Deliverable report 3.2

Process-oriented EeB KPIs in the operation, maintenance, (re)construction phases

Building and process-oriented EeB KPIs operationalized for all (re)design phases

Deliverable Report: Final version

Streamer - Optimised design methodologies for energy-efficient buildings integrated in the neighbourhood energy systems.
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Streamer
European research on energy-efficient healthcare districts

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Process-oriented EeB KPIs in the operation, maintenance, (re)construction phases

Building and process-oriented EeB KPIs operationalized for all (re)design phases

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Colophon

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Publishable executive summary

In order to cope with the energy, financial, political, societal and environmental crises, all healthcare districts in Europe are urgently seeking to substantially reduce their energy consumption and carbon emissions. In this context, they are planning to design new energy-efficient building projects, as well as energy-efficient retrofitting of existing buildings. The processes of design, construction, operation and maintenance are the key activities that underpin the success of the ambitious objective of reducing energy. To support a successful direction of the processes, there should be indicative performance criteria to which management decisions can be weighed against. This deliverable focusses on how this is done for decisions taken during the design process of a hospital building. Three sets of key performance indicators (KPIs) were defined. The most important KPI set within STREAMER is that of Energy Performance. However, in order to ensure high quality performance of a healthcare estate – and because energy saving and quality always have major impacts on the budget of a hospital – the Financial and Quality performances are also addressed. These three KPIs were operationalized in seven performance indicators (PI) that are sensitive to building-oriented, as well as process-oriented factors, stressing the fact that for example energy use is not only dependent on building and installation factors (building-oriented) but also on process factors (process-oriented), meaning the utility of the building. Calculation methods (how to calculate the performance of these indicators based on information available during the (early) design), were developed and tested at expert level. The resulting calculation measurements were validated (through a feasibility test) in two case studies: Rijnstate Hospital in the Netherlands and Careggi Hospital in Italy. The validated set of KPIs and calculation methods will be further used for integration into the decision-support tool developed in D3.6. This tool should be able to calculate and visualize the performance of different design scenario's supporting management to take a weighted decision based on the energy, financial and quality performance of the design.

List of acronyms and abbreviations

- ATL: Adaptive Temperature Limits
- BIM: Building Information Modelling
- EPB: Energy Performance of Buildings
- EPBD: Energy Performance Buildings Directive
- FTE: Full Time Equivalent
- GIS: Geospatial Information Systems
- GTO: Weighted Temperature Exceeding Hours
- HVAC/MEP: Heat, Ventilation, Air Conditioning/ Mechanical, Electrical and Plumbing
- KPI: Key Performance Indicator
- LoD: Level of Detail
- MCA: Multi-Criteria Analysis
- MOM costs: Management, Operational and Maintenance costs (Building related running costs)
- NPV: Net Present Value
- PoR: Programme of Requirement
- RE Suite: the existing real estate software tool of DEMO Consultants (P9).

- RTT: Relative Travel Time
- WPU: Weighted Patient Unit
- WPU: Weighted Personnel Unit

Terminology

BriefBuilder - *Online tool for overall quality management and requirements of a building*

Breitfuss model hospital – *Building guideline for hospitals/ architectural model for hospitals*

Dashboard - *A visual representation of the most important information needed in order to achieve one or more objectives, consolidated and arranged on a single screen so that information can be viewed in a glance*.

KPIs: ***Key Performance Indicators****. KPIs represent a set of measures focusing on those aspects of organisational performance that are the most critical for the current and future success of the organisation (Deliverable 3.1). KPIs quantify a performance category. In STREAMER, KPIs are selected taking into consideration the design solutions;*

Key Performance requirement*: This is the aimed score of a KP and it is defined by the hospital administration. For instance, a hospital administration aims to design/refurbish a hospital that scores on Energy Performance: 7, on Financial Performance: 7 and on Quality Performance: 8. Please note that these KP requirements reflect the ambitions, and are not the calculated/or predicted values of the KPIs;*

Performance category: *Is the category for which KPIs are operationalized in order to quantify the performance of this category. For STREAMER three performance categories were defined: Energy, Financial and Quality performance;*

PIs: ***Performance Indicators****. KPIs can consist of multiple performance indicators to define and calculate the KPI. In this way PIs can be regarded as 'sub-KPIs'. For example, the energy efficiency KPI consists of the PIs: energy demand efficiency and energy consumption efficiency.*

Label: *Property tag attached to a spatial component. In STREAMER labels are developed in D1.1 and provide a strong theoretical basis for enriching space related elements in the BIM, such as rooms and functional areas, with knowledge. For instance, a high hygiene class label could be assigned to a specific room in the design. This has implicit consequences for the design of that room (e.g. ventilation, material used) and as a result, these design consequences may impact the KPIs. In this way there is an indirect link between labels and KPIs.*

Contents

1. Introduction

1.1 Objective

The main objective of the STREAMER project is to create a BIM based tool that focuses on reducing, in the next 10 years, the energy used in the built environment of healthcare estates/districts throughout Europe by 50%. The processes of design, construction, operation and maintenance are the key activities that underpin the success of such an ambitious objective. Whether a single project option, multiple options, new build or refurbishment, the approach to save energy should be the same and that is that there should be indicative performance criteria to support the successful direction of the process. In Deliverable 3.1, the potential for saving energy within the existing estate was considered, and three performance categories with accompanying key performance indicators (KPIs) were addressed, which would offer this direction during the whole process from the early design towards the detailed design. The most important performance category is that of the Energy Performance. However, no healthcare project is free from the financial constraints, and the benefits of reducing energy use are mainly invisible to those looking for high quality healthcare environments. As a result, the Financial- and Quality performance were also addressed, as it is essential that energy reductions should be delivered with regard to the hospital budget and the quality of the facility. Appendix 1 shows the performance categories and KPIs that were defined in D3.1. In the current deliverable (D3.2) a selection of these KPIs is made to be further operationalized. This means that calculation methods are defined to quantify these KPIs based on information available during the (early) design process. The selected KPIs are sensitive to building-oriented as well as process-oriented factors, stressing the fact that for example, energy use is not only dependent on building and installation factors (building-oriented) but also on process factors (process-oriented), meaning the way the building is used. In this way, the objective of this report is to:

1) establish quantifying methods to predict the Energy, Financial and Quality performance of a hospital building during operations based on building information available in all stages of the design process, while taking into account the interdependency between different key performance indicators,
2) describe how these methods are integrated within the Decision support tool and the Design configurator.

As a result, various design scenarios (during the design phase) can be weighted taking into account the expected outcomes regarding the Energy, Financial and Quality performances during the operational phase of the hospital. It should be stressed that the objective is to compare different design scenarios and not to predict the real situation of a single design solution within a defined range. For example, price levels used in Financial performance calculations, may only be available for a certain country. When using these price levels for another country, the absolute outcome may not be realistic for the real situation due to different price levels in that country; however the different design scenarios can still be compared in relative terms. If relations between variables differ between countries, this rule does not apply. In this case, also comparisons are affected and should be only executed if relations between variables and KPIs are understood. For instance, if the costs for brick versus glass per square meter is 1:2 in all countries, but absolute price levels vary (5 vs 10 euro or 2 vs 4 euro). A comparison between design A and B where B has used more glass, is in all countries the most expensive scenario (although absolute costs vary). In this case relative comparisons can be made, without knowing the price levels in a specific country. However, if in country Y the costs of brick versus glass is 2:1, the comparison between A and B cannot be made based on the assumptions of another country, as for country Y scenario A would be the most expensive scenario.

Scope

This report focuses on KPIs that are calculated (predicted) based on building and HVAC/MEP information. District information is out of scope. This means that the performance of a building is calculated, not the performance of a district. Should district information be relevant for the calculation of the building performance, this information will be taken into account. In this report it is determined how KPIs can be calculated (predicted) based on the information available in the design phase. The KP requirement setting and the actual measurement of the KPIs, once the building is realized and operational, is out of scope of this report, but are necessary steps to validate predictions made and to check whether KP requirements are met.

1.2 Context

Figure 1 (see next page) shows an overview of the different STREAMER deliverables and how deliverables from different work packages are connected. This report (part of WP3) on KPI quantification methods relates to other deliverables in the following way: At the beginning of the design process the Design Configurator shapes a first design based on different inputs (WP6). Inputs are (amongst others) the Energy, Financial and Quality performances aimed for, in other words the KP requirements. These are determined by the hospital administration and need no further calculation. Once a design has been drafted, effects of different design scenarios on the selected KPIs are calculated based on the building characteristics in BIM and manual input (interface 1) necessary to execute the KPI calculation. It should be noted that different levels of detail become available during the design process. The aim is to select KPIs and define calculation methods that can deal with the level of information that is available in the early design stage (e.g. based on the schematic design and bubble diagrams). In some cases however, more detail may be needed to calculate the KPIs and these may only be calculated based on the detailed design (e.g. based on room layout, materialization).

Each KPI has its own calculation model(s), thus, there are various calculations methods available to calculate the KPIs. At first, the effects of design scenarios are visible in the individual KPI calculation tools. Although different tools are used to calculate the KPIs, all calculation tools use the same design information that is available from BIM or explicated as manual input. As an effect, inter-dependencies between the KPIs become visible since the calculation methods differ. For example, the enlargement of a window may benefit the Quality performance calculation but may decrease the Energy performance. Secondly, in order to present the output of the different calculation tools in a consistent way- *to be able to weight different design scenarios against the KP requirements*- a Decision support tool and an interface (2) is being developed (D3.6 due at M36).

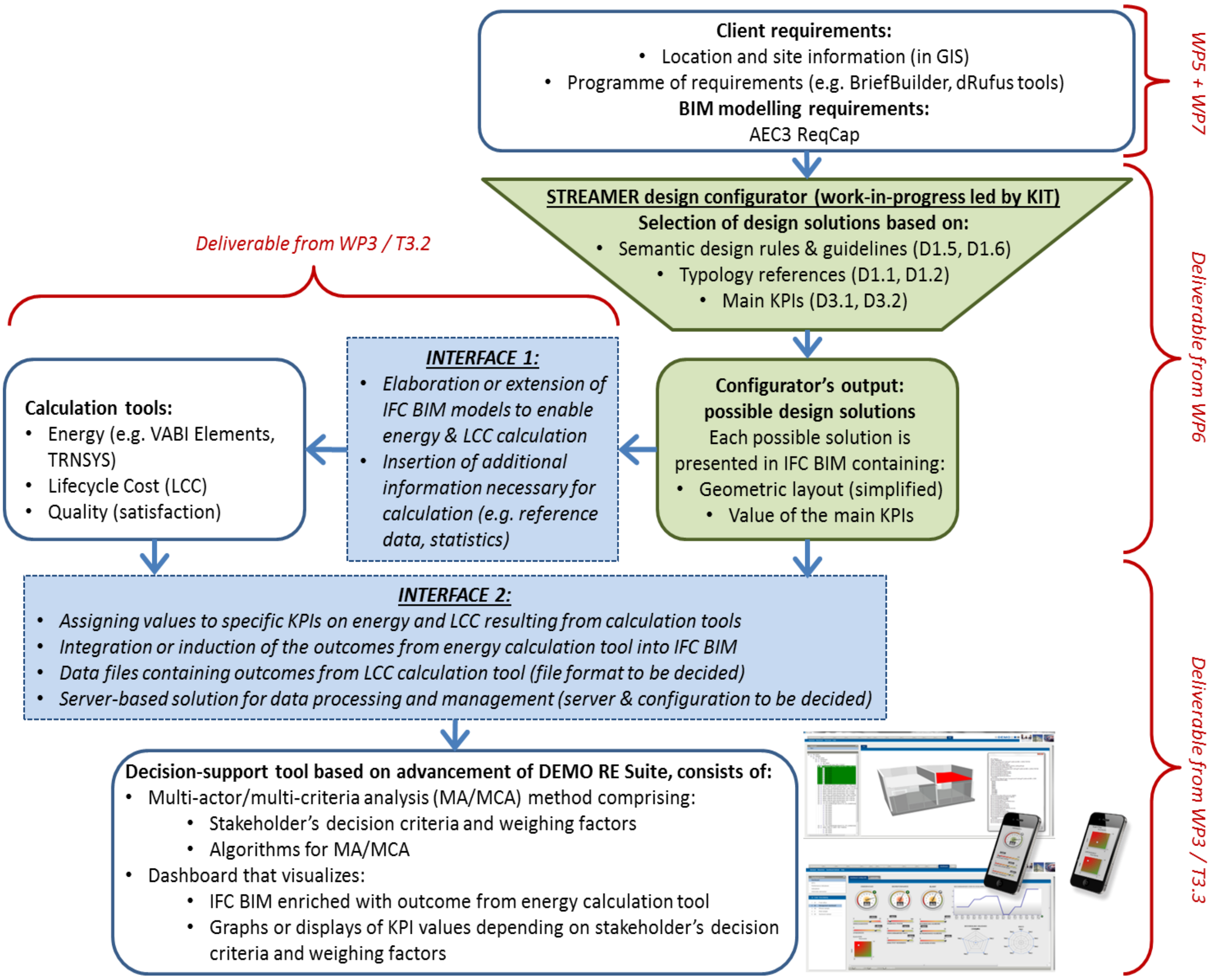


Figure 1.Context of STREAMER project (source: DMO)

1.3 Structure

The present report consists of 5 chapters: Introduction, Methodology, Selected and validated KPIs and Integration of KPIs into the ICT tools and Conclusions.

The second chapter (*Methodology*) points out the process followed and the necessary steps when selecting the appropriate KPIs for STREAMER. As a last step, all KPIs have been validated and verified at expert and end-user level.

Third chapter (*Selected and validated KPIs*) documents the KPIs and elaborates on their definition and calculation methods for a prediction of the performances of a healthcare building, while chapter four (*Integration of KPIs into the ICT tools*) deals with explaining the process of integrating the KPIs into the calculation tools available in STREAMER.

2. Methodology

In this chapter it is described the KPIs have been operationalized for the STREAMER project. First the high level operationalization process is set out in section 2.1. Each step is then described in more detail in the consecutive sections. The results of these steps are described in chapter 3: selected and validated KPIs.

2.1 KPI operationalization process

Starting point for this deliverable was the long-list of possible STREAMER KPIs that have been defined in preceding deliverable D3.1 (see also Appendix 1). Since not all KPIs defined in this long-list were viable to be operated with, the following steps were taken to obtain meaningful operational KPIs that would provide an indication of the Energy, Financial and Quality performance of a hospital design:

- Select main indicators from each of the proposed performance categories in D3.1;
- Elaborate on the detailed definition of each selected KPI;
- Define the method to compute/predict the selected KPIs based on information available during the design phase;
- Validate the KPIs definition and measuring method with experts and users;
- Identify a possible link with the semantic labelling (in conjunction with WP1).

2.2 Selection criteria

The following boundary criteria were used to select KPIs for further elaboration:

- Consistency of the unit of measurement throughout the whole design process and preferable also during the operational process. In this way predictions can be validated with the same unit of measurement.
- Use of existing calculation methods to compute/predict the KPIs.
- The input for calculation methods should be derived from BIM whenever possible (additional manual information required needs to be explicated and standardized).

2.3 Elaboration and calculation method definition

Once KPIs have been selected from the long list to be operationalized, each KPI was properly defined. Desk research was conducted to find existing calculation methods to calculate the defined KPIs. STREAMER partners were also consulted to identify existing calculation methods. Accordingly, a calculation method was selected that could be used based on information available during the design phase and preferably based on information available in BIM. The selected method was documented, units of measurements were defined and data needed to calculate the KPI was described.

2.4 Verification process

2.4.1 Experts verification

Based on a first draft of the selected and elaborated KPIs and the corresponding quantifying methods, the validation process was done by experts from DWA, NCC, TNO, DGJA and BEQ. One teleconference targeted to the experts was organised wherein the main questions regarding the selected KPIs and the calculation methods were pointed out. The experts were required to give feedback on the relevance of the proposed KPIs, the feasibility of the corresponding calculation methods and the units of measurements. Moreover, they were asked to identify any (other) existing tools for the KPIs suggested and to check whether they can be/are already integrated in the existing energy calculation tools. Feedback was gathered orally and by email. A summary of the results of the expert verification is included in Appendix 3.

2.4.2 End-user verification

After the KPIs were verified by the experts, they were validated by two of the four demonstration cases of the STREAMER project. The two healthcare districts chosen are: the Rijnstate Hospital in Arnhem, the Netherlands and Careggi Hospital (San Luca Compound) in Florence, Italy. The end-user (practical) verification was intended to check whether the definitions were clear, the agreed calculation methods could be applied in both hospitals, and whether the data is available to calculate the KPIs. A conference call was organised with Careggi. Within this approach, the role of AOUC has been regarded as double: as expert (that has developed a system for the analysis of the hospital spaces within Careggi- SACS) as well as that of the use case. A physical meeting was organised with Rijnstate. Feedback was gathered orally and by email correspondence. A summary of the results of the end-user verification is included in Appendix 3.

2.5 Link with semantic labelling

As a last step, and based on the final selected and validated KPIs, it was explored how the semantic labels defined in WP1 relate to the KPIs and if and how they could be used to calculate the KPIs.

3. Selected and validated KPIs

In this chapter the results of the KPI operationalization process are been described. These results are being presented for each performance category: Energy performance (3.1), Financial performance (3.2) and the Quality performance (3.3). Each section starts with the results of the KPI selection from the long-list of Deliverable 3.1 (see also Appendix 1). Subsequently, the validated definition, calculation method, unit of measurements and suggested data sources are being described for each selected KPI.

The seven performance indicators (categorized under Energy, Financial, and Quality performance) are:

Energy performance:

1. Energy efficiency
2. Carbon emission efficiency

Financial performance:

3. Life cycle costs

Quality performance:

4. Patient satisfaction
5. Overall quality
6. Thermal comfort
7. Operational efficiency (building efficiency and travel time efficiency)

3.1 Energy Performance

3.1.1 KPI selection

In D3.1 the following Energy Performance and Efficiency KPIs were defined:

a. Reduced primary energy and carbon emission

b. Energy and carbon targets within country regulations

c. Energy and carbon targets within EU regulations

d. Energy and carbon targets developed as industry benchmarks

e. Energy and carbon targets developed through international best practice

f. Passive system integration

g. Active system integration

h. Use of renewable technology

i. Resilience risk considered and managed

Based on this long-list it was decided to focus on a) reduced primary energy and carbon emission, as the other indicators include targets (b-e) that need to be defined but not calculated; or issues related to energy consumption (f-i) that are relevant, but less suitable for a quantitative indictor to measure energy performance. The KPIs Energy efficiency and Carbon emission efficiency were selected to operationalize the Energy performance category. In section 3.1.2 the KPI Energy efficiency is further elaborated, in section 3.1.3 the KPI Carbon emission efficiency.

3.1.2 KPI: Energy efficiency

To quantify the energy efficiency (KPI) of different design scenarios, the following two energy efficiency performance indicators (PIs) are defined:

- Energy demand (need) efficiency
- Energy consumption efficiency

In this section, both PIs are defined (Definition), accordingly their calculation method, units of measurements and suggested data sources are described (Calculation method). At last, an overview of the KPI is provided (Summary KPI: energy efficiency).

Definition

The **energy demand** defines the total energy demand of the building, which relates to the thermal quality of the building and the assumed energy demand for special hospital functions in the design. The **energy consumption** defines the amount of energy being supplied to the building by third parties (e.g. national grid, head supplied by district heating systems), which takes into account the different MEP systems of the design. Energy consumption efficiency is the most important performance indicator for energy and is directly related to the energy costs of the building.

Calculation method

Figure 2 shows the principles of calculating the energy demand and consumption of a hospital.

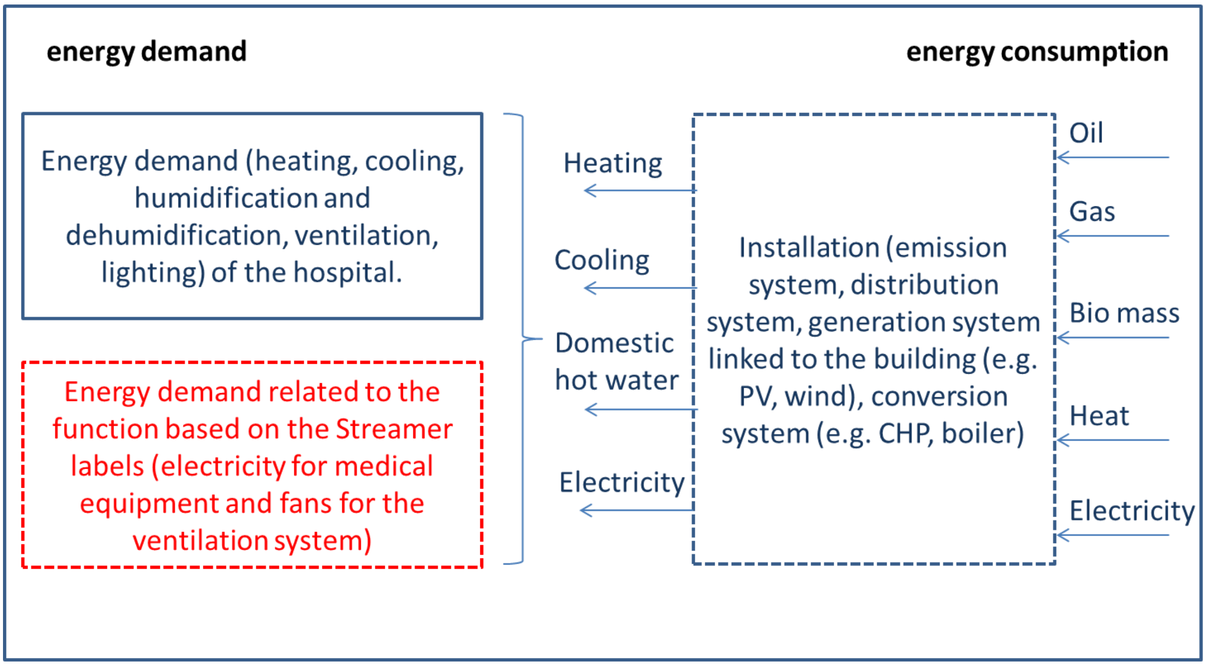


Figure 2. Principle for calculating the energy demand (need) and consumption of a hospital (source: TNO)

3.1.3 Calculating the energy demand

Calculating the energy demand

The total energy demand of the building consists of two components: 1) the energy demand of the building itself and 2) the energy demand caused by the specific functions in the building. During the design phase, the energy demand caused by the specific functions is usually disregarded because it is strongly influenced by the users of the building and is difficult to determine unambiguously. For hospitals this energy demand is determined by the primary processes taking place in the building and is a significant part of the energy demand of the hospital. Therefore, in order to quantify the energy efficiency, the energy demand should be addressed. To connect as much as possible the developments in the area of determining energy performance of buildings it is decided, where possible, to join the set of standards under development within the Energy Performance Building Directive (EPBD). For the design and large scale refurbishment of a hospital such an approach is already required from the directive, while extra work is avoided.

1) __Energy demand of the building__

The EN ISO 52016 standard “Energy performance of buildings— Calculation of the energy needs for heating and cooling, internal temperatures and heating and cooling load in a building or building zone – Part 1: Calculation procedures” is applicable to buildings at the design stage, to new buildings after construction and to existing buildings in the operational phase as well as for refurbishment. The standard is part of the "EPB set of standards" and complies with the requirements for the set of basic EPB documents that are now under development under Mandate M480. These standards will be used to determine the energy demand (need) of a building in a uniform way.

The EN ISO 52016 defines calculation methods for the assessment of:

a) the energy demand for heating, cooling, humidification and dehumidification, based on hourly or monthly calculations;

b) the operative and air temperature of spaces, based on hourly calculations;

c) the heating and cooling load, based on hourly calculations.

EN ISO 52016 requires heat gains and losses depending on other services (ventilation and lighting), by climate (solar gains) and usage (occupants and appliances). The climate part can be easily calculated according to the EN ISO 520101, where the usage is addressed by the labels (not directly but is easily calculated from this information).

The ventilation and lighting services would require a complete calculation to find the actual gains and losses. This would require more details as the early design will contain. A simple method for calculating these aspects is not foreseen in the set of basic EPB documents that are now under development under Mandate M480. In the STREAMER project a method shall be used that makes it possible to calculate the energy performance of a hospital in an early design stage. To address ventilation heat gains, an efficiency factor can be used that corrects the temperature differences (indoor and outdoor), as if there would be a heat-exchanger in the air flow. This efficiency factor has to be defined within the STREAMER project and is dependent on the quality of the building. Lighting heat gains can be simplified by the amount of heat produced per lumen light emitted. The label requirements on light are also part of the labels. The only part missing is the amount of light entering a space through windows, reducing the amount of light to be emitted by the lighting.

The total energy demand (need) for the hospital is the sum of individual services:

- Sensible energy need for heating $Q_{H;nd}$ [kWh];
- Sensible energy need for cooling $Q_{C;nd}$ [kWh];
- Demand for humidification $Q_{HUM;nd}$ [kWh];
- Demand for dehumidification $Q_{DHU;nd}$ [kWh];
- Demand for domestic hot water $Q_{W;nd}$ [kWh];
- Demand for hospital processed $Q_{HOSp;nd}$ [kWh].

Where:

nd	*Need/demand*
H	*heating*
C	*cooling*
W	*domestic hot water*
DHU	*dehumidification*
HUM	*humidification*
HOSp	*hospital specific processes*

2) *Energy demand related to the function*

The energy demands from the processes that take place in the building are not incorporated in the standard approach of the EN ISO 52016. Only the building-related energy and function are taken into account such as, (standard) lighting and (standard) ventilation. In hospitals the energy demand caused by the processes plays an important role. Additional ventilation is often necessary for patient safety (preventing infections) and extra electricity is used for medical equipment. It is estimated that about 35% of electricity demand of a hospital is caused by the ventilation, transporting air through the building, 26% is used for lighting and 6% is used for (medical) equipment, see also D1.3 "Mapping of energy-related problems and potential optimisation". The electricity demand caused by the additional ventilation ($Q_{E.vent.med;nd}$ [kWh]) and medical equipment ($Q_{E.equip.med;nd}$ [kWh]) can be calculated based on the information in the labels that are being developed in the STREAMER project (WP1). It is important to consider these demands as hospitals often produce a part of the electricity demand with own installations (e.g. Combined Heat and Power generation (CHP), Photo voltage (PV), wind).

The extra electric energy demand for hospitals ($Q_{HOSp;nd}$) caused by the primary functions for ventilation ($Q_{E.vent.med;nd}$) and medical equipment ($Q_{E.equip.med;nd}$) is calculated with the formula

$$Q_{HOSp;nd} = Q_{E.vent.med;nd} + Q_{E.equip.med;nd}$$

Energy demand of the fans caused by the function of the room or zone

Based on the amount of ventilation (label "Hygienic classes") and the usage of the room (label "User profile") the energy demand (electricity) for the ventilation can be calculated by formula:

$$Q_{E.vent.med;nd} = \sum_i \left(c_{sys.vent.med;i} \cdot u_{v.ventmed;i} \cdot A_{med;i} \cdot f_{use.med;i}\right) \cdot 8.76$$

$c_{v.vent.med;nd}$ *is the energy demand of the fan based on the type of ventilation system (Table 2), for the specific function*

$f_{use.med;nd}$ *is the percentage of usage of the function (i) based on the user profile (Table 1)*

$A_{med;nd}$ *is the net floor area in* m^2 *of the function (i) (room size, area of clinical or nonclinical functions) derived from the design (floor plan)*

$_i$ *is the zone or room*

Table 1. Operating period.

Operating period (label "User profile")	**$f_{use.med;nd}$ [-]**
Monday to Friday from 8:00 – 18:00	0.30
Monday to Friday from 8:00 – 20:00	0.36
Monday to Friday from 8:00 – 18:00 with emergency function outside this timeslot	0.33
Monday to Friday from 24 hours a day	0.72
24*7	1.00

If no additional information regarding the amount of ventilation is available the amount of ventilation ($u_{v.vent.med;nd}$) is 8.75 $m^3/h.m^2$ for clinical functions (e.g. hot floor, wards, industry, treatment rooms) and 4.68 $m^3/h.m^2$ for nonclinical functions (e.g. outpatient clinic, examination rooms, offices) [1]. For clinical functions $f_{use.med;nd}$ is 1.0 and for nonclinical functions $f_{use.med;nd}$ is 0.36.

Table 2. Energy demand based on ventilation system (NEN 2916; 2004)

Type of ventilation system	$C_{sys.vent.med;nd}$ **[W.h/m³]**
A Natural ventilation	0.00
B mechanical supply and natural exhaust	0.33
C Mechanical exhaust an natural supply	0.33
D Mechanical supply and exhaust	0.83

Example:

If a clinical function of the hospital has an area of 1,000 m² is ventilated with a mechanical supply and exhaust system the electricity used for the fans is:

$$Q_{E.vent.med;nd} = 0.83\left[\frac{W\cdot h}{m^3}\right]\cdot 8.75\left[\frac{m^3}{h\cdot m^2}\right]\cdot 1000[m^2]\cdot 1.00[-]\cdot 8.76 = 63{,}619\ kWh$$

Energy demand of the (medical) equipment caused by the function of the room or building

The energy demand for the medical equipment ($Q_{E.equip.med;nd}$ [kWh]) is derived from the labels. Based on the electrical power of the equipment (label "Equipment") and the usage of the room (label "User profile") the energy demand (electricity) for the equipment can be calculated according to:

$$Q_{E.equip.med;nd} = \sum_i (P_{E.equip.med;i}\cdot A_{med;i}\cdot f_{use.med;i})\cdot 8760$$

$P_{E.equip.med;nd}$ is the specific power of the used (medical) equipment in kW/m² of the function (i) derived from the label "Equipment"

$f_{use.med;nd}$ is the percentage of usage of the function (i) based on the user profile (Table 1)

$A_{med;nd}$ is the net floor area of the function (i) in m² derived from the design (floor plan)

$_i$ is the zone or room

If no information regarding the power needed for specific functions is provided, the specific power of the (medical) equipment ($P_{E.equip.med;nd}$) is 0.016 kW/m² for clinical functions (e.g. hot floor, wards, industry, treatment rooms) and 0.001 kW/m² for nonclinical functions (e.g. outpatient clinic, examination rooms, offices) [2]. Based on this assumption the energy demand for (medical) equipment is:

[1] Based on the NEN 2916; 2004.
[2] Based on the NEN 2916; 2004.

$$Q_{E.equip.med;nd} = \sum_i (P_{E.equip.med;i} \cdot A_{med;i} \cdot f_{use.med;i}) \cdot 8760$$

The performance indicator energy demand efficiency is calculated by dividing the total energy demand by the number of square meters gross floor area (according to e.g. the Dutch NEN2580 or other country equivalent). Note that the useful (net) floor area ($A_{use;zi}$ [m^2]) is the floor area needed as parameter to quantify specific conditions of use that are expressed per unit of floor area (e.g. occupancy), as basis for specifying the reference floor area and for the application of the simplifications and the zoning and (re-) allocation rules [SOURCE: FprEN 15603:2014].

$$A_{use;zi} = \sum_i A_{med;i}$$

Instead of the number of square meters gross floor area, we also choose the Weighted Patient Unit (WPU) as denominator (www.milieubarometer.nl/ziekenhuis). This because including an energy efficiency indicator based on only the number of square meters, may result in a trend in which there is an incentive to increase the number of square meters instead of increasing the efficiency of the hospital. For example, if a hospital has a very compact design, the energy demand (and consumption) can be relatively high due to the limited number of square meters. A less efficient but less compact hospital (more square meters) would be considered more efficient, if only looked at the energy performance per square meter. The WPU corresponds with the total production of a hospital. By using WPU as a denominator the energy performance is related to the size of the hospital production wise. The WPU is a weighted summation of the number of weighted intakes, the number of weighted first outpatient visits, the number of nursing days and the number of day nursery days. The weighing factors for these four parts are[3]:

- Weighted number of intakes: 10
- Number of nursing days: 0.49
- Number of "day nursery" days: 3.4
- Weighted number of first outpatient visits: 1.22

Based on the expected production figures the WPU of a hospital can be defined.

Calculating the energy consumption

The performance indicator energy consumed by the hospital is calculated according to the EN 15316 (Heating), EN15316 and EN16798 (cooling) and EN 16798-3, -5 and -7 (ventilation, humidification and dehumidification) by summing this amount of consumed energy (per carrier) and dividing it by the number of square meters gross floor area and weighted patient unit.

Depending on the phase of the design process different standards can be used (containing more detail) to calculate the energy efficiency of the system (distribution, generation storage, controls, etc.). Important additional standards that are part of the "EPB set of standards" are given in Table 3.

[3] www.milieubarometer.nl/ziekenhuis

Table 3. Relevant standards

Standard	Title
EN 12098-3	Controls for heating systems. Outside temperature compensated control equipment for ***electrical heating systems***
EN 12098-5	Controls for heating systems. ***Start-stop schedulers*** for heating systems
EN 12831-3	Heating systems and water based cooling systems in buildings - Method for calculation of the design heat load Part 3: ***Domestic hot water*** systems heat load and characterisation of needs
EN 15316-4-1	Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Space heating generation systems, ***combustion systems (boilers)***
EN 15316-4-2	Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Space heating generation systems, ***heat pump systems***
EN 15316-4-3	Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Heat generation systems, ***thermal solar systems***
EN 15316-4-4	Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Heat generation systems, ***building-integrated cogeneration systems***
EN 15316-4-5	Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Space heating generation systems, the performance and quality of ***district heating and large volume systems***
EN 15316-4-6	Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Heat generation systems, ***photovoltaic systems***
EN 15316-4-7	Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Space heating generation systems, ***biomass combustion systems***
EN 15316-4-8	Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Space heating generation systems, ***air heating and overhead radiant heating systems***

In the early design stage details regarding the (MEP) system are not yet known, which are relevant to determine inputs needed according to the standards. As a result, the standards cannot be used. In this phase of the design the emission efficiency, the distribution efficiency and the generation efficiency should be estimated. To do so the values are given in Table 5 up to Table 10.

The principle for the calculation of the energy consumption of a hospital in an early design phase is given in figure 3, hereunder.

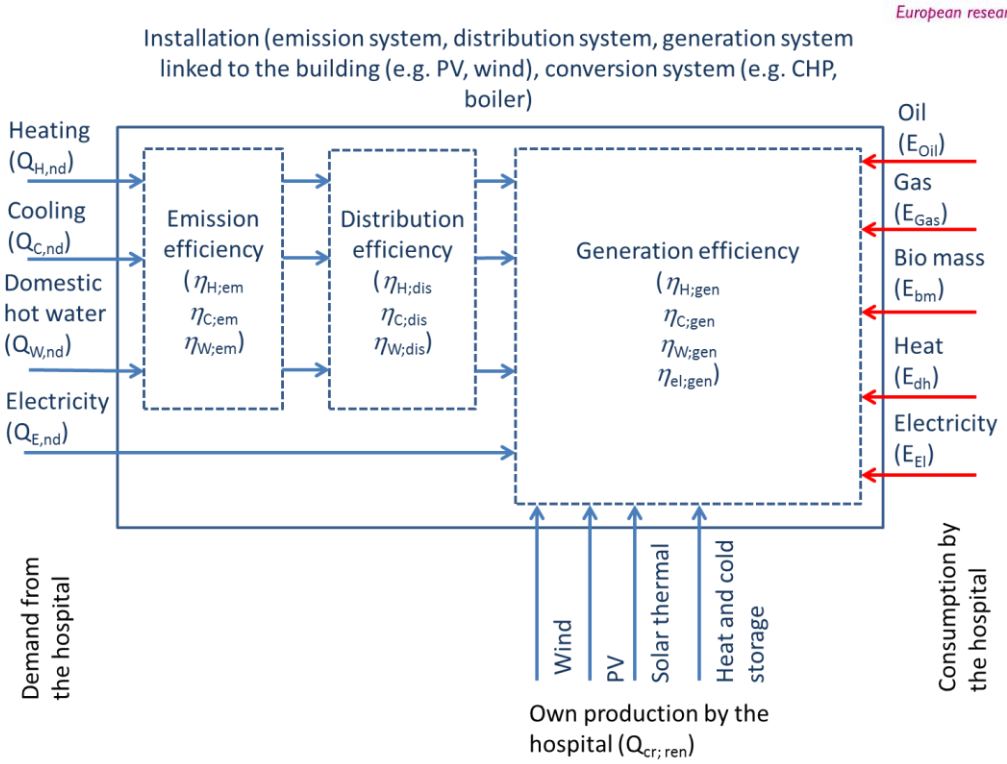


Figure 3. Principle for calculating the energy consumption of a hospital (Source: TNO)

See example of the calculation hereunder in Table 4

Table 4. Calculation example.

Step	**Formula**
Step 1; Calculation of the energy to be delivered to the emission part of the system	$Q_{H;em} = \frac{Q_{H;nd}}{\eta_{H;em}}$
Step 2; Calculation of the energy to be delivered to the distribution part of the system	$Q_{H;dis} = \frac{Q_{H;em}}{\eta_{H;dis}}$
Step 3; Calculation of the energy to be generated by conversion systems	$Q_{H;dis;nren} = Q_{H;dis} - Q_{H;ren}$
Step 4; Calculation of the delivered energy per carrier (fuel)	$E_{H;cr} = \sum_{gi} \frac{Q_{H;dis;nren} \cdot F_{H;gen;gi}}{\eta_{H;gen;gi}} + E_{H;aux;gi}$
Step 5; Summation of the energy consumption per energy carrier	$E_{cr} = \sum_{X} E_{X;cr}$ for cr ≠ el $E_{cr} = \sum_{X} (E_{X;cr} + W_{X;aux}) - E_{pr;el}$ for cr = el
X **Service**	**Cr** **Carrier**

H	*heating*	*Gas*	*gas*
C	*cooling*	*oil*	*oil*
W	*domestic hot water*	*bm*	*biomass*
V	*ventilation*	*wd*	*wood*
L	*lighting*	*dh*	*district heat*
DHU	*dehumidification*	*dc*	*district cooling*
HUM	*humidification*	*el*	*electricity*
nd	*Need/Demand*	*pr;el*	*produced electricity*

Emission efficiency

The energy demand of the building must be divided by the emission efficiency of the system to calculate the energy that must be provided by the distribution system.

Heating

Table 5. Emission efficiency (based on NEN 2916; 2014)

Type of system	**Emission efficiency $\eta_{H;em}$**		
Height of the space	**Up to 8 m**		**8 m and more**
1) Local heating, including (electric) radiant heating	1.00		0.95
2) Average system temperature	$\theta_{em;avg} \leq 50$ °C	$\theta_{em;avg} >$ 50 °C	Alle $\theta_{em;avg}$
3) Radiator heating and / or convector for outer wall; average thermal resistance of the external divisions at the location of the radiators, R_c in m^{2}K/W, equal to or greater than 2.5	1.00	0.95	0.85
4) Radiator heating and / or convector heating the outer wall; average thermal resistance of the external divisions at the location of the radiators, R_c in m^{2}K/W, less than 2.5	0.95	0.90	0.80
5) Radiator heating and / or convector heating door with radiation shield	0.95	0.90	0.80
6) Radiator heating and / or convector heater without outer radiation shield	0.90	0.85	0.75
7) Radiator heating and / or convector heating for interior or inner frame	1.00	0.95	0.85
Height of the space	**Up to 8 m**		**8 m and more**
8) Floor heating and / or wall heating and / or concrete core activation in outdoor flooring or wall; average thermal resistance of the external partitions under floor heating or wall behind the heater, Rc in m^2.K/W less than 2.5 equal to or greater than 2,5	1.00		0.95

Type of system	Emission efficiency $\eta_{H;em}$	
Height of the space	**Up to 8 m**	**8 m and more**
9) Floor heating and / or wall heating and / or concrete core activation in outdoor flooring or wall; average thermal resistance of the external partitions under floor heating or wall behind the heater, Rc in $m^2.K/W$ less than 2.5	0.95	
10) Floor heating and / or wall heating and / or concrete core activation in indoor floor or inner wall	1.00	
11) Air heating (including air conditioning and split units with heat to the air)	0.95	0.85

Cooling

$\eta_{C;em} = 1.0$

Domestic hot water

$\eta_{W;em}$ **=** 1.0 for taps located max 3m distance of the circulation system or generation system

$\eta_{W;em} = 0.8$ for taps located more that 3m distance of the circulation system or generation system

Distribution efficiency of the selected system

In the early design phase the distribution efficiency is 100% (1.0) for all water based systems (heating and cooling), for ventilation systems the distribution efficiency is 80% (0.8) and for steam systems the distribution efficiency is 80% (0.8). If more information is available more detailed calculations shall be used according to the standards given in Table 3.

The energy demand that must be delivered by distribution system shall be divided by the distribution efficiency of the system to calculate the energy that must be generated by the generating system.

Generation efficiency

The generation efficiency is based on the net calorific value of the fuels. The generation efficiency of electricity ($\eta_{el;gen}$) varies substantial for the different member states within Europe. The average value for the whole of Europe is approximately 39.9%. If no values for the national electricity production is available this value must be used ($\eta_{el;gen} = 0.399$). For all combustion equipment e.g. gas fires boilers and Combined heat and Power systems the efficiency is based on the net calorific value (NCV) or lower calorific value (LCV).

Table 6. Efficiency steam boilers water heaters and direct air heaters (based on NEN 2916; 2004).

Boiler type	Efficiency $\eta_{H;gen}$	
Gas or oil fired water heater		
Temperature level	LT (θ_{sup} ≤ 70 °C)	HT (θ_{sup} > 70 °C)
Conventional gas fired boiler	0.778	0.778
High efficiency gas fired boiler	0.972	0.944
Conventional oil fired boiler	0.722	
High efficiency oil fired boiler (with economizer)	0.888	
Gas or oil fired steam boiler		
Conventional	0.722	
High efficiency oil fired boiler (with economizer)	0.888	
Bio mass (pellet or chips) water heater or steam boiler		
Bio mass (pellet or chips) water heater or steam boiler	0.75	
Gas fired air heater (direct)		
Conventional air heater	0.833	
High efficiency air heater	1.028	

Table 7. Efficiency Combined Heat and Power systems (based on NEN 2916; 2004).

Year of production co generation	Up to 2006		After 2006		
Electric power Pel of CHP	$\varepsilon_{chp;th}$	$\varepsilon_{chp;el}$	$\varepsilon_{chp;th}$	$\varepsilon_{chp;th}$	$\varepsilon_{chp;el}$
Temperature level heating (θ_{sup})	–	–	LT (θ_{sup} ≤ 70 °C)	HT (θ_{sup} > 70 °C)	–
20 kW < P_{el} ≤ 200 kW	0.60	0.30	0.57	0.54	0.33
200 kW < P_{el} ≤ 500 kW	0.56	0.35	0.58	0.56	0.36
500 kW < P_{el} ≤ 1 000 kW	0.49	0.39	0.51	0.49	0.39
1 000 kW < P_{el} ≤ 25 MW	0.44	0.40	0.46	0.43	0.41

District heating

The efficiency of district heating (external supply) is set at 100% (1,0).

Table 8. Efficiency heat pump systems (based on NEN 2916; 2004).

Heat source	**Efficiency** $\eta_{H;gen}$					
Local and central electric heating	1,0					
	Temperature levels of the heat emitters					
	$\theta_{sup} \leq 30$ °C	**30 °C < $\theta_{sup} \leq$ 35 °C**	**35 °C < $\theta_{sup} \leq$ 40 °C**	**40 °C < $\theta_{sup} \leq 45$ °C**	**45 °C < $\theta_{sup} \leq 50$ °C**	**50 °C < $\theta_{sup} \leq$ 55 °C**
Electric heat pump:						
— Soil/outside air	3.55	3.4	3.25	3.1	2.95	2.8
— Heat from return / exhaust air	6.6	6.1	5.6	5.1	4.7	4.4
— Groundwater / aquifer	5.0	4.7	4.45	4.2	3.9	3.6
— Surface water	4.3	4.1	3.9	3.7	3.5	3.3
Gas engine heat pump						
— Soil/outside air	1.65	1.6	1.55	1.5	1.45	1.4
— Heat from return / exhaust air	2.7	2.6	2.4	2.2	2.1	2.0
— Groundwater / aquifer	2.2	2.1	2.0	1.9	1.85	1.8
— Surface water	1.95	1.9	1.85	1.8	1.75	1.7

Table 9. Efficiency Chiller systems (based on NEN 2916; 2004).

Mechanical chiller	$\eta_{C;gen}$
Electrically driven compression chiller:	
— Without further specification	3
— High temperature delivery system (> 12 °C – 18 °C)	4
— Evaporative condenser or wet cooling tower	4
— HT-delivery system (> 12 °C – 18 °C), evaporative condenser or wet cooling tower	5
— Low temperature cold source (<15 °C)	6
— HT-delivery system (> 12 °C – 18 °C) and low temperature cold source (<15 °C).	8
Gas engine driven mechanical chiller [a]:	

Mechanical chiller	$\eta_{C;gen}$
— Without further specification	$3 \times \eta_{ge}$
— High temperature delivery system (> 12 °C – 18 °C)	$4 \times \eta_{ge}$
— Evaporative condenser or wet cooling tower	$4 \times \eta_{ge}$
— HT-delivery system (> 12 °C – 18 °C), evaporative condenser or wet cooling tower	$5 \times \eta_{ge}$
— Low temperature cold source (<15 °C)	$6 \times \eta_{ge}$
— HT-delivery system (> 12 °C – 18 °C) and low temperature cold source (<15 °C).	$8 \times \eta_{ge}$
η_{ge} Mechanical efficiency gas engine (approx. 0.30-0.40, see $\varepsilon_{chp;el}$ in Table 7.	
Gas fired absorption chiller	0.8
absorption chiller: — District heating — Heat from a CHP	 $0.7 \times \eta_{H;gen;equiv;dh}$ $1.0 \times \varepsilon_{chp;th}$

Table 10. Efficiency cooling systems without chillers (based on NEN 2916; 2004).

Free cooling systems	$\eta_{C;gen}$
Cold storage / floor cooling (without insert chiller)	12
Dewpoint Cooling	11

Preferential and non-preferential generators

The β-factor shall be determined according with the formula:

$$\beta\text{-}factor = \frac{P_{H;gen;pref}}{P_{H;em;}}$$

Where:

$P_{H;gen;pref}$ the total nominal power of the preference heat generating device (s) *pref*, in kW;

$P_{H;em;}$ the maximal power of the heat emission system supplied by the heating system in kW.

The maximal power of the heat emission system can be estimated by:

$$P_{H;em;} = \frac{Q_{H;dis}}{4000 * 3.6}$$

where:

$Q_{H;dis}$ is the amount of energy for the benefit of the energy function of heating supplied to the distribution system in kWh.

The number 4000 is the finished product of the utilization of the annually maximum heat (value 0.13) and the length of the year in kilo seconds (31 536). The number 3.6 is the change rate between MJ and kWh.

Based on this β-factor the share of the preferred device $F_{H; gen;pref}$ is determined according to Table 11

Table 11. Relation between the β-factor and the share of the preferred device (based on NEN 2916; 2004).

β**-factor**	$F_{H;gen;pref}$
0.00	0
0.05	0.12
0.10	0.25
0.15	0.35
0.20	0.48
0.30	0.79
0.40	0.91
0.50	0.92
0.60	0.94
0.70	0.95
0.80	0.97
0.90	0.98
1.00 of more	1.00

– The amount of energy that shall be generated by the preferential generator is calculated with the formula:

$$Q_{\mathrm{H;dis;pref}} = Q_{\mathrm{H;dis}} * F_{H;gen;pref}$$

– The non-preferential generator(s) shall generate:

$$Q_{\mathrm{H;dis;non.pref}} = Q_{\mathrm{H;dis}} * (1 - F_{H;gen;pref})$$

Summary KPI: energy efficiency

Definition

Estimation or measurement of the energy demand and energy consumption per square meters gross floor area and per Weighted Patient Unit (WPU) of a hospital design during operations.

Calculation method demand efficiency and consumption efficiency

– Energy demand efficiency based on square meter = Energy demand (calculated according to EN 52016)/ number of square meters gross floor area

- Energy demand efficiency based on WPU (Weighted Patient Unit) = Energy demand (calculated according to EN 52016) / WPU
- Energy consumption efficiency based on square meter = Energy consumption (calculated according to EN 12098/EN 15316/EN 12831-3) / number of square meters gross floor area
- Energy consumption efficiency based on WPU = Energy consumption (calculated according to EN 12098/EN 15316/EN 12831-3/ WPU

Unit of measurement

- Energy demand and final enery conspumption of the hospital kWh/(m^2 / Year)
- Energy demand and final enery conspumption of the hostipal kWh/(WPU / Year)

Suggested data sources

- Schematic design, bubble diagram and main design dimensions
- Labels or enriched characteristics of the room (e.g. BriefBuilder)
- Structural design of the MEP system

3.1.4 KPI: Carbon emission efficiency

Definition

Estimation or measurement of the total carbon emission per hospital complex during operations. Measured per number of square meters gross floor area and WPU.

Calculation method carbon emission

Global Warming Potential is one of the most commonly used methods (see chapter 3.3.3 in report from the EU project E2ReBuild). Global Warming Potentials (GWPs) are used to compare the abilities of different greenhouse gases to trap heat in the atmosphere. GWPs are based on the heat-absorbing ability of each gas relative to that of carbon dioxide (CO_2), as well as the decay rate of each gas (the amount removed from the atmosphere over a given number of years). Carbon dioxide is used as the base for all the calculations, so its global warming potential is 1. The higher the GWP, the more heat the specific gas can keep in the atmosphere. Greenhouse gas emissions are often calculated in terms of how much CO_2 would be required to produce a similar warming effect oven the chosen time period. This is called the carbon dioxide equivalent (CO_2 eq) value and is calculated by multiplying the amount of gas by its associated GWP. Under the Kyoto Protocol, it was decided that the 100-years GWP values that are provided by the Intergovernmental Panel on Climate Change (IPCC) should be the generally accepted values. For the calculation of the CO_2 emission of the system the following conversion factors shall be used.

Table 12. Conversion factors for CO2 emission (NEN 7120 + C2).

Fuel type	**Emission factor CO_2** kg/MWh
Natural gas ($CO_{2;gas}$)	182.16

Electricity ($CO_{2;el}$)	564.94
District heating (coal/oil powered) ($CO_{2;coal;oil}$)	315.72
Waste incineration ($CO_{2;wi}$)	113.04
Wood. biomass ($CO_{2;wd;bm}$)	0.0

Units of measurement

- kg CO_2 / m²
- kg CO_2/ WPU

Suggested data sources

- Energy consumption and source of energy data see section 3.1.1.

3.2 Financial Performance

3.2.1 KPI selection

According to D3.1 only one financial key performance indicator for a hospital building was identified, namely the whole life cycle costs (LCC) of the building (See Appendix 1 for overview KPIs). Since existing methods and tools are available to calculate these costs already in an early stage of the design, the LCC method was chosen to operationalize the Financial Performance category.

3.2.2 KPI: Life cycle costs (LCC)

Definition

In general, Life Cycle Costs are all costs occurring in the life cycle of the building, costs of construction, operation (related to the building), maintenance and disposal. The aim of STREAMER is to be able to assess the expected financial performance of a (early) design and compare design scenarios based on this performance during operations for a specific function of the building. This method could be used for refurbishment and new built scenarios. If a new function is foreseen once the building is realized, or a disposal (or sales) decision needs to be taken a new assessment can be ran to make the optimized decision. STREAMER focusses on design decisions and as a result costs of disposals are excluded. The same applies to financing costs. Multiple financing options are possible with different consequences for the recurring costs. Since in STREAMER we want to take decisions based on the design consequences we excluded these costs as well, to make the comparison design based only. Thus, the following costs are included in the life cycle cost of KPI of STREAMER:

- Investment costs (capital costs)
- Operational costs (including costs in design, construction, operation and maintenance phase). Operational cost included: Energy, Water, Cleaning, Maintenance, Security, General management and technical support (based on SS-ISO 15686-5:2008)

The following cost items are excluded:

- Demolition and major renovation costs
- Financing costs (how investments are financed; e.g. interests on loan)
- Revenue (economic benefits) generated by the building
- Residual value (we assume that at the end of the lifetime, the asset has no commercial value)

As financial performance KPI we choose to integrate the investment costs and operational costs into one measure of financial performance through a net present value calculation and for comparison reasons the annual costs only.

1) LCC performance indicator = net present value of investments and operational costs
2) Annual costs

Calculation method

The net present value (NPV) is the net sum of the discounted future cash flows (the sum of the discounted earnings/benefits less the sum of the discounted costs). The NPV can also be calculated by subtracting the initial investment cost from the discounted net cash flow. If the NPV is positive the investment is profitable and the greater positive value of the NPV it is the more profitable is the investment. Since the discounted building related earnings/benefits of a hospital are difficult to estimate, the NPV method in the LCC calculation is only based on the building related costs.

For instance NCC (Partner 11 in STREAMER consortium) uses following general formula (SEK can of course be any currency):

$$LCC = I_o - \frac{R}{(1+r)^n} + \sum_{y=1}^{y=n} \frac{U_{t,y}}{(1+r)^{y-1}}$$

I_o = Initial Investment Cost (SEK)

R= Residual value (SEK)

r = Discount rate (-)

n = Life time (years)

$U_{t,y}$= Payments in year y (SEK)

- Measurement in the design phase is accomplished with the help of an assessment, using life cycle costing, on the basis of investment costs and the estimated costs in the rest of the life cycle of the building.
- Measurement in the use stage should take place with the help of assessment, using life cycle costing, on the basis of estimated cost related to the maintenance and refurbishment and verified cost of operation.
- Input and output are generated manually by ways of an excel sheet.

This represents a way to determine the most cost-effective option among different competing design scenarios. The actual calculated value is of less importance than its comparison against a number of different design scenarios.

Suggested data sources

There are three main potential sources from which information can be obtained:

- Balance sheets and bills from manufacturers, suppliers, subcontractors etc,
- Own construction's management invoices, delivery notes, historical records, accounting systems and calculations and estimations from the financial department.
- Data from economic audits and modelling techniques, like the LCC model from TNO (3.2.2.)

LCC model TNO

TNO developed, together with the Norwegian company, *Multiconsult*, a model that enables to calculate the effect of the intended investments of a hospital on the operating budget to be forecasted during development of the construction plans. The purpose of the model is to weigh-up the capital costs against the building-related costs over the entire life cycle of the building.

The following (cost) aspects are covered by the model:

- The *capital investments* specific to a certain scenario (for example a scenario could include new build 60.000 m² (at 100% costs) and refurbishment 20.000 m² at 50% of costs of a new building);
- *MOM expenses* (Management, Operation and Maintenance), also referred to as building-related running costs. These costs include, among others: maintenance, energy and cleaning. These expenses have a large impact because every square meter built also has to be maintained during the entire life cycle. Moreover, a relatively old building generally has higher MOM expenses than a newly-completed building;
- *Development costs*. It covers the cost of adaptations during the lifetime as a result of new regulations and social and medical-technological developments. These costs also vary per function;
- *Life cycle*. The life cycle is a variable that can be set, as hospitals can no longer be seen as a constant value of 40 years. For example, you might choose to erect a building for 25 years of use, and not to carry out any midlife renovation; Life cycles can be selected for specific parts of the building or building elements in case of a refurbishment.
- *Adaptability.* The building must continue to fulfil its functional requirements. The hospital will obviously want to avoid having to make modifications right at the start of the building's service life when functions are changing. Post-completion adaptations are virtually always costlier than those made during design (and construction). By varying levels of adaptability at the onset of the design process, the LCC model enables different alternatives (in terms of flexibility/adaptability) to be calculated and compared according to these aspects.

Furthermore, the model has default settings that allow cost indexes to be taken fully into account. These costs indexes are pre-set and can be manually adjusted based on the case particularities. Index figures are available for instance, in inflation rates, discount rates. This flexibility in the model allows different scenarios in early decision making to be compared, i.e. a comparison of deep renovation at 80% costs of a new building but with higher MOM-costs vs 100% new built with lower MOM costs.

Different levels of abstraction

The TNO-model works with different levels of abstraction. The information at hand at the start of a project is vastly different to that when a complete programme of requirements is on the table. The model takes this into account. The primary focus of the model is on the more strategic levels. Incidentally, the model offers the flexibility of being able to zoom in on specific aspects, while other factors continue to be handled at a higher level. For example, if the choice is made for a glass façade this requires relatively costly maintenance and cleaning.

LCC model levels:

1. *Global phase/Early design phase*: if there is little more than a target number of square meters per relevant function (OR, nursing). No specific information is available at this point.
2. *Strategic phase*: the investments can be calculated at main element level (architectural, electrical/technical, etc.) and the MOM expenses are categorized.
3. *Design phase*: this phase entails calculations at element level. The MOM costs are subdivided into 16 aspects (cleaning, energy, etc.).
4. *Calculation phase:* detailed calculation at material level takes place in this phase. It is even possible to state the frequency of maintenance and replacement per individual material type.

Key figures / benchmark data

The LCC model is filled with a large number of (historical) Dutch benchmark figures on investment costs, MOM expenses and development costs of hospitals, mainly gathered by TNO. For a specific project, one needs only to state where it deviates from this standard data and run a cross check for a cost update of these numbers. For refurbishments actual data could be used.

Differentiated building and investment costs per function

TNO makes a distinction in the average building and investment costs per m² gross area for specific hospital functions or departments. It uses differentiated prices based on a percentage of the average building and investment costs of Dutch hospitals. These differentiated costs are used in the LCC model of TNO and also used for real estate investment cost calculations that underpin the layer approach.

For example, the investment costs of hot floor functions vary between 120% and 160% of the average investment costs, as for office functions they vary between 70% and 110% of the average costs[4]. The average investment costs were updated in 2010 based on a report on building costs from 2010[5]. The cost index ranges from 2001-2015 (and is updated monthly). The index combined with the old benchmark investment cost, gives a starting point when comparing the different design scenarios.

[4] Bouwkosten zorgsector 2010 (In Dutch accessible through https://www.tno.nl/media/2953/jaarbeeld_bouwkosten_2010.pdf)

[5] The index is published on the Dutch website https://www.tno.nl/media/4737/gezondheidszorgindex.pdf

Table 13. Costs index on hospital functions/departments

Nr.	Hospital functions/departments	Differentiated basic price	LCC model	Layer
A	**Patient-related facilities**			
A1	**Nursing**			
1.	General nursing	100%	100%	Hotel
2.	Special care (intensive and coronary care)	120%	120%	Hot floor
3.	Pediatric nursing	100%	100%	Hotel
4.	Maternity & neonatology	100%	100%	Hotel
5.	Day nursing	100%	100%	Hotel
6.	Dialyses		101%	Hotel
A2	**Diagnostics and treatment**			
1.	Outpatient consultation department	90%	105%	Office
2.	General organ function diagnostics	110%	105%	Office
3.	Diagnostic imaging	120%	120%	Hot floor
4.	Nuclear medicine / radiotherapy	110%	120%	Hot floor
5.	Outpatient treatment	110%	105%	Office
6.	Emergency care	120%	120%	Hot floor
7.	Operating theatres	160%	160%	Hot floor
8.	Delivery / obstetrics	100%	120%	Hot floor
9.	Physiotherapy & rehabilitation		90%	Office
B	**Medical support services**			
1.	Central sterilization	135%	126%	Hot floor
2.	Pharmacy / dispensary	105%	110%	Industry
3.	Laboratory clinical chemistry	105%	110%	Industry
4.	Laboratory medical microbiology	105%	110%	Industry
5.	Laboratory clinical pathology	105%	110%	Industry
C	**General facilities (not-patient related)**			
C1	**Support services**			
1.	Communal area	90%	100%	Hotel/office
2.	Public facilities	90%	100%	Hotel/office
3.	Central staff accommodation	75%	80%	Office
4.	Availability services	75%	80%	Hotel/office
5.	Cleaning and distribution of beds	75%	80%	Industry
6.	Cleaning and distribution of (bed)clothing	80%	80%	Industry
7.	Locker rooms/wardrobes staff	80%	80%	Hotel/office
8.	Staff restaurant & recreation	90%	80%	Office
9.	Production kitchen	145%	145%	Industry
10.	Central warehouse	70%	80%	Industry
11.	Housekeeping services	75%	80%	Industry

12.	Workplaces technical department	75%	80%	Industry
C2	**Management and administration**			
1.	Management	75%	80%	Office
2.	Administration	75%	80%	Office
3.	Archives	70%	80%	Office
4.	Central medical administration	75%	80%	Office
5.	Education and training facilities	75%	80%	Office

It should be noted that the relations were established in the aforementioned reports. New insights in the STREAMER project could lead to an adapted or updated relation between hospital function, associated costs and layer (e.g. an additional layer for public facilities could be argued; the building costs for these functions are usually much higher than general Office or Hotel costs, due to generous height and a lot of glass surfaces). This point refers to WP1, where layers are further explored and new or updated relations can be established, based on insights from practice, other partners and the demonstration cases in WP7.

A second important differentiation that is possible with this model is to define specific life cycles for parts of buildings, departments, building elements or products. The ability to differentiate in life cycle per part of the building allows calculating different scenarios for decision making.

An example of this in the early design phase is when decisions are made with help of the layer model. The hot floor (assumed with a life cycle of 20 years) is different than a typical office building (assumed at 40 years) and has different characteristics (both in dimensions -*building height, ventilation needs*- as well as in building costs (see table above)). By allowing different design scenarios to be compared (a monolithic building (reference to a Breitfuss model hospital) designed towards the standard of a hot floor encompassing all office & hot floor functions)) is more costly in LCC terms than for instance two separate buildings (one office and one hot floor building). Over the lifetime the monolithic building is more difficult to refurbish and the investments costs for the office part are likely to be higher though the combination of the hot floor and office functions in the same building. For more examples see the report on Building differentiation of Hospital- Layers approach (Netherlands Board for Healthcare Institutions, report 611, 2007).

For comparison reasons, the different building layers have been given the following life cycles:

Hot floor *20 years*
Office *50 years*
Hotel *50 years*
Laboratory *25 years*

The model allows for differentiated cycles for, for instance, the building and MEP. As a default the model works with the assumption on technical lifespans and upgrades during the lifecycles of 0, 8% per year of the investment costs for yearly updates/replacements. Buildings with a life span of 20-25 years have a differentiated investment/upgrade cycle from buildings lasting 50 years (mid-life update).

Note that these characteristics can be used as semantic labels that are attached to the room levels. In addition, it is important to stress that the building layer is highly influenced by the decision of the design team to collocate functions. And that future adaptability/flexibility does play an important role here. The “inheritance” of properties (as discussed in Deliverable 1.5) does play an important role here. An example of this is the choice of the design team to allow future upgrading of the office function into a hot floor area. The initial layout (building height, depth, and allowance for MEP services) is already built at a higher standard level than a regular office in order to reduce the future costs of refurbishment of an office into a hot floor. At the start of the occupancy of the buildings, the rooms can get the function of an office and in the future, when more capacity is needed in the hot floor area, these spaces could be modified and customised according to favourable conditions into the new function of a hot floor.

For renovations a percentage of the new build costs are assumed for comparison reasons; typically renovations vary from light to relatively deep renovations. The type of renovation has often a specific technical lifespan and will influence the MOM costs as well as the required level of investment. Depending on the scenario at hand different options need to be discussed between the client and design team, with an initial expected level of investment (as a percentage of new built, lifespan and result on MOM-costs. The model can handle these different assumptions.

At the very detailed level different lifecycles of solutions can help to decide between solutions that have the same function (for instance a window), but carry different product specifications (wooden window frame vs. an aluminium window frame). In terms of LCC the wooden window frame is cheaper to buy, but its life cycle is shorter (say 10 years) than an aluminium frame (say 30 years). The design team could choose to select an aluminium frame, knowing that this is more expensive as an investment, but ensuring that over the lifecycle of the building, it does not need to replace it 2 or 3 times, which in terms of lifecycle costs might be beneficial.

Differentiated MOM expenses (Management, Operational and Maintenance)

Just as important as building costs or investments costs, are the inherent building related Management, Operational and Maintenance costs also referred to as building-related running costs. They encompass the hard facility management costs and are directly impacted by the design. Moreover they can be taken into LCC decision making on the basis of already early design decision regarding m², layer or other early design parameters.

These MOM expenses tend to have a large impact because every square meter built also has to be maintained during the entire life cycle. Moreover trade-offs in decisions regarding refurbishment/ new designs can be taken into account. For instance, a relatively old building generally has higher MOM expenses due to lack of insulation, old installations (with a lower efficiency) thus requiring more energy or maintenance (for instance lighting) than a newly-completed building. However, these newer buildings generally have a higher amount of comfort due to (partial or) full climatisation and this comes at a cost too.

At the very detailed level; the window frame can serve as an example here too. A wooden window frame is likely to require an occasional paint job every 5 -7 years whereas the aluminium frame is virtually free of maintenance;

these costs can be taken into account when considering design decision on product level at a very detailed level (calculation phase).

TNO has developed a benchmark price on MOM costs that can be used at the early design phase. These benchmark data were compiled from Dutch hospital data and give an average number for these costs in euro per m² gross floor area based on a total of 89 general hospitals. The costs can be indexed with use of the same index as previously referred to (footnote 1). For general application it should be investigated if these cost levels can be applied on a European scale or whether country specific adjustments should be made.

In the LCC model the following average Dutch basic prices (price level in 2007) are used:

Management: € 10, -- per m²

- *Management civil functions*
- *Property taxes*
- *Fire insurance*
- *Building insurance*

Operational costs: € 58, -- per m²

- *Maintenance: € 31, -- per m²*
  - *Staff civil maintenance: € 14, -- per m²*
  - *Cleaning costs: € 17, -- per m²*
- *Security: € 6, -- per m²*
  - *Costs of protection and surveillance*
  - *Costs of protection and surveillance by third parties*
  - *Costs of domestic/own protection of surveillance*
- *Energy costs: € 21, -- per m²*
  - *Oil*
  - *Electricity*
  - *Gas*
  - *District heating*
  - *Water*
  - *Other costs of energy*

Maintenance costs: € 44, -- per m²

- *Staff site and building bound functions*
- *Maintenance of grounds*
- *Maintenance of buildings*
- *Maintenance of installations*
- *Materials, machines and tools for maintenance*
- *Allocation for major repairs*

As an effect, first costs comparisons can be made based on m² only. The model also differentiates between the average costs of departments. Thus, once gross floor area information per department is available the calculation can be refined. Note that the energy costs per m² gross floor area are part of the LCC model. In the TNO model this is a fixed parameter, based on average costs. It is expected that, by combining knowledge from the energy KPI a better result (and more sensitive to EeB solutions) could be expected through further integration of the KPIs in one model/dashboard.

For comparison reasons between design scenarios it is advised that these figures are good enough to make distinction between design scenarios and therefore, serve as a KPI that is usable in the STREAMER context.
For individual cases one could change or alter the average costs per m² if better data are available or indicate where deviations need to be taken into account.

Converge Investment costs and MOM costs
When combining the Investment Costs together with the MOM costs (through the earlier mentioned NPV method) it is possible to allow different (early) design decision to be compared.

Unit of measurement

The proposed unit of measurement

1. NPV (LCC) in €,€/m², WPU
2. Annual costs (MOM) in €,€/m², WPU

As the unit of measurements show the costs are related to different building aspect. The first measurement only looks at the overall financial performance in terms of capital costs and operational costs of a design. This does not yet relate to any building related or activity related aspect of the organization and makes them difficult to compare on the basis of average costs (or other related benchmarks).

The second unit of measurement NPV or annual costs per square meter gross floor area relates to the size of the building. It shows how efficient in terms of costs the different designs are in comparison. It looks specifically at building related consequences of design scenarios. It is therefore, a good measurement for comparing costs between design scenarios.

The third unit of measurement (NPV or annual costs per WPU) relates the cost to the revenue earning capacity of the building in use expressed in the weighted patient unit. It is an indicator of process-efficiency and operational performance which can be used to distinguish between design scenarios that are more or less capital intensive in relation to the capability of the hospital organization to make effective use of the building. It is also a way to help building a convincing business case for investors such as banks, governments or other financiers.

Implications for further use of LCC KPI.
On the basis of the abovementioned insights on LCC costs it is advisable that the dashboard (D3.6 to be developed within WP3) would encompass the default parameters that were presented here for (early) design calculations. This could be done on the basis of departmental costs or layer cost.

It is advisable to be able to treat different buildings as separate entities (with separate properties). This would make the handling of data easier. Again different scenarios would need to be calculated to present this to the design team (based on different assumption in the LCC-model).

The default parameters need to be aligned with the semantic labels on room level and would ideally be pre-filled with these data. The layer type (and associated costs) should be a secondary source of information (as inheritance of properties from the semantic label takes precedence over pre-set labels). For instance, if an office is located in the hot floor area, the hot floor rules apply due to its inheritance of properties from the hot floor layer.

Also, the dashboard should be able to deviate on basis of the default parameters. Most importantly, it should be able to deviate per type of currency, or type of denominator (m² gross floor area or WPU). It should also be possible to adjust investment costs or MOM costs for specific cases on the level of layers or departments.

The link to the results of WP2 is crucial. The LCC calculation give an average LCC-costs based on the benchmark data in The Netherlands. If EeB solutions are presented or to be included, the effects of these solutions need to be connected to a tangible output in the LCC costs. This would allow different trade-offs to become visible and ready for decision making.

Summary KPI: Life cycle costs

Definition

- Estimation or measurement of the NPV costs associated with the investment in (capital expenditure) and operational expenditure of a hospital design, per square meter and per WPU
- Estimation or measurement of the Annual costs associated with the operational expenditure of a hospital design, per square meter and per WPU.

Calculation method

- LCC= The net present value (NPV) method adopted for hospitals (excluding earnings)/
- LCC= The net present value (NPV) method adopted for hospitals (excluding earnings)/ m²
- LCC= The net present value (NPV) method adopted for hospitals (excluding earnings)/ WPU
- Annual cost estimation
- Annual cost estimation/ m²
- Annual costs estimation/ WPU

Unit of measurement

- €
- €/m²
- €/WPU

Suggested data sources

- Schematic design, bubble diagram and main design dimensions (gross floor area of functions or layers with semantic labels + rules on inheritance of information)
- Expected life cycle of building(s)
- Discount factor
- Benchmark data (LCC model TNO) adopted with local information

3.3 Quality Performance

3.3.1 KPI selection

Table 14 shows the long-list of quality performance indicators as defined in D3.1. It includes indicators on the quality of the environment and operational efficiency (See Appendix 1 for a complete overview of KPIs as defined in D3.1)

Table 14. Quality performance indicators D3.1

Quality	Operational Efficiency
Staff satisfaction	Connectivity, adjacency, access, flexibility
Patient satisfaction	
Visitor satisfaction	
Improved clinical outcomes	
Safety and security	

Concerning the quality indicators, all indicators can be measured once the building is realized by conducting, for instance, a ‘post-occupancy evaluation’, ‘occupant satisfaction survey’ (e.g. BUS methodology, www.busmethodology.org) or by running a controlled trial to attest improved clinical or safety and security outcomes. However, not so many tools exist to measure or calculate these indicators based on information available during the design of a hospital (before realization of the hospital). In order to measure patient satisfaction and the overall quality of the building, two tools were identified.

3.3.2 KPI: Patient satisfaction

TNO (Dutch Independent Organisation for Applied Scientific Research) has developed algorithms to predict patient satisfaction based on patient room and outpatient clinic characteristics (Lebesque et al., 2014). Since the algorithms are not yet included in a calculation tool, the model does not meet the requirement of an existing calculation tool, but the calculation methods and necessary inputs have been defined. The algorithms are fairly easy to connect to BIM, as the majority of the input characteristics are building or interior related (Appendix 2). The model does meet the criteria of consistency of unit measurement, as the prediction is based on survey outcomes, which can be validated by a patient satisfaction survey once the building is realized. A disadvantage of the model is that it does not cover the hospital building as a whole, which is particularly relevant in the early design stages. Furthermore, most inputs require information that is only available in a later stage of the design. Applicability in an early design stage is possible, and should be evaluated for relevance. In particular, because design scenarios are compared. If only some of the required information is available, this information lacks in all scenario's, which enables comparison between different scenarios (as they are all lacking the same information).

Definition

Estimated self-reported patient satisfaction of the patient room and outpatient clinic on room/clinic level or total building level (average of all room/clinic scores).

Method of calculation

An algorithm was developed by TNO to calculate patient satisfaction (range 1-5) based on physical characteristics of the patient room and outpatient clinic. Appendix 2 provides the input sheets based on which design characteristics a prediction can be made. The algorithm is based on the following formula:

$$Y = \frac{1}{1 + e^{-(\omega_1 DC_1 + \omega_2 DC_2 + \omega_3 DC_3 \ldots + \omega_n DC_n + \theta)}}$$

where Y is estimated patient satisfaction.

ω_i, represents the weights connecting design characteristics (DC) to patient satisfaction indicators (which can be estimated based on design characteristics, as the algorithms are based on 400 patient surveys, evaluating 48 patient rooms in four hospital).

DCi , depict the measured value of a design characteristic.

θ is a constant. The score can be defined per room/clinic. A building/department score can be calculated by averaging the room and clinic scores of the building/department.

Units of measurement

Patient satisfaction score: range 1-5

Suggested data sources

- Input sheets (Appendix 2)
- BIM, GIS, manual data on (interior) design.
- Use of patient satisfaction algorithm (by TNO)

3.3.3 KPI: Overall quality

The National Health Service of England developed the ASPECT toolkit (2008) that is designed to manage and measure the quality of healthcare facilities. The tool can be applied to new and existing buildings, fulfilling the requirement of consistency of the unit of measurement and that of an existing tool. Although the tool does not measure/predict the indicated performance indicators, it evaluates aspects of a 'therapeutic environment' as defined in D3.1. Table 15 shows the 'therapeutic' aspects that are covered by the ASPECT tool.

Table 15.Therapeutic aspects covered in ASPECT tool.

Therapeutic aspects	Covered by ASPECT
Car parking and transport connections	NO
Clear way-finding (internal & external)	YES
Privacy & dignity	YES

Security	NO
Acoustics	YES
Natural daylight	YES, focus on control (easy to exclude)
External views	YES
Access and walking distances	NO
HAI strategy	NO
Thermal comfort	YES, focused on control
Environmental control	YES
Artificial lighting	YES, focused on control
Art	YES
Entertainment systems & ICT	NO

The tool results in a quality score and it is assumed that the higher the score, the higher the overall satisfaction of patients and staff. The advantages of this tool are that the building as a whole can be evaluated and it is available for download on the internet. Disadvantage is that the scoring needs to be done by experts. The tool provides no critical values how to score an item. For instance, the following item to score is: *'The design layout minimizes unwanted noise in staff and patient areas'* will need to be scored by the expert with a 6 (whether he/she agrees) or with a 1 (whether he/she disagrees) with this statement. Based on these scores an average total score can be calculated for a design or existing building, which might function as a quality performance indicator. Figure 4 shows the results sheet of the tool. Please note the categories (C1-8) have different total scores, as a result the total score is 47. It should be noted the more detailed the design is, the better the application of the tool. Applicability in an early design stage is possible, and should be evaluated for relevance. In particular, because design scenarios are compared. If only some of the information is available in the tool, this information is available in all scenarios, which enables comparison between different scenarios. Currently, there is no clear link to design characteristics and BIM. Criteria for evaluation could be developed and linked to information already available in BIM, however, this is currently not available.

Moreover, the tool is from 2008 and a literature update may be necessary. Also, (day) lighting is included in terms of control: whether artificial lighting can be easily controlled or whether patients and staff can easily exclude sun - and day light. Items on whether (day) lighting levels for patients and staff are sufficient and comfortable are not included even though certain day (lighting) levels impact human well-being and comfort (Boyce et al., 2003, Van den Berg, 2005). There are three routes by which properties of (day) light may positively influence health and well-being (Boyce et al., 2003, Van den Berg, 2005): through the visual system (e.g., increased visibility), the biological system (e.g., improvement of the circadian cycle), or the psychological system (e.g., alleviation of depression). Although norms exist for minimal lighting requirements for artificial lighting, namely: EN15251. Research effort is still necessary in order to identify the best luminous conditions for health outcomes (Van den Berg, 2005). In addition, windows that are too small may be a problem (not enough daylight, impaired well-being), but windows that are unprotected and are too big can represent a problem as well, in the context of overheating. Considering this, a daylight factor as additional comfort KPI was not included.

Results summary:

		1	2	3	4	5	6	
C1:	► Privacy, company and dignity							0 of 5 scored
C2:	► Views							0 of 5 scored
C3:	► Nature and outdoors							0 of 3 scored
C4:	► Comfort and control							0 of 6 scored

C5:	► Legibility of place	0 of 6 scored
C6:	► Interior appearance	0 of 8 scored
C7:	► Facilities	0 of 8 scored
C8:	► Staff	0 of 6 scored

Figure 4: Results sheet ASPECT tool.

Definition
Total score on the quality scan of the hospital environment (ASPECT tool)

Calculation method
ASPECT tool: Expert opinion, ranking scores between 1 (disagree) - 6 (agree)

Units of measurement:
Total quality score (maximum score 47points)

Suggested data sources:
- 3D- Representation/impression of the design
- The evaluation tool can be retrieved from: http://webarchive.nationalarchives.gov.uk/20130107105354/http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_082087

As indicated in Table 15 not all aspects that are relevant for a 'therapeutic environment' are covered by the ASPECT tool. Moreover, the tool and the satisfaction model are not specifically sensitive to energy reduction interventions. For instance, the impact of a change in the ventilation system might not influence the quality prediction, as only the controllability of the system is evaluated which might have not changed. Since STREAMER is about reducing energy consumption, also a more specific energy related comfort KPI was defined that is sensitive to energy reduction interventions.

3.3.4 KPI: Thermal Comfort

According to EN15251 energy consumption of buildings depends significantly on the criteria used for the indoor environment. Criteria used for the indoor environment depend on the level of envisaged comfort, health and productivity of the occupants of the building. Aspects of the environment that determine comfort levels and impinge energy use include:

- Thermal comfort
- Air quality comfort
- Acoustic comfort
- Visual comfort ((day)lighting)

The EN 15251 specifies criteria for each aspect depending on the quality category of a building and for some aspects provides calculation methods how to calculate whether criteria are met and how to measure the performance once the building is realized. It should be stressed, however, that fulfilling the given criteria does not mean 100% acceptance and guaranteed comfort levels by the occupants. Due to individual differences and preferences it may be very difficult to satisfy everybody in a space. Individual control of the environment or individual adaptation (clothing, activity) is an important factor to influence comfort or level of acceptance (de Korte et al., 2015). As van Hoof and Hensen (2006) mentioned, when investigating comfort among older adults, *"there is no need for prescriptive standards if individual control is provided in order to optimise the indoor environment to personal needs."*

In the end, the experienced comfort level of the occupants is the ultimate comfort performance indicator. Since this cannot be measured during the design phase, and since controllability of the indoor environment is covered in the overall quality assessment tool, computing the expected deviations from the criteria for each of the comfort aspects seems an acceptable method to calculate the performance of comfort. As a result, for each indicator requirements should set based on the quality criteria of the building or space (Table 16 shows an example from EN 15251). The requirements may be updated for healhcare settings specifically, as the residentual bedroom criteria may not apply to all patient rooms.This is outside the scope of this report, but is covered in WP1, where the comfort requirements will be included in a *"Comfort label".*

Table 16. Example requirements for indoor environment based on quality category of the building

Criteria of indoor environment	**Category of this building**	**Design Criteria**
Thermal conditions in winter	II	20-24 ^oC
Thermal conditions in summer	III	22-27 ^oC
Air quality indicator, CO2	II	500 ppm above outdoor
Ventilation rate	II	1 l/sm^2
Lighting		E_m >500 lx; UGR <19; 80< R_a
Acoustic environment		Indoor noise < 35 *dB* (A) Noise from outdoors <55 *dB*(A)

The building category refers to building categories that are presented by a number of standards (ISO7730, ASHRAE 55, EN 15251). The categories are according to the closeness with which the indoor conditions are controlled. Design criteria are linked to this categorisation. A lower category means higher quality criteria. In this way, norms can be applied to different type of spaces/buildings. Table 17 shows these building categories. We refer to EN 15251 for the specific criteria used per building category for each comfort indicator.

Table 17. Building categories as defined by different standards (ISO7730, ASHRAE 55, EN 15251)

Category	**Explanation**
I	High level of expectation only used for spaces occupied by very sensitive and fragile persons
II	Normal expectation for new buildings and renovation
III	A moderate expectation (used for existing buildings)

The next step would be to calculate the deviations from the requirements based on design input. Unfortunately, not all indicators have existing methodologies to do this in the design phase, and can only be validated/ measured once the building is realized. Since the focus of this deliverable is on the calculation of the indicators based on design input (see scope) it has been decided to only include thermal comfort as a comfort KPI in the STREAMER project. This has been decided taking into account the following:

– The aim of STREAMER is to compare design scenarios already in a very early design stage. In this stage thermal comfort is the only parameter that can be calculated based on high level building or space information with existing methodologies and simulation models (EN 15251, Van der Linden et al., 2006, prEN 15265 and prEN 15255).
– Design decisions made that influence thermal comfort, such as the use of concrete core heating, are taken in an early design stage and are difficult to change in a later stage. This makes thermal comfort a more relevant indicator to be evaluated in an early design stage than for instance lighting and acoustic comfort performances as these performances are easier and less costly to adjust in a later design phase. Also, controllability of daylight and artificial lighting and noise are covered in the overall quality indicator.
– Air quality comfort is an interesting parameter as unlike temperature, carbon dioxide levels, for example, cannot be sensed directly (Rigger et al., 2015). As a result, the air quality will not directly impact user comfort experiences. However, health effects of indoor air pollution have been documented (Bentayeb et al., 2015; Hulin et al., 2012), which makes it less of a comfort but a health indicator. Based on the expected air pollution in a building or space (depending on many parameters and sources such as number of persons (time of occupation), emissions from activities (treatment, humidity, heavy use of machinery), emissions from furnishing, flooring materials and cleaning products etc.), ventilation rates criteria are provided to guarantee acceptable air quality comfort levels. We refer to EN 15251 for the criteria per building category. Whether these ventilation rates are reached can only be computed in the design phase based on very detailed information about for instance the length of and number of curves in ducts of the ventilation system, which only comes available in a very late stage of the design phase. Moreover, no existing calculation methods have been found to compute this indicator, therefore, it was decided to not include air quality comfort as comfort indicator.

Thermal comfort

Thermal comfort is the thermal sensation of a space that is perceived by its occupants. We refer to EN 15251 for an overview of the criteria and existing calculation methods. For STREAMER it is important that the thermal performance of a total building and on room level can be calculated. In that way, thermal performance may be linked to labels as defined in WP1. Since in a hospital different mechanical and electrical systems can be used, we choose the hourly criteria to be used as comfort KPI. It has to be kept in mind that this KPI can only be calculated when there is a detailed design. In the early design stages the calculation method is not applicable.

Definition

- Average number of hours of temperature deviation from the standard per year
- Maximum number of hours of temperature deviation from the standard per year

For standards we refer to EN 15251.

Calculation method:

- Weighted Temperature Exceeding Hours (GTO)
- Adaptive Temperature Limits (ATG)

See Raue et al., 2006 for the detailed calculation method. Methods are often already included in the energy simulation software.

Units of measurement

- Hours of temperature deviation from the standard per year

Suggested data sources

- Energy simulation program that includes GTO or ATG

3.3.5 KPI: Operational Efficiency

As table 14 shows, connectivity, adjacency, access, and flexibility are building related aspects mentioned in relation to operational efficiency in environments in D3.1. These aspects typically influence the operational efficiency in a building, but are not indicators to measure or predict the operational efficiency. Therefore, other KPIs need to be defined to make the influence of these aspects comparable in terms of a quantified performance indicator.

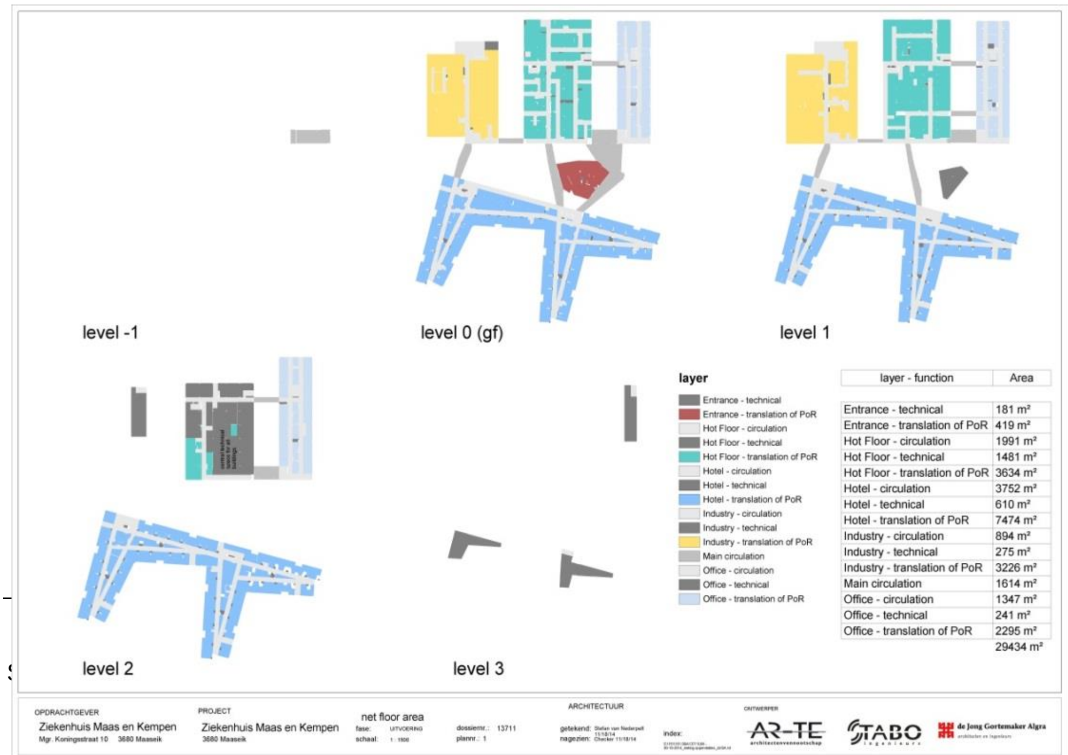
Operational efficiency is a level of performance that describes a process that uses the lowest amount of inputs to create the greatest amount of outputs. In terms of a building this relates to how efficient the building is in supporting the operational activities within the building (building efficiency); and how efficient are the processes in the building, given the building (process efficiency). For instance, the logistic plan of a hospital may impact the efficiency of processes due to increased or decreased travel time. As a result, two indicators were defined to operationalize Operational Efficiency: a building efficiency indicator and a travel time efficiency indicator.

PI Building efficiency

Definition

The building efficiency is defined as the calculated ratio between net and gross floor area of the hospital design. The higher to one, the more efficient the building is.

Calculation method



We refer to the Dutch norm NEN 2850 or other national codes to determine this ratio. Since designs are compared it is important that the same calculation method is used in a design comparison within a project. Different calculation methods can be used between projects. Figure 5 and 6 show an example of the net and gross floor area of a hospital design respectively. The net to gross ratio is 89%, which can be differentiated per layer.

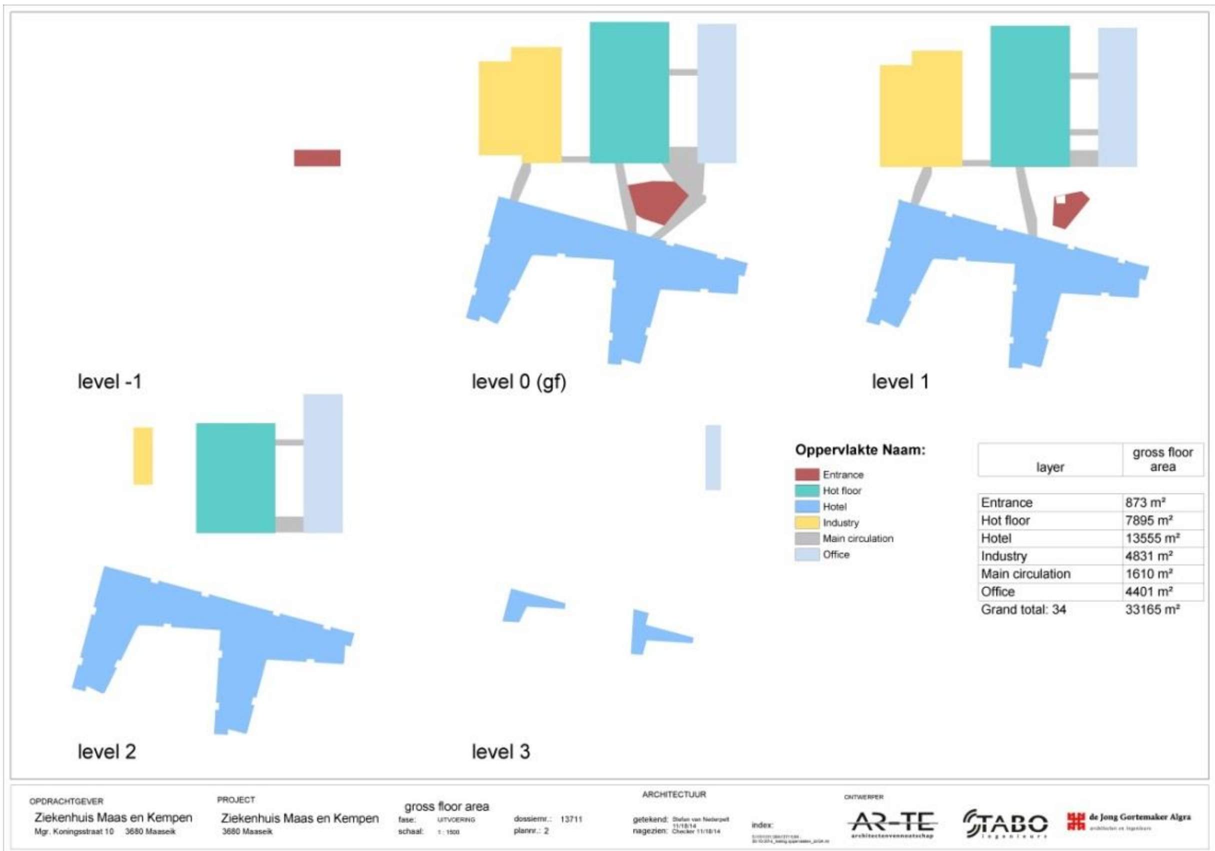


Figure 5. Net floor area

Figure 6. Gross floor area

Units of measurement

Ratio between net and gross floor area (percentage).

Suggested data sources

- Floor and technical plans
- BIM once every space and the exterior walls have been modelled.

PI Travel time efficiency

Only one method was found to calculate process efficiency based on design information. TNO (Hoogh et al., 2010, only available in Dutch) has developed a method to calculate the travel time needed for patient transport based on a design layout and to calculate the FTE reduction by changing the layout. The average travel time of personnel per square meter and PWU can be used as an operational efficiency indicator in the STREAMER project. The indicator meets the STREAMER inclusion criteria. There is an existing calculation method, only distances (horizontal and vertical) and frequencies of selected staff routes are needed as input, of which the distances can be retrieved from BIM information. Moreover, the method can be applied once the mass study is available.

Definition

Total daily weighted travel time of personnel (including staff only and patient transport times) per square meter and weighted patient unit.

Calculation method

Determine the routes to include in the analysis. Please be aware that the optimal designs for these routes are calculated. Routes that are not included are out of scope, thus make sure important routes are included based on frequency of use or medical relevance.

Frequent patient transport routes include: Operating department - General nursing/child nursing, Emergency Department - imaging & diagnostics.

Total daily weighted travel time of personnel (TWTT) = V1+V2+…Vn patient transport + V1+V2+…Vn staff only

where

V patient transport = RTT patient transport * F (times 2 when two staff members are needed to transport patients in bed)

V staff only = RTT staff only * F

RTT = (Rt1+ Rt2+ Rt..)/number of routes)

Rt patient transport= distance of route/ 0,85 + height difference * 6,4 + 60 (if ≠0)

Rt staff only = distance of route/ 1,4 + height difference * 6,4 + 60 (if ≠0)

TRTT patient transport = RR1 + RR2+ RR..n patient transport

TRTT staff only = RR1 + RR2+ RR..n staff only

Route

Route is the (shortest) distance to travel from one department to another and is measured from the access to access of a department and in the centre of a corridor.

Route-time (Rt)

The time needed to travel the indicated route. This includes waiting time and use of elevators/stairs. We calculated an average walking speed of 0,85 m/s (3,0 km/h) for patient transport (walking with bed) and 1,4 m/s (5,0 km/h) for staff only. Average waiting time for elevator use is assumed on average 20 seconds, average handling time and entering/leaving on average 40 seconds and average elevator transition time to next floor 6, 4 seconds (based on standards used by elevator suppliers REF).

Relative travel time (RTT)

The average travel time is the average time when multiple routes are possible between departments. If only one route exists the Rt applies.

Total relative travel time (TRTT)

The sum of all RTT's of selected routes.

Frequency (F)

The frequency determines how often the route is used on a daily basis, expressed in total number travels/day.

Weighted travel time (WTT)

This is the product of the frequency of a route and the RTT. The total weighted travel time is the sum of the WTT's of the selected routes.

Units of measurement

- Hours/ M²
- Hours/ WPU

Suggested data sources

- Floor plans
- Estimated daily frequencies of personnel (staff only and patient transport) routes
- Route selection

By including travel time (for staff) efficiency as operational efficiency indicator we point out the connectivity of departments (frequency of distances) and adjacency (distance of routes). It should be noted that the flexibility of the building (whether the building can be easily adapted to future needs) is a relevant indicator for hospital administrations. Focusing on, for instance, the ratio gross/net floor area might provide the incentive to optimize this ratio which may result in less layout options, less possibilities to separate logistics routes and limited flexibility. Although *staff travel time* is included as additional operational efficiency indicator, which may provide an incentive to not only optimize on building efficiency, negative impacts on flexibility should also be taken into account when choosing for different design scenarios. This is however, out of the scope of the STREAMER project as only energy, financial and quality performance indicators were selected.

3.4 Overview of LoD required to calculate KPIs

As have been mentioned in the above sections, some KPIs can be calculated/ estimated rather early in the design process, while others need a more advanced level of detail (LoD). Table 18 summarizes per KPI whether it can be calculated based on information available in the early design (e.g. including the schematic design, bubble diagram) and/ or detailed design (e.g. including the room layout, materialization). "V" indicates that it is possible; "X" indicates that it is not possible with the current calculation method.

KPI	Early design	Detailed design
Energy performance		
1. Energy efficiency	V	V
2. Carbon emission efficiency	V	V
Financial performance		
3. Life cycle costs	V	V
Quality performance		
4. Patient satisfaction	X	V
5. Overall quality	V	V
6. Thermal comfort	X	V
7. Operational efficiency	V	V

3.5 Exploring the relation between KPIs with WP 1's semantic labels

In WP1 semantic labels have been identified to be able to give each room or functional area in a design a distinctive character based on its function. Based on its label, requirements for a room follow (as the label class requirements need to be met) and design options for a room are ruled out. For example, if a room has a high hygiene class label, natural ventilation is not an option. In this way labels provide requirements and design solution boundaries and hence, support the requirement tool and design configurator tool. As an effect, labels help to define KP requirements. For instance, for the room with the high hygiene class label, it could be argued that the energy efficiency KP requirement may be lower compared to a room with a lower hygiene class label and that the LCC KP requirement may be higher. The relation with the Quality KPIs requirements is less evident. In order to link the labels with KP requirements the implication of each label on the KPIs defined, need to be established. By providing this link, labels can fine-tune KP requirements on room level. There is no direct relation between the labels and the calculation of KPIs. KPIs are calculated based on design solutions. As labels support requirement setting and design solution boundary definition, they impact the choice for design solutions. Thus, there is an indirect relation between the labels of WP1 and the calculated KPIs via the design solutions, but no direct link has been identified.

4. Integration of KPIs into the STREAMER ICT tools

4.1 Requirement Tool, Design Configurator, and Calculation Tool

Within the STREAMER project, several tools are used to support the design process of energy-efficient hospitals. These tools are:

- Requirement tools and the design configurator, which are able to support the design team and stakeholders to structure, compose and verify their design needs and possible solutions.
- Calculation tools, covering energy analysis and simulation, lifecycle cost (LCC) and quality/satisfaction. These tools are able to provide an insight into the energy, financial and quality performance of rooms and/or parts of the building depending on their function and properties.
- Design decision-support tool.

Relation between the KPIs and the Requirement Tool:

In most situations, the KPIs correspond with certain norms or standards regarding hospital design and/or energy efficiency (Nedin, 2014). These norms or standards can be part of the (client) requirement for developing design solutions. For example, the norms for maximum temperature or maximum daylight exposure for certain rooms / facilities. Such norms together with the client requirements can be inserted in a Requirement Tool (e.g. BriefBuilder; see illustration in Figure 8).

Within this concept, the information flow starts with the conceptualization of a Programme of Requirement (PoR) by the hospital (The hospital can be supported by consultants/experts, depending on the required level of complexity and expert knowledge). These ideas about room size, comfort requirements, energy profiles, materialization, furniture, etc. are structured and formalized by using a requirements tool (Koster et al, 2015).

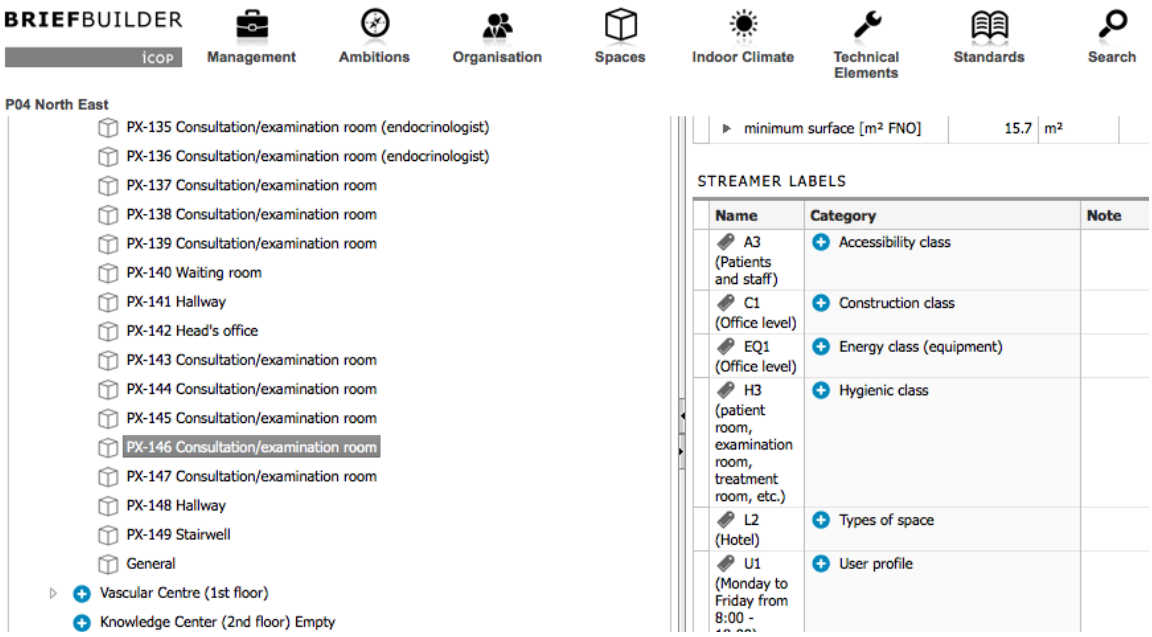


Figure 7. Illustration of the Requirement Tool- BriefBuilder

The requirements serve as input for the Design Configurator. The Design Configurator will select, compose and configure a set of possible design solutions that meet these requirements.

The performance of these design solutions will be measured, partly against the KPIs. The calculation of the KPI values of each design solution will be done by the selected calculation tools (especially in terms of energy performance and lifecycle cost). Within the STREAMER project, it has been decided not to depend on a single energy calculation tool. Various stakeholders within the project consortium deploy various tools (Hilaire, 2015). The interfacing solution intends to facilitate these tools within the STREAMER design decision-making process.

The overview of the inter-relationship is shown in the scheme below (Figure 8).

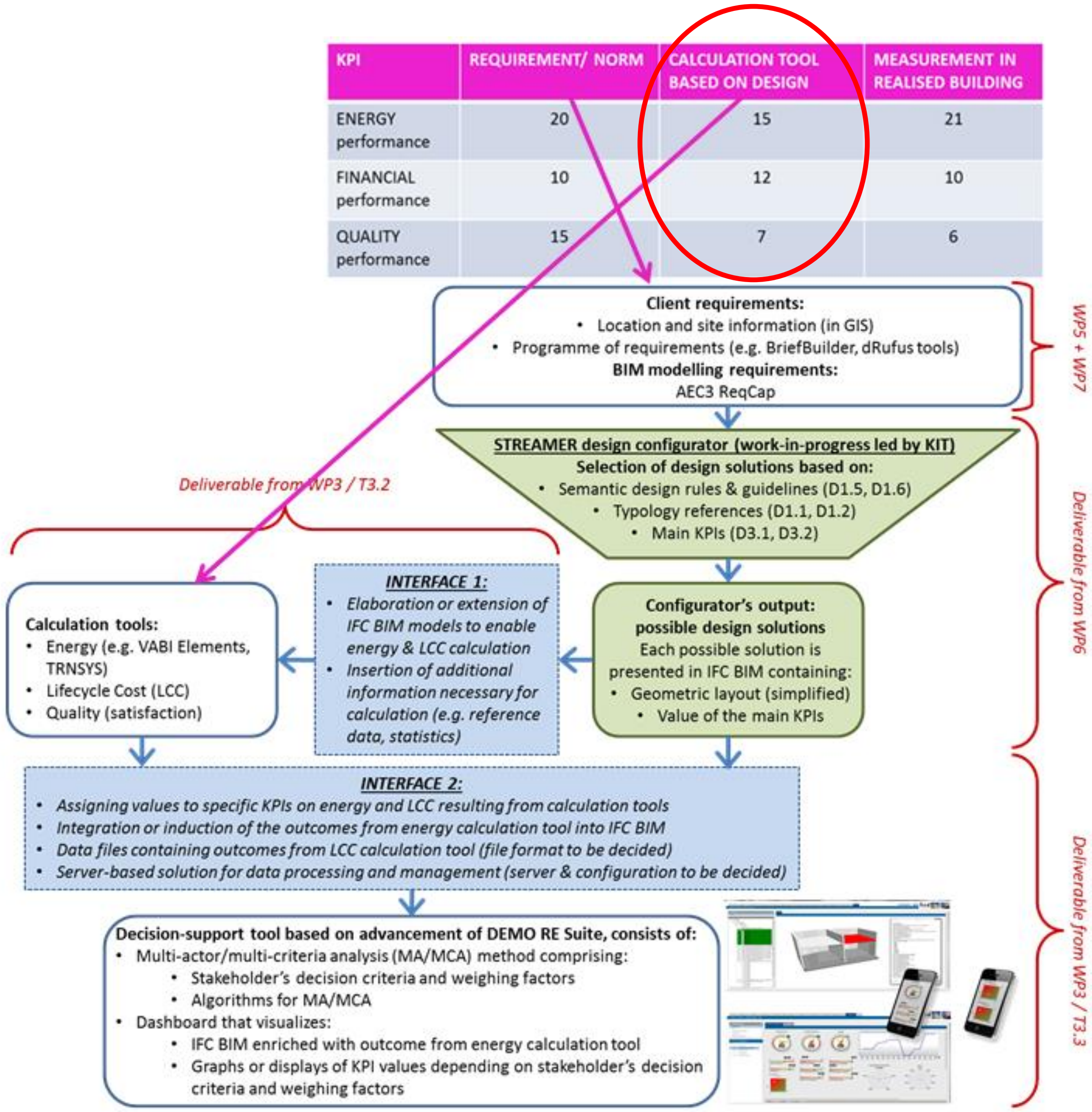


Figure 8. Schematic representation of the relations between KPIs, Requirements, Design Configurator and Calculation Tools

4.2 Design Decision-Support Tool

The design decision-support tool (which will later be delivered in deliverable D3.6) uses Multi-Criteria Analysis (MCA) techniques, which are suitable to cope with the STREAMER design complexity. The main component to present information to the end-users or decision-makers is a Dashboard. The STREAMER decision-support tool is based on enhancement of the existing RE Suite tool developed by DMO (Delft et al, 2015).

The analytical / computational module within the decision-support tool is based on Multi Criteria Analysis (MCA). Within this MCA, the Key Performance Indicators (KPIs) can be inserted along with the inclusion of certain weighing factors. Different indicators can be combined according to a certain formula to enable multiple decision criteria. An example of this technique can be illustrated using an example from the previous project (Sebastian et al., 2013); see Figure 9.

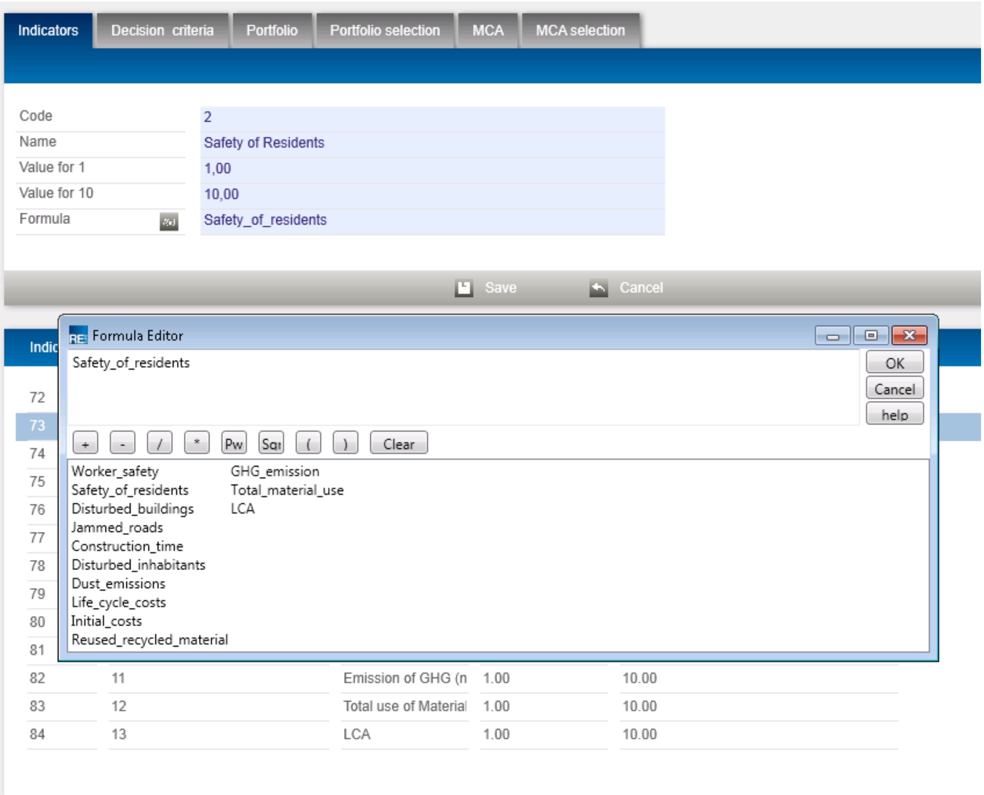


Figure 9. Illustration [example from previous project] of how indicators are defined and inserted through the Formula Editor

For each design option, an analysis of the KPIs can be performed. Comparison between several design scenarios based on a coherent set of KPIs can also be processed. The analysis results can be presented in a 3D diagram. The user can customize the graphic representation. The MCA allows the user of the decision-support tool to select a maximum of 10 criteria that will be analyzed and presented in a Spider diagram. The user can also customize the representation in the Spider diagram (see example in Figure 10).

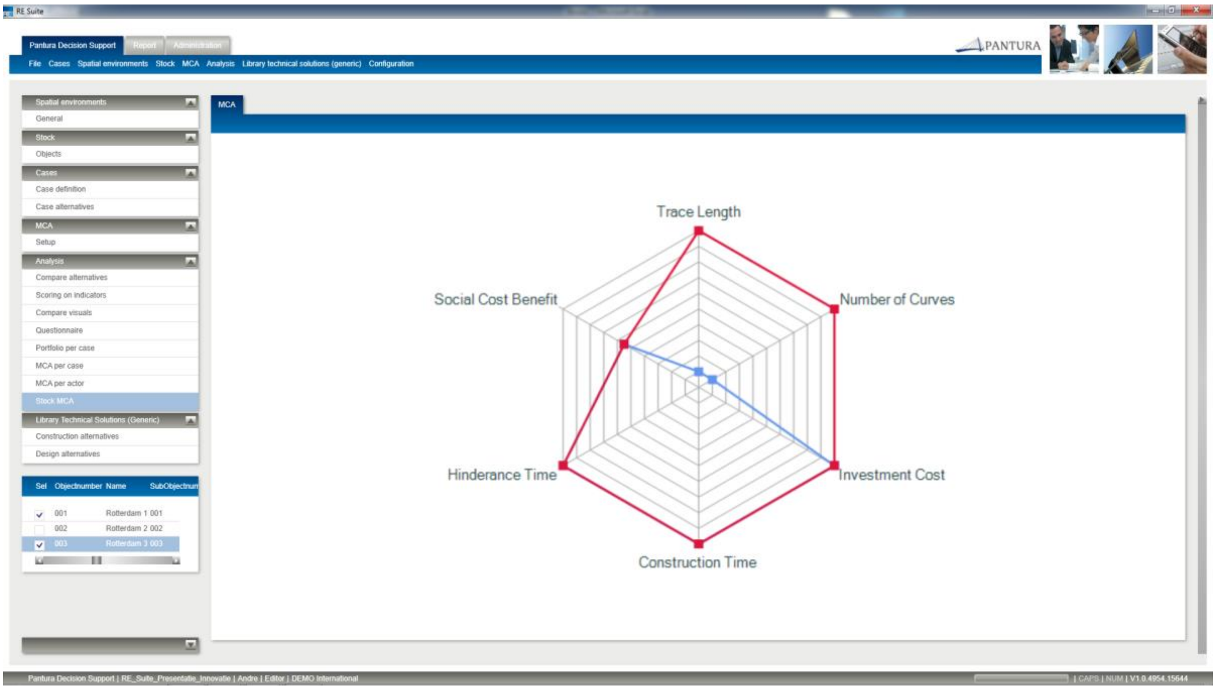


Figure 10. Illustration [example from previous project] of spider diagram visualizing the calculation output of the KPIs

Performance comparison between several design options, based on the calculation outcomes of the KPIs, can be presented in stack chars where the decision criteria and weighing factors are also displayed. The design team or stakeholder can adjust the criteria and weighing factors. The results are displayed interactively (see example in Figure 11).

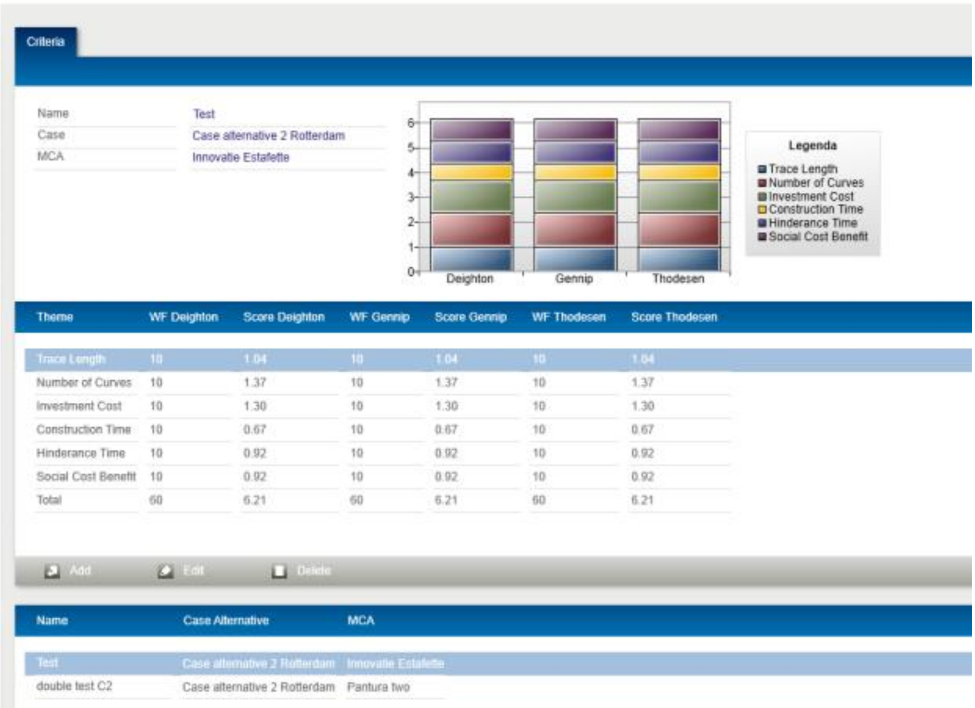


Figure 11. Illustration [example from previous project] of stack charts showing comparison of several design scenarios and possible adjustment of decision criteria and weighing factors

KPIs can be presented in various graphical forms on a dashboard. If there is only one KPI, it can be displayed as a traffic light or a fuel gauge (one dimension). When two KPIs are related to each other they can be displayed in an X/Y diagram. For a multi-criteria analysis a group of KPIs can be displayed as a spider diagram. Functionality will be added to the RE Suite (the existing software tool by DMO) to create dashboards and add dashboard elements to them (traffic light, X/Y diagrams and spider diagrams). These elements can be dragged onto the dashboard from a toolbar (right expandable panel, and be positioned by the user. By clicking the right mouse button on the dashboard element, the user can configure the KPIs to be displayed on the dashboard element. The dashboard can be configured to be automatically refreshed at desired intervals, for instance one hour (see example in Figure 12).

Figure 12: Illustration [example from previous project] of a dashboard showing the KPIs and calculation results on desktop and mobile applications

In conclusion, the decision-support tool and the mechanism to integrate KPIs (based on MCA techniques and algorithms) are available based on a state-of-the-art software solution by DMO. In the STREAMER project, this existing software will be enhanced. The required information elements, indicators, KPIs and reports will be analyzed and defined in collaborative research, and subsequently configured by DMO. This will be done in order to have a basic set of KPIs, dashboards and reports available. These can then be configured and fine-tuned by the end-users.

4.3 Exploring the relation between KPIs with WP1 semantic labels

In WP1 semantic labels have been identified to be able to give each room or functional area in a design a distinctive character based on its function. Based on its label, requirements for a room follow (as the label class requirements need to be met) and design options for a room are ruled out. For example, if a room has a high hygiene class label, natural ventilation is not an option. In this way labels provide requirements and design solution boundaries and hence, support the requirement tool and design configurator tool. As an effect, labels help to define KP requirements. For instance, for the room with the high hygiene class label, it could be argued that the energy efficiency KP requirement may be lower compared to a room with a lower hygiene class label and that the LCC KP requirement may be higher. The relation with the Quality KPIs requirements is less evident. In order to link the labels with KP requirements the implication of each label on the KPIs defined, need to be established. By providing this link, labels can fine-tune KP requirements on room level. There is no direct relation between the labels and the calculation of KPIs. KPIs are calculated based on design solutions. As labels support requirement setting and design solution boundary definition, they impact the choice for design solutions. Thus, there is an indirect relation between the labels of WP1 and the calculated KPIs via the design solutions, but no direct link has been identified.

5. Conclusions

The aim of Deliverable 3.2 was to identify indicative performance indicators and corresponding calculation methods to which management decisions can be weighed against, when designing energy efficient healthcare buildings. As a result of focusing on energy performance in our research *–being the prime consideration for the STREAMER project* - and applying various selection criteria on the long-list of KPIs developed previously in D3.1, the following seven performance indicators (categorized under Energy, Financial, and Quality performance), were operationalized:

Energy performance:

8. Energy efficiency
9. Carbon emission efficiency

Financial performance:

10. Life cycle costs

Quality performance:

11. Patient satisfaction
12. Overall quality
13. Thermal comfort
14. Operational efficiency (building efficiency and travel time efficiency)

The performance indicators are sensitive not only to building-oriented, but also to process-oriented factors. Calculation methods (or the way to calculate the performance of these indicators) based on the information available at an early stage of the design, were developed and tested at expert level. Subsequently, the resulting calculation measurements were validated, through a feasibility test in two case studies within STREAMER: the Rijnstate Hospital in the Netherlands and Careggi Hospital in Italy.

The validated set of KPIs and calculation methods will be further used for integration into the decision-support tool developed in D3.6 (due at M36). This tool should be able to calculate and visualize the performance of different design scenarios supporting management to take a weighted decision based on the energy, financial and quality performance of the design.

In exploring the links with the semantic labels of WP 1, it appeared that these labels seem supportive in KP requirement setting and that there is a clear link with the requirement tool and design configurator tool. Further research is necessary to evaluate the relation between the labels and KP requirements to establish this link. No direct relation between the labels and the KPI calculation was identified, as the KPI's are calculated based on design solutions and not based on requirements. Further research is needed on how the design solutions are documented in BIM and how the KPI calculation tools can use this information to calculate the KPIs.

6. References

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Standards and Directives

Energy

EN ISO 52016 - *Energy performance of buildings -- Calculation of the energy needs for heating and cooling, internal temperatures and heating and cooling load in a building or building zone*

EN ISO 520101 - *Energy performance of buildings -- Overarching Assessment Procedures. External environment conditions -- Part 1: Calculation Procedures*

Mandate M480 - *from the EC to CEN for the elaboration and adoption of standards in accordance with the recast EPBD*

EN 12098-3 - *Controls for heating systems. Outside temperature compensated control equipment for electrical heating systems*

EN 12098-5 - *Controls for heating systems. Start-stop schedulers for heating systems*

EN 12831-3 - *Heating systems and water based cooling systems in buildings - Method for calculation of the design heat load Part 3: Domestic hot water systems heat load and characterisation of needs*

EN 15316-4-1 - *Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Space heating generation systems, combustion systems (boilers)*

EN 15316-4-2 - *Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Space heating generation systems, heat pump systems*

EN 15316-4-3 - *Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Heat generation systems, thermal solar systems*

EN 15316-4-4 - *Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Heat generation systems, building-integrated cogeneration systems*

EN 15316-4-5 - *Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Space heating generation systems, the performance and quality of district heating and large volume systems*

EN 15316-4-6 - *Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Heat generation systems, photovoltaic systems*

EN 15316-4-7- *Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Space heating generation systems, biomass combustion systems*

EN 15316-4-8 - *Heating systems in buildings. Method for calculation of system energy requirements and system efficiencies. Space heating generation systems, air heating and overhead radiant heating systems*

NEN 2916; 2004 - *Energy performance of non-residential buildings – Determination method*

NEN 7120 + C2; 2011 - *Energy performance of buildings - Determination method*

Financial /LCC

SS-ISO 15686-5:2008- *Buildings and constructed assets -- Service-life planning -- Part 5: Life-cycle costing*

Quality

EN15251 -*Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.*

ISO7730 - Ergonomics *of the thermal environment- Analytical determinations and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.*

ASHRAE 55 - *Thermal Environmental Conditions for Human Occupancy*

prEN 15265 - *Thermal performance of buildings – Calculation of energy use for space heating and cooling – General criteria and validation procedures*

prEN 15255 - *Thermal performance of buildings – Sensible room cooling load calculation – General criteria and validation procedures*

NEN 2850 – *Dutch Norms with definitions and methods to determine spatial characteristics of buildings and areas.*

APPENDIX 1

Selected STREAMER KPIs

PROPOSED performance categories in D3.1	DEFINED KPIs in D3.1 Long list	Selected KPI in D3.2 Short list
ENERGY PERFORMANCE AND EFFICIENCY	✓ Reduced primary energy and carbon emission ✓ Energy and carbon targets within country regulations ✓ Energy and carbon targets within EU regulations ✓ Energy and carbon targets developed as industry benchmarks ✓ Energy and carbon targets developed through international best practice ✓ Passive system integration ✓ Active system integration ✓ Use of renewable technology ✓ Resilience risk considered and managed	✓ Energy efficiency ✓ Carbon emission efficiency
FINANCIAL ANALYSIS BASED ON WHOLE LIFE COSTING	✓ Whole life costing methodology	✓ Life cycle cost
QUALITY OF THE ENVIRONMENT AND OPERATIONAL EFFICIENCY	✓ Staff satisfaction ✓ Patient satisfaction ✓ Visitor satisfaction ✓ Connectivity, adjacency, access and flexibility ✓ Improved clinical outcomes ✓ Safety and security	✓ Thermal comfort ✓ Patient satisfaction ✓ Overall quality ✓ Operational efficiency

APPENDIX 2

Input sheet patient room

Characteristic	Specification	Unit of measurement
Number of bed in room		#
Length of the room		m
Width of the room		m
Surface room		m2
Ration surface room/number of beds		%
Ceiling height		cm
Window available		1 yes/ 0 no
(part of) the façade can be opened		1 yes/ 0 no
Patient can open window from bed		1 yes/ 0 no
Several window positions possible		1 yes/ 0 no
Accessibility and heaviness to control window		(0=good accessibility and control, 0.5=heavy to control and good accessibility or easy to control and poor accessibility, 1= heavy to control and poor accessibility)
Glare caused by daylight and reflection can be prevented or controlled		1 yes/ 0 no
Patient can control glare from bed		1 yes/ 0 no
Inside view from other buildings is possible; standing		1 yes/ 0 no
Inside view from other buildings is possible: in bed		1 yes/ 0 no
Distance to nearest building with possible views inside room; standing		in meters, standing for window
Distance to nearest building with possible views inside room, from bed position		in meters, from bed position
Views from other building sections can be controlled		1 yes/ 0 no
Views from other building sections can be controlled from bedside		1 yes/ 0 no
Width of the façade opening		m
Height of the façade opening		m
Surface of the façade opening		m
Surface façade opening/surface room		%
Height of the parapet		m
View from bed	Green	%

Characteristic	Specification	Unit of measurement
	Good looking buildings	%
	Poor looking buildings	%
	Sky	%
	View traffic outside	1 yes/ 0 no
	View on people outside	1 yes/ 0 no
	View on activities outside	1 yes/ 0 no
View standing	Green	%
	Good looking buildings	%
	Poor looking buildings	%
	Sky	%
	View on traffic outside	1 yes/ 0 no
	View on people outside	1 yes/ 0 no
	View on activities outside	1 yes/ 0 no
View on corridor		%
View on activities (for example, game area, coffee corner)		1 yes/ 0 no
Distance from room door to reception		m
Distance from door to lounge at the reception (door to door)		m
Door between the corridor and room can remain completely open		1 yes/ 0 no
Door between the corridor and room can remain partially open		1 yes/ 0 no
Even if door is closed, visual contact is possible		1 yes/ 0 no
Views into room from the public (traffic) space is possible		1 yes/ 0 no
Patient can control the extent of bothering views from corridor		1 yes/ 0 no
Patient can control the extent of bothering views from corridor from bed		1 yes/ 0 no
Art and/or images used/ surface walls		%
theme nature		1 yes/ 0 no
theme people/animals		1 yes/ 0 no
theme city		1 yes/ 0 no
theme abstract		1 yes/ 0 no
Attention paid to decoration ceiling		1 yes/ 0 no
Nature in the room		1 yes/ 0 no
Heating	air heating	1 yes/ 0 no
	floor heating	1 yes/ 0 no
	built-in ceiling	1 yes/ 0 no
	built-in wall	1 yes/ 0 no

Characteristic	Specification	Unit of measurement
	built-in floor	1 yes/ 0 no
	separate unit on wall	1 yes/ 0 no
	separate single unit	1 yes/ 0 no
Amount of mechanical openings in ceiling		#
Amount of mechanical openings above entrance		#
Natural ventilation possible		(0=no/1=yes)
Average temperature	During day summer	C
	During night summer	C
	During day winter	C
	During day winter	C
Patient can control temperature		1 yes/ 0 no
patient can control temperature from bed		1 yes/ 0 no
Amount artificial light	Central lighting	Lx requirement
	Local lighting	Lx requirement
	Bedside lighting	Lx requirement
	Night lights	Lx requirement
Patient can adjust/control light		1 yes/ 0 no
Patient can control light from bed		1 yes/ 0 no
Patient can adjust light levels stepless		1 yes/ 0 no
Patient can alert staff from room using a call system		1 yes/ 0 no
Indirect supervision by staff ensured		1=if door is closed still supervision available (window, camera), 0=no supervision if door is closed
The room is easy to clean		1= fixed interior, 2= not easily movable interior, 3= easily movable interior, 4= interior fixed to the wall, not touching the floor
Floor with rounded corners		1 yes/ 0 no
Availability pin boards		1 yes/ 0 no
Material type floor	Steal	1 yes/ 0 no
	Smooth tiles	1 yes/ 0 no
	Rough tiles	1 yes/ 0 no
	Bare concrete	1 yes/ 0 no
	Concrete with stucco	1 yes/ 0 no
	Bluestone	1 yes/ 0 no
	Bricks	1 yes/ 0 no
	Smooth plastic/synthetic	1 yes/ 0 no
	Plastic with texture	1 yes/ 0 no
	Softboard plates	1 yes/ 0 no
	Natural looking materials	1 yes/ 0 no
	Wood	1 yes/ 0 no

Characteristic	Specification	Unit of measurement
	Carpet, low pile	1 yes/ 0 no
	Carpet, high pile	1 yes/ 0 no
Material type wall	Steal	1 yes/ 0 no
	Concrete	1 yes/ 0 no
	Stucco	1 yes/ 0 no
	Bluestone	1 yes/ 0 no
	Bricks	1 yes/ 0 no
	Smooth plastic/synthetic	1 yes/ 0 no
	Plastic with texture	1 yes/ 0 no
	Soft board plates	1 yes/ 0 no
	Natural looking material	1 yes/ 0 no
	Wood	1 yes/ 0 no
	Wallpaper	1 yes/ 0 no
Material type ceiling	Steal	1 yes/ 0 no
	Concrete	1 yes/ 0 no
	Stucco	1 yes/ 0 no
	Smooth plastic/synthetic	1 yes/ 0 no
	Plastic with texture	1 yes/ 0 no
	Soft board plates	1 yes/ 0 no
	Natural looking material	1 yes/ 0 no
	Wood	1 yes/ 0 no
Interior design	Leather sofa present	1 yes/ 0 no
	Sofa with textile coating present	1 yes/ 0 no
	Chairs available with domestic design, for example fabric cover/textile coating	1 yes/ 0 no
	Folding chairs available	1 yes/ 0 no
	Blinds with solid colour	1 yes/ 0 no
	Blinds with patterns	1 yes/ 0 no
	Blinds with patterns on both sides (inside-and outside of the blind)	1 yes/ 0 no
	Blankets with solid colour	1 yes/ 0 no
	Blankets with patterns	1 yes/ 0 no
	Smooth blankets	1 yes/ 0 no
	Blankets with texture	1 yes/ 0 no
	Interior at least 10 years old	1 yes/ 0 no
Colour of the floor	Red	%
	Orange	%
	Yellow	%
	Green	%
	Blue	%
	Indigo	%
	Violet	%
	Black	%

Characteristic	Specification	Unit of measurement
	Grey	%
	White	%
	Ground colours	%
Colour of the walls	Red	%
	Orange	%
	Yellow	%
	Green	%
	Blue	%
	Indigo	%
	Violet	%
	Black	%
	Grey	%
	White	%
	Ground colours	%
Colour of ceiling	Red	%
	Orange	%
	Yellow	%
	Green	%
	Blue	%
	Indigo	%
	Violet	%
	Black	%
	Grey	%
	White	%
	Ground colours	%
Number of colours floor		#
Number of colours wall		#
Number of colours ceiling		#
Pattern present floor		1 yes/ 0 no
Different colour intensities present floor		1 yes/ 0 no
Patterns present wall		1 yes/ 0 no
Different colour intensities presented on wall		1 yes/ 0 no
Patient may have telephone		1 yes/ 0 no
Patient may have (wireless) internet		1 yes/ 0 no
Patient can place personal stuff		1 yes/ 0 no
Patient can hang personal stuff		1 yes/ 0 no
Availability of closet		1 yes/ 0 no
	Closet in room	1 yes/ 0 no
	Individual closet	1 yes/ 0 no
	Door in closet	1 yes/ 0 no
	Lock on door closet	1 yes/ 0 no

Characteristic	Specification	Unit of measurement
	Closet volume	m3
Family/friends can stay the night		1 yes/ 0 no
	in the room of the patient	1 yes/ 0 no
	at the ward of the patient	1 yes/ 0 no
	Elsewhere in the hospital	1 yes/ 0 no
Number of seats available for visit		#
Number of folded folding chairs for visitors		#

Input sheet outpatient clinic

Characteristic	Specification	Unit of measurement
Hospital		
Floor level		
Outpatient clinic waiting room		
Daylight	Direct access	1 yes/ 0 no
	Indirect access	1 yes/ 0 no
	No access	1 yes/ 0 no
Location window	Facade	1 yes/ 0 no
	Roof	1 yes/ 0 no
Windows wall 1	width	cm
	height	cm
	amount	#
	distance between windows	cm
Windows wall 2	width	cm
	height	cm
	amount	#
	distance between windows	cm
Windows wall 3	width	cm
	height	cm
	amount	#
	distance between windows	cm
Windows wall 4	width	cm
	height	cm
	amount	#
	distance between windows	cm
Windows roof	width	cm
	height	cm
	amount	#
	distance between windows	cm
Total window surface walls	Width	cm
	height	cm
	average amount	#
	total m2	m²
Total window surface roof	width	cm
	height	cm
	average amount	#
	total m2	m²
Daylight	Ratio daylight/ floor surface	%
Blinds	None	1 yes/ 0 no

Characteristic	Specification	Unit of measurement
	Screens inside	1 yes/ 0 no
	Blinds outside	1 yes/ 0 no
	Fall out sun blinds	1 yes/ 0 no
	Blinded windows	1 yes/ 0 no
	Shadowing by nature	1 yes/ 0 no
	Otherwise	1 yes/ 0 no
	Controllable	1 yes/ 0 no
	Height parapet	m
	Indoor balcony	1 yes/ 0 no
Artificial light waiting area	Sitting areas A (lounge sofa)	Lx (requirement)
	Sitting areas B (lounge chairs)	Lx (requirement)
	Sitting areas C (chained chairs)	Lx (requirement)
	Sitting areas D (chairs around table)	Lx (requirement)
	Sitting areas E (different setting)	Lx (requirement)
	Average waiting room	Lx (requirement)
Armature	Ceiling direct	1 yes/ 0 no
	Ceiling indirect	1 yes/ 0 no
	Pendant	1 yes/ 0 no
	Wall direct	1 yes/ 0 no
	Wall indirect	1 yes/ 0 no
	Standing	1 yes/ 0 no
Controllable	on/off	1 yes/ 0 no
	Dimmer	1 yes/ 0 no
Function	Functional lights	#
	Atmospheric lights	#
	Atmospheric/functional lights ratio	%
Temperature	Requirement average	C
Type	Ventilation ducts	1 yes/ 0 no
	Radiators	1 yes/ 0 no
	Floor heating	1 yes/ 0 no
	Otherwise	1 yes/ 0 no
Acoustics	Requirement waiting area	dB(A)
	Requirement registration area	dB(A)
Air	Windows can be opened	1 yes/ 0 no
Privacy	Secluded from other visitors corridor	1 yes/ 0 no
	Waiting area is main corridor	1 yes/ 0 no
	Shielded corridor back office	1 yes/ 0 no
	Bothering views from other buildings	1 yes/ 0 no
	Bothering views from other areas	1 yes/ 0 no
Shielding desk	Visual	1 yes/ 0 no
	Acoustic	1 yes/ 0 no

Characteristic	Specification	Unit of measurement
	Non	1 yes/ 0 no
Distance from person to person	A opposite	m
	A next to	m
	B opposite	m
	B next to	m
	C opposite	m
	C next to	m
	D opposite	m
	D next to	m
	E opposite	m
	E next to	m
	Average opposite to each other	m
	Average next to each other	m
Seating position A (Lounge sofa)	number	#
	seat height	cm
	Height handrail	cm
	Height backrest	cm
	Total seating surface	m²
	Adjustable	1 yes/ 0 no
Seating position B (Lounge chairs)	number	#
	seat height	cm
	Height handrail	cm
	Height backrest	cm
	Total seating surface	m²
	Adjustable	1 yes/ 0 no
Seating position C (Chained chairs)	number	#
	seat height	cm
	Height handrail	cm
	Height backrest	cm
	Total seating surface	m²
	Adjustable	1 yes/ 0 no
Seating position D (Chairs around table)	number	#
	seat height	cm
	Height handrail	cm
	Height backrest	cm
	Total seating surface	m²
	Adjustable	1 yes/ 0 no
Seating position E (Different setting)	number	#
	seat height	cm
	Height handrail	cm
	Height backrest	cm

Characteristic	Specification	Unit of measurement
	Total seating surface	m²
	Adjustable	1 yes/ 0 no
Total seating positions	Total #	#
	Average seat height	cm
	Average height handrail	cm
	Average height backrest	cm
	Average m2	m²
	Average adjustable	1 yes/ 0 no
Ratio seating area/floor area	seating area m2 /flooring m2	%
Seating possibility	Along wall/glass	1 yes/ 0 no
	In the area in groups	1 yes/ 0 no
	Separately	1 yes/ 0 no
	Otherwise	1 yes/ 0 no
Wall decoration	Number	#
	Nature theme	1 yes/ 0 no
	Size decoration	m2
	Size walls	m2
	Ratio decoration/wall surface	%
Other decoration	Plants	#
	Statues	1 yes/ 0 no
	Other	#
	TV	#
	Indication waiting time	#
	Visible from all seats (1/0)	1 yes/ 0 no
Waiting Area	surface	m2
Shape	Rectangle	1 yes/ 0 no
	Square	1 yes/ 0 no
	L-shape	1 yes/ 0 no
	T-shape	1 yes/ 0 no
	Z-shape	1 yes/ 0 no
Height	waiting area	m
	corridor	m
Flooring type	Linoleum / marmoleum	1 yes/ 0 no
	Tiles	1 yes/ 0 no
	Carpet	1 yes/ 0 no
	Wood	1 yes/ 0 no
Wall finishing	Stucco, wallpaper	1 yes/ 0 no
	Photo wallpaper	1 yes/ 0 no
	Glass (steel or stainless steel)	1 yes/ 0 no
	Wood	1 yes/ 0 no
Ceiling	System	1 yes/ 0 no

Characteristic	Specification	Unit of measurement
	Absorbent	1 yes/ 0 no
Material seat	Leather	1 yes/ 0 no
	Fabric	1 yes/ 0 no
	Plastic/synthetic	1 yes/ 0 no
	Wood	1 yes/ 0 no
Material backrest	Leather	1 yes/ 0 no
	Fabric	1 yes/ 0 no
	Plastic/synthetic	1 yes/ 0 no
	Wood	1 yes/ 0 no
	Metal	1 yes/ 0 no
Toilet		1 yes/ 0 no
Disabled toilet		1 yes/ 0 no
Routing	Distance waiting area- treatment aream	m
	Distance registration vs seat	m
	Distance seat vs toilet	m
	Distance reception desk- entrance outpatient clinic	m
Way finding Type	Colour	1 yes/ 0 no
	Number	1 yes/ 0 no
	Naming	1 yes/ 0 no
	Picture	1 yes/ 0 no
	Otherwise	1 yes/ 0 no
Accessibility	Wheelchair friendly	1 yes/ 0 no
	pedestal zones without ramp	1 yes/ 0 no
	Furniture close to each other	1 yes/ 0 no
	Doors close automatically (closers)	1 yes/ 0 no
	Desk it too high for wheelchair users	1 yes/ 0 no
	Otherwise	1 yes/ 0 no
Colour Furniture	Green	%
	Brown	%
	Yellow	%
	Red	%
	Blue	%
	Grey	%
	White	%
	Black	%
	Orange	%
	Purple	%
	Number of colours	#
Colour Ceiling	Green	%
	Brown	%

Characteristic	Specification	Unit of measurement
	Yellow	%
	Red	%
	Blue	%
	Grey	%
	White	%
	Black	%
	Orange	%
	Purple	%
	Number of colours	#
Colour Floor	Green	%
	Brown	%
	Yellow	%
	Red	%
	Blue	%
	Grey	%
	White	%
	Black	%
	Orange	%
	Purple	%
	Number of colours	#
Colour Wall	Green	%
	Brown	%
	Yellow	%
	Red	%
	Blue	%
	Grey	%
	White	%
	Black	%
	Orange	%
	Purple	%
	Number of colours	#
View standing	Nature	1 yes/ 0 no
	Urban	1 yes/ 0 no
View sitting	Nature	1 yes/ 0 no
	Urban	1 yes/ 0 no
Distance buildings in view		m
Registration		
Registration process	Digital Column	#
	Registration desk	#
	No registration	1 yes/ 0 no
Way of being informed	oral	1 yes/ 0 no

Characteristic	Specification	Unit of measurement
	written	1 yes/ 0 no
	digital	1 yes/ 0 no
	not informed	1 yes/ 0 no

APPENDIX 3

Expert and end-user verification results

Experts verification	Energy: BEQ, DWA	Finance/ Quality: NCC, DJGA, AOUC
Are the calculation methods well defined?	<u>*Suggestions:*</u> - use an extra tool in the pre-design phase to calculate the energy on room level (VABI and TRNSYS do not support that yet); - Problem posed by the different energy calculation software used in STREAMER; use of different algorithms; - Define the mandatory requirements that should be met by the chosen software. - Enhance link to WP1 labels (on calculation energy demand)	- Overall calculation methods well defined
Are the formulas correct?	- Overall formula's well defined	- Elaboration of the calculation formula's
Is it feasible to use this quantifying method?	- Need for additional information in the pre-design stage for detailed calculation (end-use; expected consumption range; thermal exchange; pollutant country specific emissions; sanitary requirements, etc.)	No remark
What are other existing methods?	No remark	- Life Cycle Cost: LCC tool from NCC.
What are the suggested sources (for data collection)?	No remark	- Use of floor and technical plans

KPIs	BEQ, DWA	NCC, DJGA, AOUC
Energy efficiency	No remark	- Medical equipment uses much less energy and ventilation more
Carbon emission efficiency	No remark	No remark
Life cycle costs and annual costs	No remark	No remark
Patient satisfaction	No remark	No remark
Overall quality	No remark	No remark
Thermal comfort	- comfort can be better predicted in a later stage of the building process	- Thermal comfort methods only applicable in late design stage
Operational efficiency (building efficiency and travel time efficiency)	No remark	- Operational efficiency: m^2 vs. m^3 - Recommended to use the floor and technical plans of the hospital design

End-User verification KPIs	Careggi hospital	Rijnstate hospital
Energy efficiency	Data available	- Data available based on the labels differentiation - Seems only relevant for mid-life renovation - Energy generation, water pomp, solars, etc.
Carbon emission efficiency	Could be made available	- No remark
Life cycle costs	- LCC based on floor area (m^2). - LCC TNO calculation method largely applicable San Luca Compound: the gross/net floor area – divided into the four layers - is easily achievable whereas obtaining the basic prices seems to be more complicated (in terms of time-consuming rather than availability of data).	- Difficulty in using the TNO LCC tool when connecting the costs for building extension - If data is available seems only relevant for mid-life renovation

Patient satisfaction	- No remark	- No remark
Overall quality	Data available (different calculation method)	Data available - Seems only relevant for new building project (North East wing)
Thermal comfort	- No remark	- No remark
Operational efficiency (building efficiency and travel time efficiency)	- measures of the routes are easily extractable because the model of the three buildings is already geo-referenced; the definition of the routes to be included in the analysis is harder but possible. - frequency is harder to be defined however a possible estimation can be made.	- Data available, only relevant for new building project (North East wing) - Term operational efficiency a bit unclear, suggestion to split into building efficiency and travel time efficiency)

As the user verification shows there were some concerns about the application of the KPIs in refurbishment projects compared to new buildings. All KPIs can be applied in both type of projects, which is more clearly addressed in the deliverable. To sum up, there was no opposition for the proposed KPIs and the corresponding calculation methods from both the experts and the hospitals. In addition, the methodology had been found compliant to the European Norms, and therefore, the approach can be adopted in different European countries. In order to validate the KPIs at a later moment in the project, data is available and the use cases are willing to provide this for possible calculations.