Reference values of the environmental impact of building services systems

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Abstract. Within the scope of the present study, reference values for embodied energy, greenhouse gas emissions and total environmental impact of heating, ventilation, sanitary and electrical systems were compiled. The focus was put on building services systems that are common and widespread in residential, administrative and school buildings. The main objective of the study was to convert the existing data into user-friendly reference values, which should allow an evaluation and optimization during the early phases of project planning of the environmental impact of building services systems.

1. Introduction
According to life cycle inventory studies, one quarter to one third of the embodied energy of a new building can be attributed to the technical installations. Yet, presently there are virtually no optimization tools for minimizing the environmental impact of building services systems. This applies particularly to the early phase of project planning. Besides this, there is a general lack of applicable life cycle assessment data.

Within the scope of the present study, reference values for embodied energy, greenhouse gas emissions and total environmental impact [1] of heating, ventilation, sanitary and electrical systems were compiled. The focus was put on building services systems that are common in residential, administrative and school buildings.

Recommendations for minimizing the environmental impact can be derived primarily from those elements that have high relevance, variability and controllability. The environmental impact of the various components of the building services systems were therefore examined in terms of these three parameters. The key questions were: In which elements is the environmental impact particularly high (relevance)? In which different approaches are the relative differences particularly large (variability)? Which system components can be modified during the planning and building process and how easily (controllability)?

The main goal of the study was the development of a user-friendly compilation of reference values of the environmental impact of building services systems to be used as an evaluation, optimization and decision tool by architects, engineers and planners during the first stages of a construction project. In this paper we present a brief overview of the approach taken in the course of the project and a short summary of the main outcome. The complete results with all new calculated reference values for embodied energy, greenhouse gas emissions and total environmental impact of heating, ventilation, sanitary and electrical systems are included and discussed in detail in the final project report [2].
2. Methodology
The approach taken encompasses the following steps:

- Literature search on the subject
- Assessment of the applicability of the current tools dealing with embodied energy in buildings (e.g. KBOB recommendation 2009/1:2016 for sustainable buildings [3] and tools accompanying the Swiss standards SIA 2032 [4] and SIA 2040 [5])
- Analysis of the available data and case study buildings. The data was primarily derived from existing studies and tools like for example the Swiss KBOB recommendation
- Investigation of the main building components of the heating, ventilation, sanitary and electricity systems with respect to relevance and variability of their environmental impact, as well as assessment of the controllability on the choice of the components during the planning and execution phases of a construction project
- Systemic impact analysis of the main components of the building services systems and additional selected parameters, in order to identify the interdependences and the main drivers and indicators in the systems
- Identification of the revision needs based on the KBOB recommendation
- Extrapolation and/or calculation of new reference values where necessary and possible

3. Background data
Data from thirteen residential buildings, six office buildings, three school buildings and three retirement homes was available for the present study. The data was taken from the published studies [6] for the sanitary and electrical systems and [7] for the heating and ventilation systems.

4. Results
Based on the life cycle assessment data of the examined buildings, the share of embodied energy, greenhouse gas emissions and total environmental impact was calculated for each main component of the heating, ventilation, sanitary and electrical systems.

For each building, the environmental impact contribution of each subprocess (classification according to the Swiss standard SIA 411 [8]) was calculated as a percentage of the total environmental impact of the respective building services system (heating, ventilation, sanitary and electrical). The maximum value of each subprocess among all buildings was regarded as an indicator of the relevance of that particular subprocess. The calculated standard deviation served as an indicator of the variability.

The evaluation of the controllability on the choice of the building services components during the planning and execution phases of a construction project was carried out in the course of a workshop by five industry experts.

The results of the assessment of relevance, variability and controllability are summarized in the Tables 1 to 4. The tables include the system components that are already listed in the current version of the KBOB recommendation, as well as the proposed additional system components. The tables also show the assigned priority for the elaboration of the reference values, determined on the base of relevance, variability and controllability of the respective system component. For the system components with priority 1 and 2, new reference values of embodied energy, greenhouse gas emissions and total environmental impact were calculated. Figure 1 and Table 5 show as an example the considered data set and the calculated reference values for brine/water heat pumps. The complete results with all new calculated reference values are compiled and discussed in detail in the final report of the project [2]. The system components with priority 3, on the other hand, are not or only marginally discussed: they are either not sufficiently widespread, are of little relevance with regard to the embodied energy, or there was no data available.
Table 1. Heating systems: proposed components and classification according to SIA 411 [8].

| Subprocess (SIA 411) | Embodied energy Relevance | Controllability Relevance | Component | Reference | Priority |
|----------------------|---------------------------|----------------------------|------------|-----------|----------|
| Sources/Sinks        | +++                       | +                          | Borehole heat exchanger for brine/water heat pump | Length [m] | •        |
|                      |                           |                            | Furnace (wood, pellet, gas, oil) | ERS [m^2] | 1        |
|                      |                           |                            | District heating substation | ERS [m^2] | 1        |
|                      |                           |                            | Air/water heat pump | ERS [m^2] | 1        |
|                      |                           |                            | Brine/water heat pump | ERS [m^2] | 1        |
|                      |                           |                            | Water/water heat pump | ERS [m^2] | 1        |
| Transformation       | ++                        | +                          | Flat plate solar thermal collector for hot water SFH | Area [m^2] | •        |
|                      |                           |                            | Flat plate solar thermal collector for heating and hot water SFH | Area [m^2] | •        |
|                      |                           |                            | Flat plate solar thermal collector for hot water MFR | Area [m^2] | •        |
|                      |                           |                            | Evacuated solar thermal tube collector for heating and hot water SFH | Area [m^2] | •        |
| Storage              | n/a                       | n/a                        | Heat distribution, residential building | ERS [m^2] | •        |
| Distribution         | +++                       | +                          | Heat distribution, office building | ERS [m^2] | •        |
|                      |                           |                            | Heat distribution, school building | ERS [m^2] | 1        |
| Room/Delivery        | +++                       | ++                         | Radiators | ERS [m^2] | •        |
|                      |                           |                            | Floor heating | ERS [m^2] | •        |
|                      |                           |                            | Ceiling heating and cooling | ERS [m^2] | •        |
|                      |                           |                            | Forced air heating | ERS [m^2] | •        |

* +++=very high, ++=high, ++=moderate, +=low, n/a=data not available

Table 2. Ventilation systems: proposed components and classification according to SIA 411 [8].

| Subprocess (SIA 411) | Embodied energy Relevance | Controllability Relevance | Component | Reference | Priority |
|----------------------|---------------------------|----------------------------|------------|-----------|----------|
| Sources/Sinks        | n/a                       | n/a                        | Earth-air heat exchangers, residential buildings | ERS [m^2] | •        |
|                      |                           |                            | Earth-air heat exchanger (short), office buildings (0.27 m^2/m^2 ERS) | ERS [m^2] | •        |
|                      |                           |                            | Earth-air heat exchanger (long), office buildings (0.67 m^2/m^2 ERS) | ERS [m^2] | •        |
| Transformation       | +++                       | +                          | Air handling unit | AFR [m^3/h] | 1        |
|                      |                           |                            | Exhaust air handling unit | AFR [m^3/h] | 2        |
| Storage              | n/a                       | n/a                        | Window-integrated air handling unit 10-30 m^3/h | Per unit | •        |
| Distribution         | +++                       | +                          | Air distribution, 1, 2, 4, 6, 8 m^3/(h m^2 ERS) | ERS [m^2] | 1        |
|                      |                           |                            | Efficient air distribution | CC [-] | 1        |
|                      |                           |                            | Inefficient air distribution | CC [-] | 1        |
|                      |                           |                            | Cascade ventilation or supply from adjacent zone | OA [m^2] | 1        |

* +++=very high, +++=high, ++=moderate, +=low, n/a=data not available

1 ERS=energy reference surface, AFR=air flow rate, CC=correction coefficient, OA=overflown area

* •=already present in KBOB recommendation 2009/1:2016 [3]
### Table 3. Sanitary systems: proposed components and classification according to SIA 411 [8].

| Subprocess (SIA 411) | Embodied energy Relevance | Controllability Relevance | Component | Reference | Priority |
|----------------------|---------------------------|---------------------------|-----------|-----------|----------|
| Sources/Sinks        | n/a                       | n/a                       | Rainwater harvesting | ERS [m²]  | 3        |
|                      |                           |                           | Greywater reuse    | ERS [m²]  | 3        |
| Transformation       | n/a                       | n/a                       | Hot water storage tank | Volume [l] | 1        |
|                      |                           |                           | Storage water heater | Volume [l] | 1        |
| Storage              | ++                        | +                         | Combined storage tank | Volume [l] | 2        |
|                      |                           | +                         | Tankless water heater | Mass [kg]  | 3        |
|                      |                           | +                         | Heat pump water heater | Mass [kg]  | 1        |
| Distribution         | +++                       | +++                       | Water distribution, residential building | ERS [m²]  | 1        |
|                      | +++                       | ++                       | Water distribution, office building (simple) | ERS [m²]  | 3        |
|                      | +++                       | ++                       | Water distribution, office building, (complex) | ERS [m²]  | 3        |
|                      | +++                       | +                        | Water distribution, school building (simple) | ERS [m²]  | 3        |
|                      | +++                       | +                        | Water distribution, school building (complex) | ERS [m²]  | 3        |
| Room/Delivery        | +++                       | +++                       | Bathroom, residential (WC, bathtub or shower, sink) | No rooms | 1        |
|                      | +++                       | ++                       | Toilet, office (WCs, sinks) | No rooms | 1        |
|                      | +++                       | +                        | Locker room with showers, office (showers, sinks) | No rooms | 1        |
|                      | +++                       | +                        | Toilet, school (WCs, sinks) | No rooms | 1        |
|                      | +++                       | +                        | Locker room with showers, school (showers, sinks) | No rooms | 1        |
|                      | +++                       | ++                       | Washing machine and dryer stack | No stacks | 1        |

*++++=very high, +++=high, ++=moderate, +=low, n/a=data not available

*ERS=energy reference surface

| Source/Sinks          | Embodied energy Relevance | Controllability Relevance | Component | Reference | Priority |
|-----------------------|---------------------------|---------------------------|-----------|-----------|----------|
| Transformation        | n/a                       | n/a                       | Photovoltaic system | P [kWp] | ●        |
|                      |                           |                           | Photovoltaic system, pitched roof | P [kWp] | ●        |
| Storage               | n/a                       | n/a                       | Photovoltaic system, flat roof | P [kWp] | ●        |
|                      |                           | n/a                       | Photovoltaic system, facade | P [kWp] | ●        |
|                      |                           |                           | Photovoltaic thermal hybrid solar collector (PVT) | CC [-] | 3        |
| Distribution          | +++                       | 0                         | Lead-acid battery | E [kWh] | 1        |
|                      |                           | +                         | Lithium-ion battery | E [kWh] | 1        |
|                      |                           | +                         | Sodium-nickel chloride battery | E [kWh] | 1        |
|                      |                           | +                         | Vanadium redox flow battery | E [kWh] | 1        |
|                      |                           | +                         | Hydrogen storage | E [kWh] | 1        |
| Room/Delivery         | +                         | 0                         | Electrical wiring and devices, residential building | ERS [m²]  | 1        |
|                      |                           | +                         | Electrical wiring and devices, office building | ERS [m²]  | 2        |
|                      |                           | +                         | Electrical wiring and devices, school building | ERS [m²]  | 3        |
|                      |                           | +                         | Inefficient distribution | CC [-] | 1        |

*++++=very high, +++=high, ++=moderate, +=low, 0=none, n/a=data not available

*E=energy stored, P=maximal power, ERS=energy reference surface, CC=correction coefficient

*●=already present in KBOB recommendation 2009/1:2016 [3]
Figure 1. Mass versus power for different brine/water heat pumps available on the market.

| Component                        | Mean mass (kg) | Primary energy (MJ) | Primary energy non-renewable [embodied energy] (MJ) | Greenhouse gas emissions (kg CO₂-eq) | Total environmental impact (UBP) |
|----------------------------------|----------------|---------------------|-----------------------------------------------------|-------------------------------------|----------------------------------|
| Brine/water heat pump (per kg)   | 1              | 115.73              | 106.00                                               | 11.60                               | 22'500                           |
| Brine/water heat pump 8 kW       | 151            | 17475               | 16006                                               | 1'752                               | 3'397'500                        |
| Brine/water heat pump 13 kW      | 194            | 22'452              | 20'564                                              | 2'250                               | 4'365'000                        |
| Brine/water heat pump 20 kW      | 262            | 30'321              | 27'772                                              | 3'039                               | 5'895'000                        |
| Brine/water heat pump 40 kW      | 445            | 51'500              | 47'170                                              | 5'162                               | 10'012'500                       |
| Brine/water heat pump 100 kW     | 825            | 95'477              | 87'450                                              | 9'570                               | 18'562'500                       |
| Brine/water heat pump 200 kW     | 1'288          | 149'060             | 136'528                                             | 14'941                              | 28'980'000                       |
5. Conclusions
For each examined building services system (heating, ventilation, sanitary and electrical), additional system components could be identified, which are not yet included in the KBOB recommendation. For these system components, the corresponding reference values of embodied energy, greenhouse gas emissions and total environmental impact were compiled, in order to provide a basis for the extension of the existing decision tools that can be consulted by architects, engineers and planners in an early project planning phase.

Important system components for which no suitable data was available were identified (see for instance the water distribution in office and school buildings). The study has shown that these components are significant in terms of environmental impact. It would thus be appropriate to fill the existing gap in the future with the elaboration of the necessary life cycle assessment data.

The analysis of the existing estimation tools, such as the KBOB recommendation, has also shown that a higher level of detail in the subdivision of the building services systems in their major components is needed. The individual systems were therefore partitioned into their respective subprocesses according to the systematic of SIA 411. These additional selection options are important as they enable practitioners to better reproduce the characteristics of a construction project. In this way, not only a more effective and correct assessment of the environmental impact can be achieved, but possibly also a higher acceptance of the resulting tool among the target group.

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