities

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Abbreviations

BS	Biological stabilisation
C	Carbon
CO2	Carbon dioxide
DOC	Degradable organic carbon
DIP	Deinking pulp
eq	Equivalents
ELCD	European LCA data platform
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
ISWM	Integrated solid waste management
kg	Kilogramme
LCA	Life cycle assessment
MBS	Mechanical biological stabilisation
MBT	Mechanical biological treatment
MPS	Mechanical physical stabilisation
MJ	Megajoule
MSW	Municipal solid waste
MSWI	Municipal solid waste incineration
PE	Polyethylene
PO	Polyolefins
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl chloride
RDF	Refuse-derived fuel
t	Metric tonne
WtE	Waste to energy

1 Determination and evaluation of CO_2 equivalent emission sources from waste production

The waste management sector contributes to the anthropogenic greenhouse effect primarily through emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

Basically, the calculation method used follows the Life Cycle Assessment (LCA) method. Different waste management strategies can be compared by calculating the GHG emissions of the different recycled (typically glass, paper and cardboard, plastics, metals, organic waste) and disposed of waste fractions over their whole life cycle. The emissions of all residual waste or recycling streams respectively and calculates the total GHG emissions of all process stages in CO_2 equivalents. The emissions calculated also include all emissions caused by a given quantity of treated waste. This means that when waste is sent to landfill, for example, the calculated GHG emissions, given in tonne CO2 equivalents per tonne waste, include the cumulated emissions this waste amount will generate during its degradation. This method corresponds to the "Tier 1" approach described in IPCC (1996, 2006).

At every stage of the recycling and disposal chains GHG emissions occur for each single waste fraction. Recycling activities lead to secondary products ("secondary raw materials"), which substitute for primary raw materials or fossil fuels ("waste-to-energy"). The benefits from the substitution of primary raw materials or fossil fuels are calculated as credits according to the emissions avoided in the corresponding processes, pursuant to the LCA method. The accounting procedures applied for the use of secondary raw materials encompass every stage in the process, from the separation of waste to sorting and preparing waste, as well as transport emissions. Only the emissions from waste collection were neglected as they depend on the distances covered for the transportation of waste from their source to the waste treatment and disposal sites that vary considerably from case to case. As a result, it was decided that it is not included in the project scope.

1.1 Determination of waste sources and types in tourist accommodations

In most tourism facilities guest rooms, kitchens, restaurants, laundries, offices, gardens and conference rooms generate large volumes of solid waste and wastewater. The number of sources in a tourist accommodation will depend on the facilities and services offered and the associated waste. There are four significant activity areas in tourist facilities that mainly generate solid waste and wastewater including accommodation, food and beverage, maintenance of open spaces and grounds, and administrative and office functions.

I. Accommodation Sector (rooms)

Accommodation facilities generate various types of solid waste:

- newspapers and magazines
- cleansing agent containers used by housekeeping and laundry services
- flowers in guestrooms and public areas
- plastic shampoo and cosmetic soap bottles
- old towels, linens, bed sheets and furniture
- paint and varnishes, used fittings, fixtures and plumbing supplies, refrigerators and other bulk items.

II. Food and Beverage Services

Most restaurants or restaurant/bar sections of hotels, guesthouses or golf courses dispose of large quantities of solid waste including:

- empty cans, bottles, tins and glass
- food
- small non-refillable product containers (sugar, salt, pepper, flour and cream)
- paper serviettes, coasters, straws, toothpicks and cocktail napkins
- used aprons, kitchen towels and napkins.

III. Open Spaces and Grounds

Landscaping and gardening activities at golf courses and many hotels generate ground related solid waste including:

- plant trimmings
- empty pesticide/insecticide bottles and fertilizer packs, pesticides, insecticides and fertilizer products (which are often hazardous).

IV. Administrative and Office Functions

A facility's main office, front desk and shipping/receiving areas create solid waste including:

- paper and envelopes
- travel pamphlets and brochures which are often quickly discarded by tourists.

1.2 Determination of the characteristics of waste produced in tourist accommodations

Waste composition is one of the main factors influencing GHG emissions from solid waste treatment, because different waste fractions contain different amounts of regenerative and/or degradable organic carbon (DOC) and fossil carbon. DOC is crucial for landfill gas generation, while only fossil carbon contributes to climate change in case of incineration. CO_2 from organic carbon is considered neutral to the climate because it originates from plants that bonded atmospheric CO_2.

A hotel's solid waste stream is as diverse as it is enormous. Office paper, restaurant food waste, amenity bottles, plastic and aluminum beverage containers, countless cardboard packaging boxes, heavy machinery, and guestroom furnishings all find their way into a property's dumpster. Although this waste is diverse, the hotels typically generate a fairly consistent type of waste. The majority is paper and food waste, and there are lesser amounts of metals, plastic and glass. This profile is similar to the standard municipal solid waste stream coming from residential communities, largely because a hotel is much like a big house.

However, the composition of waste in tourist accommodations may be more diverse than household waste as it includes waste from rooms, offices, restaurants, bars, shops, mini markets, each of which have a unique waste composition. Mixed wastes also vary in character within the tourist accommodation. For example, the waste from the kitchen of a hotel will vary considerably in composition to the waste arising from the bedrooms of the same hotel.

Variations in a hotel's waste composition can be attributed to differences in the scope of operations and target market of the hotel. For example, limited-service hotels and motels often do not offer an on-site restaurant. This eliminates most of the food waste that makes up a large portion of a full-service hotel's waste stream. Some hotels cater to business travelers who leave office paper-type waste behind; other hotels cater to families on vacation who leave a lot of container waste (take-out boxes and bags, soda bottles and cans); and others cater to the convention and trade-show market which generates significant cardboard waste. Hotels with bars which sell non-returnable bottles and hotels that provide water bottles to each room will be characterized by large percentages of glass in their waste. Moreover, hotels that provide amenities such as shampoo, conditioner, lotion, bath gel in single-use small bottles to each guest raise significantly the percentage of plastic to the total waste generation.

In order to calculate the composition of waste for each tourist accommodation, the tourist establishments were categorized in three main groups: (i) Bed & Breakfast, (ii) Hotels without restaurants, (iii) Hotels with Restaurants. The categorization is in consistence with the number of services offered in a tourist accommodation, with the first group offering limited services and the last group offering - at least - restaurant.

Waste composition by establishment type is based on information collated from a detailed audit of waste collected from 27 hotels in the West Oxfordshire region, England and is presented in the following Table .

Table 1: Waste composition for three types of tourist accommodations

Waste type	Bed & Breakfast %	Hotels without restaurant %	Hotels with Restaurant %
paper packaging	0,75	0,35	0,5
paper other	20,31	13,66	11,93
cardboard packaging	10,76	8,17	7,47
cardboard other	0,25	0,23	0,41
glass packaging	11,19	14,54	9,8
glass other	1,28	0,01	0,37
metals packaging	2,24	1,59	4,42
metals other	1,14	0,42	0,4
plastic packaging	13,09	8,97	7,57
plastic other	0,25	0,99	0,26
kitchen	25,86	38,46	52,98

garden	2,03	0,55	0,54
other	10,85	12,06	3,34
Total	**100**	**100**	**100**

Another important aspect is the calorific value, which varies as a function of waste composition. For example, usually, the higher the organic waste content in municipal solid waste (MSW); the lower the calorific value is caused by the typically higher water content of the waste. Table shows the percentages used for total and fossil carbon content of the waste fractions according to (IPCC 2006).

Based on the defined waste composition, the regenerative carbon content, fossil carbon content and calorific value parameters are calculated by taking the respective carbon content and calorific value of each waste fraction and multiplying with the percentage of each waste fraction.

Table 2: Carbon content waste fractions - Total and fossil carbon (IPCC 2006)

Type of waste	C total	C fossil	
Food waste	15.2%	0%	% wet waste
Garden and park waste	19.6%	0%	% wet waste
Paper, cardboard	41.4%	1%	% wet waste
Plastics	75.0%	100%	% wet waste
Glass	0%	0%	% wet waste
Ferrous metals	0%	0%	% wet waste
Aluminium	0%	0%	% wet waste
Textiles	40.0%	20%	% wet waste
Rubber, leather	56.3%	20%	% wet waste
Nappies (diapers)	28.0%	10%	% wet waste
Wood	42.5%	0%	% wet waste

Mineral waste	0.0%	0%	% wet waste
Others	2.7%	100%	% wet waste

Table shows the calorific values of the waste fractions used in the calculations. The table also shows the estimated water content of organic waste and non-specified waste ("Others") in case of a low or high water content.

Table 3: Calorific value waste fractions

Fraction	**Calorific value**	
Organic waste low water content	4	MJ/kg wet waste
Organic waste high water content	2	MJ/kg wet waste
Paper	11.5	MJ/kg wet waste
Plastics	31.5	MJ/kg wet waste
Glass	0	MJ/kg wet waste
Metals	0	MJ/kg wet waste
Textiles, rubber, leather	14.6	MJ/kg wet waste
Wood	15	MJ/kg wet waste
Mineral waste	0	MJ/kg wet waste
Others low water content	8.4	MJ/kg wet waste
Others high water content	5	MJ/kg wet waste

Source: (AEA 2001); wood IFEU estimate

1.3 Assessment of the quantity of waste generated in a tourist accommodation

An initial step in assessing a facility's solid waste management situation is to determine the actual levels of solid waste being produced. Depending on the scale of a facility and the sophistication of its management and staff, the assessment can be done on an overall basis (i.e. waste from the overall facility) or dealt with at a high level of precision (i.e. assessment by activity). In larger-scale facilities, this evaluation could be carried out separately in areas such as food and beverage, accommodation and groundskeeping. This allows for better estimation of the synthesis of waste produced depending on the nature of activities carried out in a particular area of the facility. For this to be achieved, the waste generated from each area should be collected separately. If this is not the case and waste from all areas are gathered to the same collection bins, the total volume of waste can be estimated. In both cases, waste volume is estimated by multiplying the number and volume of bins with the number of times waste are collected, usually in a monthly basis.

To assess the likely weight of waste, the volume of waste is multiplied by the factor that best correlates to the accommodation type. The factors used are presented in Table

Table 4: Factors for estimating waste weight per accommodation type

Accommodation type	Average weight of waste per litre
Bed & breakfast	0,079
Hotel without restaurant	0,050
Hotels with restaurant	0,064

To assess the weight of waste generated per guest per night, the total waste weight is divided by the number of guest nights recorded for each month.

In the case where recycling programmes are implemented in a tourist accommodation, the achieved recycling rates are calculated by multiplying the number and volume of separate collection bins of recyclables with the number of times waste are collected, usually in a monthly basis. The recycling rates change the original waste composition of the remaining waste and consequently the waste characteristics.

1.4 Identification of GHG emissions from waste treatment

Treatment methods for waste generated in a tourist accommodation are the same with those applied for municipal waste as they contain the same types of waste. Treatment methods depend on the waste stream to be treated. Generally waste streams for the purpose of treatment are segregated in (i) source separated organic waste, BMW, (ii) source separated packaging waste, PW and (iii) non separated waste or mixed waste, MSW. According to the nature and the specific characteristics of each of the above mentioned waste streams, the respective treatment technologies are presented in the following sections.

1.4.1 Treatment of source separated organic waste, BMW

The bulk volume of organic waste in a tourist accommodation is generated in the restaurant and bars (food waste) or at the gardens and athletic grounds (yard waste) and thus can be easily separated at source provided that specific bins for organic waste collection are available at those areas and that the staff is trained to segregate waste streams. Organic waste may be treated by applying either the technology of composting or anaerobic digestion (AD).

1.4.1.1 Composting

Composting is defined as the aerobic, or oxygen requiring process during which the organic matter is decomposed by micro-organisms under controlled conditions to a biologically stable end product. During composting the microorganisms consume oxygen for the bio-oxidation of the organic matter resulting in the generation of heat, carbon dioxide and water vapor, which are released into the atmosphere (Ipek et al., 2002; Epstein, 1997). At the same time, the volume and mass of the organic raw material is reduced significantly transforming it into a stable organic final product which can be used as soil conditioner, improver as well as for land reclamation (Hogg et al., 2009; Epstein, 1997; Engeli et al., 1993; Carry et al., 1990; Toffey, 1990). The rate of the organic matter decomposition depends upon the evolution of the environmental conditions (e.g. temperature, moisture, oxygen) which regulate the growth of aerobic micro-organisms. Therefore, composting is the “controlled” aerobic biodegradation of most organic (biologically derived carbon-containing) solid matter meaning that the environmental conditions are controlled throughout the process. In that way composting differentiates from the decomposition which occurs in nature (Gidarakos, 2007). Nevertheless, the biochemical process in composting and in the natural decomposition of the organic matter is the same.

For the composting of organic waste a ratio of 50% open and 50% encapsulated composting plants is assumed. Open composting is managed with diesel-engined machinery and the diesel demand was calculated as 1.5 l/t organic waste.

The composting process transforms 35% of the total feedstock inserted into compost, while 7% is evaporated and the rest 58% are residues of the process. The energy requirements of this technology is approximately 0,04 MWh/tn.

The GHG emissions from composting are roughly one third CO_2 emissions from electricity and diesel demand, the remainder are methane and nitrous oxide (N_2O) emissions from the composting process and resulting from the agricultural use of compost. Products were considered to be one third immature compost, which is used mainly in agricultural applications. For matured compost it was estimated that 20% are used in agriculture, about 40% for gardening purposes in professional and leisure applications or as a substrate. The rest becomes substrate material for recultivation purposes. The application pattern determines the substituted primary material. The agricultural application substitutes for mineral fertilizer, depending on the nutrient content in the compost. If the compost is used as a substrate or as humus supply then peat and/or bark humus is substituted for, depending on the content of organic matter in the compost. When compost is used for recultivation no primary material is substituted for, because usually only waste material is used for these purposes.

1.4.1.2 Anaerobic digestion

Anaerobic digestion is defined as the biological process during which the organic material is decomposed by anaerobic microorganisms in the absence of dissolved oxygen (i.e. anaerobic conditions). Anaerobic microorganisms digest the input organic material which is converted through anaerobic degradation into a more stabilized form, while a high energy gas mixture (biogas) consisting mainly of methane (CH_4) and carbon dioxide (CO_2), is generated. After the completion of the digestion procedure, the digestate is subjected to an open composting facility for compost production. It is assumed that the digestate is dewatered and a ratio of 50% direct application and 50% post-composting take place. The produced biogas is utilized for in situ energy production. The electricity that is produced can be used for the digestion system's self – consumption or it can be sold.

The process of anaerobic digestion produces 35% biogas and 30% compost, while 48% is evaporated and the rest 7% are residues. The AD process consumes 0,055 MWh for every tone of feedstock treated and produces 0,224 MWh/tn.

With a gas production rate of 100 m³ per tonne of organic waste and a methane content of 62%, the biogas can be used in a combined heat and power plant. Modern plants of this type have energy efficiency for electricity of 37.5% and heat of 43%. In the methodology followed only the net electricity produced is credited. Heat production is neglected because it is usually difficult to find an external customer.

Main GHG emissions are methane emissions from the digestion process and nitrous oxide emissions from agricultural applications. Application of the matured digestion compost is similar to application of matured compost from composting and the benefits were calculated in the same way. The electricity replaced is compared to electricity generation as indicated by the country-specific electricity mix.

1.4.2 Treatment of source separated packaging waste, PW

The bulk volume of packaging waste in a tourist accommodation is generated in the restaurants and bars (empty bottles, cans) as well as in the administrative areas (corrugated cardboard) and thus can be separated easily at source, provided that specific bins for packaging waste collection are available at those areas and that the staff is trained to segregate waste streams. Packaging waste are treated at a material recovery facility (MRF).

1.4.2.1 Material recovery

Material recovery is the most viable technological choice for the treatment of source separated PW since the target material will be collected separately. The separate collection of recyclables can be fulfilled:

- Either by collecting the recyclables from more than one waste bins, each bin containing a different waste stream. After the collection procedure, the already separated recyclables are delivered to the MRF for packaging in order to be sold to the respective markets.

- Or by collecting the recyclables from a single waste bin. After the collection procedure, the mixed recyclables are separated to the MRF.

MRFs serve as an intermediate processing step between the collection of recyclable materials from waste generators and the sale of recyclable materials to markets for use in making new products. There are basically four components of a MRF facility: sorting, processing, storage, and load-out.

Generally, at a material recovery facility 57% of the total feedstock is recovered, comprising of 10% ferrous metals, 2,6% aluminium, 27% plastic, 18% paper, 10% glass and 3% wood while 29% is the residues of the process. A MRF consumes 0,025 MWh of energy on average for every tonne of waste.

<u>Emission factors for paper and cardboard</u>

The GHG emission factor for paper and cardboard recycling includes sorting and production of deinking pulp (DIP). An overall sorting loss of 1% during the sorting process and 5.3% residues and sludge at the DIP were subtracted from existing plant data. It is assumed that these residues are incinerated in waste to energy (WtE) plants for municipal solid waste and co-incinerated at an industrial power plant. The assumption for primary production was made to take the equivalent pulp production into consideration. It was assumed that the primary fibre consists of 50% thermomechanical pulp (e.g. for newspapers) of European production and 50% of Kraft pulp (sulphate pulp) of Nordic production. The benefits of energy generation from incineration of the residues are included.

<u>Emission factors for plastics</u>

The GHG emission factor for plastics represents a mixture of 80% polyolefins (PO), 10% PET, 5% PS and 5% PVC, assumed as typical. In general, the GHG emission factor includes sorting and treating for secondary flakes.

Polyolefins (PO) are a mixture of PE and PP. The electricity demand at the sorting and treatment plant was calculated from typical existing plants (IFEU/HTP 2001). About 20% sorting and treatment residues were assumed to go to MSWI plants with energy recovery. A mix consisting of 50% PP, 25% high density PE (HDPE) and 25% low density PE (LDPE) was assumed for the substituted primary production. Data from primary production were taken from Plastics Europe. Because secondary granulates have a lower performance than primary material, a functional equivalence was established using a substitution factor of 0,7. The benefits of energy generation from incineration of sorting and treatment residues are included.

For Polyethylene Terephthalate (PET), about 30% sorting residue was assumed as sorting and production losses, which go to MSWI plants with energy recovery. Data for the substituted primary PET production were taken from Plastics Europe. Because recycled PET is of high quality, a substitution factor of 1 was applied here. The benefits of energy generation from incineration of the residues are included.

For Polystyrene (PS), about 20% sorting residue was assumed as sorting and production losses, which go to MSWI plants with energy recovery. Data for the substituted primary PS production was taken from Plastics Europe. Because secondary PS is of high quality, a substitution factor of 0,9 was applied here. The benefits of energy generation from incineration of sorting and treatment residues are included.

For Polyvinyl Chloride (PVC), about 20% sorting residue was assumed as sorting and production losses, which go to MSWI plant with energy recovery. Data for primary PVC production were taken from calculations by Plastics Europe. IFEU prepared a data update for the European Council of Vinyl Manufacturers and Plastics Europe, which is included. The primary production of suspension PVC was chosen as reference. A substitution factor of 0.9 was estimated and applied here. The benefits of energy generation from incineration of sorting and treatment residues are included.

Emission factors for glass

The approach for glass and its system boundaries is different to other materials. This is due to the fact that glass factories normally operate with a mixture of primary material and glass from the waste stream. As data sets exist only for different shares of waste glass input, a specific model for glass production was developed. An additional sorting step to eliminate caps and labels is considered, the fate of the 3% sorting residues was ignored. The waste glass is then introduced into the smelting devices. The saved effort of using secondary glass was calculated from existing glass factory data. This is a non-linear relationship and is valid for a range between 50% and 90% of secondary glass (100% secondary glass input is technically not feasible). The GHG emission factor was calculated with a share of 75%.

Emission factors for steel

It is difficult to distinguish between primary steel production and secondary steel production using the information published by the steel industry. The only available data (European LCA Data Platform, ELCD[1]) distinguishes between the two technologies, but it already includes credits for recycling. Unfortunately, no information is available from the steel industry to differentiate the figures. In (Prognos/IFEU/INFA 2008) the official global steel production figures from the ELCD web page ("steel rebar GLO") were used, including primary and secondary steel. However, this figure applies to both primary and secondary steel. A different approach was chosen by assuming that steel production is the same regardless of whether pig iron or scrap is introduced into the furnace. Therefore, recycling ferrous metals substitutes for the production of pig iron, which is calculated based on data provided in Umberto[2].

Emission factors for aluminium

Secondary aluminium is produced by separate smelting facilities. The data used is taken from European aluminium industry publications. Primary aluminium data from European industry are from 2002 and – in contrast to the steel industry – does not include any credits for recycling. A recycling rate of 88% is assumed in the data set of the European LCA Data Platform.

Emission factors for textiles

Several obstacles render the generation of figures for material recycling or reuse of textiles difficult. No descriptions of production processes for secondary textiles or researchable details on which textiles are exported from the EU for reuse purposes are available. In addition, it is difficult to assess which primary material would have been substituted by such material recycling or reuse, because the type of textile fibre (cotton or synthetic) and its distribution is unknown. In (Prognos/IFEU/INFA 2008) it was assumed that textiles are exported to and reused in non-EU countries. Thus, the emissions from textile recycling roughly correspond to emissions for shipping.

[1] http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm

[2] Umberto version 5.5 (life cycle assessment tool), main sources: Ecoinvent, Rentz et al.

Additionally, it was assumed that reused textiles consist of one third cotton fibre and two thirds synthetic, polyester textile fibre. The lifetime of the reused textiles was assumed to be half of primary textiles, and a substitution factor of 0,5 was applied for the substitution of primary products.

1.4.3 Treatment of mixed waste, MSW

Waste produced in a tourist accommodation may not be separated at source. In that case, mixed waste can be treated mechanically in order for the different waste streams to be sorted and then the organic waste stream to be further treated, biologically. The aforementioned process is called Mechanical Biological Treatment (MBT) which, according to the desired end products, is subdivided in (i) MBT with composting, (ii) MBT with anaerobic digestion and (iii) MBT with biodrying. After the mechanical biological treatment of waste, a thermal treatment method can be applied such as incineration, pyrolysis, gasification or plasma gasification. Thermal treatment can be applied to mixed waste before MBT, however this method is not usually preferred as it is not as effective.

1.4.3.1 Mechanical Biological Treatment

A mechanical biological treatment system is a waste processing facility that combines a waste sorting facility with biological treatment methods. MBT systems vary greatly in their complexity and functionality.

The "mechanical" element is usually an automated mechanical sorting stage. This either removes recyclable elements from a mixed waste stream (such as metals, plastics, glass and paper) or processes them. MBTs typically involve a combination of screens, magnetic separation, eddy current separation, optical separation and air classification.

The mechanical sorting processes recover a part of MSW as recyclable materials, while another part formulates a combustible product known as ‘Refuse Derived Fuel (RDF) which covers a wide range of materials sorted in such a manner in order to obtain high calorific value. RDF can be incinerated in power stations, pyrolysis and gasification systems, co-incinerated in other industrial combustion processes for energy production.

MBT with composting

This technology is using mechanical separation equipment for the production of recyclables and Refuse Derived Fuel (RDF). The remaining fraction which has high proportion of organic matter is led to a composting facility for biological treatment. Depending on the desired products, the mechanical process may produce equal percentage of recyclables (3% iron, 1% aluminium, 4% plastic, 8% paper, total 15%) and RDF (15%) or mainly RDF (27%) and recyclables (4%). The composting process of the organic fraction transforms 15% of the total feedstock into compost, while 22% is evaporated and 34% constitutes the process residues. The energy consumed per tonne of waste treated is higher when producing mainly RDF (0,08 MWh/tn) than when producing equal percentage of recyclables (0,06 MWh/tn).

In the methodology followed it is assumed that the separated RDF fraction is co-incinerated in a cement kiln or in a dedicated incineration plant. The RDF is specified with a calorific value of 13.3 MJ/kg waste and a fossil carbon content of approx. 19%. Thus the co-incineration causes fossil CO_2 emissions corresponding to the fossil carbon content with assumed complete incineration. The benefit of co-incineration is the substitution of fossil fuels with a typical input mix in Germany of 29.4% hard coal, 53.1% lignite, 11.8% coke, 4.4% heavy fuel oil, and 1.3% others (VDZ 2008). It is assumed that the impurities are treated in a MSWI plant. They are defined as typical MSW in Germany with a calorific value of 9.2 MJ/kg and a fossil carbon content of approx. 9%. Thus the incineration causes fossil CO_2 emissions corresponding to the fossil carbon content with assumed complete incineration. In Germany most MSWI plants produce energy from waste incineration. On average, the net electrical efficiency is 10%, and the thermal efficiency 30%. The emissions from conventional electricity and heat production avoided are also taken into account. For electricity generation the CO_2 emissions are defined by the country-specific electricity mix, an average value was used for heat (50% oil, 50% natural gas).

MBT with anaerobic digestion

This technology is using mechanical separation equipment for the production of recyclables and RDF. The remaining fraction which has high proportion of organic matter is led to an AD for biogas production. After the completion of the digestion, the digestate is subjected to an open composting facility for compost production.

Depending on the desired products, the mechanical process may produce equal percentage of recyclables (3% iron, 1% aluminium, 4% plastic, 8% paper, total 15%) and RDF (15%) or mainly RDF (27%) and recyclables (4%). The anaerobic process of the organic fraction transforms 8% of the total feedstock into biogas and 15% into compost, while 14% is evaporated and 34% constitutes the process residues. The energy produced is approximately 0,12 MWh per tonne of waste treated while the energy consumed is higher when producing mainly RDF (0,1 MWh/tn) than when producing equal percentage of recyclables (0,08 MWh/tn).

In the methodology followed it is assumed that the separated RDF fraction is co-incinerated in a cement kiln or in a dedicated incineration plant. The RDF is specified with a calorific value of 13.3 MJ/kg waste and a fossil carbon content of approx. 19%. Thus the co-incineration causes fossil CO_2 emissions corresponding to the fossil carbon content with assumed complete incineration. The benefit of co-incineration is the substitution of fossil fuels with a typical input mix in Germany of 29.4% hard coal, 53.1% lignite, 11.8% coke, 4.4% heavy fuel oil, and 1.3% others (VDZ 2008). It is assumed that the impurities are treated in a MSWI plant. They are defined as typical MSW in Germany with a calorific value of 9.2 MJ/kg and a fossil carbon content of approx. 9%. Thus the incineration causes fossil CO_2 emissions corresponding to the fossil carbon content with assumed complete incineration. In Germany most MSWI plants produce energy from waste incineration. On average, the net electrical efficiency is 10%, and the thermal efficiency 30%. The emissions from conventional electricity and heat production avoided are also taken into account. For electricity generation the CO_2 emissions are defined by the country-specific electricity mix, an average value was used for heat (50% oil, 50% natural gas).

<u>MBT with biodrying</u>

Biodrying is a variation of aerobic decomposition, used within mechanical-biological treatment (MBT) plants to dry and partially stabilise residual municipal waste. The first stage of the biodrying procedure is the removal of ferrous and non-ferrous metals. The process involves the rapid heating of waste through the action of aerobic microbes. During this partial composting stage the heat generated by the microbes result in rapid drying of the waste. Biodrying can produce a high quality solid recovered fuel (SRF), high in biomass content. Ferrous and non ferrous metals removal accounts for approximately 4% of the total feedstock inserted, while it is estimated that the SRF produced is 55%, 25% is evaporated and the remaining 16% constitutes the process residues. Typically, the energy consumed for biodrying is 0,14 MWh per tonne of waste treated.

MBT technologies can be combined in order to achieve the optimum results as for the recycling and energy recovery from MSW. To this end, the implementation of a MBT is not always limited to one type but it can also include more than one type of the above mentioned MBTs. Some MBT systems incorporate both anaerobic digestion and composting treatment methods. This may either take the form of a full anaerobic digestion phase, followed by post - composting of the produced digestate. Alternatively a partial anaerobic digestion phase can be induced on water that is percolated through the initial substrate, dissolving the readily available organic matter, with the remaining material being sent to a windrow composting facility.

1.4.3.2 Incineration

Incineration, which is commonly referred as combustion, is the oxidization of the chemical compounds with oxygen (O_2) in order to transform the chemical energy of solid waste organic matter into thermal energy. The incineration of carbon-based materials can be implemented in an oxygen-rich environment (greater than stoichiometric), typically at temperatures higher than 850^{o}C. The incineration of waste is one of the oldest thermal treatment technologies and the most commonly used worldwide.

The process produces a waste gas comprised primarily of carbon dioxide (CO_2) and water gas (H_2O). Air emissions also include nitrogen oxides, sulphur dioxide, etc. The most important factor during the process is the presence of oxygen. During the full combustion there is oxygen in excess and, consequently, the stoichiometric coefficient of oxygen in the combustion reaction is higher than the value “1”. In theory, if the coefficient is equal to “1”, no carbon monoxide (CO) is produced and the average gas temperature is 1,200°C.

According to a typical mass balance of the incineration process, 6% of the total feedstock inserted is ferrous and non ferrous metals removed, while it is estimated that 70% is evaporated and the remaining 24% constitutes the process residues.

The rest of the input is converted into energy. The typical amount of energy that can be produced per tonne of MSW is about 0,55 MWh. The energy consumed is 0,14 MWh per tonne of waste treated.

As a rough rule of thumb it can be assumed that self-sustaining incineration usually requires a minimum calorific value of about 6 MJ/kg waste. The main relevant emissions in terms of climate change are fossil CO_2 emissions resulting from incineration of fossil carbon contained in waste. As a conservative simplification, complete combustion is assumed for technologically advanced MSWI plants. The fate of the ash and slag output products is not considered in the methodology. Modern MSWI plants usually produce energy. If MSWI plants have a steam turbine then they produce electricity and in some cases heat. If only electricity is produced the maximum electrical efficiency is about 20% for thermodynamic reasons. If heat is also produced the electrical efficiency is lower. The degree of heat production depends on whether it is possible to sell the heat.

The emissions avoided by the substitution of electricity and heat production are defined by the country-specific electricity mix; an average value was used for heat (50% oil, 50% natural gas).

1.4.3.3 Disposal

There will always be residual waste which cannot be reduced, recycled or reused. Residual waste can be disposed in many ways. Following, the disposal options are presented in this section.

<u>Unburned scattered waste</u>

Scattered waste is waste randomly thrown into the landscape. It decomposes under aerobic conditions. In this way no methane emissions occur from waste degradation.

<u>Open burning of scattered waste</u>

In some cases scattered waste is burned openly. The uncontrolled combustion of waste results in emissions of toxic substances. These toxic substances have no influence on climate change. However, climate change is affected by open burning because fossil carbon in the waste is oxidised to CO_2. In the methodology followed, open burning is calculated as complete oxidation of the fossil carbon contained in the waste. Considering the uncertainty of the quantities burned in the open and because the incompletely burned remains will decompose over time this is an insignificant simplification.

Wild dumps/unmanaged disposal site

Wild dumps are uncontrolled and/or unmanaged landfills. In contrast to scattering, the waste is not disposed of over a wide area but at one location with deep disposal at a depth of roughly greater than five meters. Under these conditions the waste mainly decomposes anaerobically. The same applies to disposal sites where the waste is deposited in water such as a pond, river or wetland. Methane is generated under anaerobic conditions. The resulting methane emissions from wild dumps are calculated as equal to methane emissions from "controlled dump/landfill without gas collection". This may overestimate methane emissions slightly; according to (IPCC 2006) unmanaged disposal sites produce less methane than managed anaerobic disposal sites because a larger fraction of waste decomposes aerobically in the upper layer in unmanaged disposal sites. In (IPCC 2006) this is taken into consideration by methane correction factors for unmanaged deep, unmanaged shallow and managed semi-aerobic disposal sites. The simplification in the methodology followed appears reasonable because generally no reliable data exist about the type of wild dump, let alone the total amount of waste being scattered or deep deposited.

Controlled dump/landfill without gas collection

According to (IPCC 2006) managed disposal sites must use controlled placement of waste. For example, waste should be directed to specific areas, a degree of control over scavenging and over fires should be exercised. Furthermore, managed disposal sites will include at least either cover material or mechanical compacting or levelling of the waste. Here, managed disposal sites without and with gas collection are differentiated, because this is a relevant factor for GHG emissions. In general, waste disposal is calculated following the IPCC Guidelines for National Greenhouse Gas Inventories (1996, 2006). The theoretical gas yield methodology is used to compare the different waste management options. This methodology is the simplest method for calculating methane emissions from waste disposal. It assumes that all potential methane is released from waste in the year that the waste is disposed of. Although, this is not what actually occurs, it is necessary for comparing different waste management options because only then are all future emissions for one tonne of waste taken into account for a correct comparison.

Sanitary landfill with gas collection

As discussed above, methane emissions from waste disposal are calculated consistently for all landfill types. In general, this accounts for the methane generation potential, if sanitary landfill gas is collected. These potential methane emissions are reduced as a function of gas collection efficiency and the type of gas treatment. Furthermore, sanitary landfills usually cover the final waste body with methane-oxidising material. This fact is considered using the oxidation factor of 10% for managed, covered landfills according to (IPCC 2006) .

Gas collection efficiency in this context means the share of all potentially generated methane from a given quantity of waste that can be captured, or in other words, the ratio of collected landfill gas relative to the total generated landfill gas from a given quantity of waste. Measurements of efficiencies at gas recovery projects (IPCC 2006) have reported efficiencies between 9 and above 90 percent. These measurements reflect a momentary situation. Over the lifetime of a landfill it is assumed that only about 50% of all potentially methane generated can be captured even using technically advanced gas collection techniques. For example, in Germany, where the landfill ban for MSW came into effect in 2005, and where all landfills are sanitary and include a gas collection system, the gas efficiency rate was reported to be 60% in the 2007. This means that although no more MSW was disposed of in comparison to 2005 and all landfills are closed and covered, still only 60% of the methane generated was captured in the 2007 for technical reasons. The average net efficiency of gas collection is time dependent. In the early stages of waste disposal to landfill, the waste is not generally covered. Only a small quantity of generated methane can therefore be captured in this phase. Later, when the waste body is covered, more of the methane generated can be captured although 100% is still not achieved due to technical limitations.

The collected landfill gas may remain untreated but vented, e.g. with a simple chimney to prevent self incineration of the waste body. Methane emissions are not reduced in this model. Alternatively, the gas can be flared. In this model methane is oxidised to

CO_2, which is climate-neutral because it comes from regenerative carbon. Finally, the collected gas can be used for electricity generation. A combined heat and power plant is considered with a net electrical efficiency of 30%. The produced heat is not taken into account because it is generally difficult to find an external customer. The replaced electricity is credited with GHG emissions from electricity generation as indicated by the country-specific electricity mix.

1.4.4 Electricity generation

Electricity generation produces GHG emissions. Usually, these are direct emissions from fuel combustion (mainly CO_2 from oxidation of the fossil carbon in the fuel) and indirect emissions from the supply of fuels, e.g. methane emissions from the mine during coal mining. Overall, the specific quantity of GHG emissions per kilowatt hour electricity depends on the energy carriers or mix of energy carriers used for electricity generation. The highest GHG emissions result from coal and oil as they have the highest fossil carbon content relative to energy content. The lowest GHG emissions from fossil fuels result from natural gas because natural gas has a low carbon content relative to energy content. Almost no GHG emissions at all result from such renewable energy sources as wind or water and from nuclear power plants, as in these cases no fossil carbon is burned. These emission factors only refer to direct CO_2 emissions from fuel combustion. Worldwide data on GHG emissions from electricity generation, including indirect emissions, are not available. Nevertheless, the underestimation by disregarding indirect GHG emissions for electricity production is not too significant in relation to the importance of methane emissions from landfill.

The CO_2 emission factors for electricity production are used in this section to calculate the GHG emissions from electricity demand, but also to calculate the benefit from electricity generated by a waste treatment technology (e.g. incineration).

2 Determination and evaluation of CO_2 equivalent emission sources from wastewater production

Wastewater can be a source of methane (CH_4) when treated or disposed anaerobically. It can also be a source of nitrous oxide (N_2O) emissions. Carbon dioxide (CO_2) emissions from wastewater are not considered in the *IPCC Guidelines* because these are of biogenic origin and should not be included in national total emissions.

The major form of wastewater generated by a tourism facility is domestic sewage from bathing and toilet flushing. Wastewater is also produced by laundry, cooling/heating and kitchen functions. Wastewater may be treated on site (uncollected), sewered to a centralized plant (collected) or disposed untreated nearby or via an outfall.

Treatment and discharge systems can sharply differ between countries. Also, treatment and discharge systems can differ for rural and urban users, and for urban high income and urban low-income users. Sewers may be open or closed. In urban areas in developing countries and some developed countries, sewer systems may consist of networks of open canals, gutters, and ditches, which are referred to as open sewers. In most developed countries and in high-income urban areas in other countries, sewers are usually closed and underground. Wastewater in closed underground sewers is not believed to be a significant source of CH_4. The situation is different for wastewater in open sewers, because it is subject to heating from the sun and the sewers may be stagnant allowing for anaerobic conditions to emit CH_4. (Doorn *et al*., 1997).

The most common wastewater treatment methods are centralized aerobic wastewater treatment plants and lagoons for both domestic and industrial wastewater. To avoid high discharge fees or to meet regulatory standards, many large industrial facilities pre-treat their wastewater before releasing it into the sewage system. Domestic wastewater may also be treated in on-site septic systems. These are advanced systems that may treat wastewater from one or several households. They consist of an anaerobic underground tank and a drainage field for the treatment of effluent from the tank. Some developed countries continue to dispose of untreated domestic wastewater via an outfall or pipeline into a water body, such as the ocean.

The degree of wastewater treatment varies in most developing countries. Domestic wastewater is treated in centralized plants, pit latrines, septic systems or disposed of in unmanaged lagoons or waterways, via open or closed sewers. In some coastal cities domestic wastewater is discharged directly into the ocean. Pit latrines are lined or unlined holes of up to several meters deep, which may be fitted with a toilet for convenience.

Centralized wastewater treatment methods can be classified as primary, secondary, and tertiary treatment. In primary treatment, physical barriers remove larger solids from the wastewater. Remaining particulates are then allowed to settle. Secondary treatment consists of a combination of biological processes that promote biodegradation by micro-organisms. These may include aerobic stabilisation ponds, trickling filters, and activated sludge processes, as well as anaerobic reactors and lagoons. Tertiary treatment processes are used to further purify the wastewater of pathogens, contaminants, and remaining nutrients such as nitrogen and phosphorus compounds. This is achieved using one or a combination of processes that can include maturation/polishing ponds, biological processes, advanced filtration, carbon adsorption, ion exchange, and disinfection. Sludge is produced in all of the primary, secondary and tertiary stages of treatment. Sludge that is produced in primary treatment consists of solids that are removed from the wastewater and is not accounted for in this category.

Sludge produced in secondary and tertiary treatment results from biological growth in the biomass, as well as the collection of small particles. This sludge must be treated further before it can be safely disposed of. Methods of sludge treatment include aerobic and anaerobic stabilisation (digestion), conditioning, centrifugation, composting, and drying.

***Methane* (*CH4*)**

Wastewater as well as its sludge components can produce CH_4 if it degrades anaerobically. The extent of CH_4 production depends primarily on the quantity of degradable organic material in the wastewater, the temperature, and the type of treatment system. With increases in temperature, the rate of CH_4 production increases. This is especially important in uncontrolled systems and in warm climates. Below 15°C, significant CH_4 production is unlikely because methanogens are not active and the lagoon will serve principally as a sedimentation tank. However, when the temperature rises above 15°C, CH_4 production is likely to resume.

The principal factor in determining the CH_4 generation potential of wastewater is the amount of degradable organic material in the wastewater. Common parameter used to measure the organic component of the wastewater is the Biochemical Oxygen Demand. Under the same conditions, wastewater with higher BOD concentrations will generally yield more CH_4 than wastewater with lower BOD concentrations.

The BOD concentration indicates only the amount of carbon that is aerobically biodegradable. The standard measurement for BOD is a 5-day test, denoted as BOD5. The term 'BOD' in this chapter refers to BOD_5. Since the BOD is an aerobic parameter, it may be less appropriate for determining the organic components in anaerobic environments. Also, both the type of wastewater and the type of bacteria present in the wastewater influence the BOD concentration of the wastewater.

***Nitrous Oxide* (*N_2O*)**

Nitrous oxide (N_2O) is associated with the degradation of nitrogen components in the wastewater, e.g., urea, nitrate and protein. Domestic wastewater includes human sewage mixed with other household wastewater, which can include effluent from shower drains, sink drains, washing machines, etc. Centralized wastewater treatment systems may include a variety of processes, ranging from lagooning to advanced tertiary treatment technology for removing nitrogen compounds. After being processed, treated effluent is typically discharged to a receiving water environment (e.g., river, lake, estuary, etc.). Direct emissions of N_2O may be generated during both nitrification and denitrification of the nitrogen present. Both processes can occur in the plant and in the water body that is receiving the effluent. Nitrification is an aerobic process converting ammonia and other nitrogen compounds into nitrate (NO_3^-), while denitrification occurs under anoxic conditions (without free oxygen), and involves the biological conversion of nitrate into dinitrogen gas (N_2). Nitrous oxide can be an intermediate product of both processes, but is more often associated with denitrification.

Table 5: CH_4 and N_2O emission potentials for wastewater and sludge treatment and discharge systems

Types of treatment and disposal				**CH_4 and N_2O emission potentials**
Collected	Untreated	River discharge		Stagnant, oxygen-deficient rivers and lakes may allow for anaerobic decomposition to produce CH_4. Rivers, lakes and estuaries are likely sources of N_2O.
		Sewers (closed and under ground)		Not a source of CH_4/N_2O.
		Sewers (open)		Stagnant, overloaded open collection sewers or ditches/canals are likely significant sources of CH_4.
	Treated	Aerobic treatment	Centralized aerobic wastewater treatment plants	May produce limited CH_4 from anaerobic pockets. Poorly designed or managed aerobic treatment systems produce CH_4. Advanced plants with nutrient removal (nitrification and denitrification) are small but distinct sources of N_2O.
			Sludge anaerobic treatment in centralized aerobic wastewater treatment plant	Sludge may be a significant source of CH_4 if emitted CH_4 is not recovered and flared.
			Aerobic shallow ponds	Unlikely source of CH_4/N_2O. Poorly designed or managed aerobic systems produce CH4.
			Anaerobic lagoons	Likely source of CH_4.
		Anaerobictreatment	Anaerobic reactors	Not a source of N_2O.
				May be a significant source of CH_4 if emitted CH_4 is not recovered and flared.
Uncollected	Septic tanks			Frequent solids removal reduces CH_4 production.
	Open pits/Latrines			Pits/latrines are likely to produce CH_4 when temperature and retention time are favourable.
	River discharge			See above.

2.1 Methane emissions from wastewater

Emissions are a function of the amount of organic waste generated and an emission factor that characterises the extent to which this waste generates CH_4. Wastewater treatment facilities can include anaerobic process steps. CH4 generated at such facilities can be recovered and combusted in a flare or energy device. The amount of CH_4 that is flared or recovered for energy use should be subtracted from total emissions through the use of a separate CH_4 recovery parameter. The default for sludge removal is zero. The default for CH_4 recovery is zero. Emissions from flaring are not significant, as the CO_2 emissions are of biogenic origin, and the CH_4 and N_2O emissions are very small so they are not estimated. The default maximum CH_4 producing capacity (B_o) for domestic wastewater is 0,6 kg CH4/kg BOD.

Organically degradable material in the wastewater (TOW) is a function of human population and BOD generation per person. It is expressed in terms of biochemical oxygen demand (kg BOD/year). The equation for TOW is:

$$TOW = P \cdot BOD \cdot 0.001 \cdot 365$$

Where:

TOW = total organics in wastewater in inventory year, kg BOD/yr

P = population, (person)

BOD = per capita BOD, g/person/day,

0.001 = conversion from grams BOD to kg BOD

2.2 Nitrous oxide emissions from wastewater

Nitrous oxide (N_2O) emissions can occur as direct emissions from treatment plants or from indirect emissions from wastewater after disposal of effluent into waterways, lakes or the sea. Direct emissions from nitrification and denitrification at wastewater treatment plants may be considered as a minor source. Accordingly, this section addresses indirect N_2O emissions from wastewater treatment effluent that is discharged into aquatic environments. The simplified general equation is as follows:

$$N_2O\ Emissions = N_{EFFLUENT} \cdot EF_{EFFLUENT} \cdot 44 / 28$$

Where:

N_2O emissions = N_2O emissions in inventory year, kg N_2O/yr

$N_{EFFLUENT}$ = nitrogen in the effluent discharged to aquatic environments, kg N/yr

$EF_{EFFLUENT}$ = emission factor for N_2O emissions from discharged to wastewater, kg N_2O-N/kg N

The factor 44/28 is the conversion of kg N_2O-N into kg N_2O.

The default IPCC emission factor for N_2O emissions from domestic wastewater nitrogen effluent is 0.005 (0.0005 - 0.25) kg N_2O-N/kg N. This emission factor is based on limited field data and on specific assumptions regarding the occurrence of nitrification and denitrification in rivers and in estuaries. The first assumption is that all nitrogen is discharged with the effluent. The second assumption is that N_2O production in rivers and estuaries is directly related to nitrification and denitrification and, thus, to the nitrogen that is discharged into the river.

3 Determination and evaluation of CO_2 equivalent emission sources from energy consumption

3.1 Introduction

In this report the calculation methods used for the assessment of the annual energy use for usage of an accommodation is given.

This standard specifies a general framework for the assessment of overall energy use of a building, and the calculation of overall energy ratings in terms of primary energy, CO_2 emissions and of parameters defined by national energy policy. Separate standards calculate the energy consumption of services within a building (heating, cooling, hot water, ventilation, lighting etc) and produce results that are used here in combination to show overall energy use. The assessment is not limited to the building alone, but takes into account the wider environmental impact of the energy supply chain.

Energy certification of buildings requires a method that is applicable to both new and existing buildings, and which treats them in an equivalent way. Therefore, a methodology to obtain equivalent results from different sets of data is presented in this standard. A methodology to assess missing data and to calculate a standard energy use for space heating and cooling, ventilation, domestic hot water and lighting is provided. This standard also provides a methodology to assess the energy effectiveness of possible improvements. Local values for factors and coefficients needed to calculate the primary energy consumption and CO_2 emissions related to energy policy should be defined in a national annex.

At this point must be stressed that energy is not produced, but only transformed. In this standard however, according to common sense, energy is used in one form by systems that generate other forms of energy. At its final stage in the building, energy is used to provide services (heating, cooling, ventilation, hot water, lighting, etc.).

3.2 Energy uses

The main installations consist of heating, cooling, ventilation and/or air-conditioning, domestic hot water, distribution, artificial lighting, and control systems. These systems are discussed in more detail next:

- Heating systems: Central heat production (oil fired or gas fired boilers); district heating (from fuel or biomass plants); combined heat and power; solar thermal collectors; heat pumps (electricity).
- Cooling systems: Central cold production (electric compression chillers or thermal driven chillers); central heat pumps; district cooling; combined heat, cool, and power (trigeneration); multi-split systems (local heat pumps).
- Ventilation and/or air-conditioning systems: Central air-handling units; local air-conditioning units (i.e. split units, compact wall units); natural ventilation; chilled ceiling; exploitation of thermal mass – e.g. walls with active layers.
- Domestic hot water systems: Central hot water tanks coupled with central heat production; Local electric hot water tanks; Local gas heaters; Solar collectors; District heating.
- Distribution systems: heat distribution pipes/ducts; hot water distribution pipes; chilled water distribution pipes; air-supply and air-exhaust ducts.
- Artificial lighting systems: Incandescent, fluorescent; high vapour; energy efficient lighting systems
- Control systems: Simple time controls; space thermostats; central system temperature regulation; building management systems – BMS.

This includes auxiliary energy and losses of all systems. Energy for lighting in residential buildings, as well as energy for other uses (e.g. electrical appliances, cooking, industrial processes) in all types of buildings is also included.

Moreover each building can have several zones with different set-point temperatures, and can have intermittent heating and cooling. The calculation interval is either one month or one hour. For residential buildings, the calculation can also be performed on the basis of the heating and/or cooling season.

Depending on the purpose of the calculation, it may be decided nationally to provide specific calculation rules for spaces that are dominated by process heat (e.g. indoor swimming pool, computer/server room or kitchen in a restaurant).

This choice typically depends on the use of the building (residential, office, etc.), the complexity of the building and/or systems, the application (energy performance requirement, energy performance certificate or recommended energy performance measures, other). The boundaries for the energy performance assessment shall be clearly defined before the assessment. The system boundary includes all inside and outside areas associated with the building, where energy is consumed or produced. Inside the system boundary the system losses are detailed, outside the system boundary they are taken into account in the conversion factor. Energy can be imported or exported through the building boundary. Some of these energy streams can be quantified by meters (e.g. gas, electricity, district heating and water) in case the system devices (boiler, chillers, cooling tower, etc.) are located outside the building envelope.

The building boundary for energy carriers is the meters for gas, electricity, district heating and water, the loading port of the storage facility for liquid and solid energy wares. If a part of a technical building system (e.g. boiler, chillers, cooling tower, etc.) is located outside the building envelope, it is nevertheless considered to be inside the boundaries, and its system losses are taken into account.

3.2.1 Energy Use for Space Heating and Cooling

The main inputs needed for this International Standard are the following:

- transmission and ventilation properties;
- heat gains from internal heat sources, solar properties;
- climate data;
- description of building and building components, systems and use;
- comfort requirements (set-point temperatures and ventilation rates);
- data related to the heating, cooling, hot water, ventilation and lighting systems:
    1. Partition of building into different zones for the calculation (different systems may require different zones);
    2. Energy losses dissipated and recoverable or recovered in the building (internal heat gains, recovery of ventilation heat loss);

3. Airflow rate and temperature of ventilation supply air (if centrally pre-heated or pre-cooled) and associated energy use for air circulation and pre-heating or pre-cooling;
4. Controls

The main outputs are the following:

- Annual energy needs for space heating and cooling;
- Annual energy use for space heating and cooling;
- Length of heating and cooling season (for system running hours) affecting the energy use and auxiliary energy of season-length-dependent technical building systems for heating, cooling and ventilation.

Additional outputs are the following:

- Monthly values of energy needs and energy use (informative);
- Monthly values of main elements in the energy balance, e.g. transmission, ventilation, internal heat gains, solar heat;
- Contribution of passive solar gains;
- System losses (from heating, cooling, hot water, ventilation and lighting systems), recovered in the building.

The energy (heat) balance at the building zone level includes the following terms (only sensible heat is considered):

- transmission heat transfer between the conditioned space and the external environment, governed by the difference between the temperature of the conditioned zone and the external temperature;
- ventilation heat transfer (by natural ventilation or by a mechanical ventilation system), governed by the difference between the temperature of the conditioned zone and the supply air temperature;
- transmission and ventilation heat transfer between adjacent zones, governed by the difference between the temperature of the conditioned zone and the internal temperature in the adjacent space;

- internal heat gains (including negative gains from heat sinks), for instance from persons, appliances, lighting and heat dissipated in, or absorbed by, heating, cooling, hot water or ventilation systems;
- solar heat gains (which can be direct, e.g. through windows, or indirect, e.g. via absorption in opaque building elements);
- storage of heat in, or release of stored heat from, the mass of the building;
- energy need for heating: if the zone is heated, a heating system supplies heat in order to raise the internal temperature to the required minimum level (the set-point for heating);
- energy need for cooling: if the zone is cooled, a cooling system extracts heat in order to lower the internal temperature to the required maximum level (the set-point for cooling).

Degree Days

When the outdoor temperature is below the base temperature (see box on page 3), the heating system needs to provide heat. Since heat loss from a building is directly proportional to the indoor-to-outdoor temperature difference, it follows that the energy consumption of a heated building over a period of time should be related to the sum of these temperature differences over this period. The usual time period is 24 hours, hence the term degree-days, but it is possible to work with degree-hours. (Degree-days are in fact mean degree-hours, or degree-hours divided by 24). In order to appreciate the use of degree-days for building energy applications it is important to address some of the key concepts of this seemingly simple idea.

It must be stressed that, particularly for estimation purposes, degree-day techniques can only provide approximate results since there are a number of simplifying assumptions that need to be made. These assumptions particularly relate to the use of average conditions (internal temperatures, casual gains, air infiltration rates etc), and that these can be used in conjunction with each other to provide a good approximation of building response. The advantage to their use, therefore, lies in their relative ease and speed of use, and all of the information required to conduct estimation analysis is available from the building design.

Degree days Calculations

$$HDD\ (T)\ /\ CDD\ (T) = (|T_{Base} - T_{Monthly\ Average}|) \times D$$

where

HDD = Heating Degree Days

CDD = Cooling Degree Days

T_{Base} = Desired temperature in the building

$T_{Monthly\ Average}$ = Monthly Average Temperature

D = Number of days

In case of degree-hours then D is replaced by H as follows:

$$H = 24 \times D$$

The aforementioned equation needs $T_{Monthly\ Average}$ to be already in the database, while T could be defined by the user.

The base temperature is central to the successful understanding and use of degree-days. It is formally defined, but this brief description introduces the concept. In a heated building during cold weather heat is lost to the external environment. Some of this heat is replaced by casual heat gains to the space — from people, lights, machines and solar gains — while the rest is supplied by the heating system. Since the casual gains provide a contribution to the heating within the building, there will be some outdoor temperature, below the occupied set point temperature, at which the heating system will not need to run. At this point the casual gains equal the heat loss. This temperature will be the base temperature for the building (sometimes called the balance point temperature [ASHRAE 2001]).

The difficulty that arises is that casual gains vary throughout the day, from day to day, and throughout the season. In addition the base temperature depends on the building's thermal characteristics such as its heat loss coefficient, thermal capacity, and heat loss mechanisms such as the infiltration rate that may vary with time. This means that to define the base temperature it is necessary to take average values of these variables over a suitable time period (for example a month). The uncertainty in the accuracy of the results therefore increases with decreasing time scale, i.e. daily energy estimates are likely to be less accurate than monthly ones [Day 1999].

<u>Heat transfer</u>

The building can have several zones with different set-point temperatures, and can have intermittent heating and cooling. The calculation interval is either one month or one hour. For residential buildings, the calculation can also be performed on the basis of the heating and/or cooling season.

This International Standard also gives an alternative simple hourly method, using hourly user schedules (such as temperature set-points, ventilation modes or operation schedules of movable solar shading).

<u>Heat transfer by transmission</u>

The calculation procedure depends on the type of calculation method, but the assumptions (on environment conditions, user behaviour and controls) [Clause 8 – ISO 13790-2008]

For each building zone and each calculation step (month or season), the building energy need (demand) for space heating, QH,nd, for conditions of continuous heating, is calculated as given by the following equation:

Heating energy demand (kW·h) = overall heat loss coefficient (kW·K–1) x degree-days (K·day) x 24 (h·day–1) x Usage Coefficient (h)

<u>Thermal zones</u>

The building is partitioned into several zones (multi-zone calculation), taking no account of thermal coupling between the zones. For a multi-zone calculation without

thermal coupling between zones (calculation with uncoupled zones), any heat transfer by thermal conduction or by air movement is not taken into account. The calculation with uncoupled zones is regarded as an independent series of single zone calculations. However, boundary conditions and input data may be coupled, for instance because different zones may share the same heating system or the same internal heat source.
For zones sharing the same heating and cooling system, the energy demand for heating and cooling is the sum of the energy demand calculated for the individual zones. For zones not sharing the same heating and cooling system, the energy use for the building is the sum of the energy use calculated for the individual zones.

Climate data

Hourly climatic data is needed for the preparation of monthly climatic values and climate dependent coefficients.

Calculation method

Carbontour adopts the quasi-steady state calculation method, calculating the heat balance over a month. The monthly calculation gives reasonable results on an annual basis, but the results for individual months close to the beginning and the end of the heating and cooling season can have errors relative to the actual profile of cooling and heating demands. In the quasi-steady state methods, the dynamic effects are taken into account by introducing correlation factors:

For heating: a utilisation factor for the internal and solar heat sources takes account of the fact that only part of the internal and solar heat sources is utilised to decrease the energy demand for heating; the rest leading to an undesired increase of the internal temperature above the set point. In this approach, the heat balance ignores the non-utilised heat sources, which is counterbalanced by the fact that it ignores at the same time the resulting extra transmission and ventilation heat transfer from the space considered due to the increased internal temperature above the set point.
The effect of thermal inertia in case of intermittent heating or switch-off can be taken into account by introducing an adjustment to the set point temperature or a correction on the calculated heat demand.

For each building zone, the energy demand for space heating for each calculation period (month) is calculated according to:

$$Q_{NH} = Q_{L,H} - \eta_{G,H} \cdot Q_{G,H}$$

Subject to Q_{NH} > 0

Where (for each building zone, and for each month):
Q_{NH} is the building energy demand for heating, in MJ;
$Q_{L,H}$ is the total heat transfer for the heating mode, in MJ;
$Q_{G,H}$ are the total heat sources for the heating mode, in MJ;
$n_{G,H}$ is the dimensionless gain utilisation factor. It is a function of mainly the gain-loss ratio and the thermal inertia of the building.

If applicable, corrections are applied.

For cooling: (mirror image of the approach for heating) a utilisation factor for the transmission and ventilation heat transfer takes account of the fact that only part of the transmission and ventilation heat transfer is utilised to decrease the cooling needs, the “non-utilised” transmission and ventilation heat transfers occur during periods or moments (e.g. nights) when they have no effect on the cooling needs occurring during other periods or moments (e.g. days). In this approach, the heat balance ignores the non-utilised transmission and ventilation heat transfer; this is counterbalanced by the fact that it ignores that the cooling set point is not always reached. With this formulation it is explicitly shown how the heat transfer attributes to the reduction of the building energy needs for cooling. The effect of thermal inertia in the case of intermittent cooling or switch-off can be taken into account by introducing an adjustment on the set point temperature or an adjustment on the calculated cooling needs.

For each building zone, the energy demand for space cooling for each calculation period (month) is calculated according to:

$$Q_{NC} = Q_{G,C} - n_{L,C} \cdot Q_{L,C}$$

Subject to *Q*NC <□0

Where (for each building zone, and for each month)
*Q*NC is the building energy demand for cooling, in MJ;
*Q*L,C is the total heat transfer for the cooling mode, in MJ;
*Q*G,C are the total heat sources for the cooling mode, in MJ;
*n*L,C is the dimensionless utilisation factor for heat losses. It is a function of mainly the loss-gain ratio and inertia of the building.

If applicable, corrections are applied.

3.2.2 Energy Use for Ventilation

Electrical energy input to a ventilation system for air transport and heat recovery (not including energy input for pre-heating or pre-cooling the air) and energy input to a humidification system to satisfy the need for humidification. The requirement can be expressed as the efficiency of heat recovery units according to EN 308. The requirement on the specific fan power of the ventilation system can be defined according the categories defined in EN 13779. The requirement can be expressed as the energy need for ventilation.

3.2.3 Energy Use for Hot Water

Calculating your hot water demand depends on how many household appliances use hot water, like your shower or bath, faucet, and dishwasher; the amount and speed of water consumption; and the percentage of hot water used from the total amount of water. These variables --- especially the latter, since water meters don't measure demand by temperature and itemizing heating bills do not measure water passed through a heater --- makes exact hot water demand tricky to determine. However, it is possible to calculate an approximate amount by measuring demand and monitoring tendencies of personal water use.

- Establish a line of division between hot and cold water. Typically the two extremes are measured in 30 to 45 degree differences in Fahrenheit (50 degrees is cold, 86 to 95 degrees is hot) and 20 to 25 degrees for Celsius (10 degrees is cold, 30 to 35 degrees is hot).

- Estimate the percentage of hot water usage from the total. For instance, if all water used for showers or baths is spent on hot water, then 100 percent of the total time spent showering is hot water usage. Meanwhile, if faucet usage is evenly split between hot and cold, then hot water usage can be estimated at 50 percent.
- Measure the flow speed of the different appliances. Newer shower heads, faucets, dishwashers and other appliances will include flow speed, measured in gallons per minute, on the box. Another way to measure is to time how long it takes for each water source to fill a one gallon container. Divide 60 by the number of seconds it took to calculate gallons per minute.
- For example: a faucet filling one gallon in 23 seconds has a flow speed of approximately 2.61 gallons per minute (60 / 23 = 2.608).
- Measure the time used for each water source, and multiply the time in minutes by gallons per minute for that appliance.
- For example: a faucet used for 40 minutes at 2.61 gallons per minute has an approximate total hot water use of 104.4 gallons.
- Multiply the total water use by the percentage of hot water use.
- For example, if 70 percent of all water used for that faucet is hot water, then 104.4 times 70 percent equals 73.08 gallons of hot water.

Demand for each zone is calculated as:

DHW Demand (MJ/month) = Database demand * 4.18 /1000 * zone AREA * ΔT

Where

Database demand = l/m2 (per month), from the Activity database (Appendix C).
ΔT = temp difference (deg K that water is heated up), taken as 50K.
4.18 /1000 = specific heat capacity of water in MJ/kgK
zone AREA = m2

Calculate distribution loss for each zone for each month (MJ/month). If the dead leg length is greater than 3m, then distribution losses are calculated as:

distribution loss = 0.17* Demand

Where
0.17 is the default monthly DHW distribution loss (MJ/month) per monthly, and
DHW energy demand (MJ/ month).

3.2.4 Energy Use for Lighting

Lighting consumes about 19% of the total generated electricity (IEA 2006). It accounts for 30% to 40% of the total energy consumption in buildings. The annual lighting electricity consumption per square meter of the building varies between 20 to 50 kWh/m2, a (SEA 2007, STIL 2007).
There is a trend in the international community to reduce the electricity consumption of lighting with new technology to below 10 kWh/m2 per year. The possible ways to reduce lighting energy consumption include: minimum possible power density, use of light sources with high luminous efficacy, use of lighting control systems and utilization of daylight.
The quality of light must be maintained when installed power for lighting is reduced. In this Guidebook different design concepts and new products, illustrated with case studies, show how lighting energy consumption can be reduced.

In the building sector, the potential for energy savings and improvements in indoor environment is often high. New buildings may have low energy consumption for heating, but on the other hand have higher electricity consumption than older ones. This is due to increased electricity use for ventilation, cooling, lighting and office equipment (Blomsterberg et al, 2007).

Daylight and solar radiation have a great influence on the energy flows in the building. Therefore the façade, and especially the glassed area of the façade could be seen as an energy filter. A way to reduce the energy flow through the façade is to use shades to block the solar radiation, utilize daylight to reduce the need of artificial lighting and therefore reduce the need of energy for cooling (LEED 2009). But at the same time, the indoor environment has to be maintained to prevent discomfort for the users.

Lighting energy is calculated according to CEN EN 15193-1. Inputs to this calculationinclude lighting power, duration of operation including the impact of occupancy, and terms to deal with the contribution of daylight under different control regimes.

3.2.5 Energy for Heated Pool

The evaporation of water from a water surface, as an open tank, a swimming pool or similar, depends the temperature in the water and the temperature in the air, the actual humidity of the air and the velocity of the air above the surface.

The amount of evaporated water can be expressed with the empirical equation as:

$$g = \Theta A (x_s - x)$$

where

g = amount of evaporated water (kg/h)

Θ = (25 + 19 v) = evaporation coefficient (kg/m^2h)

v = velocity of air above the water surface (m/s)

A = water surface area (m^2)

x_s = humidity ratio in saturated air at the same temperature as the water surface (kg/kg) (kg H_2O in kg Dry Air)

x = humidity ratio in the air (kg/kg) (kg H_2O in kg Dry Air)

Most of the heat required for the evaporation is taken from the water itself. To maintain the water temperature heat must be supplied.

The heat supplied can be calculated as:

$$q = h_{we}\, g$$

where

q = heat supplied (kJ/s, kW)

h_{we} = 2270 - evaporation heat of water (kJ/kg)

3.3 Renewable energy systems (RES)

3.3.1 Photovoltaic system

A photovoltaic system (or PV system) is a system which uses one or more solar panels to convert sunlight into electricity. It consists of multiple components, including the photovoltaic modules, mechanical and electrical connections and mountings and means of regulating and/or modifying the electrical output.

The power that one module can produce is seldom enough to meet requirements of a home or a business, so the modules are linked together to form an array. Most PV arrays use an inverter to convert the DC power produced by the modules into alternating current that can power lights, motors, and other loads. The modules in a PV array are usually first connected in series to obtain the desired voltage; the individual strings are then connected in parallel to allow the system to produce more current. Solar arrays are typically measured under STC (standard test conditions) or PTC (PVUSA test conditions), in watts, kilowatts, or even megawatts.

The energy yield given by the photovoltaic system (PV) is calculated according to the collector orientation and inclination. In order to calculate the radiation at the PV module the hourly radiation data has been processed to yield values of global solar radiation for various orientations and inclinations. The PV electricity generated is calculated by applying two factors to the solar resource at the collector plane: the module conversion of efficiency (whose value depends on the technology chosen) and the system losses (inverter losses, module shading, AC losses, module temperature, etc.).

3.3.2 Wind generators

A wind turbine is a device that converts kinetic energy from the wind into mechanical energy. If the mechanical energy is used to produce electricity, the device may be called a wind generator or wind charger. If the mechanical energy is used to drive machinery, such as for grinding grain or pumping water, the device is called a windmill or wind pump. Developed for over a millennium, today's wind turbines are manufactured in a range of vertical and horizontal axis types. The smallest turbines are used for applications such as battery charging or auxiliary power on sailing boats; while large grid-connected arrays of turbines are becoming an increasingly large source of commercial electric power. The methodology followed to calculate the electricity generated by wind turbines is based on the Average Power Density Method. Electricity produced by the wind turbine is obtained by estimating the average power density of the wind throughout a year using the hourly CIBSE data and by applying a turbine efficiency of conversion. Correction of the wind resource due to turbine height and terrain type is allowed for.

3.3.3 CHP generators

Cogeneration (also combined heat and power, CHP) is the use of a heat engine or a power station to simultaneously generate both electricity and useful heat.

All thermal power plants emit a certain amount of heat during electricity generation. This can be released into the natural environment through cooling towers, flue gas, or by other means. By contrast, CHP captures some or all of the by-product heat for heating purposes, either very close to the plant, or—especially in Scandinavia and eastern Europe—as hot water for district heating with temperatures ranging from approximately 80 to 130 °C. This is also called Combined Heat and Power District Heating or CHPDH. Small CHP plants are an example of decentralized energy.

Fuel type: specifies the fuel type used for the CHP generator Thermal seasonal efficiency: refers to the thermal seasonal efficiency of the CHP plant calculated as the annual useful heat supplied by the CHP engine divided by the annual energy of the fuel supplied (using the higher calorific power) Building space heating supplied: specifies the percentage of the building space heating demand supplied by the CHP generator

Building DHW supplied: specifies the percentage of the DHW demand supplied by the CHP generator. Heat to power ratio: The heat to power ratio of the CHP plant is calculated for the annual operation as the annual useful heat supplied divided by annual electricity generated

Every CHP application involves the recovery of otherwise wasted thermal energy to produce additional power or useful thermal energy. Because CHP is highly efficient, it reduces emissions of traditional air pollutants and carbon dioxide, the leading greenhouse gas associated with global climate change.

Efficiency is a prominent metric used to evaluate CHP performance and compare it to SHP. This Web page identifies and describes the two methodologies most commonly used to determine the efficiency of a CHP system: total system efficiency and effective electric efficiency. The illustration below illustrates the potential efficiency gains of CHP when compared to SHP.

3.3.3.1 Key Terms Used in Calculating CHP Efficiency

Calculating a CHP system's efficiency requires an understanding of several key terms, described below.

- **CHP system.** The CHP system includes the unit in which fuel is consumed (e.g. turbine, boiler, engine), the electric generator, and the heat recovery unit that transforms otherwise wasted heat to useable thermal energy.
- **Total fuel energy input (Q_{FUEL}).** The thermal energy associated with the total fuel input. Total fuel input is the sum of all the fuel used by the CHP system. The total fuel energy input is often determined by multiplying the quantity of fuel consumed by the heating value of the fuel.

  Commonly accepted heating values for natural gas, coal, and diesel fuel are:

  - 1020 Btu per cubic foot of natural gas
  - 10,157 Btu per pound of coal
  - 138,000 Btu per gallon of diesel fuel

- **Net useful power output (W_E).** Net useful power output is the gross power produced by the electric generator minus any parasitic electric losses in other words, the electrical power used to support the CHP system. (An example of a parasitic electric loss is the electricity that may be used to compress the natural gas before the gas can be fired in a turbine.)

- **Net useful thermal output (ΣQ_{TH}).** Net useful thermal output is equal to the gross useful thermal output of the CHP system minus the thermal input. An example of thermal input is the energy of the condensate return and makeup water fed to a heat recovery steam generator (HRSG). Net useful thermal output represents the otherwise wasted thermal energy that was recovered by the CHP system.

  Gross useful thermal output is the thermal output of a CHP system *utilized* by the host facility. The term utilized is important here. Any thermal output that is not used should not be considered. Consider, for example, a CHP system that produces 10,000 pounds of steam per hour, with 90 percent of the steam used for space heating and the remaining 10 percent exhausted in a cooling tower. The energy content of 9,000 pounds of steam per hour is the gross useful thermal output.

3.3.3.2 Calculating Effective Electric Efficiency

Effective electric efficiency calculations allow for a direct comparison of CHP to conventional power generation system performance (e.g., electricity produced from central stations, which is how the majority of electricity is produced in the United States). Effective electric efficiency (ξEE) can be calculated using the equation below, where (W_E) is the net useful power output, (ΣQ_{TH}) is the sum of the net useful thermal outputs, (Q_{FUEL}) is the total fuel input, and $\propto$ equals the efficiency of the conventional technology that otherwise would be used to produce the useful thermal energy output if the CHP system did not exist:

$$\varepsilon_{EE} = \frac{W_E}{Q_{FUEL} - \Sigma (Q_{TH} / \alpha)}$$

For example, if a CHP system is natural gas fired and produces steam, then a represents the efficiency of a conventional natural gas-fired boiler. Typical a values for boilers are: 0.8 for natural gas-fired boiler, 0.75 for a biomass-fired boiler, and 0.83 for a coal-fired boiler.

The calculation of effective electric efficiency is essentially the CHP net electric output divided by the additional fuel the CHP system consumes over and above what would have been used by conventional systems to produce the thermal output for the site. In other words, this metric measures how effectively the CHP system generates power once the thermal demand of a site has been met.

Typical effective electrical efficiencies for combustion turbine-based CHP systems are in the range of 51 to 69 percent. Typical effective electrical efficiencies for reciprocating engine-based CHP systems are in the range of 69 to 84 percent.

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