Streamer
European research on energy-efficient healthcare districts

D1.3

Mapping of energy-related problems and potential optimisation

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Mapping of energy-related problems and potential optimisation

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Colophon

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Abstract

The scope of Deliverable D1.3 is the identification of key problems areas and need for modernization related to typologies of existing healthcare districts. It should provide a model-based analysis of the potential optimization and comparative analysis to the standard design guideline.
Therefore, the core concept of this deliverable is to define a method that collects the energy related problems mapped and provide data useful for the implementation of retrofit solutions to be adopted.

The approach we follow in this deliverable is to look at both the demand side and supply side of energy. We see the hospital building (and its resulting energy use) as an answer between the organizational need for activities, within a specific set of boundary conditions and the solution in the form of a building that helps to resolve these demands.

In this deliverable we will first explore on a more detailed level the demand profiles (activity and building based energy analysis) to determine where we can make the best effort in realizing a significant energy reduction. Then, a method is described by which energy efficient retrofit solutions can be selected for specific situations in hospitals. The format for a matrix is suggested in which expert knowledge about energy consumption, label properties of BIM elements, and energy aspects is captured.

Publishable executive summary

Looking at the major trends for hospitals, where we can determine three distinct drivers that possibly influence the demand for (more) energy.

1. More intense usage of spaces (more treatments per bed during prolonged periods of the day) -> impact on electricity use;
2. An increased demand for comfort (from partially air-conditioned to fully air-conditioned buildings, impacts specifically on ventilation);
3. More intense diagnostic & treatment possibilities and demands for these heavier treatments in hospitals (as lighter cases are treated at other places) -> expected impact on electricity use

These trends are more or less universal in Europe. Indeed, resembling patterns of energy consumption can be found throughout a wide variation of building typologies, of all ages.
According to that, it is crucial to identify the patterns STREAMER should focus on in order to implement successful interventions.

The scope of Deliverable D1.3 is the identification of key problem areas and need for modernization related to typologies of existing healthcare districts. It should provide a model-based analysis of the potential optimization and comparative analysis to the standard design guideline.
Therefore, the core concept of this deliverable is to define a methodology to identify the aspects that are the most energy consuming, so with the maximum potential for EE improvement in the context of hospital activities, and to map this demand with potential supply of MEP systems. The labels are used to realize this mapping. The building envelope has been approached differently, because those building components are not easily linkable to labels. Control mechanisms are not considered.

A first step is to map where energy is used and how different aspects, such as hospital activities, building typologies and HVAC/MEP design influence the energy demand. This will help to map areas or aspects for improvement. Therefore the aim of this analysis is to find out which aspects are most likely to influence energy demand and to identify the main energy consumptive factors.
According to that, it is possible to define focus areas on which more effort could be put in order to achieve a 50% reduction in energy demand according to the STREAMER objectives.
Therefore, we first explore the demand profiles (activity and building based energy analysis) on a more detailed level to determine where we can make the best effort in realizing a significant energy reduction.

The activity-based analysis has been conducted through the results of a Swedish project called the STIL2-project, measurement data has been collected from as much as 159 health care premises. Unfortunately, the big amount of measured data needed to answer the question is not easily available in the EU countries.
The results from the STIL2 project show how electricity is being used and how much is used for lighting, for ventilation and for electrical equipment etc. Based on measurements of annual energy use in 159

healthcare premises in Sweden, ventilation and lighting are the largest users of electricity in healthcare premises, also in hospitals and larger medical centers with electricity-demanding clinical equipment. The highest share of the total electricity consumption was used in fans in the ventilation system (35 %); also electricity for lighting corresponded to a high share (26 % of total electricity) of the total electricity use.
According to this, there is potential for large energy savings for ventilation by adjusting operating times to suit occupancy times, by adjusting air flow rates to actual needs and by changing to more efficient ventilation units, while there is large potential for energy savings for lighting by turning it on only when it's needed and by replacing conventional lighting technologies with more efficient lighting technologies.

Results from Swedish hospitals, large medical centres and other healthcare facilities show that medical equipment only corresponds to 6 % of the electricity used (for other purposes than heating), of which X-ray equipment constituted the largest user. For nursing homes for elderly, rehab centres and similar facilities, the medical equipment only corresponds 0.2 % of total electricity use.

Afterwards, the building based analysis has been conducted. The aim was to define how the building typology influences the energy demand of an healthcare building.
The characteristics of compactness, deep and narrow floor plans greatly influence energy consumption.
When the benefits of natural ventilation and daylight are not considered, compactness is an energy-saving characteristic because the less energy loss through the building envelope (including foundation and roof) is limited.
Although less compact, narrow plans allow for energy reduction, when use of daylight and natural ventilation are properly included in the MEP concept. Also, the KPI quality of the environment can be better facilitated by narrow floor plan layout. However, some functional requirements cannot be met by a narrow plan (As pointed out in D1.1, hot floor and industry layers are not easily compatible with the narrow plan layout), so narrow and deep floor plan types will continue to co-exist in hospital design.

Although some general pro’s and cons of various building typologies can be defined from the perspective of energy consumption, there are no clear conclusions to be drawn on the relation between building typology and energy consumption. This is because all typologies can contain both types of floor plan. (Even for the pavilion typology, which because of its historic context solely consists of narrow plans). If a new build hospital were to be designed according to the pavilion typology, some of the buildings would certainly be based on a deep floor plan).

Moreover, this deliverable focuses on retrofitting scenarios. In retrofitting, changing the typological building layout is generally out of scope. Instead, the focus should be on how HVAC systems, functional configuration and building envelope can be reconfigured within the building layout.
However, D1.4 will also describe design rules which will be elaborated starting from the results of the analysis here developed on energy demand profiles (both activity and building based energy analysis) to determine where we can make the best effort in realizing a significant energy reduction.

The key point for the rest of this deliverable is to provide a methodology to reduce the current demand for energy (1) with types of interventions that will help to assist in achieving these reductions in a more efficient way (2).

Indeed, starting from the findings of the analysis above explained, a method is described by which in D1.4 energy efficient retrofit solutions can be selected for specific situations in hospitals. The format for a matrix is suggested in which expert knowledge about energy consumption, label properties of BIM elements, and energy aspects is captured. The content of the matrix however is dependent on other STREAMER deliverables in WP 1, 2 and 7.

By the time we start the follow-up deliverable 1.4, the matrix is expected to be ready for completion and the developed method can be tested on the test cases with the retrofitting experiences in mind.

When analysing existing buildings, it is not only interesting to know which building service uses which energy source (electricity, heat, cold, medical compressed air, as mentioned in chapter 2), but also which area of the hospital requires this energy and in what quantity.

In the STREAMER project, template profiles of label properties have to be made for common functional areas and rooms in a hospital (as described in Deliverable 1.5). The experts within the STREAMER consortium will assign property labels to these functional areas and rooms.

KNOWLEDGE FIELD				energy	energy	energy	energy
	ASPECT			Electricity consumption	Heat consumption	Cold consumption	Medical compressed air consumption
		INSTANCE					
			DESCRIPTION	for ventilation, lighting, equipment, ...			includes Helium, pressurized air, oxygen, CO2, Nitrous oxide, N2
GIS/BIM	functional area	Outpatient department	described in D1.1, page 64-68	low	high	medium	medium
GIS/BIM	functional area	Intensive care ward	described in D1.1, page 64-68	high	medium	medium	high

Fragment of the “inter-aspect schedule”, showing some examples for the relation between functional areas and energy consumption.

GIS/BIM elements related to energy supply contain various MEP systems (instances), which are also called Building services Systems (aspect). Some examples of MEP systems are: natural ventilation, low temperature floor heating, medical gases distribution system, etc. By creating energy consumption profiles for these systems, it is possible to filter the systems that consume the most energy for every energy aspect.

KNOWLEDGE FIELD				energy	energy	energy	energy
	ASPECT			Electricity consumption	Heat consumption	Cold consumption	Medical compressed air consumption
		INSTANCE					
			DESCRIPTION	for ventilation, lighting, equipment, ...			includes Helium, pressurized air, oxygen, CO2, Nitrous oxide, N2
GIS/BIM	building services system (ventilation)	natural ventilation system with VAV mechanical ventilation backup	Ventilation systems (Uniclass2 SS_65_40)	low	no relation	no relation	no relation
GIS/BIM	building services system (ventilation)	100% mechanical ventilation system; Variable Air Volume	Ventilation systems (Uniclass2 SS_65_40)	medium	no relation	no relation	no relation
GIS/BIM	building services system (ventilation)	100% mechanical ventilation system; Constant Air Volume	Ventilation systems (Uniclass2 SS_65_40)	high	no relation	no relation	no relation
GIS/BIM	building services system (heating)	low temperature ceiling heating system	Climatic ceiling and beam systems (Uniclass Ss_60_40_13)	no relation	low	no relation	no relation
GIS/BIM	building services system (heating)	low temperature floor heating system	Heating systems (Uniclass2 SS_60_40_37)	no relation	low	no relation	no relation
GIS/BIM	building services system (heating)	air heating system	Air conditioning systems (Uniclass2 SS_65_80)	no relation	high	no relation	no relation

Fragment of the "inter-aspect schedule", showing some examples for the relation between Building services Systems and energy consumption.

Matching supply and demand is obviously one of the most important aspects of MEP design. As such, it is not new. However, in the STREAMER methodology, information should be available early in the design process. In the deliverable, a methodology is explained in which MEP solutions can be matched with standard design guidelines. Or more specifically; how label-enriched building services systems can be matched with label-enriched rooms and functional areas. The goal is to use energy-efficient MEP solutions to supply the energy demanded by the rooms and functional areas.

To demonstrate the methodology, label values have been assigned to two functional areas (Intensive care and Outpatient department). An impression of how the mapping of label values and spaces looks like in the inter-aspect schedule:

KNOWLEDGE FIELD				expert knowledge	expert knowledge	expert knowledge	expert knowledge	expert knowledge
	ASPECT			Hygienic class	Hygienic class	Hygienic class	Hygienic class	Hygienic class
		INSTANCE		H1	H2	H3	H4	H5
			DESCRIPTION	hygienic requirements related to reception activities	hygienic requirements related to office activities	hygienic requirements related to medical examination and treatment activities	hygienic requirements related to surgical activities	hygienic requirements related to laboratory activities
GIS/BIM	functional area	Outpatient department	described in D1.1, page 64-68	no relation	v	no relation	no relation	no relation
GIS/BIM	functional area	Intensive care ward	described in D1.1, page 64-68	no relation	no relation	no relation	v	no relation

Fragment of the "inter-aspect schedule", showing some examples of label values related to functional areas (demand).

For mapping of supply and demand, the same labelling system should also be used to describe the supply side. In this case, the labels represent the capacities of the building services system.

KNOWLEDGE FIELD				expert knowledge	expert knowledge	expert knowledge	expert knowledge	expert knowledge
	ASPECT			Hygienic class	Hygienic class	Hygienic class	Hygienic class	Hygienic class
		INSTANCE		H1	H2	H3	H4	H5
			DESCRIPTION	hygienic requirements related to reception activities	hygienic requirements related to office activities	hygienic requirements related to medical examination and treatment activities	hygienic requirements related to surgical activities	hygienic requirements related to laboratory activities
GIS/BIM	building services system (ventilation)	natural ventilation system with VAV mechanical ventilation backup	Ventilation systems (Uniclass2 SS_65_40)	v	v	no relation	no relation	no relation
GIS/BIM	building services system (ventilation)	100% mechanical ventilation system; Variable Air Volume	Ventilation systems (Uniclass2 SS_65_40)	v	v	v	v	v
GIS/BIM	building services system (ventilation)	100% mechanical ventilation system; Constant Air Volume	Ventilation systems (Uniclass2 SS_65_40)	v	v	v	v	v

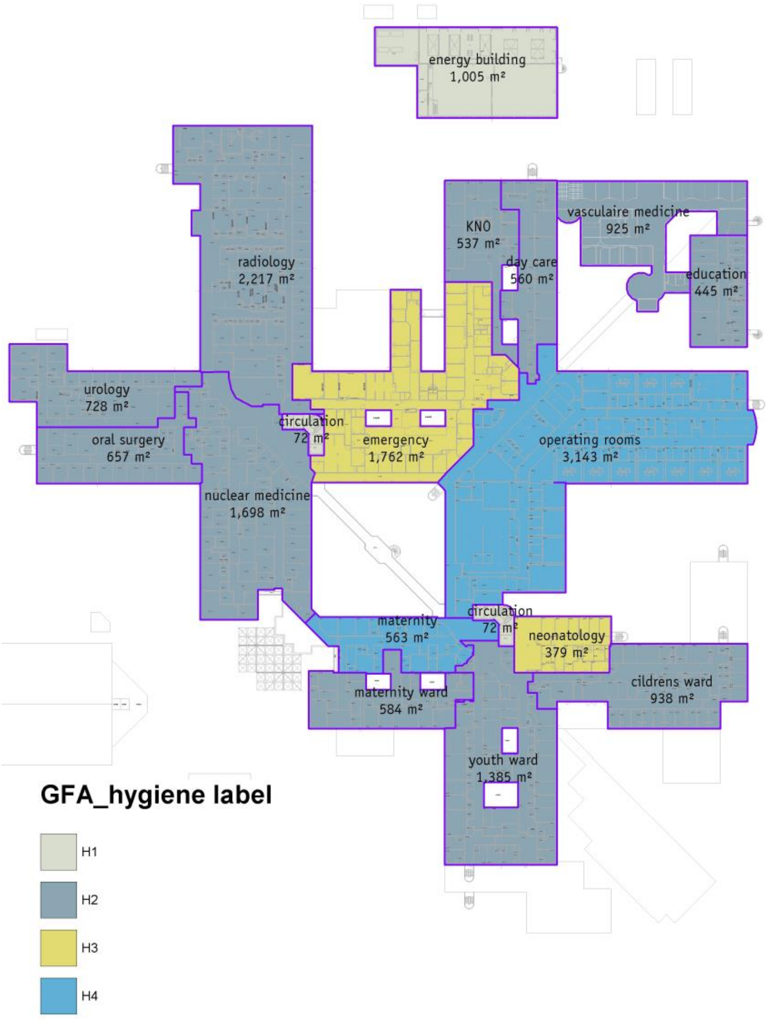
Fragment of the “inter-aspect schedule”, showing some examples of label values related to Building services systems (supply).

Energy systems related to ventilation have a relation with 3 labels: Hygienic class, Indoor Quality and HVAC/Lighting. Natural ventilation is compatible with a limited amount of label values, whereas mechanical ventilation is compatible with all label values.

Looking at these label values on the demand side, it is clear that natural ventilation is only compatible with the Outpatient department, and both mechanical ventilation systems are compatible with both the Outpatient and the Intensive care department.

Obviously, mapping MEP systems to spaces by comparing schedules for every space is far from ideal as a working method. It’s a lot faster to use the visualization possibilities of a BIM.

As the label methodology is based on labels assigned to spaces, a first step for the design team is to create a basic BIM of the hospital designated for retrofit. The BIM should contain at least the functional areas, rooms or both. By following the procedure described above, the functional focus areas can be determined and the semantic labels can be added to the properties of rooms and/or functional areas in at least these focus areas.



Screenshot from Revit depicting a floor plan of the Rijnstate hospital in which the hygiene label properties of a functional area have been assigned specific colors. (GFA = Gross Floor Area)

The model will give insight into the distribution of functions with similar properties, making it easier for the design team to signal inefficiencies, which allows defining the scope of retrofit interventions.

It is possible to define three levels of retrofit intervention, depending on how many of these "aspects" the retrofit intervention involves

1. Retrofit intervention on one level: it involves only the building envelope, <u>or</u> the space layout, <u>or</u> the HVAC systems (e.g. move of a department, replacement of a system, etc.)
2. Retrofit intervention on two levels: the intervention operates on two different aspects among building envelope, space layout, HVAC systems (e.g. implementation of ETICS and replacement of the heating system, etc.)
3. Retrofit intervention on three levels: the intervention involves the building envelope, the space layout and the HVAC systems (e.g. extension of a wing or a floor, etc.)

In the scope of WP1 (D1.4) and WP2 (D2.2 and D2.5) all the possible retrofit scenarios will be defined.

In order to identify real-case scenarios the experiences of the four STREAMER hospitals with energy consumption and retrofitting projects have been reported. In D1.4, this information will be used to describe scenarios supporting the method introduced in Chapter 3, as soon as the matrix had been filled with information from other work packages.
The aim of these descriptions is to report the energy behavior of each hospital according to the building typology and the activity developed and, thus, to describe which retrofit solutions have a proven positive effect on energy consumption.
The analysis starts with the description of the functional layout of activity in relation to the building typology, the definition of the Bouwcollege layers areas and the energy consumption data, identifying also the most energy consuming factors for each case.
Moreover, the advantages and disadvantages of building typology in relation to energy and also the ones independent from the building typology are illustrated.
Then, the STREAMER hospitals provided information about retrofitting solutions (both MEP and architectural) that has proven/would prove positive in relation to energy consumption.

The results of D1.3 will provide inputs for the development of future deliverables.
Within the scope of WP1, the knowledge acquired in D1.3 will be crucial to define deliverable D1.2 and D1.4.
D1.2 aims to define all the parameters related to typology that define the labels which will be attached to BIM objects.

In D1.4 retrofit scenarios for common and generic situations will be developed by following the method described with a matrix in D1.3, Chapter 3. This will allow selecting energy efficient retrofit solutions for specific situation in hospitals, starting from the aspects that need to be retrofitted in priority. A consistent development of the labels and application in all deliverables of WP 1,2 and 3 is crucial for the success of the methodology.

The experiences of the four STREAMER will be used to test the method in order to select energy efficient retrofit solutions for specific situations in hospitals.
Optimization measures will be combined into scenarios, and take into account the most common practical, “real-life”, complexities hospitals face, such as temporary moving, disturbance of the primary process, etc.

D1.4 will also describe design rules which will be elaborated starting from the results of the analysis here developed on energy demand profiles (activity and building based energy analysis) to determine where we can make the best effort in realizing a significant energy reduction.

Moreover, the D2.2 and D2.5 results can be seen as knowledge provider for the methodology developed in D1.3 and the scenarios proposed in D1.4, as they are focusing on possible EeB technological solutions (MEP, layout or envelope) to realize a retrofitting.

List of acronyms and abbreviations

- **AHU:** Air Handler Unit
- **BIM**: Building Information Modeling
- **BMS**: Building Management System
- **CAV**: Constant Air Volume
- **CSSD**: Central Sterile Services Department
- **EeB**: Energy efficient Buildings
- **GIS** : Geographic Information System
- **HD**: Healthcare District
- **HVAC**: Heating, Ventilation, Air Conditioning
- **KPI**: Key Performance Indicator
- **MEP**: Mechanical, Electrical, Plumbing technologies
- **PoR**: Programme of Requirements
- **PV**: Photovoltaic
- **S.A.C.S**: Sistema di Analisi delle Consistenze Strutturali (System for the Analysis of Hospital Equipment)
- **STIL2** : Research into energy consumption in non-residential buildings by the Swedish Energy Agency
- **VAV**: Variable Air Aolume

Definitions

Inter-aspect schedule – (also referred to as "matrix" by some STREAMER partners). The inter-aspect schedule was originally developed in D1.5 and contains expert knowledge in the research fields of energy, GIS/BIM, KPI's, and semantic labels. The inter-aspect schedule has been modified to accommodate the methodology described in this deliverable. Related definitions are:

Research field: topic within STREAMER

Aspect: topic / item within a research field

Instance: subtopic / subitem of an aspect

Label: property attached to spatial component, also called "semantic label"

Semantics: the study of meaning. It focuses on the relation between signifiers, like words, phrases, signs, and symbols, and what they stand for, their denotation". (Source: Wikipedia)

In the STREAMER context, examples of signifiers can be: a wall, a room, a KPI, the concept of natural ventilation etc.

Activity focus area: area of the hospital requires lot of energy and in what quantity.

MEP focus area: the systems that consume the most energy for every energy aspect.

Contents

1. Introduction and scope

Looking at the trends for hospitals we can determine three distinct drivers that possibly influence the demand for (more) energy compared to the office function.

1. More intense usage of spaces (more treatments per bed during prolonged periods of the day) -> impact on electricity use;
2. An increased demand for comfort (from partially air-conditioned to fully air-conditioned buildings, impacts specifically on ventilation);
3. More intense diagnostic & treatment possibilities and demands for these heavier treatments in hospitals (as lighter cases are treated at other places) -> expected impact on electricity use

These trends are more or less universal in Europe. Indeed, resembling patterns of energy consumption can be found throughout a wide variation of building typologies, of all ages.
According to that, it is crucial to identify the patterns STREAMER should focus on in order to implement successful interventions.

According to the DOW, Task 1.2 concerns the mapping of the current problems in healthcare districts, the analysis of optimization potentials and the development of the most effective retrofitting scenarios, focusing on EeB aspects.
The scope of Deliverable D1.3 is the identification of key problems areas and need for modernization related to typologies of existing healthcare districts; model-based analysis of the potential optimization and comparative analysis to the standard design guideline.
Therefore, the core concept of this deliverable is to define a method that collects the energy related problems mapped and provide data useful for the implementation of retrofit solutions to be adopted.

A first step is to map where energy is used and how different aspects, such as hospital activities, building typologies and HVAC/MEP design influence the energy demand. This will help to map areas or aspect for improvement. Therefore the aim of this analysis is to find out which aspects are most likely to influence energy demand and to identify the main energy consumptive factors.
According to that, it is possible to define few focus areas on which more effort could be put in order to achieve a 50% reduction in energy demand according to the STREAMER objectives.

The approach we follow in this deliverable is to look at both the demand side and supply side of energy . We see the hospital building (and its resulting energy use) as an answer between the organizational need for activities, within a specific set of boundary conditions and the solution in the form of a building that helps to resolve these demands.

The sum of the demand profile of a hospital is the made up of:

- the energy demand caused by the activity level;
- the required boundary conditions to perform these activities in.

The sum of the above two will result in a net energy profile (of demand). The gross energy profile is determined by the ability to deliver this net energy profile through the sum of the supply side factors that determine the gross energy profile:

The total energy used is caused by the reaction of the design team:

- The architectural design (layout, orientation, materialization, location and climate zone)
- The HVAC/MEP design and solutions used and the efficiencies of these systems
- Any surplus capacity to enable future flexibility.

In this deliverable we will first explore on a more detailed level the demand profiles (activity and building based energy analysis) to determine where we can make the best effort in realizing a significant energy reduction.

Then, a method is described by which energy efficient retrofit solutions can be selected for specific situations in hospitals. Modifications to the inter-aspect schedule as developed in D1.5 are suggested in which expert knowledge about energy consumption, label properties of BIM elements, and energy aspects is captured. The content of the inter-aspect schedule remains dependent on other STREAMER deliverables in WP 1, 2 and 7. By the time the follow-up deliverable 1.4 is started, the inter-aspect schedule is expected to contain the required data so the developed method can be used on the test cases with the retrofitting experiences in mind.

2. Activity and building-based energy analysis

2.1 Activity based hospital energy consumption

In this section, the following question is addressed: *"Which building and healthcare services have the greatest impact on building energy use in an average hospital in an average climate zone?"*

A big amount of measured data is needed to answer the question of the largest energy users in hospitals. The answers may be different for different hospitals as well as for different climate zones. However, energy demand for space heating and space cooling will not be the same for hospitals in different climate zones, but a higher demand for space cooling in subtropical areas (e.g. Italy) will, to some extent, be compensated by a lower demand for space heating.

In order to answer which are the largest energy users in hospitals, this section focuses on activity-based electricity use which enable comparisons of electricity use for different departments and healthcare services in different countries. Unfortunately, the big amount of measured data needed to answer the question is not easily available in the EU countries. However, in a Swedish project called the STIL2-project, measurement data has been collected from as much as 159 health care premises. The results of the study are presented in this deliverable. Although the focus is on hospitals, the energy consumption of other healthcare services (large medical centres, polyclinics, residential elderly care, rehab centres) is also shown. After all, a hospital is a collection of different functions, sometime including the ones just mentioned. Separate mentioning of usage data will only increase accuracy.

In order to enable comparisons with energy use for other hospitals within the STREAMER project as well as for other European hospitals, the energy use is presented per square meter net floor area of the heated/cooled part of the building (A_{temp}[1]). Even though different countries use different floor areas, this is considered a more straightforward approach than presenting total energy use, which is only relevant for one specific hospital. Most important is to present which floor area is used and to give a definition.

The question mentioned at the start of this paragraph will be addressed by starting with an overview of the different energy demands and a presentation of measurement data on a highly aggregated level based on annual average use for different categories of Swedish healthcare premises. Thereafter, it is discussed which building and healthcare services have the greatest impact on the seasonal, weekly, daily and hourly energy use based on experience from the Netherlands. Finally, conclusions are discussed.

2.1.1 Overview of the different energy demands in healthcare premises

Hospitals use a variety of energy sources. The most important energy demands in a hospital are heat, cold, electricity (and compressed air). These are used for among others the following applications:

[1] Atemp is defined as "the floor area in those parts of the building intended to be heated to more than 10 °C, and bounded by the inner surface of the climate screen" (Göransson, 2008).

Heat is used in the form of steam and in the form of hot water. Steam is used for among others the kitchens, humidification in HVAC (large part) and a small part for sterilisation. In addition steam is used to transport heat over longer distances. Hot water is used in the form of central heating and tap water. Cold is mainly used in climate control systems, for cooling and drying the ventilation air. In many cases cold is generated centrally by means of compression coolers.

Electricity is used for a wide variety of purposes. The largest electricity consumers in a hospital are mechanical ventilation (fans), lighting, cooling machines, air compressors, circulation pumps, medical equipment and office equipment. Compressed air can be divided into two main categories; medical and technical air. Medical compressed air refers to direct treatment and care of patients. Examples include breathing apparatus and surgical tools driven by compressed air. Medical compressed air is subject to very high standards for availability and quality. Compressed air that is not directly related to patients is called technical compressed air. Examples include HVAC control systems, workshop applications or keeping containers under pressure

2.1.2 General introduction to energy patterns and energy profiles

There have been several projects in Europe[2] and national studies for instance in The Netherlands[3], UK and Sweden that have tried to define how and where energy is used in a hospital and how the energy consumption patterns are influenced by seasonal cycles, functional properties, orientation, geographical location, age and building typology. These studies have not resulted in a final answer as hoped, as many factors are of influence.

The actual knowledge to determine how much energy a hospital uses on a more detailed level is far more difficult to find and can be attributed to many different factors. Often, the energy consumption is taken from the energy bill. The amount billed is the amount of energy used for a hospital for a period of time. More detailed information could be gathered at main stations or sub-stations of energy sources for instance from electricity, gas, coal, oil or other sources of energy carriers or pipelines. This top-down approach on energy consumption often ends here.

Due to the fact that data on a more detailed level than total building is not available or comparable, we have to base ourselves on the second best available answer; that of an expert opinion. The STREAMER project is trying to create a grip on these functional operations, areas and demands that have the highest impact on the total demand for energy. This would give an indication where the overall targeted energy reduction of 50% can be achieved and where in the rest of the STREAMER project we should focus the research efforts.

When answering the question of the largest energy users in hospitals it is not only important to consider the annual energy use, but also to consider when over the year, season, week or day, the energy is

2 For instance: RES-Hospitals, Hospilot, GreenHospital.

3 MJA3 afspraken Academische Ziekenhuizen, NFU; http://www.nfu.nl/actueel/energieverbruik-umcs-kan-veel-efficienter.

used. This is necessary information for identifying inefficient use of energy and potential energy savings. In the Netherlands, there are exemplary measurements made on a weekly, daily and hourly basis which provide information about when energy is used and when energy is needed. Currently these measurements are used in Rijnstate hospital and feed information into the STREAMER-project (see Chapter 4).

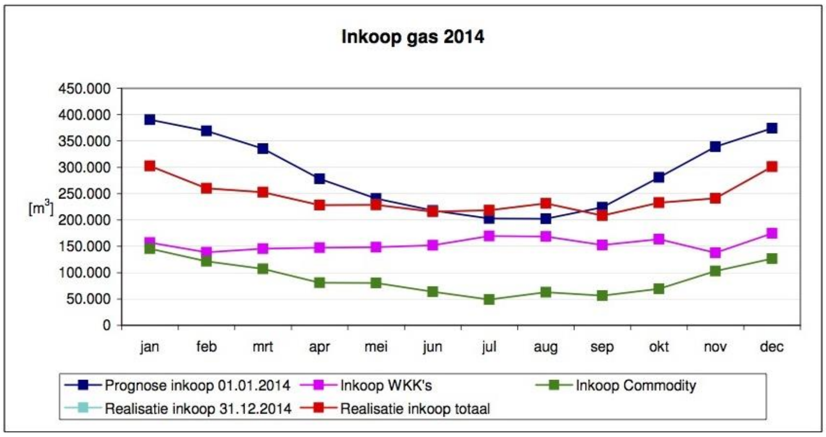
Unfortunately, most of the real-estate owners of Europe's hospitals know very little about the amount of energy that is used for different building layers (hotel, hot floor, industry, office, etc.) and for different departments and healthcare services (day hospital, emergency, kitchen, etc.). The information that is available concerns the total amount of energy used.

We see the hospital building (and its energy use) as an answer between the organizational need for activities, within a specific set of boundary conditions, and the solution in the form of a building that helps to resolve these demands. The sum of the demand profile of a hospital is the made up of:

- the energy demand caused by the activity level;
- the required boundary conditions to perform these activities in.

To further define the energy use of a hospital and to use the knowledge to such an extent that energy savings be achieved in the design phase, the key aspect is to understand how energy is needed to fulfil certain working or hygienic conditions, functioning of services and equipment and how the pattern of energy use is changing in different cycles:

- Seasonal cycles (summer / winter),
- Weekly cycles (weekdays / weekends) and
- Daily cycles (24h cycle)



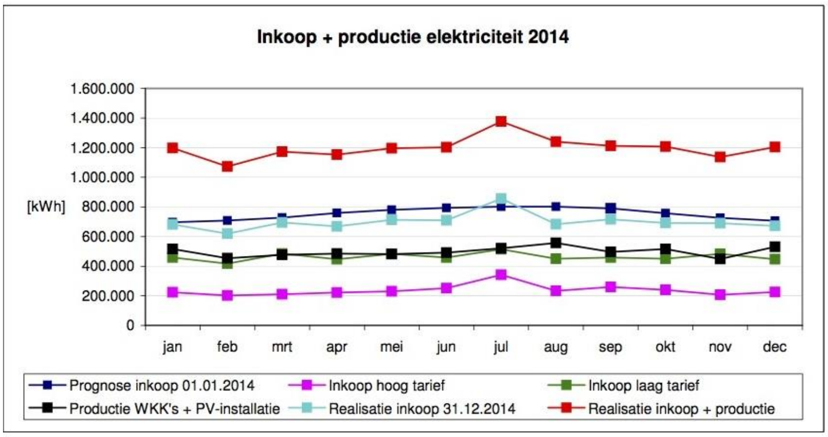


Figure 1 Seasonal cycle of a large academic medical centre in the Netherlands

Figure 1 shows the yearly profile of Rijnstate hospital for gas and electricity consumption for the year 2014 (red lines).

There is a large base load and a relatively low effect / influence of season temperature or outside conditions. The large base load is therefore not so much affected by additional heating or cooling demands as a result of changing season or weather conditions. This is not to say that the weather conditions have no effect at all. In the winter, heating is required, and in the summer, cooling is required. The base load is also related to the fact that it cannot be controlled (is always “on”); indoor climate is kept at a constant level (independent of outdoor) and the building management system is reactive (programmed) towards these demands. More important to note is that the system often is not able to handle local (indoor) climate conditions; in most cases the hospital is seen as one mono-functional block, with specific areas that need adapted climatic conditions.

Gemiddeld uurverbruik per dag normweek (kW)

Uur / Dag	ma	di	wo	do	vr	za	zo	Uurtotaal (kWh)
0:00	1.5	1.8	2.4	1.9	1.8	1.5	1.5	12
1:00	1.5	1.8	2.4	1.9	1.7	1.5	1.5	12
2:00	1.5	2.4	2.4	1.8	1.8	1.5	1.5	13
3:00	1.5	2.4	2.4	1.8	1.7	1.5	1.5	13
4:00	1.5	2.4	2.4	1.9	1.7	1.5	1.5	13
5:00	1.5	2.4	2.5	1.8	1.8	1.5	1.5	13
6:00	2.9	3.9	3.8	3.2	2.2	1.5	1.5	19
7:00	4.7	6.1	6.0	5.3	4.3	1.5	1.5	29
8:00	7.1	8.6	8.2	8.2	5.9	1.6	1.5	41
9:00	8.0	9.6	8.7	8.9	6.6	1.6	1.5	45
10:00	8.2	9.6	8.7	9.1	6.8	1.6	1.5	46
11:00	8.2	9.9	8.7	9.4	7.1	1.6	1.5	46
12:00	8.2	10.2	8.6	9.6	6.9	1.6	1.5	47
13:00	8.6	11.3	8.7	10.1	6.8	1.6	1.5	49
14:00	8.4	11.4	8.4	9.7	6.9	1.7	1.5	48
15:00	7.9	10.7	7.8	9.0	6.4	1.5	1.5	45
16:00	6.0	8.7	6.1	6.9	4.5	1.5	1.5	35
17:00	3.6	5.2	3.8	3.9	2.7	1.5	1.5	22
18:00	2.4	3.5	2.5	2.8	2.0	1.5	1.5	16
19:00	2.0	2.9	2.1	2.0	1.6	1.6	1.5	14
20:00	1.9	2.7	2.0	1.9	1.5	1.6	1.5	13
21:00	1.9	2.5	1.9	1.9	1.5	1.5	1.5	13
22:00	1.9	2.4	1.9	1.8	1.5	1.5	1.5	12
23:00	1.9	2.4	1.8	1.8	1.5	1.5	1.5	12
Dagtotaal (kWh)	103	135	114	117	87	37	36	629

Figure 2 Weekly and daily energy use of an office in a large academic medical centre (source Plugwise, ErasmusMC data on energy use in an office use, summer 2012).

The same baseline pattern can be detected in weekly and daily cycles, as can be seen below. More than half of the energy use takes place outside office hours in this office department of a hospital. Typically, the assumption of a 24h day operating function is deeply ingrained in this specific set-up. High energy users in this case are the coffee machine and the copy machine.

As can be seen from the previous figure, it is important to target he right type of intervention to achieve the necessary energy reduction. One further example is the case of lighting. Lighting causes around 40% of the demand for electricity. The easiest way to save energy is not to need (additional) lighting or to switch off lighting when nobody is present (reduce demand). The next example shows how, through a mix of lighting control systems and ultra-efficient lighting solutions, a potential large saving can be made.

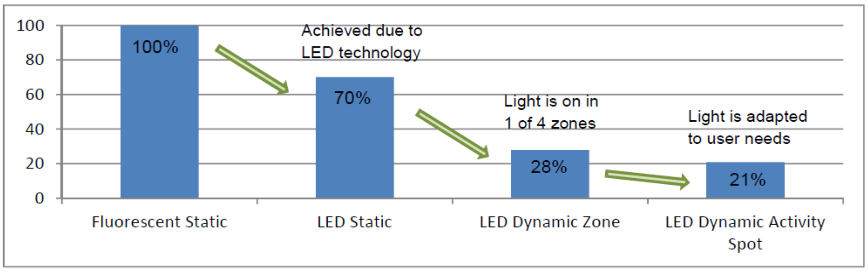


Figure 3 Lighting example

In the abovementioned figure a clear demonstration is showing how changing the light (from fluorescent to LED and to zoned lighting or light at the right place at the right time could help achieve energy saving

(Y-axis is energy consumption), not compromising comfort and safety of staff/patients[4]. The last step (from zoned lighting to Dynamic Activity Spot is a 25% reduction of energy user. By using advanced BMS-systems these types of energy savings are within reach of hospitals and can contribute to the planned energy saving.

2.1.3 Annual average energy use for different healthcare premises

In this section, energy statistics are presented for different categories of Swedish health care premises in order to get a better picture of the greatest energy demands in hospitals. The energy mapping was performed within the Swedish project called STIL-project, which included mapping of 159 health care premises in 26 Swedish municipalities, see Figure 4 (SEA, 2008). These include hospitals, larger medical centres, rehabilitation and other similar 24-hour care facilities, and residential care for the elderly.

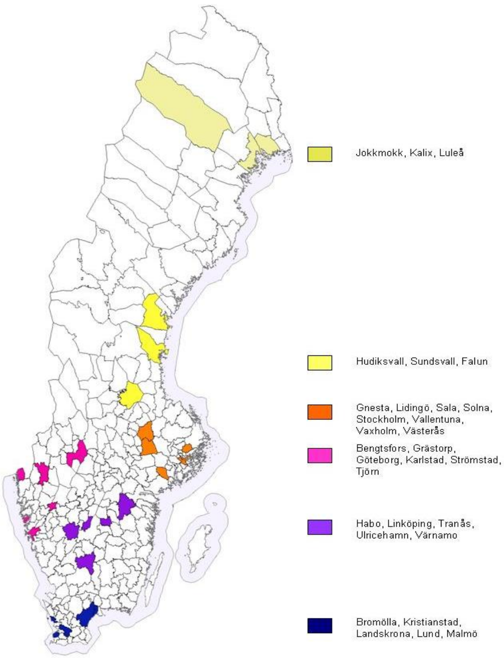


Figure 4 Location of 159 health care premises in 26 Swedish municipalities included in the energy mapping project STIL2 (SEA, 2008).

In Table 1, the energy use in health care premises 2006 and 2007 is presented in total and separately for 69 hospitals, 11 large medical centres (and polyclinics), 55 retirement homes and 24 rehab care centres (and similar). As shown, the average total energy use in the premises was 218 kWh/m^2, year. The use of electricity (for other purposes than for heating) varies between 50 to 95 kWh/m^2. The large hospitals are

[4] Activity Controlled Dynamic Lighting is a decentralized lighting concept that has been developed by TNO. It's technology is patented and based on decentralized detection and activation of lighting points to provide light when it is needed at the point it is needed, without compromising feelings of safety and comfort.

the major users of electricity. Rehabilitation centres and other types of residential care, centres for persons with different disabilities etc. are shown to have a high demand of electricity for heating.

In premises with a high energy use relative the floor area, this is often explained by high space heat demand. This can often be explained by the combination of poor insulation and high air flows with insufficient heat recovery. A very low energy use can be explained by low use of electricity for ventilation and lighting and that there is no electric heating. However, a low energy use can also be explained by the fact that certain buildings are not in use or not occupied by the staff or clients (SEA, 2008).

	Hospitals	Large medical centres, polyclinics	Residential care of the elderly	Rehab care centres and similar	All these types of care	
Electricity (except	95	69	61	50	78	kWh/m^2
heating)	4	2	5	32	5	kWh/m^2
Electricity for heating	117	166	125	109	132	kWh/m^2
Other heating energy	6	0	0	0	3	kWh/m^2
District cooling						
Total energy use for building and healthcare services	222	237	191	191	218	kWh/m^2

Table 1 Average total annual energy use (kWh/m2 Atemp, year) for different categories of Swedish health care premises 2006-2007 (Göransson, 2008).

2.1.4 Annual average electricity use for different healthcare premises and purposes

In 2006 and 2007, the total electricity use (excl. electricity for heating) in 159 health care premises included in the STIL-project was estimated at 77.8 kWh/m^2, year. In Figure 5 the electricity use is presented split into different categories of use. The highest share of the total electricity consumption was used in fans in the ventilation system (29.3 kWh/m^2, year, 35.2 % of total electricity). Also electricity for lighting corresponded to a high share (21.7 kWh/m^2, year, 26.0 % of total electricity) of the total electricity use. Health care facilities have high staffing 24 hours a day and need for varied lighting. In total, the medical equipment only corresponded to 4.5 % of the electricity used in health care premises. Note that a lot of the laundry work and food preparation for large hospitals was carried out in buildings outside those that were surveyed in the STIL2-project, which means that more electricity is used for these services then presented in this report.

As shown, the greatest potential for savings is in lighting and ventilation. At the time of the STIL-project, it was estimated that more energy-efficient lighting could reduce the electricity used by 12 kWh/m^2 per year in the Swedish health care premises. It was also estimated that improved ventilation systems with air flows adjusted to the specific needs for the health care services could lead to a further reduction of the electricity use by 12 kWh/m^2, year. The health care floor area in Sweden of 21.000.000 m^2 implies that 0.5 TWh per year could be saved by these two measures (SEA, 2008).

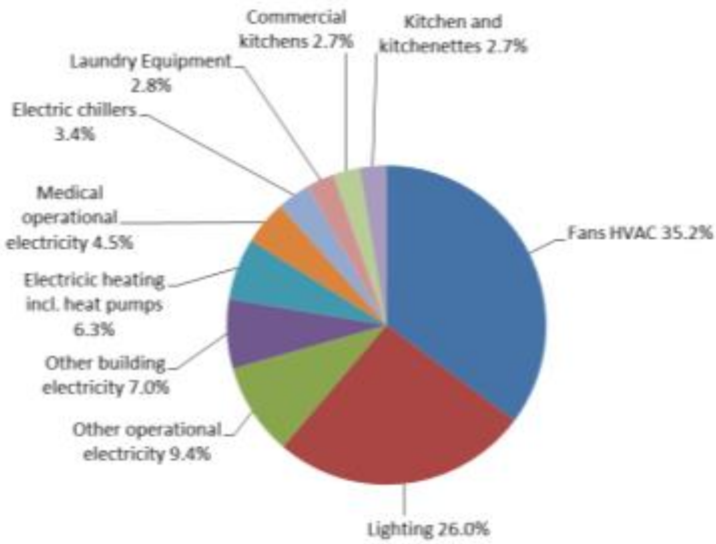


Figure 5 Average electricity use in 159 health care premises in Sweden, split into the use for different types of building services and activities (SEA, 2008).

In Figure 6 and Figure 7, electricity use for laundry, kitchens and clinical equipment, as well as for other activity-related purposes, is presented for Swedish hospitals and large medical centres and polyclinics (Figure 6) and for Swedish nursing homes for elderly, rehab centres and similar facilities (Figure 7). The result is clear – lighting and fans are the major users of electricity (for other purposes than for heating) for both Swedish hospitals and large medical centres and polyclinics and for nursing homes for elderly, rehab centres and similar facilities. For hospitals and large medical centres and polyclinics, the medical equipment corresponds to 6 % of total electricity use, where for nursing homes for elderly, rehab centres and similar facilities, the medical equipment only corresponds 0.2 % of total electricity use.

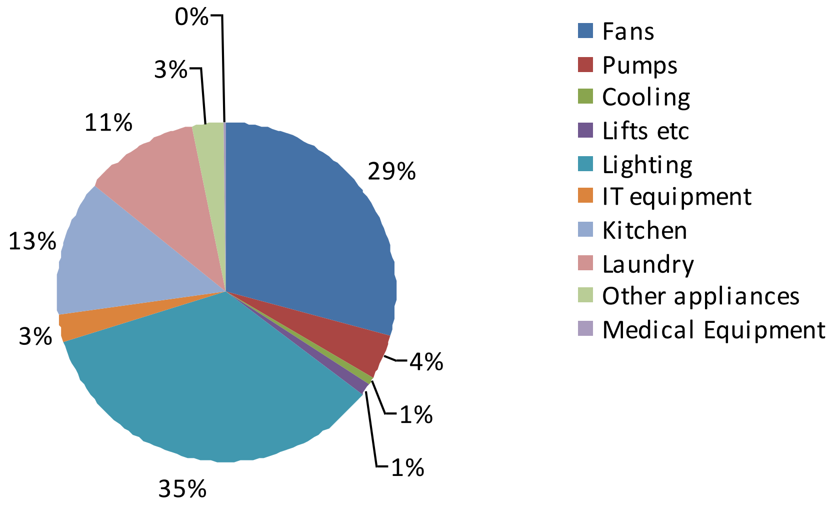


Figure 6 Share of the electricity used for fans, lighting, laundry, kitchens and clinical equipment, as well as for other activity-related purposes, in Swedish hospitals and large medical centres and polyclinics (Göransson, 2008).

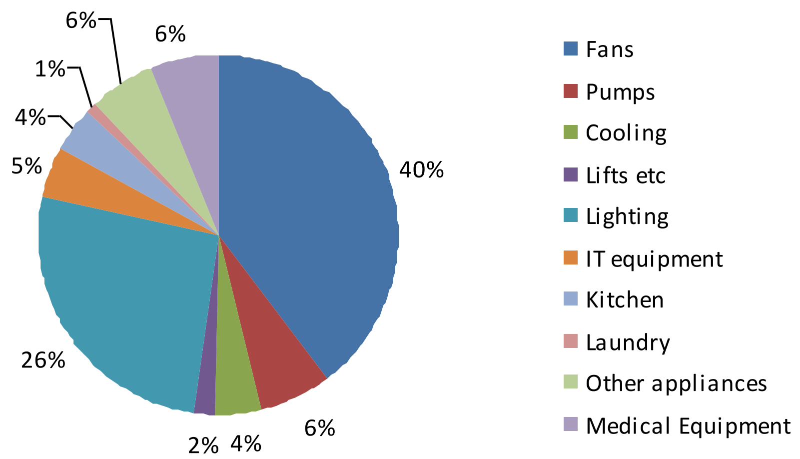


Figure 7 Share of the electricity used for fans, lighting, laundry, kitchens and clinical equipment, as well as for other activity-related purposes, in Swedish nursing homes for elderly, rehab centres and similar facilities (Göransson, 2008).

In Figure 8, the electricity demand is presented separately for all 159 healthcare premises included in the STIL2-project. The figure shows the variations in total electricity demand and in the share of electricity used for fans, lighting, laundry, kitchens and clinical equipment, as well as for other activity-related purposes for all these 159 healthcare premises. Only four of these have a higher electricity demand than 200 kWh/m^2, year. Electricity demand varies from 10 kWh/m^2, year up to as much as 500 kWh/m^2, year (values not shown).

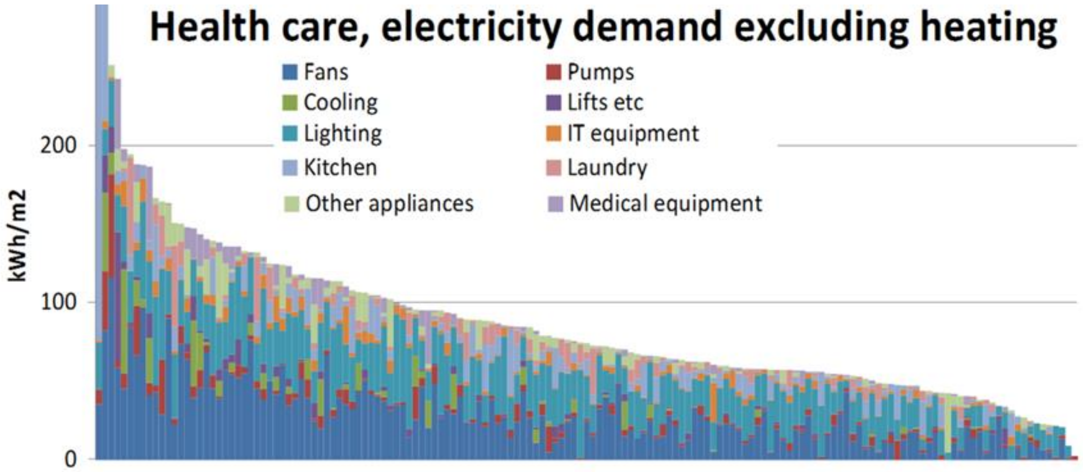


Figure 8 Electricity demand presented separately for all 159 healthcare premises sorted in descending order (Göransson, 2008).

A detailed look on electricity used for fans

Almost all healthcare premises in the STIL2-project have mechanical ventilation with both supply and exhaust air fans. As much as 87% of the ventilation systems incorporated heat recovery (SEA, 2008). Figure 9 presents the share of the different type of ventilation systems used. As shown, the majority of the premises (84%) have constant air volume systems (CAV), which means that the air volume is not adjusted to different needs over the day and week.

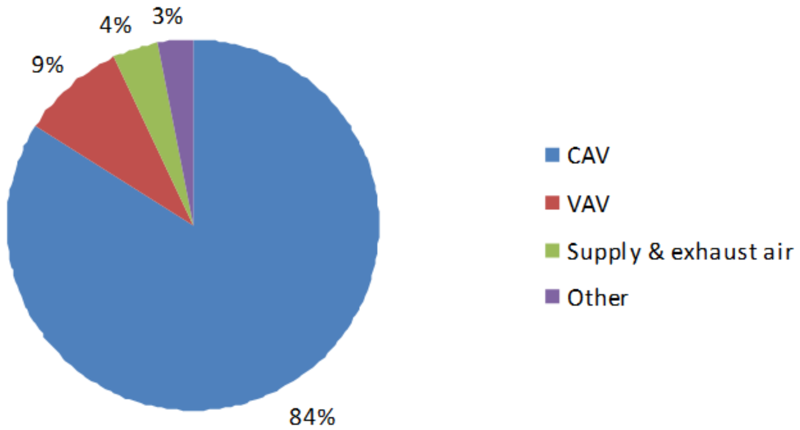


Figure 9 Share of different types of ventilation systems used in 159 Swedish healthcare premises (Göransson, 2008).

Table 2 presents details of the fans and air change rates in the different categories of healthcare premises. As mentioned earlier, the fans uses in average 29 kWh/m^2, year and varies from 10 to 33 kWh/m^2, year. The number of air changes per hour vary between 0.4 to 2.7.

The running times of the fans vary between 5900 hours up to 7350 hours per year for the different categories of healthcare premises. In average, the fans are running for 6670 hours per year, which corresponds to over 18 hours per day. This can be compared to running times of fans in schools and offices (also included in the STIL-project) of in average 3500 and 4100 hours per year, respectively (SEA, 2010). Operating times in care facilities can vary widely, from daytime use only up to continuous 24-hour operation. In many of the studied healthcare buildings, fans run continuously throughout the year. However, the use of electricity (in kWh/m^2), is higher for categories that work for less than twelve hours per day than for those working for longer than this (Göransson, 2008).

	Hospitals	Large medical centres, polyclinics	Residential care of the elderly	Rehab care centres and similar	All these types of care	
Electricity for fans, by area	33.2	30.8	17.9	10.1	29.3	kWh/m^2
Operating time, calculated[5]	5900	7350	7100	6500	6670	hours/year
Air changes per hour	2.7	1.8	1.4	0.4	1.6	changes/hour

Table 2 Details of the fans and air change rates in the different types of healthcare premises (Göransson, 2008).

A detailed look on electricity used for lighting

In average, the lighting in the 159 Swedish healthcare premises is switched on 2450 hours per year and uses 21.7 kWh electricity per square meter and year, see Table 3. The lighting capacity installed totals 7.3 W/m^2 for large medical centres and polyclinics and 9.6 W/m^2 for retirement homes.

	Hospitals	Large medical centres, polyclinics	Residential care of the elderly	Rehab care centres and similar	All these types of care	
Electricity for lighting, by area	23.5	15.4	19.7	21.0	21.7	kWh/m^2
Operating time, calculated[6]	2400	1750	2800	2300	2450	hours/yr
Installed power	9	7.3	9.6	9	9.1	W/m^2

Table 3 Information of lighting in different categories of Swedish healthcare premises (Göransson, 2008).

The least efficient lighting used in the 159 Swedish healthcare premises corresponds to over 75 % of all electricity used for lighting, see Figure 10. Conventional fluorescent tubes correspond to 56 % and incandescent lighting for 26 % of the total capacity for lighting. Incandescent lighting is found mostly in residential care and rehabilitation centres, see Figure 11.

[5] Operating time has been calculated by dividing the annual electricity use of the fans by their installed power demand capacity.

[6] Operating time has been calculated per building, by dividing the annual electricity use for lighting by the installed capacity of all lighting.

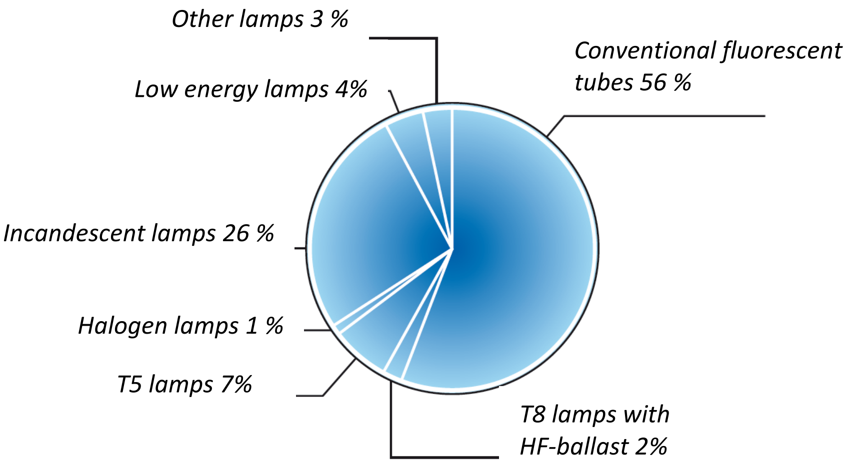


Figure 10 Installed lighting capacity for Swedish healthcare premises (picture based on SEA, 2010).

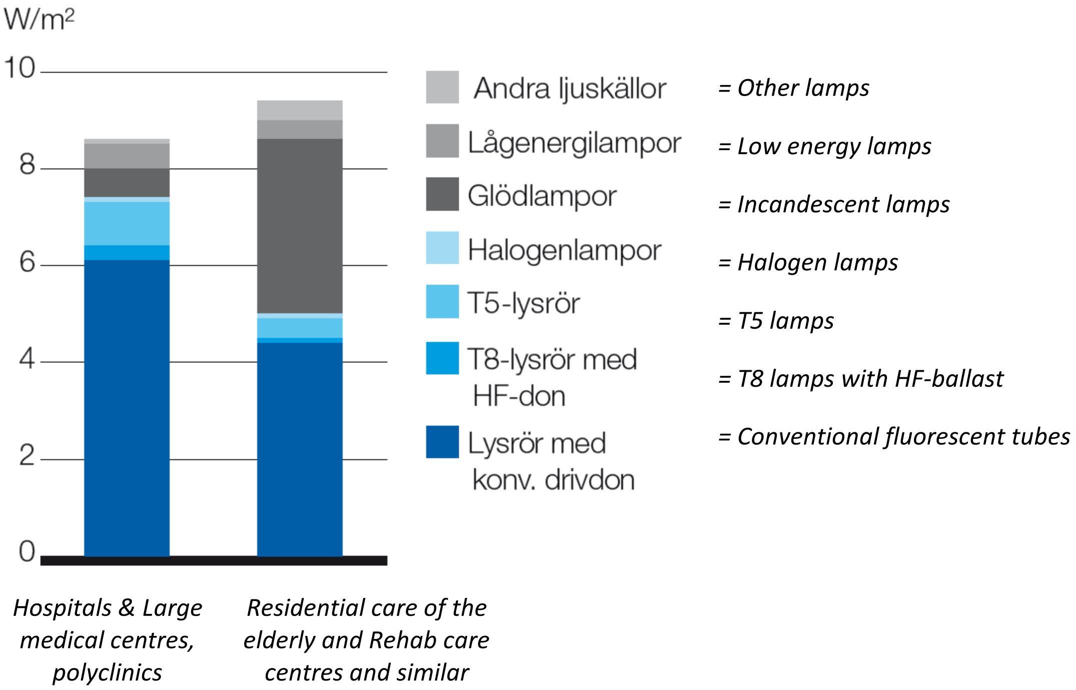


Figure 11 Installed lighting capacity for different categories of Swedish healthcare premises (picture based on SEA, 2010).

A detailed look on electricity used for clinical equipment in healthcare facilities

Special clinical equipment is concentrated in hospitals and larger medical centers. The use of electricity for other purposes than for heating is presented for hospitals, large medical centers and other healthcare facilities in In

Table 4. It is shown that the clinical equipment is not a dominant user of electricity (5.1 kWh/m^2). Even for hospitals and medical centers it is not the dominant user (Göransson, 2008).

Ventilation fans	34.0 kWh/m2	40%
Other building services and comfort cooling	10.5 kWh/m2	12%
Lighting	22.1 kWh/m2	26%
Various types of electrical equipment	18.5 kWh/m2	22%
- of which clinical equipment	5.1 kWh/m2	6%

Table 4 Electricity (excluding that for heating) used in hospitals, large medical centres and other healthcare facilities (Göransson, 2008)

For a more detailed result of how the use of electricity is split among different clinical equipment, see Figure 12. As shown, the X-ray equipment constituted the largest user.

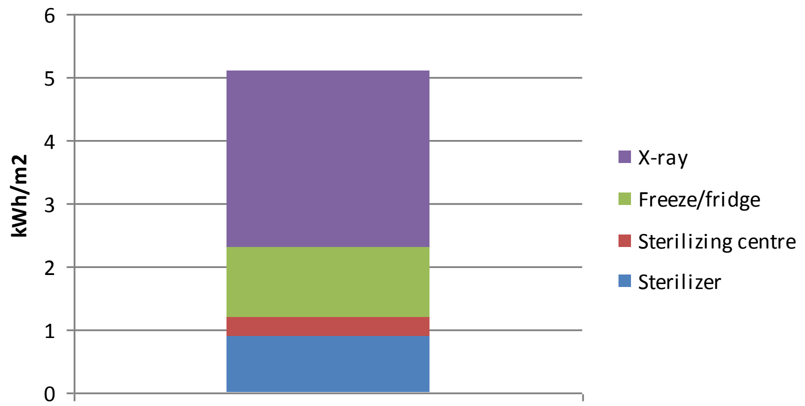


Figure 12 Electricity use for clinical equipment in Swedish hospitals, large medical centres and other healthcare facilities presented split into the use for each activity (Göransson, 2008).

Within the STIL2-report, the different energy needs for the clinical equipment have been described as follows (Göransson, 2008).

> **“Radiology equipment**: This includes x-ray equipment, MRI scanners and computed tomography equipment. X-ray equipment produces images of the internal body organs by producing x-rays that are aimed at the part of the body concerned. X-radiation requires a lot of energy, and x-ray generators usually have power requirements in the 30 - 100 kW range, although this is required for only a few hundredths of a second. Electricity use on standby is less, but most of the energy is lost in total as no-load losses. A magnetic resonance imaging scanner (MRI scanner) produces images of internal organs by measuring the different responses of the tissue molecules when subjected to a strong magnetic field. In the same way as with ordinary x-ray equipment, most of the losses occur as no-load losses. MRI scanners also have a high cooling requirement. Computed tomography is used to create three-dimensional images of internal parts of the body. The machine produces a number of two-dimensional x-ray images, which are then stitched together to produce a three-dimensional

image. The x-ray generator in such a scanner usually has a momentary power demand of 50 - 100 kW, with exposure times of up to a few seconds. Again, there is a cooling requirement, which is generally provided centrally for the entire radiology department.

Clinical refrigeration and freezing: Clinical equipment of this type is encountered in all healthcare categories, but mostly in hospital, larger medical centres and polyclinics. There is a range of cooling requirements, from ordinary refrigerator temperatures down to -80 °C.

Cleaning and disinfection: Spray disinfectors are used mainly in large hospitals for cleaning bedpans, while dishwasher-type disinfectors are used for cleaning instruments. Autoclaves produce steam for sterilising instruments, and are used in surgical departments and elsewhere.

Central sterilisation units: are found only in hospitals, and have only relatively modest electricity demand.

Other clinical equipment: In addition to the above clearly specified equipment groups, the surveyors were free to include data for other equipment etc. that was regarded as intended for clinical purposes. Such equipment has an energy demand of 1 - 2 kWh/m^2."

2.1.5 Discussion

In retrofitting, changing the typological building layout is generally out of scope. Instead, the focus is on how MEP systems, functional spaces, rooms and building envelope can be reconfigured within a given building layout.

Ventilation and lighting, the major energy users

The results from the STIL2 project show how electricity is being used and how much is used for lighting, for ventilation and for electrical equipment etc. Based on measurements of annual energy use in 159 healthcare premises in Sweden, ventilation and lighting are the largest users of electricity in healthcare premises, also in hospitals and larger medical centers with electricity-demanding clinical equipment. The highest share of the total electricity consumption was used in fans in the ventilation system (35 %); also electricity for lighting corresponded to a high share (26 % of total electricity) of the total electricity use.

There is potential for large energy savings for ventilation by adjusting operating times to suit occupancy times, by adjusting air flow rates to actual needs and by changing to more efficient ventilation units. The high use of electricity for fans is explained by the fact that the majority of the premises (84 %) have constant air volume systems (CAV), which means that the air volume is not adjusted to different needs over the day and week. Thus, there is a huge energy saving potential if these systems were changed to variable air volume systems (VAV) and if the air volumes were optimized and adjusted to the needs over the day, the weeks and over the years (e.g. when health care facilities change location inside the hospital building). This would result not only in a lower electricity use, but also in a lower demand for heating and cooling.

Note that most Swedish healthcare premises have centralised ventilation systems, which means that the electricity for ventilation is lower than if decentralised ventilation systems were used instead. Large units are much more energy-efficient than small ones. Since decentralised ventilation systems are common in many other European hospitals, there is a large energy saving potential if these systems were changed to centralised systems, or at least that the decentralised units are operated by a central operation unit. The possibility to change pressure, air flows and indoor temperatures in specific rooms should be limited to certain ranges, so that the entire system will work in an efficient way.

There is large potential for energy savings for lighting by turning it on only when it's needed and by replacing conventional lighting technologies with more efficient lighting technologies. Installation of occupancy sensors and other lighting control systems will reduce the electricity use for lighting. The least efficient lighting used in the 159 Swedish healthcare premises corresponds to over 75 % of all installed lighting capacity. There is potential for large energy savings by replacement of conventional fluorescent tubes to T5 luminaires and incandescent bulbs to low-energy/LED lamps in Swedish healthcare premises. This is also a possibility in other European hospitals.

Medical equipment, a minor energy user

The planning and operation of terminals and medical equipment is not the real estate owner's business. The staff needs to have the control of the medical equipment, when it is switched on/off. However, some equipment is more energy-efficient than others and some solutions for the steam production influence the total energy use of the buildings. Results from Swedish hospitals, large medical centres and other healthcare facilities show that medical equipment only corresponds to 6 % of the electricity used (for other purposes than heating), of which X-ray equipment constituted the largest user. For nursing homes for elderly, rehab centres and similar facilities, the medical equipment only corresponds 0.2 % of total electricity use.

For the Swedish hospitals, large medical centres and other healthcare facilities, there is only a small demand for electricity for sterilisation (about 1 kWh/m^2). The steam is produced directly at the locations where it is needed in decentralised network-connected autoclaves (with electricity-driven steam generation). This is a much more energy-efficient way of handling the steam production compared to if the steam were produced in large central units, and distributed in pipes within the hospital area, which requires a high pressure and results in high heat losses. There has been a transition from centralised steam generation to decentralized electricity-based steam generation in Swedish healthcare buildings. If the same transition were made for other hospitals, the heat losses would be much lower.

The functions determine the energy load profiles

Most important aspect to remember is that energy is needed to fulfil a function, and that the function determines the demand for energy for a certain period. Knowledge of functioning of the hospital and the border conditions, for instance minimal (legal) requirements for functioning from a quality perspective, or indoor climate perspectives, are key ingredients to determine the energy demands of a hospital function. The ultimate fulfilment of these energy demands is taken care of via the design of the building, the installed MEP/HVAC systems and the proper supply of electricity to meet the demands of the medical and other equipment.

The challenge that can be formulated is to develop the right (flexible) type of buildings that are inherently comfortable and usable for its function, but demand the least amount of HVAC/MEP solutions for the air-conditioning of rooms and areas. By least amount, we express that we should aim to minimize use of any HVAC/MEP solutions and that the quality of the design should encompass the use of natural ventilation, natural resources (heat/cold), difference in day/night temperatures etc..

This would require innovation in building design (and building process design). Secondly, being able to provide the right type of climate at the right spot at the right time. Hereto we would require advanced BMS-systems and decentralized energy efficient MEP/HVAC systems. The systems need to be able to control at the level of a room the indoor climate. Thirdly the best combination of local solutions may be optimized at a higher level; an exchange of heat/cold at a higher level (rooms-departments-buildings-neighbourhoods) could lead to a lower overall (additional) demand for energy.

Key question is to determine where the demands are high in a hospital and for which period of time these demands are high. The demands relate here to the conditions that are required to be able to successfully execute the services of a hospital. In terms of building services we can only offer ventilation (with heating and cooling) as the largest contributor to the energy consumption. The second most energy consuming building services is lighting.

Depending on the expected performance and running times, the possible co-location of service, the rules, regulation and preferences and the widely ranging possibilities it seems logical to make use of the STREAMER labels to determine the optimal spatial configuration. It seems that the design of functions, related to the organisation profile (strategy) of the hospital organisation is therefore of utmost importance. In chapter 3, this concept is presented as part of a design methodology.

In terms of activity related energy we have clearly demonstrated that (medical) electrical equipment used in parts of the hospital are most energy consuming. A lot of this electrical equipment can be shut off when not in use. However the implicit assumption is that a hospital is a 24/7/365 operation, possibly requiring any type of equipment at any moment. So start up times should be avoided and the behaviour of switching equipment off after use (when possible) is not always common behaviour. Critically, even for a normal office department easy energy saving could be achieved, when “kill” switches are used outside office working hours.

2.2 Building shape-based hospital energy consumption

In D1.1, Chapter 3, nine general arrangements that capture most common hospital typologies have been described with matching energy-related features. The aim was to define how the building typology influences the energy demand of a healthcare building.

On a rough scale, building typologies have different performance levels of energy loss due to:

- The amount of building envelope (compact building structures have less outer surface thus less energy loss by transmission).

- The length of transport distances for HVAC systems, which has a relation with the shape of certain typologies.

However, there are three reasons why the relation between building typology and energy consumption is problematic:
Firstly, this deliverable focuses on retrofitting scenarios. In retrofitting, changing the typological building layout is generally out of scope. Instead, the focus is on how HVAC systems, functional configuration and building envelope can be reconfigured within the building layout.
Secondly, there is no energy consumption data available that can be related solely to the effect of a certain typological configuration.
Finally, although some general pro's and cons of various building typologies can be defined from the perspective of energy consumption, there are no clear conclusions to be drawn on the relation between building typology and the amount of energy consumption. This is because all typologies can contain both narrow and deep floor plans. (In D1.1 the concepts of narrow-plan and deep-plan forms have been described).

The narrow plan has been ascribed a better performance over the deep plan regarding energy consumption and patient/people comfort. Main reason for this is that narrow floor plans have more rooms located next to the façade instead of inside the building, providing more natural daylight and possibilities for natural ventilation concepts. However, when the benefits of natural ventilation and daylight are not considered, compactness is an energy-saving characteristic because the energy loss through the building envelope (including foundation and roof) is limited.
Although less compact, narrow plans allow for downsizing of MEP systems and for reducing the amount of energy used, as long as daylight and natural ventilation are properly included in the MEP concept.
So, a narrow building with natural ventilation and daylight is generally preferred above a deep building with mechanical ventilation and artificial lighting. A narrow building with mechanical ventilation and artificial lighting is the "worst of both worlds". Note: a fully naturally ventilated building in cold or average climate zones is not desirable, neither from the energy, nor from the comfort point of view. In the winter, this would result in severe energy loss caused by hot air constantly being replaced by cold, fresh air. So, when we talk about the "integration of natural ventilation into the MEP concept", we mean that natural ventilation is used when allowed by the outside climate at that moment. A mechanical ventilation system will always be present as back-up when it's too cold outside. In hot climates, this principle is also true; natural ventilation will increase the amount of energy spent on cooling.

Although based on these conclusions it may be tempting to prescribe narrow plan solutions for every hospital, it is important to realize that the narrow plan is not compatible with some common floor plan layouts in hospitals. This can be explained by using the layering system. Two of the layers fit into the narrow plan concept easily: in-patient accommodation (Hotel) and the out-patient/consulting and administration facilities (Admin). Both share the characteristic of being patient focused. Hence the need for daylight, views and natural ventilation. The Hotel layer will of course be a 24/7 whilst the Admin layer will be more of a 10 hour day 5 days a week. The two layers that will not fit easily into the narrow plan format are diagnostic & treatment, operation theatres and CSSD (Hot Floor), pharmacy, laboratories, catering, laundry, plant rooms (Industry). The Industry layer deserves a special mention because the pharmacy, laboratories and catering facilities associated with this layer may well lend themselves to the narrow plan concept. However, a bigger issue is that CSSD, laboratories, catering and the laundry facilities associated with this layer have over the past 20 years or so been outsourced to specialist suppliers and/or moved off site to a central services hub. The Hot Floor has specific clinical requirements including ventilation, air conditioning, air pressure gradients, artificial lighting and deep plan spatial requirement to house large imaging machines.

As mentioned, changing the shape of existing hospital buildings is generally out of scope in renovation scenarios. Therefore the narrow / deep plan concept, like the building typologies, has not been further integrated in this deliverable. However, the properties that give the narrow plan the advantage over the deep plan are integrated in the methodology described in the next chapter.

2.1.6 Conclusion

The key point for the rest of this deliverable is to provide a methodology to reduce the current demand for energy with types of interventions that will help to assist in achieving these reductions in a more efficient way.

As it seems unlikely that STREAMER is capable of changing the way the primary process of the delivery of medical services is organized and how the demands for certain types of quality of indoor environments are regulated, we are not able to intervene in the energy demands that are needed to perform these activities nor the organizational strategy how to deliver these medical services.
What can be achieved is linking the right types of activities to each other; basically following the semantic labels as defined in D1.5 and check for alignment in energy demands and similarities in factors that determine the total demand of that room/function. The ideas would be to co-locate functions that have the same type of performance requirements (as it is likely that they have similar types of energy demand, for the same type of cycle) . This is described in the methodology introduced in chapter 3.

Reducing the demand for energy in a more efficient way in renovation scenarios involves making the right design choices (positioning of functions, configuration of building envelope), in relation to an efficient HVAC/MEP systems layout and installing intelligent ways to control these (BMS-systems). In new build situations, the design team will have more freedom in choosing appropriate building typologies, deep / narrow plan configurations and orientation.

Clearly, the STREAMER methodology should be a holistic methodology combining expert knowledge of all abovementioned disciplines.

3. Label and energy profile based STREAMER methodology

3.1 Evolution of the “inter-aspect schedule”

In STREAMER deliverable 1.5, the “inter-aspect schedule” was developed. In this schedule, the relations between various aspects of the STREAMER project were described. The aspects are: Hospital Questions (Questions relevant for hospital organizations within the scope of STREAMER), KPI’s (Key Performance Indicators), expert knowledge (Semantic property labels), energy (e.g. heating, ventilation, etc.) and GIS/BIM elements (objects and information that is included in the GIS/BIM model).

This information is intended to help the stakeholders in the design process to understand which information and responsibilities are related to a specific aspect of the design.

The schedule is intended to grow along with the STREAMER project. It was created in D1.5 and has been modified in D1.3. These modifications were necessary to allow design teams to use the methodology as described in this chapter. Modifications include:

Hospital questions: no changes.

KPI’s: no changes. At the time of writing this deliverable, the KPI’s are still under development.

GIS/BIM elements: Based on developments in STREAMER Task 5.3, Building services systems have been added as a new aspect (supply side). These building services systems are groups of elements. By using systems rather than individual elements, it is possible to describe content on both abstract and detailed level without listing all the individual components. Some examples of building services systems are: District cooling distribution network systems, Air conditioning systems, Lighting systems etc.
The demand side was already in the matrix (functional area, room), as well as the building envelope.

Expert knowledge (Semantic property labels): The labeling method as developed aims to identify parameters and information and transfer these aspects into the semantic BIM database. The labels have been introduced in the D1.1 report, developed further in D1.5 and tested in D7.3. At the time of writing, the labels are still under development in D1.6.

Energy: the energy aspects have been modified to be able to relate them to the newly introduced BIM aspects “Building services systems” and focus on only the most important aspects. As a result, the amount of energy aspects has been significantly reduced. To distinguish between energy production and consumption, separate aspects have been created. The energy aspects are now:

- Electricity consumption
- Heat consumption
- Cold consumption
- Compressed air consumption
- Electricity production
- Heat production
- Cold production
- Compressed air production
- Energy storage
- Energy loss
- Outside climate

The inter-aspect schedule can be used in the STREAMER methodology by interpreting the relations between the aspects (KPI, label, energy, BIM element) in a specific way. How this works is explained in the following paragraphs.

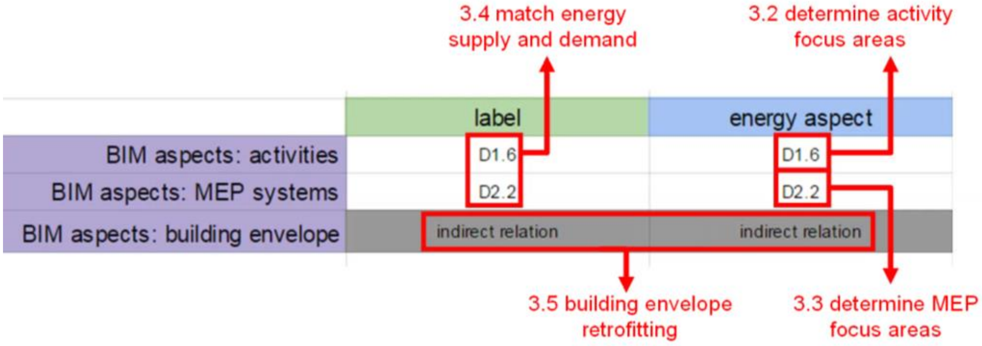


Figure 13: simplified “inter-aspect schedule” showing the purposes of the relations. The Deliverables in which the relations are expected to be provided are mentioned in the cells.

3.2 Determining activity focus areas

When analysing existing buildings, it is not only interesting to know which building service uses which energy source (electricity, heat, cold, medical compressed air, as mentioned in chapter 2), but also which area of the hospital requires this energy and in what quantity.

This analysis is often very difficult because an average hospital consists of very large number of functional areas and rooms with different demands profiles. To make matters more complicated, energy consumption profiles of functional areas and rooms are usually not available.

In the STREAMER project, template profiles of label properties have to be made for common functional areas and rooms in a hospital (as described in Deliverable 1.5). The experts within the STREAMER consortium will assign property labels to these functional areas and rooms. It will be a substantial amount of work which is intended to take place in Deliverable 1.6 (due in M48, 17 months after this deliverable).

KNOWLEDGE FIELD				energy	energy	energy	energy	energy
	ASPECT			Electricity consumption	Heat consumption	Cold consumption	Medical compressed air consumption
		INSTANCE					
			DESCRIPTION	for ventilation, lighting, equipment, ...			includes Helium, pressurized air, oxygen, CO2, Nitrous oxide, N2
GIS/BIM	functional area	Outpatient department	described in D1.1, page 64-68	low	high	medium	medium
GIS/BIM	functional area	Intensive care ward	described in D1.1, page 64-68	high	medium	medium	high

Figure 14: Fragment of the “inter-aspect schedule”, showing some examples for the relation between functional areas and energy consumption.

Although theoretically, the energy profiles for electricity, heating, cooling and medical gases could be derived from the labels, at the moment of writing this deliverable, this is not possible. (The current set of labels was created with mainly validation of space positioning in mind, it is not clear yet whether updates to the labelling system will provide more insight into the actual energy consumption). To demonstrate the methodology developed here, label and energy consumption properties have been assigned to a few functional areas and rooms, as can be seen in the following screenshot of the inter-aspect schedule.

The cells at the intersection of the aspects/instances describe the amount of energy consumed. Four entries are possible: high / moderate / low / no relation. Clearly, these are just indications on a very coarse level. Any functional area or room with a high level of energy consumption can be seen as interesting for further consideration.
Unfortunately, there is no energy consumption data available on either functional area or room level, not even in the detailed STIL study. However, in the case this information would become available, it could be used within the same proposed framework. Until then, the energy profiles will have to based on expert opinion rather than evidence.

3.3 Determining MEP focus areas

GIS/BIM elements related to energy supply contain various MEP systems (instances), which are also called Building services Systems (aspect). Some examples of MEP systems are: natural ventilation, low temperature floor heating, medical gases distribution system, etc. By creating energy consumption profiles for these systems, it is possible to filter the systems that consume the most energy for every energy aspect. As with the focus areas of the previous paragraph, energy consumption profiles have been added to only a few MEP systems to demonstrate the methodology, as can be seen in the following screenshot of the inter-aspect schedule.

KNOWLEDGE FIELD	ASPECT	INSTANCE	DESCRIPTION	energy	energy	energy	energy
				Electricity consumption	Heat consumption	Cold consumption	Medical compressed air consumption
				for ventilation, lighting, equipment, ...			includes Helium, pressurized air, oxygen, CO2, Nitrous oxide, N2
GIS/BIM	building services system (ventilation)	natural ventilation system with VAV mechanical ventilation backup	Ventilation systems (Uniclass2 SS_65_40)	low	no relation	no relation	no relation
GIS/BIM	building services system (ventilation)	100% mechanical ventilation system; Variable Air Volume	Ventilation systems (Uniclass2 SS_65_40)	medium	no relation	no relation	no relation
GIS/BIM	building services system (ventilation)	100% mechanical ventilation system; Constant Air Volume	Ventilation systems (Uniclass2 SS_65_40)	high	no relation	no relation	no relation
GIS/BIM	building services system (heating)	low temperature ceiling heating system	Climatic ceiling and beam systems (Uniclass Ss_60_40_13)	no relation	low	no relation	no relation
GIS/BIM	building services system (heating)	low temperature floor heating system	Heating systems (Uniclass2 SS_60_40_37)	no relation	low	no relation	no relation
GIS/BIM	building services system (heating)	air heating system	Air conditioning systems (Uniclass2 SS_65_80)	no relation	high	no relation	no relation

Figure 15: Fragment of the “inter-aspect schedule”, showing some examples for the relation between Building services Systems and energy consumption.

It is important to emphasize the abstract level of information provided here. The goal of this methodology is not to make detailed assumptions about the energy consumption of new build or existing hospitals, but to quickly provide design suggestions for new build situations or to analyse the improvement potential of existing hospitals based on a coarse-level BIM. A full input for mapping of Building services systems to energy consumption profiles is expected in Deliverable 2.2, which is due in M24.

3.4 Matching energy supply and demand using the label approach

Matching supply and demand is obviously one of the most important aspects of MEP design. As such, it is not new. However, in the STREAMER methodology, information should be available early in the design process. Thus, a method must be developed that enables the MEP designers to make well-informed decisions based on early/abstract design information. Also, the methodology should be suitable for existing buildings as well as new build situations. In the DOW, the term "standard design guidelines" is used in the description of the deliverable: "…Model-based analysis of the optimisation potentials and comparative analysis to the standard design guidelines." In this paragraph, a methodology is explained in which MEP solutions can be matched with standard design guidelines. Or, more specifically, how label-enriched building services systems can be matched with label-enriched rooms and functional areas. The goal is to use energy-efficient MEP solutions to supply the energy demanded by the rooms and functional areas.

As mentioned, the development of standard design guidelines is under development in D1.6. For the purpose of this deliverable, label values have been assigned to two functional areas (Intensive care and Outpatient department). An impression of how the mapping of label values and spaces looks like in the inter-aspect schedule:

KNOWLEDGE FIELD	ASPECT	INSTANCE	DESCRIPTION					
				expert knowledge	expert knowledge	expert knowledge	expert knowledge	expert knowledge
				Hygienic class	Hygienic class	Hygienic class	Hygienic class	Hygienic class
				H1	H2	H3	H4	H5
				hygienic requirements related to reception activities	hygienic requirements related to office activities	hygienic requirements related to medical examination and treatment activities	hygienic requirements related to surgical activities	hygienic requirements related to laboratory activities
GIS/BIM	functional area	Outpatient department	described in D1.1, page 64-68	no relation	v	no relation	no relation	no relation
GIS/BIM	functional area	Intensive care ward	described in D1.1, page 64-68	no relation	no relation	no relation	v	no relation

Figure 16: Fragment of the “inter-aspect schedule”, showing some examples of label values related to functional areas (demand).

A complete list of label values for these functional areas cannot be displayed inside this document due to the format of the schedule, but can be represented in a table (table 5):

Label	Intensive care	Outpatient department
Bouwcollege layer	Hot Floor	Hotel
Hygienic class	H3	H2
Accessibility	A2	A2
User profile	U4	U4
Safety	S1	S2
Equipment	EQ5 + EQ6 + EQ7	EQ2
Construction	C2 +C3	C1
Indoor quality	IQ3	IQ2
HVAC and lighting	HL3	HL1
Layout	No relation	No relation
Compactness	No relation	No relation
Mass	No relation	No relation
Form typology	No relation	No relation
Organization	No relation	No relation

Table 5

For mapping of supply and demand, the same labelling system should also be used to describe the supply side. In this case, the labels represent the capacities of the building services system. In chapter 2 of this deliverable, an overview and analysis of energy consuming factors in hospitals has been provided, with a focus on electricity consumption. Clearly, ventilation and lighting were identified as main consumers (together they are responsible for approximately 60% of total electricity consumption). This paragraph shows the mapping of ventilation building services to functional areas to demonstrate the methodology developed in this deliverable. If necessary in a later phase of STREAMER, the other energy aspects heat, cold and medical compressed air can be added in a similar way.

KNOWLEDGE FIELD				expert knowledge	expert knowledge	expert knowledge	expert knowledge	expert knowledge
	ASPECT			Hygienic class	Hygienic class	Hygienic class	Hygienic class	Hygienic class
		INSTANCE		H1	H2	H3	H4	H5
			DESCRIPTION	hygienic requirements related to reception activities	hygienic requirements related to office activities	hygienic requirements related to medical examination and treatment activities	hygienic requirements related to surgical activities	hygienic requirements related to laboratory activities
GIS/BIM	building services system (ventilation)	natural ventilation system with VAV mechanical ventilation backup	Ventilation systems (Uniclass2 SS_65_40)	v	v	no relation	no relation	no relation
GIS/BIM	building services system (ventilation)	100% mechanical ventilation system; Variable Air Volume	Ventilation systems (Uniclass2 SS_65_40)	v	v	v	v	v
GIS/BIM	building services system (ventilation)	100% mechanical ventilation system; Constant Air Volume	Ventilation systems (Uniclass2 SS_65_40)	v	v	v	v	v

Figure 17:Fragment of the “inter-aspect schedule”, showing some examples of label values related to Building services systems (supply).

Again, a complete list of label values for these building systems cannot be displayed inside this document due to the format of the schedule, but can be represented in a table (table 6):

Label	Natural ventilation with VAV mechanical ventilation backup[7]	100% Mechanical ventilation (VAV)	100% Mechanical ventilation (CAV)
Bouwcollege layer	No relation	No relation	No relation
Hygienic class	H1 + H2	H1 – H5	H1 – H5
Accessibility	No relation	No relation	No relation
User profile	No relation	No relation	No relation
Safety	No relation	No relation	No relation
Equipment	No relation	No relation	No relation
Construction	No relation	No relation	No relation
Indoor quality	IQ1 + IQ2	IQ1 - IQ5	IQ1 - IQ5
HVAC and lighting	HL1	HL1 – HL4	HL1 – HL4
Layout	No relation	No relation	No relation
Compactness	No relation	No relation	No relation
Mass	No relation	No relation	No relation
Form typology	No relation	No relation	No relation
Organization	No relation	No relation	No relation

Table 6

A demonstration of how this mapping works by using the example above:

Energy systems related to ventilation have a relation with 3 labels: Hygienic class, Indoor Quality and HVAC/Lighting. Natural ventilation is compatible with a limited amount of label values, whereas mechanical ventilation is compatible with all label values.

Looking at these label values on the demand side, it is clear that Natural ventilation is only compatible with the Outpatient department, and both mechanical ventilation systems are compatible with both the Outpatient and the Intensive care department.

The challenge is to develop the right (flexible) type of buildings that are comfortable and practical, but demand the least amount of energy for air-conditioning. The image in paragraph 3.3 clearly shows that natural ventilation with VAV mechanical ventilation backup is the most energy saving system, followed by VAV Mechanical ventilation. CAV Mechanical ventilation uses the most energy.

So the ideal mapping is:

Outpatient department: Natural ventilation system with VAV mechanical ventilation backup

Intensive care: 100% VAV Mechanical ventilation

[7] Natural ventilation is only desirable when outside temperatures are close to indoor temperatures. Venting spaces 100% naturally in hot summers or cold winters would result in high energy loss, which would have to be compensated with substantial amount of heating or cooling. Therefore natural ventilation is always backed up with a mechanical ventilation system.

Obviously, mapping MEP systems to spaces by comparing schedules for every space is far from ideal as a working method. It's a lot faster to use the visualization possibilities of a BIM:

As the label methodology is based on labels assigned to spaces, a first step for the design team is to create a basic BIM of the hospital designated for retrofit. The BIM should contain at least the functional areas, rooms or both. By following the procedure described in paragraph 3.2, the functional focus areas can be determined and the semantic labels can be added to the properties of rooms and/or functional areas in at least these focus areas.

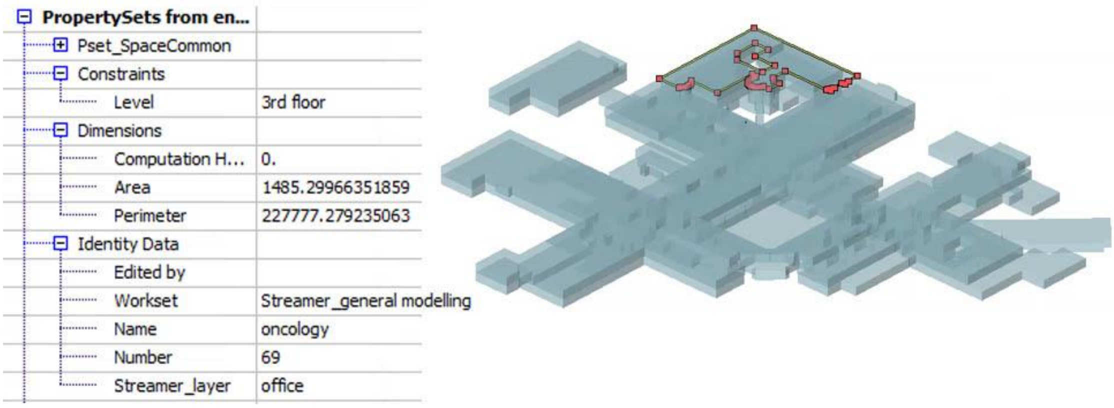


Figure 18:Combined screenshots from FZK viewer depicting an IFC file of the Rijnstate hospital extension with a functional area selected. The label values belong to the identity data.

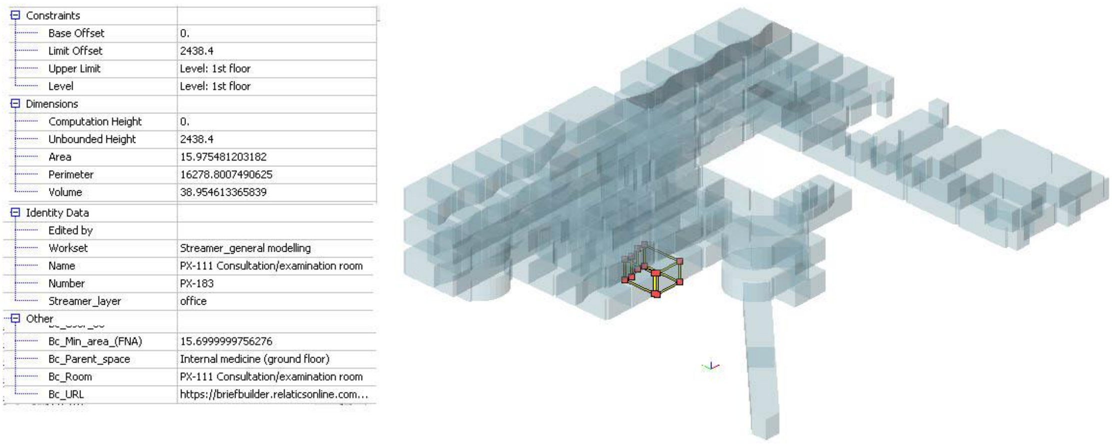


Figure 19: Combined screenshots from FZK viewer depicting an IFC file of the Rijnstate hospital extension with a room selected. The label values belong to the identity data.

The property values of the rooms and/or functional areas can also be visualized using color schemes:

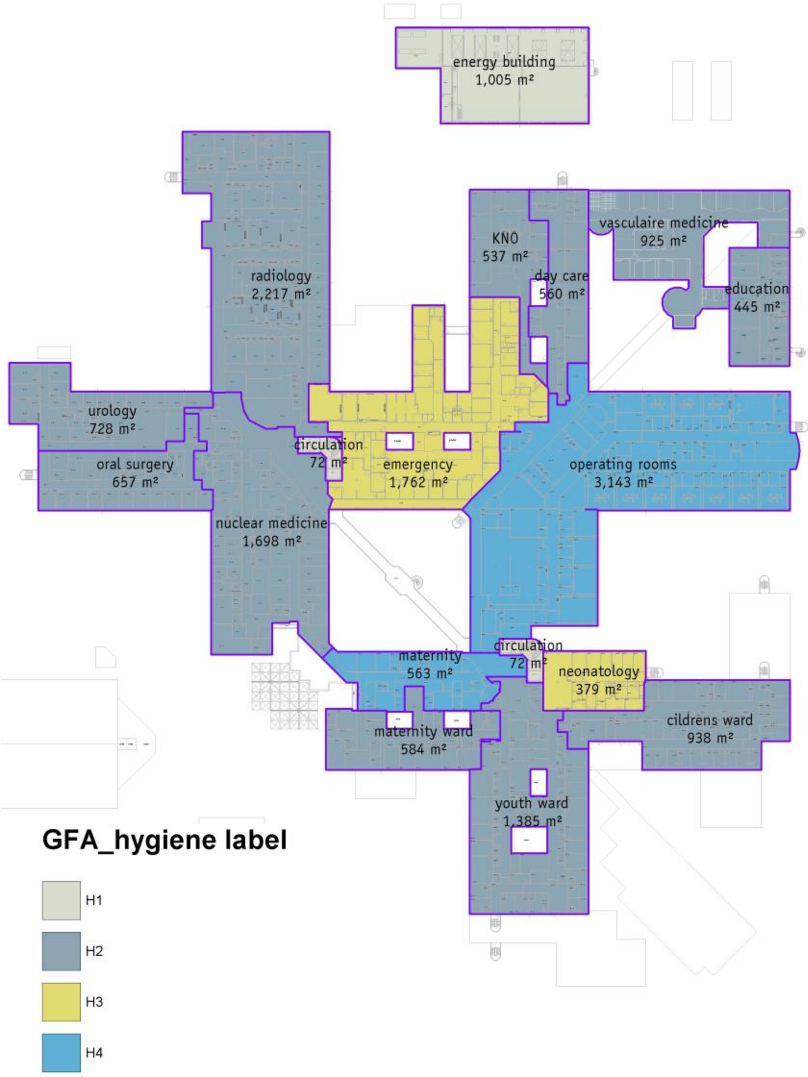


Figure 20 Screenshot from Revit depicting a floor plan of the Rijnstate hospital in which the hygiene label properties of a functional area have been assigned specific colors. (GFA = Gross Floor Area)

The MEP systems can be visualized in a similar way, in case this information would be added to the same rooms and/or functional areas in the architectural model. The floor plan will give insight into the distribution of functions with similar properties, making it easier for the design team to signal inefficiencies.

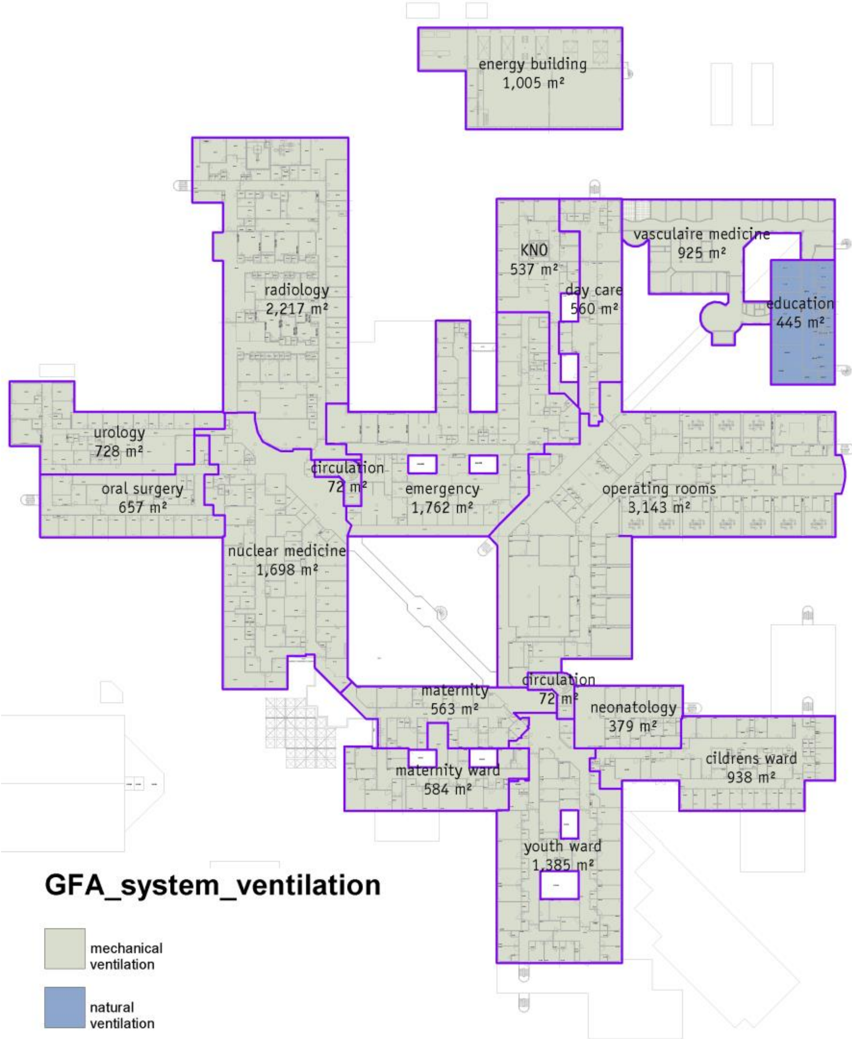


Figure 21 Screenshot from Revit depicting a floor plan of the Rijnstate hospital in which the MEP systems (ventilation) properties of a functional area have been assigned specific colors. (GFA = Gross Floor Area). Note: the values for natural/mechanical ventilation have NOT been verified by Rijnstate.

The database structure of the BIM allows schedules to be generated directly from the model. These schedules can be exported to excel format, which might create opportunities for automated design validation.

Schedule: 0_Area Schedule (GFA) - 240 streamer_model Rijnstate NO_nederpelts.rvt

2nd floor	KNO	536.5 m²	office	H2	mechanical vent
2nd floor	day care	559.6 m²	hotel	H2	mechanical vent
2nd floor	education	445.0 m²	office	H2	natural ventilatio
2nd floor	emergency	1762.3 m²	hot floor	H3	mechanical vent
2nd floor	operating rooms	3142.9 m²	hot floor	H4	mechanical vent
2nd floor	neonatology	378.8 m²	hotel	H3	mechanical vent
2nd floor	cildrens ward	938.0 m²	hotel	H2	mechanical vent
2nd floor	youth ward	1385.1 m²	hotel	H2	mechanical vent
2nd floor	maternity ward	583.7 m²	hotel	H2	mechanical vent
2nd floor	maternity	563.0 m²	hot floor	H4	mechanical vent
2nd floor	nuclear medicine	1697.6 m²	hot floor	H2	mechanical vent
2nd floor	urology	727.6 m²	office	H2	mechanical vent
2nd floor	oral surgery	657.4 m²	hot floor	H2	mechanical vent
2nd floor	radiology	2216.9 m²	hot floor	H2	mechanical vent
2nd floor	circulation	72.0 m²	other	H1	mechanical vent
2nd floor	circulation	71.6 m²	other	H1	mechanical vent
2nd floor	vasculaire medicine	925.3 m²	office	H2	mechanical vent
2nd floor	energy building	1004.8 m²	industry	H1	mechanical vent
		17668.0 m²			

Figure 22 Screenshot from Revit depicting a functional area schedule of the Rijnstate hospital that shows the properties of the functional areas. (GFA = Gross Floor Area)

Although the information supplied by this methodology should help the design team to better identify where and which improvements can be realized in existing hospitals, the methodology described here can be seen as no more than a very basic proof of concept. Further improvement of a method for mapping still depends on the following developments:

- Relatively simple design rules that adequately capture the often complex variables of a design situation have to be developed in D1.4 and D1.6. This sounds easier than it seems, because all KPI’s have to be taken into consideration to ensure a balanced result between energy consumption, financial performance and quality of the environment.
- It is unclear where the MEP properties belong in the BIM. Ideally they are attached to the same rooms and functional areas the labels are attached to. However, these belong to the architects’ model. Some testing (WP7) needs to be done; can the MEP properties be attached to the HVAC zone object inside the MEP model? If so, how can these properties be compared and visualised? Can existing model checking software provide this functionality (e.g. Solibri model checker)?
- Will this methodology lead to valuable insights on the functionality of the design configurator? If so, is automated mapping achievable?

3.5 Building envelope retrofitting

In a retrofitting project the building envelope (containing exterior walls, roofs, windows, etc.) cannot be neglected. Especially in the STREAMER process, where a holistic optimization of spatial configuration, MEP- and building envelope solutions for an energy efficient building is key.

It is possible to define three levels of retrofit intervention, depending on how many of these “aspects” the retrofit intervention involves:

1. Retrofit intervention on one level: it involves only the building envelope, or the space layout, or the HVAC systems (e.g. move of a department, replacement of a system, etc)
2. Retrofit intervention on two levels: the intervention operates on two different aspects among building envelope, space layout, HVAC systems (e.g. implementation of ETICS and replacement of the heating system, etc.)
3. Retrofit intervention on three levels: the intervention involves the building envelope, the space layout and the HVAC systems (e.g. extension of a wing or a floor, etc.)

In the scope of WP1 (D1.4) and WP2 (D2.2 and D2.5) all the possible retrofit scenarios will be defined.

BIM/model-based analysis is expected to improve collaboration between architects and building services engineers in early design phases. However, the energy aspects and the labels can hardly be related to individual building envelope elements. This makes the label-based methodology as demonstrated in previous paragraphs unsuitable to support the decision making process regarding building envelope configuration.

Also, not all building envelope improvements are dependent on MEP systems configuration. In general, better insulation and a higher level of air tightness are an improvement. In D2.4, already a lot of building envelope solutions have been listed and described in detail.

This doesn't mean there are no possibilities to validate the compatibility between the building envelope and the MEP systems. Again focusing on the major electricity users ventilation and lighting, two relations are quite obvious:

Artificial lighting systems can be switched off or turned down in rooms with windows during the day, and rooms that require natural ventilation should have a vent somewhere in the façade (usually integrated in the window). Yet despite the apparent simplicity of these relations, most hospital buildings still have the light on at maximum level right next to the windows and a lot of spaces in which natural ventilation would have been possible have no vents in the walls or windows.

To be researched is how the model checking can best be achieved. For instance, is it possible to check whether all the rooms with the property "natural ventilation" are bounded by a window supporting a vent? This is to be researched in D1.4, and/or in WP7.

This model checking method has a rather limited scope regarding building envelope configuration. We have to realize that building envelope configuration is highly dependent on project-specific technical, climate and orientation factors, which makes it very hard to incorporate these considerations into the STREAMER methodology. On the other hand, there is plenty of excellent literature available to designers regarding this subject, and the described STREAMER methodology can be followed independently of more complex building envelope configuration considerations.

4. Retrofit solutions in STREAMER hospitals

This paragraph describes the experiences of the four STREAMER hospitals with energy consumption and retrofitting projects. In D1.4, this information will be used to describe scenarios supporting the method introduced in Chapter 3, as soon as the inter-aspect schedule has been filled with information from other Work Packages.

The aim of these descriptions is to report the energy behavior of each hospital according to the building typology and the activity developed and, thus, to describe which retrofit solutions have a proven positive effect on energy consumption.

The analysis starts with the description of the functional layout of activity in relation to the building typology, the definition of the Bouwcollege layers areas and the energy consumption data, identifying also the most energy consuming factors for each case.

Moreover, the advantages and disadvantages of building typology in relation to energy and also the ones independent from the building typology are illustrated.

Then, the STREAMER hospitals provided information about retrofitting solutions (both MEP and architectural) that has proven/would prove positive in relation to energy consumption.

4.1 Rotherham hospital - UK

82,051 m^2 Gross floor area

Building typology:

Vertical 5 storey with 4 detached single storey buildings

Model:

Roof	Plant Rooms, Lift Rooms
A Level	Wards x 10; Central Stores; Linen Room; Mattress Decontamination Unit; Pharmacy Manufacture; Pathology Labs; Medical Physics; Restaurant; Coronary Care Unit; Angiography; Phlebotomy; Photopheresis; Clinical Engineering; Sterile Services; Nutrition & Dietetics; Offices
B Level	Wards x 10; Accident & Emergency; Orthopedic Clinic; Central Treatment; Theatre Admissions Unit; Operating Theatres; Clinical Radiology; Delivery Suite; Special Care Baby Unit; ITU/HDU; Medical Illustration; Offices
C Level	Wards x 2; Admissions & Reception; Outpatients Dept; Therapy Services; Dermatology; Endoscopy; Genito-Urinary Medicine; Pharmacy Dispensary; Day Surgery Unit; Children's Clinic; Breast Screening Unit; Cancer/Chemotherapy Suite; Bereavement Centre; Pre-Admissions Centre; Offices
D Level	Ward x 1; Library; Diabetes Centre; Medical Education; Lecture Theatre; General Management; Social Workers; Offices
E Level	Day Hospital; Offices

A Level = 5th floor (Top). Street level access

B Level = 4th Floor. Access via A & E Dept

C Level = 3rd Floor. Main entrance

D Level = 2nd Floor. Access via Education Centre

E Level = 1st Floor (Bottom). Access via Moorgate Wing

All levels have ground level access due to the undulation of the land

m^2 TRF layer model

Hot Floor	16,991 m^2
Industry	4,781 m^2
Hotel	19,714 m^2
Office	12,759 m^2

Energy consumption

Natural gas	36,553,450 kWh
Electricity	3,482,709 kWh
Total energy	**40,036,159 kWh**

CHP input fuel (natural gas)	21,843,635 kWh
CHP electricity generation	7,759,791 kWh
CHP thermal recoup	6,374,000 kWh

Major Energy consumption

Ventilation

Cooling

Heating

Lighting

Small power

Advantages / disadvantages Building Typology in relation to energy

Advantages:

Only 5 storeys relates to a lower energy consumption attributable to lifts when compared to a high rise building. Also there would be fewer lifts required, again resulting in a reduction in energy

Rooftop plant rooms are situated very near to the areas that they serve, allowing for easier access and repairs / fault finding. All services, and dry and wet risers are therefore kept local to the areas served.

A HV ring main serves all sections of the site via sub stations, rather than having one central distribution point. Logistically this is sensible and is an advantage during power outages and shutdown work. Several generators supply various areas in the event of power failure

Pumping heat from services on a low rise building would not be as energy intensive as a high rise

Disadvantages:

This typical 1970s building has a large proportion of wooden framed single glazed windows which are very energy inefficient.

On a high rise building there may be sub stations on different levels resulting in less cable run and voltage drop, but with a site that is spread over a large area, such as Rotherham Hospital, there may be substantial losses around the HV ring and between the transformers in the substation and the building

Due to the slope of the land the top floor is the largest by area and subsequently this results in a very large rooftop area, which will allow for more heat to escape than in a narrower, high rise building

A low rise, wide plan building like Rotherham would result in courtyards being utilised and this would require more artificial lighting as natural daylight would be reduced due to this design feature.

Advantages / disadvantages energy (independent, not related to building typology)

Advantages

- Most areas now have local heating controls. Ward areas are being upgraded at present.

- Pneumatic controls are being replaced and upgraded with electrical controls.
- Energy efficient lighting is being installed to replace older inefficient models.

Disadvantages:

- 50% of AHUs and pumps are not inverter driven, therefore energy savings are lost
- Main boilers are old and inefficient
- CHP/Boiler arrangement is not designed so as to optimise heating infrastructure
- Boiler controls are not configured so as to cycle boilers and prevent damage due to excessive running
- 70% of AHUs are older plant and require upgrading

- **Earlier projects**
- Installation of LED lighting
- Improvements to BMS hardware and software
- Installation of pipe insulation site wide

Data / findings monitoring

HVAC	15% of the electricity consumption
Lighting	15% of the electricity consumption
Cooling	30% of the electricity consumption
Heating	40% of the electricity consumption

Scenario's MEP systems

Various interventions have been identified that will improve building energy efficiency including:

- Installation of LED lighting complete with presence/absence control and dimming
- Underfloor heating
- Acoustic ceilings
- Thermal insulation to walls
- Triple glazing
- Improved heating controls and time scheduling

4.2 Rijnstate hospital - NL

81.477 m^2 (BVO)

Building typology:

Podium with 1 (2 connected) towers

Model

9	Elevator		
8	Elevator	Elevator	
7	Clinic	Clinic	
6	Clinic	Clinic	
5	Clinic	Clinic	
4	Cl. + CCU + IC/MC	Cl.+ Dotter	
3	Technigue: HVAC		
2	Out Patient, Offices, Restaurant, Auditorium, Facilities, Pathology Labs		
1	Operating Theatre, Acute, Radiology, Nucleair Labs, Gynecology, Childrens Ward,		
G.F.	Out Patient, Dialyses		Technique
B	PET/CT, Services, Sterile services		Technique

G.F. = Ground Floor

B = Basement

1 = 1st layer

2 = 2nd layer

…

m^2 TNO layer model

Total	81.477
Hot Floor	2.145
Industry	1.379
Hotel	14.308
Office	28.379
General	22.537
Technical	9.719
Lease	3.010

Energy consumption

Natural gas 3.464.514 m3 = 109.652 GJ*

Electricity 7.259.655 kWh = 26.135 GJ

Total energy = 135.787 GJ

135.787 GJ / 81.477 m2

1,66 GJ / m^2 bvo

Turn over 337,6 mln

GJ/turn over

135.787 / 337.600.000

402,21 GJ / mln turn over

*34.377 GJ Boiler and 75.275 GJ CHP (co-generation)

Major Energy consumption

Air distribution

Lighting

Cooling

Heating

Energy consumption

HVAC 25% of the electricity consumption (calculated)

Lighting? (estimated 25 % of the electricity consumption)

Cooling? (estimated 10 % of the total energy consumption)

Heating? (36% of the total energy consumption)

Advantages / disadvantages Building Typology in relation to energy

Advantages:

- Departments Out Patient are located on the ground floor. Other departments which have relation together are located on the same level/area. As result, short walking distances and less elevator use.
- The building has sun protection.
- Ventilation equipment is located in the centre of the building (3rd floor). This means less infra of airducts and energy consumption.
- General technical equipment (Heating, Cooling, Steam, Plumbing, Electrical) are located in a technical building near the main building. As result, easy accessible for maintenance, conveniently arranged
- Energy exchange because of small distances between central installed equipment

Disadvantages:

- Air Handling units which take the fresh air from the wood site of the building needs very frequent maintenance (changing filters).
- The façade frames 1995 insulating capacity is not optimal.
- Extension the existing building with 10.000 m2.

Advantages / disadvantages energy (independent, not related to building typology)

Advantages

- Energy efficient lighting and daylight controlled lighting is being installed in last and coming up projects.
- Pneumatic controlled equipment (fire dampers, control valves) are upgraded to electrical controlled.
- The fresh air ducts are insulated insite are upgraded to extern insulated ducts.
- 15 % Air handling units and pumps upgrading to inverter driven.
- Some AHU's installed change over systems heating/cooling.

Disadvantages

- Insulating value facade/roof (technology 1995 compared to 2015)
- Generation through CHP 1995 less efficient
- Energy loss because of long distribution systems and insulation aging.
- Building Management System 1995, functional not high efficient.
- In 1995 all Air handling systems and central heating systems high temperature heating.
- In 1995 all Air handling systems low temperature cooling.
- Electrical system has 4 preference circuits. This is confusing and complex in maintenance.
- The fresh air ducts are insulated inside. After 20 years of use the ducts have large pressure loss.
- 85 % of air handling units and pumps are not inverter driven.
- Built in 1995, not the latest high efficient.

Advantages / disadvantages retrofit solutions related to building typology

Advantages

Central power plant, central heating, central steam: easy to maintain, replace

Easy to fit in a smart grid

Extension the existing building with 10.000 m2 with state of the art MEP solutions.

Retrofit the MEP systems of the existing building with state of the art solutions.

Some examples

Earlier, now and future projects

Building

Triple glazing

Sun protection (screens)

Use efficient facades

Solar roof

Electrical
Use green electricity
LED lighting
Day light controlled
Movement controlled lighting

Mechanical
Efficient ventilation (displacement ventilation)

Scenario MEP systems
Solar water heater
Heat pumps
Efficient CHP
Aquifer system
City heating
AHU's and pumps inverter driven
AHU's: Change over systems heating/cooling.
AHU's: High temperature heating upgrading to low temperature heating.
AHU'S: Low temperature cooling upgrading tot high temperature cooling.
AHU'S: More efficient heat recovery
Low steam pressure were possible
Upgrading BMS
Permanent BMS and energy monitoring

Energy consumption future
Our target-objective is to use the same amount of energy after 10.000 m^2 extension and retrofitting as we use now.

4.3 Careggi hospital - IT

San Luca Vecchio: 278 space units - 57 beds - 3,615 m^2

San Luca Volano: 242 space units - 4.662 m^2

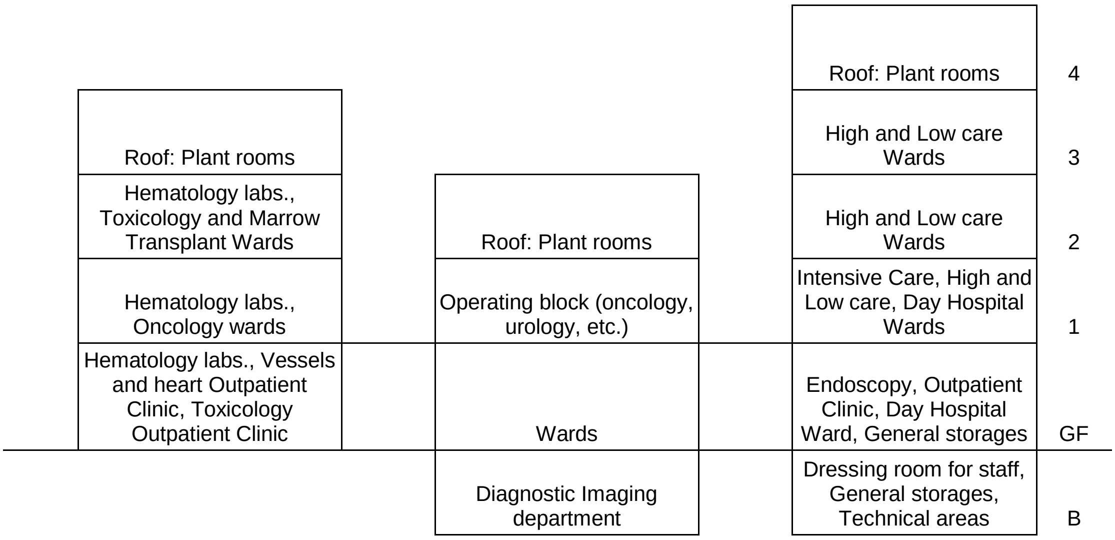
San Luca Nuovo: 817 space units - 219 beds - 13,784 m^2

Whole area of the San Luca complex: 22,061 m^2

Building typology:

Linked pavilion or finger plan

Model:



m^2 layer model

Hot Floor 2331 m^2

Industry 6140 m^2

Hotel 10210 m^2

Office 3380 m^2

Energy consumption

Current total electrical energy use 4,296,500 kWh_e/year: (average 2008-2012)

Current total heat demand 2,438,500 kWh_P/year: (average 2008-2013) *note*: requirements associated to heating thermal end uses are expressed in terms of primary energy - fuels: natural gas and fuel oil BTZ – considering the correspondent lower calorific value

Current total cooling demand kWh/year: 953,500 kWh_P/year note: estimated through an evaluation of the summer peak of the electric demand

Major Energy consumption

Heating 20-25 %

Cooling 15-20 %

Lighting and other plants/appliances 55-65 %

Lighting about 20 %

HVAC about 25 %

Appliances about 10 %

Note: the figures above have been calculated considering the available data published in the Deliverable 7.5 considering all the items in terms of primary energy. Data are available only for San Luca Nuovo and San Luca Volano.

Advantages / disadvantages Building Typology in relation to energy

Advantages:

- The two buildings San Luca Nuovo and San Luca Volano have thermally-efficient modern envelopes since they have been recently refurbished/built. Elements of the envelopes in both cases show acceptable U values for both opaque and transparent items.
- Top floors of the buildings normally consist in unoccupied rooms: there buffer spaces below the rooftop areas acts as buffer zones modulating the more intense thermal stress occurring during daytime major heat gains in winter, cooling loads in summer;
- In San Luca Vecchio pavilion technical areas are located beyond the last floor used by the facility, in San Luca Nuovo the buffer zones extend for over the 70 % of the last floor ceilings, whereas the reaming 30 %, even though is dedicated to technical end uses as well, is in direct contact with outdoor air failing in their buffer task.

Disadvantages:

- San Luca Vecchio is an old building that is very obsolete in terms of its envelope showing U-values that are far from be efficient. These building have also a large proportion of wooden framed single glazed windows with poor U-values.

Advantages / disadvantages energy (independent, not related to building typology)

Advantages

- Temperature sensors are very widespread in all the three buildings.
  San Luca Volano shows the most sophisticated technologies since the presence of the operating theatres, however even in Sal Luca Nuovo, all the clinics and the in-patient spaces are provided by thermostats. In San Luca Vecchio an indirect control is possible thanks to some gauges installed within the return duct of the heating circuit.
- AHUs fans and pumps are inverter driven In San Luca Nuovo and San Luca Volano buildings.
- The new large Careggi CHP serve the three buildings providing electricity and recovered steam to almost all the indoor spaces at a very high energy efficiency.
- Absorption chillers help in recovering exhausted heat during the summer operations of the CHP increasing the overall efficiency of the processes.

Disadvantages:

- At present lighting systems are not so efficient (modern lamps, led etc, are installed only in few areas of the three buildings).
- Some old boilers still operate serving some limited areas in San Luca Vecchio pavilion.
- Many obsolete splits/AHUs are installed at room levels achieving their task in a very inefficient way because of their obsolescence and the lack of optimization in their operational schedule. The 80 % of these machines are in San Luca Vecchio, whereas the remaing 20 % operate in San Luca Nuovo Pavilion.

- **Earlier projects**
- Installation of the large CHP providing electricity, heating and cooling to the three pavilions and many other departments and buildings of Careggi health district;
- Installation of Absorption Chillers to further increase the overall efficiency of the CHP recovering wasted heat during summer;
- Improvements to SACS software

Scenario's MEP systems

Various interventions have been identified that will improve building energy efficiency including:

- Installation of LED lighting complete with presence/absence control and dimming;
- Thermal insulation to walls in San Luca Vecchio building;
- Triple glazing in San Luca Vecchio building;
- Improved heating controls and time scheduling in San Luca Vecchio building;
- Solar roof (photovoltaic systems have to be preferred);
- Use green electricity;
- LED lighting to be adopted in all the three pavilions;
- Replacement of local single room splits/AHUs extending the areas served by the central plant if and where it is possible;
- AHU'S more efficient heat recovery;
- Permanent BMS and energy monitoring;
- Installation of local (Department levels) heat and power meters in order to compare the sanitary activities that take places in the different parts of the buildings and to understand which have to be considered the priority of intervention in sought of the fulfilment of an enhanced energy efficiency.

Energy consumption future

The targets are:

- to further optimize the demand in San Luca Nuovo and San Luca Volano
- to strongly enhanced the energy efficiency of San Luca Vecchio, if necessary considering heavy Intervention of refurbishments.

4.4 APHP - FR

Gaston Cordier building (located in the “Pitié Salpétrière” Universitary healthcare district)

26,300 m² (net floor area)

Building typology:

Vertical 8 storey

Model:

8. Mechanical rooms	
7. Orthopaedic hospitalization Orthopaedic administrative offices	
6. Orthopaedic hospitalization	
5. Urology hospitalization Urology and kidney transplant administrative offices	
4. Urology and kidney transplant consultations Urology hospitalization Urology and kidney transplant outpatient surgery	
3. Nephrology hospitalization and consultations Hemodialysis center	
2. General, visceral and endocrinal hospitalization and consultations	
1. Care unit	
GF. Emergency and radiology	
B1. Operating rooms - Mechanical rooms	

Energy consumption (estimate)

Electric consumption: 7,000,000 kWh (estimate) (around 266 kWh/m²)

Thermal consumption (steam): 6,100,000 kWh (estimate) (around 232 kWh/m²)

TOTAL energy consumption = 13,100,00 kWh

Major energy consumption

Heating

Cooling

Ventilation

Lightning

Medical technology – Offices

Advantages / disadvantages Building Typology in relation to energy

Advantages:

- The location of the mechanical rooms make it possible to reduce distance with the areas they serve (less losses of energy exchange)
- Percentage of glazing within the wall is important

Disadvantages:

- Gaston Cordier is representative of a lot of buildings built at the end of 1960's / beginning of 1970's i.e. this building is very energy-consuming and its facades are porous (infrared thermography performed shows important thermal bridges around the windows (double glazing with roller blind) and inside insulation dates back the construction)
- The solar orientation was not taken into account for the construction of the building (no optimisation of the natural daylight – some offices/nursing stations, etc. do not have access to direct sunlight in spite of the numerous windows in the building).

Advantages / disadvantages energy (independent, not related to building typology)

Advantages:

- BMS implemented for AHUs that serve 12 operating rooms, sterilisation and recording gallery, outside corridor, annexe room, emergencies, recovery room, labs
- The district heating system is supplied by the urban heating network
- HV ring on the site
- Redundant transformers (less important losses)

Disadvantages:

- There is no meter on the building which would make it possible to know precisely the electricity and heating consumption
- In the corridors, the lamps run 24/7. In the rooms, there are managed by the patients.
- No regulator on pumps and AHU
- The delivery units (for heat) are static heating radiators (with no thermostatic valves).
- Lot of heat provided by urban heating network the is lost (no recovery system)
- Several AHUs are old and require upgrading
- Every operating room has its own inverter
- There is no transformer with reduced losses
- There is no air recovery system for the AHUs.

Earlier projects

- Installation of low energy consuming lighting (e.g. LED)
- Pipes insulation

Data / findings monitoring

Main electricity consumptions (estimate)

Cooling	25% of the electricity consumption
Ventilation	23% of the electricity consumption

Lighting	16% of the electricity consumption
Medical technology – Offices	16% of the electricity consumption
Sterilization workshop	7% of the electricity consumption

Temperatures

Hospitalization :

- summer : outside temperature

- winter: 22°

Operating rooms, emergencies, intensive care, radiology, sterilization: 22° (winter and summer)

Scenario's MEP systems?

- Installation of motion detectors / infra-red sensors
- Active facades
- Wall insulation

5. Current and future developments in STREAMER

5.1 Expected content of D1.4

In D1.4, retrofit scenarios for common and generic situations will be developed by following the method described with a matrix in D1.3, Chapter 3. The matrix, in which expert knowledge about energy consumption, label properties of BIM elements, and energy aspects are related, is dependent on content coming from WP 1, 2 and 7.

The experiences of the four STREAMER hospitals will be used to test the methodology in order to select energy efficient retrofit solutions for specific situations in hospitals.

Optimization measures will be combined into scenarios, and take into account the most common practical, "real-life", complexities hospitals face, such as temporary moving, disturbance of the primary process, etc.

The method here defined should address the main energy-related problems. Starting from the findings of the analysis conducted in chapter 2, it is possible to define and classify the factors that influence the energy behavior of the hospital at each scale level.

Based on the analysis, ventilation and lighting are the largest users of electricity in healthcare premises, also in hospitals and larger medical centers with electricity-demanding clinical equipment. Medical equipment only corresponds to 6 % of the electricity used (for other purposes than heating), of which X-ray equipment constituted the largest user.

In addition, the building base analysis revealed that compactness, deep and narrow floor plans also influence energy consumption. According to that, it is possible to conduct energy evaluation at the most appropriate level and to identify the object of potential optimization in a retrofitting intervention. Indeed, each factor should be related to the object of intervention it affects, whether it is a building component, an HVAC component or the functional layout of the building. Indeed, as STREAMER proposes a design process in which a holistic optimization of spatial configuration, MEP- and building envelope solutions for an energy efficient building is key, this would guide the designer in the identification of the level of intervention to apply.

Therefore, the retrofit scenarios would be classified according to the levels of retrofit intervention as described in this deliverable:

1. Retrofit intervention on one level: it involves only the building envelope, <u>or</u> the space layout, <u>or</u> the HVAC systems (e.g. move of a department, replacement of a system, etc.)
2. Retrofit intervention on two levels: the intervention operates on two different aspects among building envelope, space layout, HVAC systems (e.g. implementation of ETICS and replacement of the heating system, etc.)
3. Retrofit intervention on three levels: the intervention involves the building envelope, the space layout and the HVAC systems (e.g. extension of a wing or a floor, etc.)

Of course, this process should be translated and included in the semantic interface. As a result, it will define the key steps in which the design team can dialogue with the BIM in order to make the best choice to achieve the energy optimization.

Moreover, based on the key energy-related factors emerged from Chapter 2 on energy profiles, it will be possible to make progress in the definition of the labeling system, first introduced in D1.1 and then elaborated in D1.5.

Therefore, the process would lead to define in detail which are the most crucial and influencing labels and to clear the system from the ones not essential within the aim of STREAMER project.

Here after follows a table that describes the process here defined. The table (table 7) would be attentive elaborated and improved within the D1.4 scope.

Scale Level	**Energy related factors**	**Object of potential optimization in a retrofitting intervention**		
		Building systems and components	**HVAC systems and components**	**Functional layout**
DISTRICT	Buildings layout configuration			**X**
	HVAC configuration		**X**	
	….			
BUILDING	Building layout			**X**
	Ventilation concept	**X**	**X**	
	Daylight	**X**	**X**	
	Compactness, mass			**X**
	Envelope technical solution	**X**		
	Bouwcollege layers		**X**	**X**
	...			
FUNCTIONAL AREA	Departments layout	**X**	**X**	
	Connections and proximities			**X**
	Operational usage		**X**	
	Bouwcollege layers			**X**
	….			
ROOMS	Ventilation system		**X**	
	Lighting system and control		**X**	
	Medical equipment		**X**	
	Comfort level	**X**	**X**	
	….			

Table 7

D1.4 will also describe design rules which will be elaborated starting from the results of the analysis here developed on energy demand profiles (activity and building based energy analysis) to determine where we can make the best effort in realizing a significant energy reduction.

5.2 Dependencies with other STREAMER tasks

STREAMER deliverables that have provided input for D1.3 are:

- D1.1; relation between building typology and energy-related features
- D1.5; relations between BIM elements, energy aspects and labels
- D3.1; definitions of the KPI´s
- D7.3; test of the labels system on Rijnstate hospital

This deliverable will allow the following actions to be taken in other STREAMER deliverables:

- WP1; Due to the strong kinship between the methodology for retrofit and new building design, the methodology described in this deliverable will be used for upcoming deliverables in T1.2 and T1.3
- WP2; the mapping methodology described in chapter 3 will need to be supported by the descriptions and properties of MEP systems in WP2. This goes for the demand side (activity) as well as the supply side (building solutions). The emphasis on systems contributing most to energy reduction should be driven by conclusions from energy research. The research conducted here in chapter 2 could be a good starting point.
- WP5; the "building blocks" with parametric and semantic properties can be defined to support/ make possible the mapping methodology described in chapter 3.
- WP7; The test cases are ideal opportunities to test the methodology described here. Testing in a real situation is required to validate if the method described in this deliverable provides a workable solution. Due to the holistic nature of the approach, partners from WP2 should actively contribute to this effort.

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