SEVENTH FRAMEWORK PROGRAMME OF THE EUROPEAN COMMUNITY
(EC GRANT AGREEMENT N° 26088)

ICT PLATFORM FOR HOLISTIC ENERGY EFFICIENCY SIMULATION AND LIFECYCLE MANAGEMENT OF PUBLIC USE FACILITIES

Deliverable D9.2.2:
Recording evidence on benefits and costs
[final specification]

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0.2	Introduction and functionalities of the HESMOS IVEL	M.C. Geißler (BAM-DE)	28.02.2013
0.3	Methodology to report benefits of process, building performance and cost optimisation	M.C. Geißler (BAM-DE)	07.06.2013
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Project of SEVENTH FRAMEWORK PROGRAMME OF THE EUROPEAN COMMUNITY		
Dissemination Level		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Executive summary

The main objective of WP 9 is to validate the operation of the selected public use facilities comparing current practice and new capabilities enabled by HESMOS developments using the defined energy-related Key Performance Indicators as well as expert rules and procedures.

The work package is structured into four **tasks**:

- T9.1 Requirements synthesis and energy-related key performance indicators (eKPIs)
- T9.2 Recording evidence on benefits and costs (initial and final specification)
- T9.3 System deployment and pilot demonstrators
- T9.4 Evaluation of the deployed system and further needs

This deliverable covers task T9.2.2 Recording evidence on benefits and costs [final specification] of the work performed in WP9 and comprises:

- Introduction of the HESMOS Integrated Virtual Energy Laboratory (IVEL), including its functionalities and components
- Description of the methodologies to report evidence on benefits and costs, including the benefits of process and building performance optimisation and the implementation costs
- Report of the benefits and costs on the performed pilot projects with regard to process and building optimisation
- Conclusions

The deliverable report is structured into **4 parts**.

In the **first part** the HEMOS IVEL, its components and the functionalities of the specific life cycle phases design and tendering, operation as well as retrofitting and refurbishment is introduced. The **second part** provides a set-up of methodologies to report evidence on benefits and costs. The methodology to report benefits on processes comprises the comparison of conventional processes performed on the pilot projects and the standardised processes supported by HESMOS IVEL as well as the documentation of “reduction in process time” which influences process costs and of “optimised process quality” which influences employee satisfaction. The methodology for reporting of “optimisation of the building quality” comprises previous defined energy – related Key Performance Indicators (eKPI) - final energy, greenhouse gas emissions, thermal comfort and life cycle costs – for comparison of design alternatives during early design phase. Additionally, a Measurement & Verification (M&V) plan according to the International Performance and Verification Protocol (IPMVP) had to be set up to document energy conservation measures and energy, CO_2 as well as cost savings. In the **third part** the HESMOS IVEL is validated on the two pilot projects of BAM Deutschland AG. The analysis of the processes comprises the expert point of view that compared their former way of working on the pilot projects with the new capabilities of the HESMOS IVEL. In addition the optimisations of the building quality and costs are documented in a sustainability assessment as well as a Measurement and Verification Plan. Finally, the **fourth chapter** summarises the conclusions of this deliverable.

Three partners were involved in the RTD work:

- **BAM**: Overall WP9 coordination, contributions in design optimisation, realisation and operation of PPP projects as well as two pilot projects for the validation of the HESMOS IVEL. BAM provided also various experiences in BIM technology and processes and is the main author of the deliverable report.
- **OPB**: Contribution of its experience in energy-efficient design and engineering as well as energy consulting and result testing
- **TUD-CIB:** Structuring, reviewing, editing and final approval of the report.

1 Introduction to the HESMOS IVEL

The HESMOS Integrated Virtual Energy Laboratory (IVEL) is a web-based design and lifecycle management platform based on an energy-enhanced Building Information Model (eeBIM). The integrated project team can log in to the HESMOS Virtual Energy Laboratory from everywhere where internet access is available and provide their data centrally for simulations, monitoring and decision-making. For the design phase the HESMOS IVEL supports decision-making among different building shell design alternatives and during operation phase sensor data from Building Automation Systems (BAS) can be monitored regarding system performance of ventilation equipment as well as thermal comfort conditions.

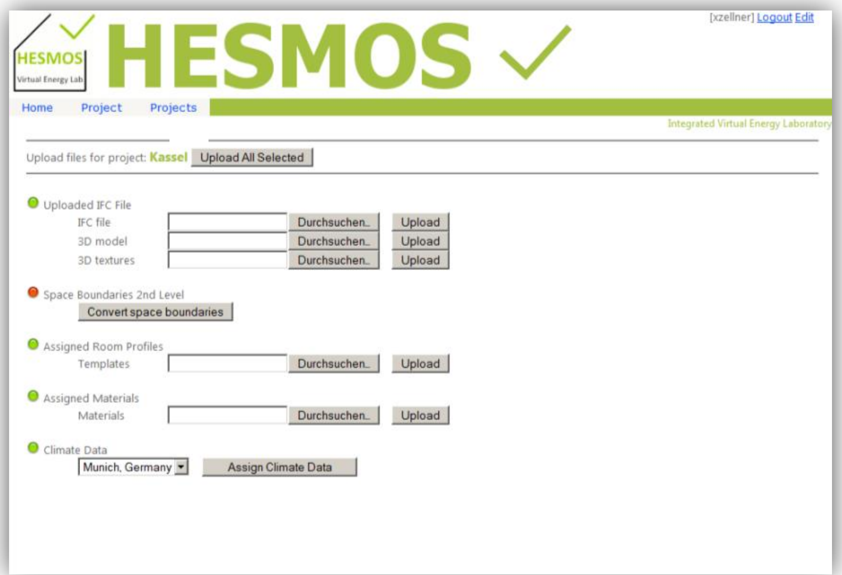


Figure 1: HESMOS Integrated Virtual Energy Laboratory

1.1 Components of the HESMOS IVEL

The main components of the HESMOS IVEL are:

- **Design Module:** A CAD system which supports the design team by establishing a 3D model for model based quantity take off, energy simulations as well as facility management.
- **Energy Computing Module:** Energy solvers which support energy simulation of construction elements, single spaces as well as the overall building, based on energy-enhanced Building Information Model data.
- **Reporting and Analysis Module:** A post-processing module for analysis of simulation results and recording of energy-related Key Performance Indicators (eKPIs).
- **Public Access Module:** A navigator which provides the results of energy performance simulation regarding energy-related key performance indicators (eKPI) for informed decision-making in all lifecycle phases.
- **Monitoring Module:** Intelligent access services to Building Automation Systems (BAS) incorporate BAS data in simulation studies and control strategies.

- **Facility Management Module:** WebROOMEX to monitor thermal comfort conditions and Granlund Manager Metrix to monitor system performance.

1.2 Functionalities of the HESMOS IVEL

The HESMOS IVEL components provide different types of functionalities. In this chapter an overview of HESMOS components and their respective functionalities is provided for the building life cycle phases design and tendering as well as operational and optimisation phases.

1.2.1 Design and Tendering Phase (Use Case 1)

During the design and tendering phase, the HESMOS Integrated Virtual Energy Laboratory facilitates decision-making to identify the optimum type of the buildings shell components (roof, exterior walls and windows) by transparently comparing different alternatives early in the design process. The design scenario and the functionalities of the HESMOS IVEL are described step by step in the following flow chart.

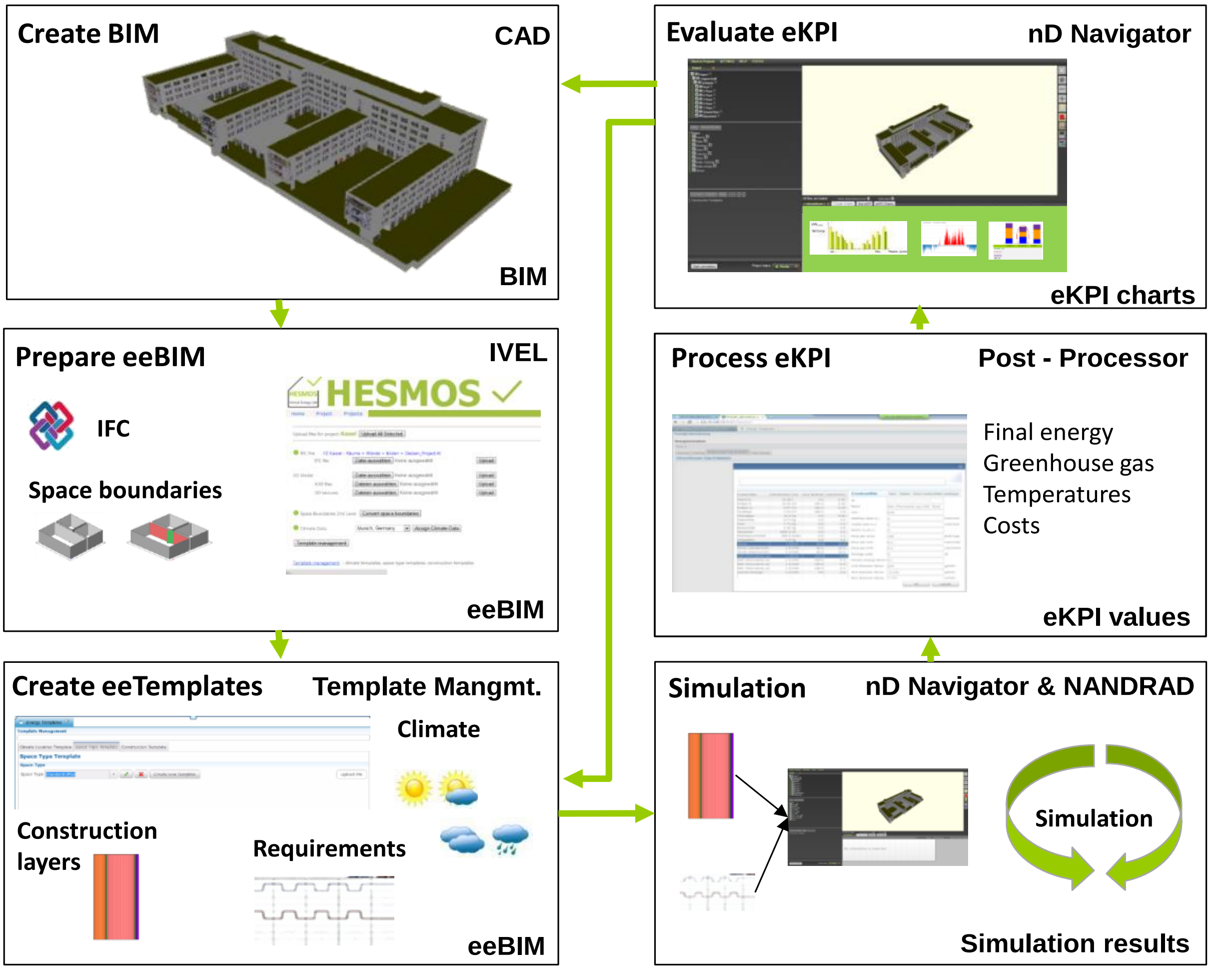


Figure 2: Guidance through the Design Scenario

Create the Building Information Model (BIM)

As basis for quantity take off, comfort and energy simulations the 3D geometry model should be created according to modelling standards. For these purposes it is necessary that e.g. parts of the building shell which should have different qualities are modelled as separate elements. In the early design phase it is sufficient that e.g. the walls are created as one layer and enriched with construction type templates including all building physical properties from IVEL data base, because alternatives should be analysed first before detailing the model.

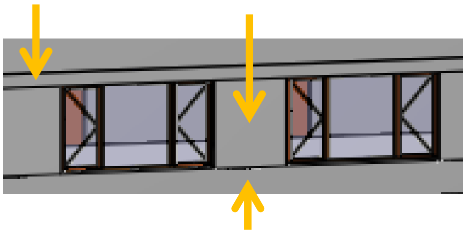
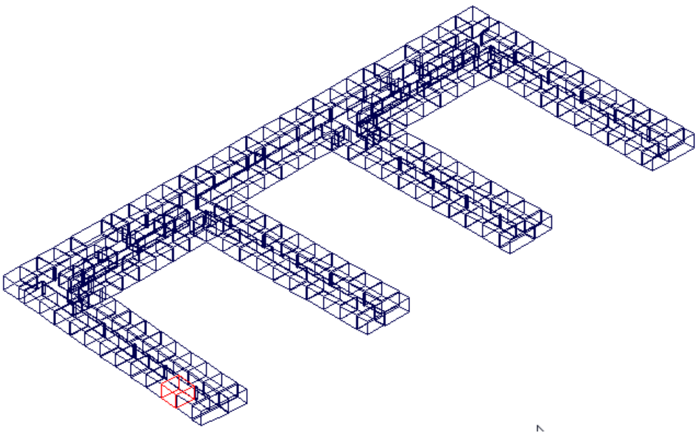


Figure 3: Differentiation of elements with different qualities

For an easy enrichment of the model with standard templates from the data base it is necessary to agree with the architect on a naming convention. To fasten the requirements management process the architect should give the rooms besides the name and function a classification, in HESMOS we use the DIN 277 classification, because both pilot projects are in Germany, that the requirements from EU norms or specific client requirements do not have to be mapped room by room but can be mapped to the group which belong to the same classification.



1.1	LivingArea
1.2	Lounge
1.3	Lounge
1.4	WaitingRoom
1.5	DiningArea
1.6	DetainingRoom
2.1	StandardOffice
2.2	StandardOffice
2.3	MeetingRoom
2.4	TechnicalDrawingRoom
2.5	TicketHall
2.6	StandardOffice
2.7	StandardOffice
2.8	OfficeEquipmentRoom
2.9	StandardOffice
3.1	Workshop
3.2	Workshop
3.3	CommonLab
3.4	CommonLab
3.5	CommonLab
3.6	PlantAnimalBreedingLab
3.7	PlantAnimalBreedingLab
3.8	Kitchen
3.9	SpecialLab
4.1	CommonStore
4.2	CollectionRoom
4.3	ColdStore
....	

Figure 4: Classification of rooms

Prepare the energy-enhanced Building Information Model (eeBIM)

To prepare the BIM for simulations and estimation, it is uploaded as IFC file – the standard exchange format - in the nD Navigator, the web-based graphical user interface of HESMOS IVEL. Once uploaded to the nD Navigator the first level space boundaries defined by surfaces of the building elements are converted for thermal energy simulations to second level space boundaries which are subdivided in any of the following cases: differences in materials and/or material assemblies, differences in spaces or zones on the other side of the building etc. And the climate data has to be uploaded either as test reference year from the German weather service or as measured weather data from the location where the project should be realised.

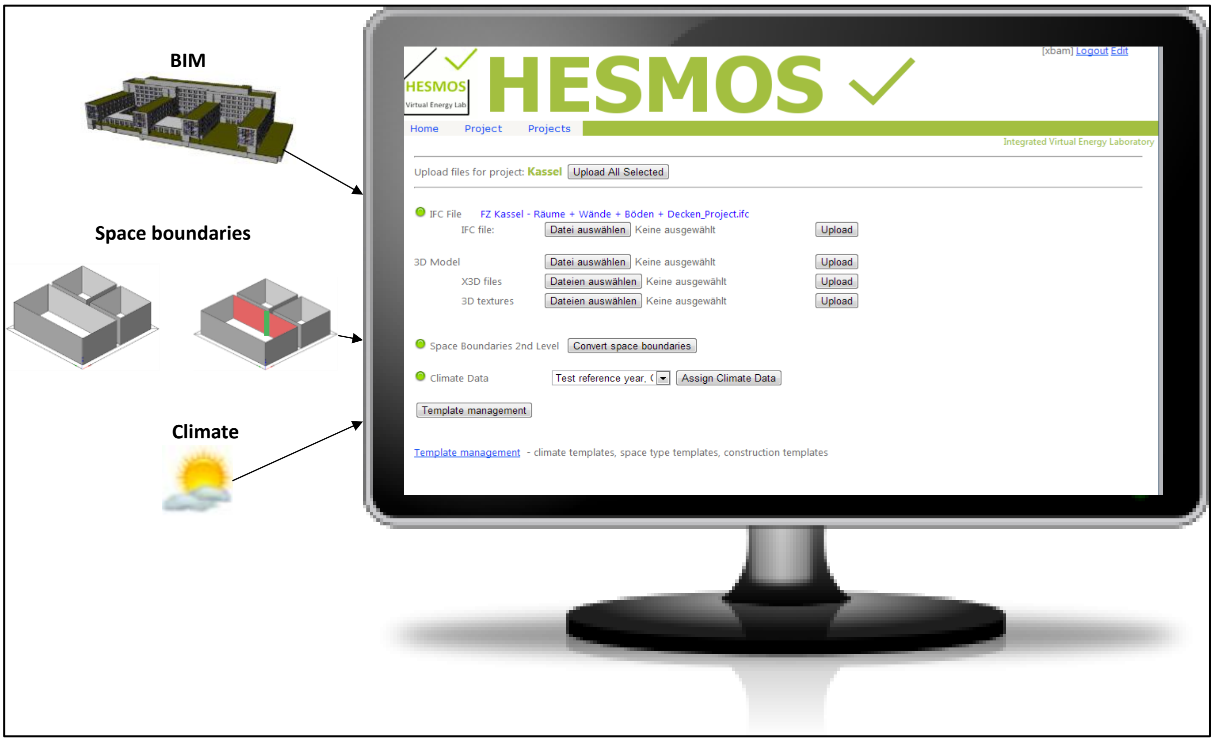


Figure 5: HESMOS platform – upload of IFC and conversion for simulations

Create eeTemplates to enrich the model

In an early design phase if a relatively simple model is provided by the architect and the alternative with the best cost-quality ratio should be identified, sets of material properties which define a construction type can be chosen from the HESMOS IVEL data base or can be created on the Graphical User Interface (GUI) of the data base to enrich the model. In these construction templates there is also the possibility to assign a cost figure for the specific construction type as input for LCC estimation and comparison of alternatives. Additionally, on the HESMOS IVEL data base there are also space templates available as a predefined set of parameters from EU norms e.g. min./ max. temperatures, air flow rates etc., which can also be adapted according to specific client requirements.

Space Templates

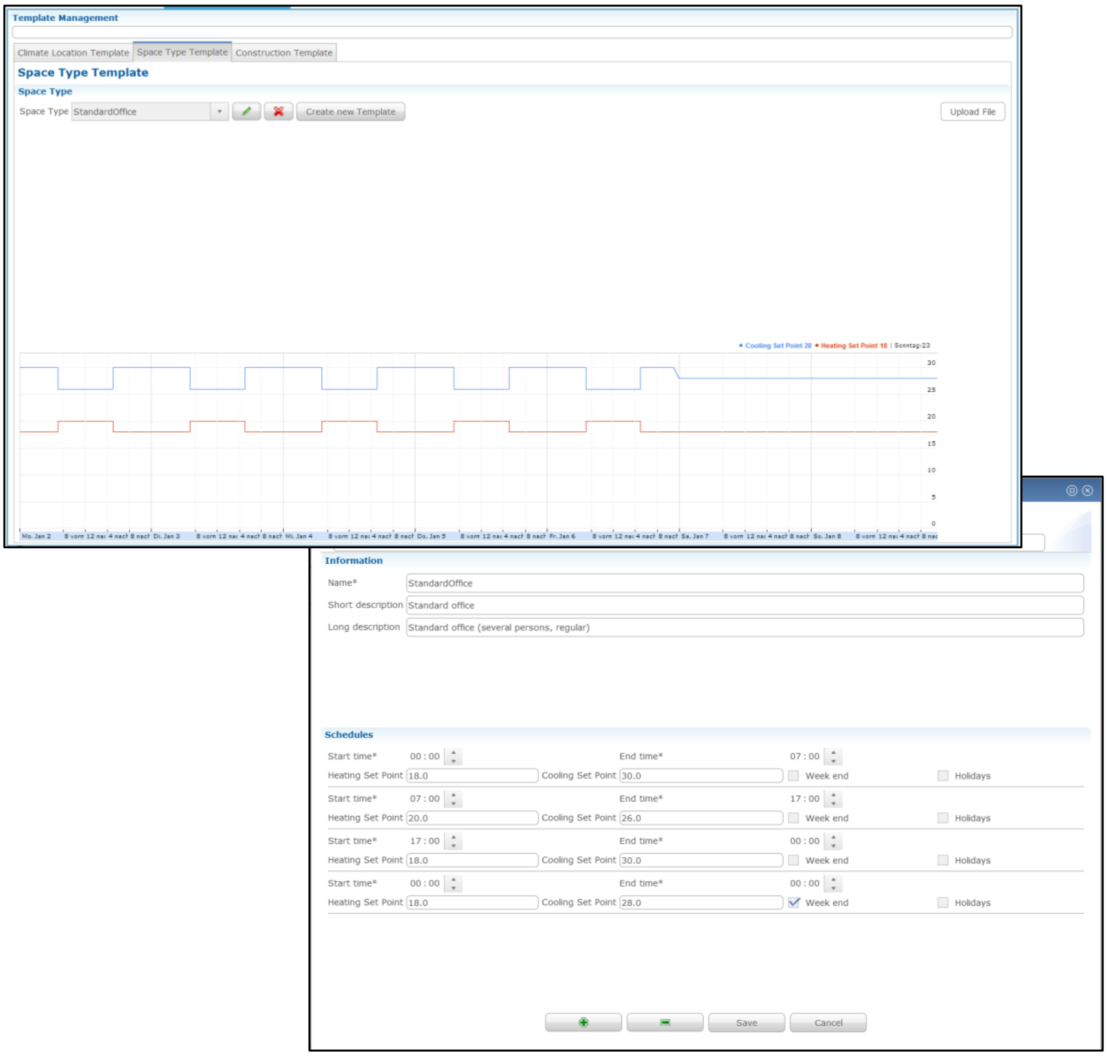


Figure 6: Standard Space Templates on the IVEL data base

Construction Templates

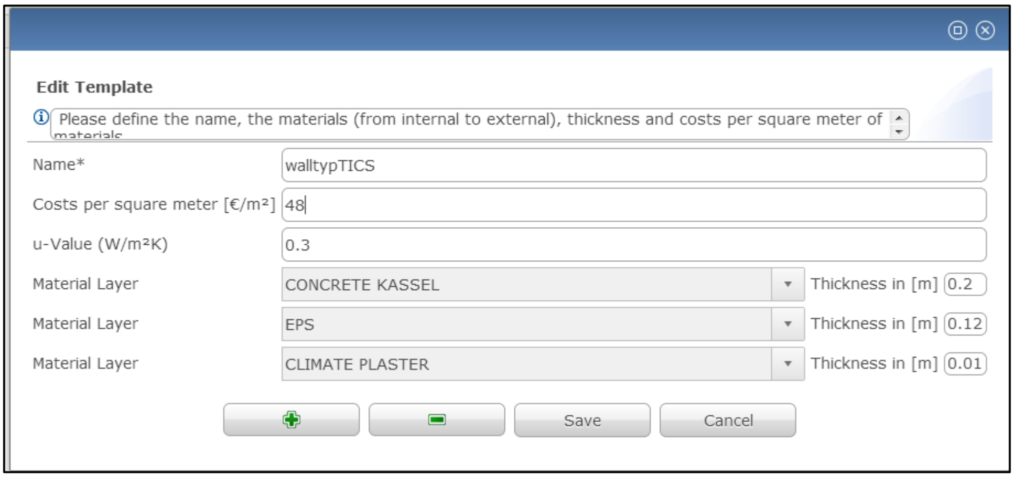


Figure 7: Construction Templates on the IVEL data base

Prepare and perform simulation

For a fast creation of building shell alternatives, construction type eeTemplates with the necessary building physical properties are automatically assigned to the elements either by name of the element in an early design phase or in a more detailed design phase the materials are read from the IFC and the appropriate construction type is mapped to the element. To create an additional alternative the assignment of another construction type can be easily done by multi-selecting all elements for which the type has to be changed. To streamline the requirements management process for the end-user space templates or specific client requirements are automatically assigned to the classification of the rooms agreed with the architect. If the preparation of the simulation is ready it can be performed with NANDRAD a simulation solver developed by TUDs' Institute of Building Climatology. This solver provides a very detailed simulation of net energy and thermal comfort conditions. Because the zones which can be simulated are limited, the size of the building causes long simulation runs and because different building shell alternatives should be compared to find the one with the best cost quality ratio, the HESMOS project team agreed to simulate one representative part of the building and process the result for the whole building. The NANDRAD simulation solver is still under development and does not include at the moment a comprehensive HVAC simulation model. However, NANDRAD is really open for integration of specialized simulation models. The simulation results are hourly data for heating and cooling net energy as well as temperatures, data which will be aggregated for decision-making in the post-processing.

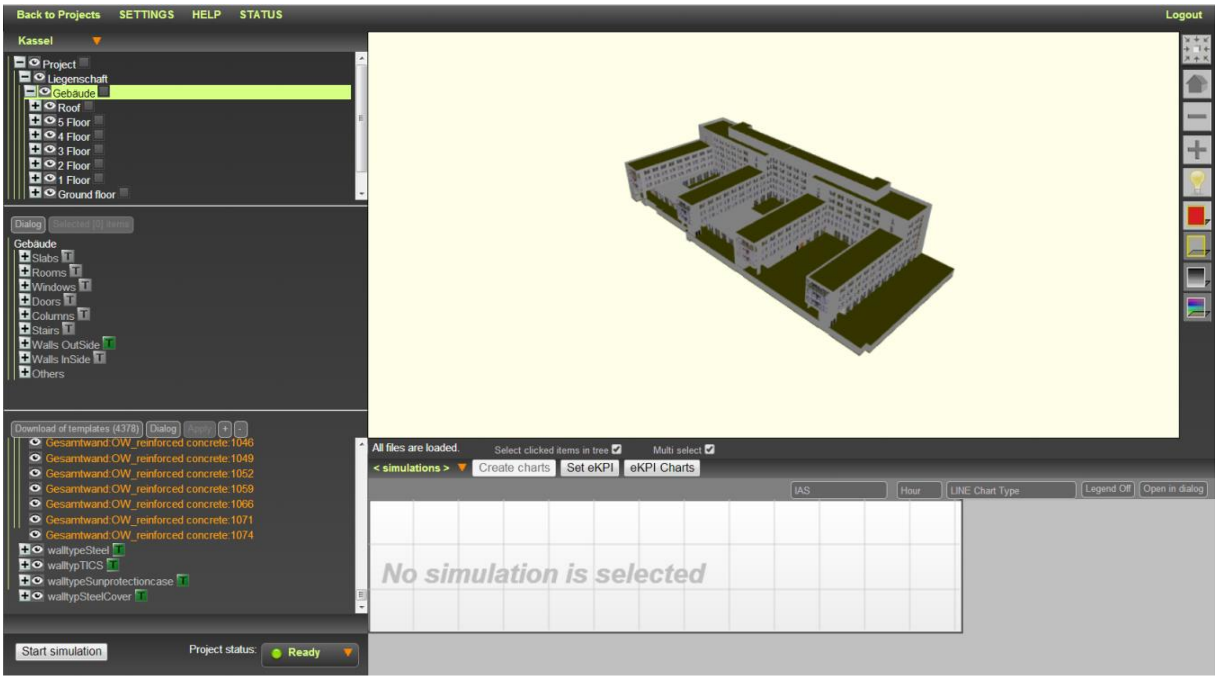


Figure 8: nD Navigator graphical user interface to enrich the model to an eeBIM

Process energy-related Key Performance Indicators (eKPI)

The simulation results are hourly data of heat and cooling net energy as well as temperatures which have to be processed regarding eKPIs for transparent decision-making among building shell alternatives. With the user input of a plant expenditure figure for heating and cooling the final energy is calculated in the post-processing view.

To evaluate the impacts on the environment the energy concept can be evaluated regarding greenhouse gas house emissions and energy costs by choosing combustibles from the HESMOS IVEL database which can also be altered based on requests to the energy supplier. The investment costs are calculated for the building shell and windows based on the areas from the IFC and the cost figures from the specific templates chosen.

Final energy

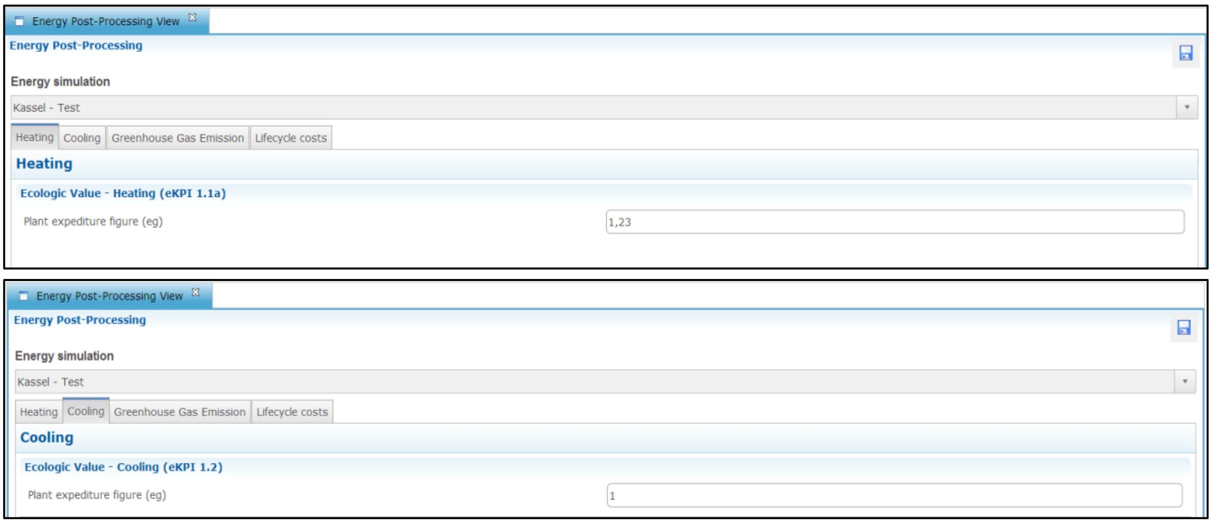


Figure 9: Prepare the simulation results – conversion from net energy to final energy

Greenhouse gases and energy prices

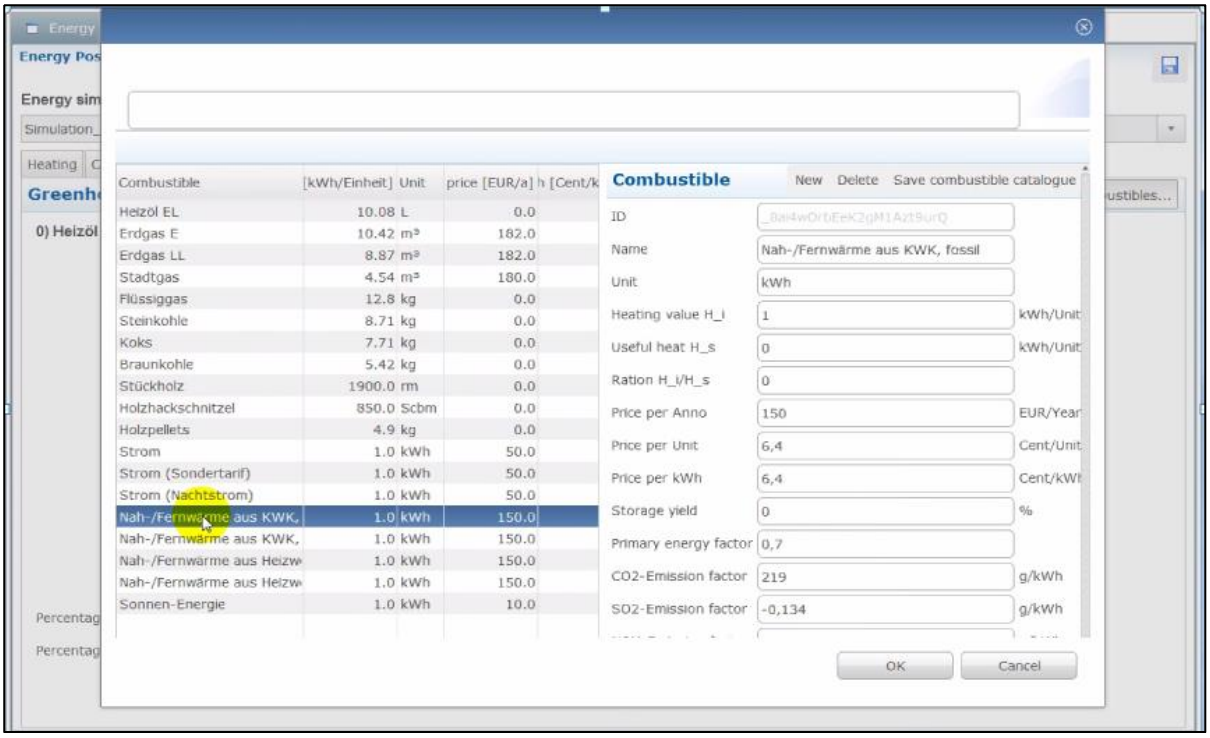


Figure 10: Choose combustible with emissions and energy prise

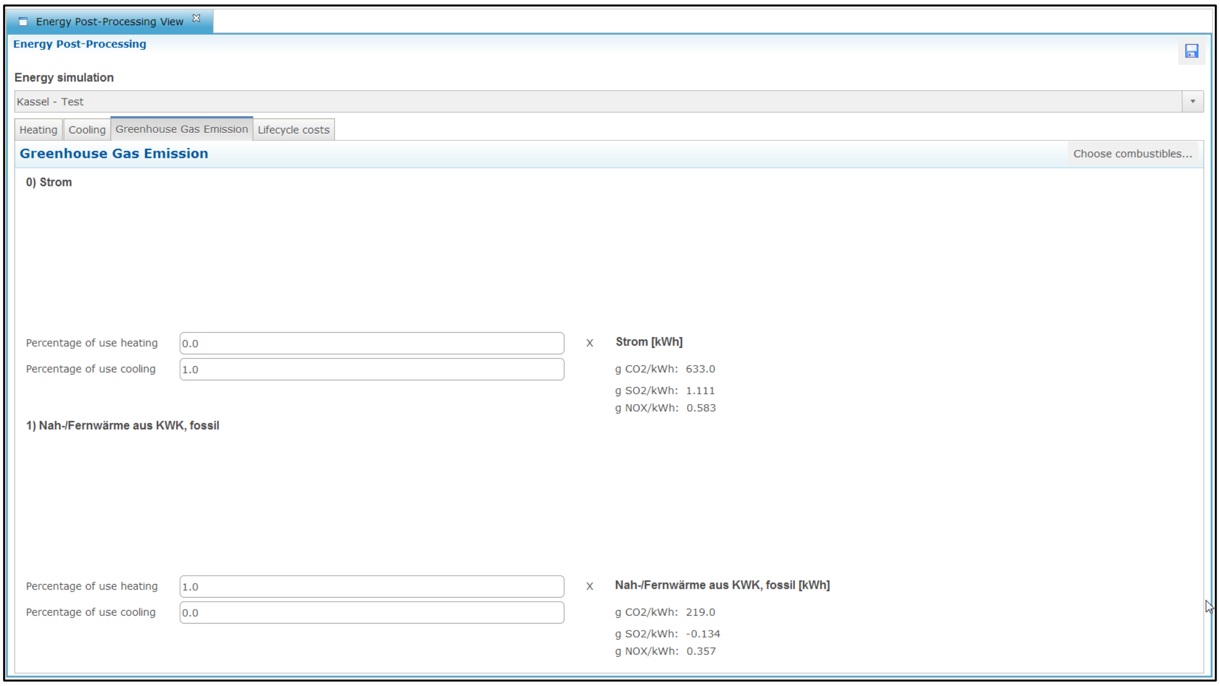


Figure 11: Estimation of greenhouse gas emissions based on the chosen energy concept

Life Cycle Costs

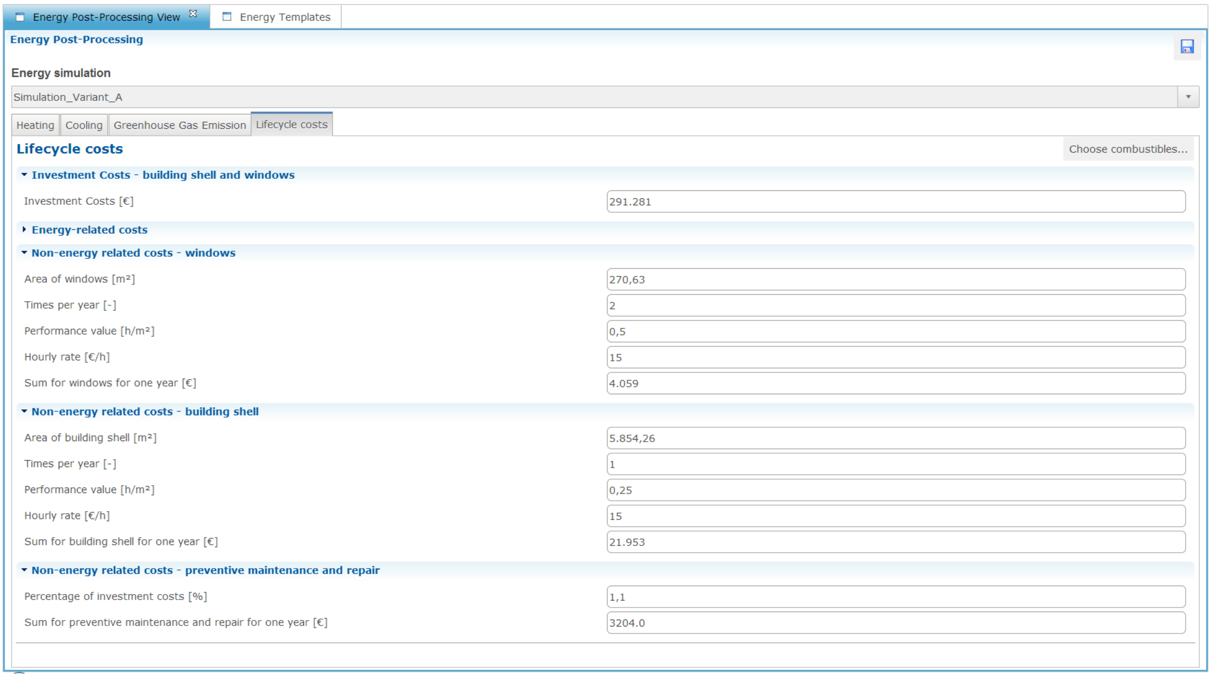


Figure 12: Estimation of life cycle costs of the building shell and windows

Evaluate eKPI

By transparently comparing alternatives regarding the eKPI

- Final energy
- Temperature profiles
- Temperature over- / underruns
- Greenhouse gas emissions
- Life Cycle Costs

in the nD Navigator diagrams, value tables as well as highlighted elements in the 3 D model, the alternative with the best cost quality ratio can be identified.

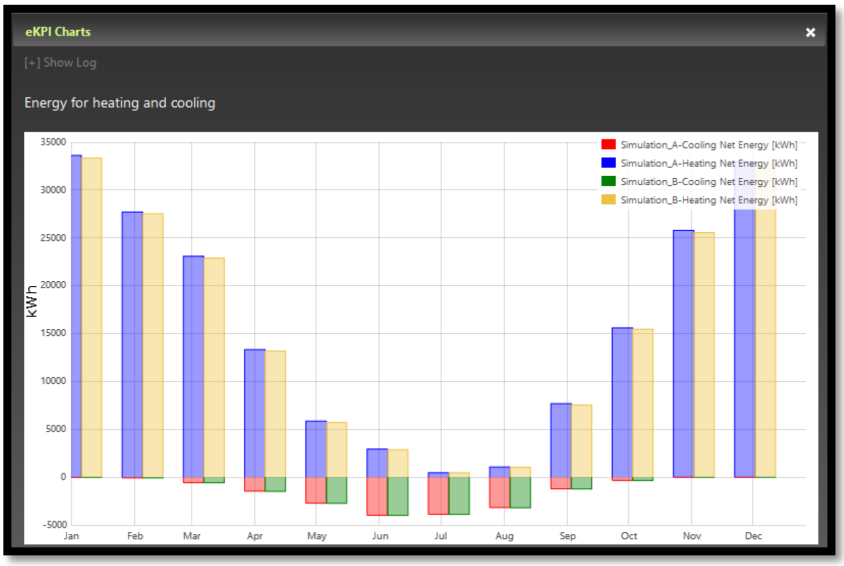


Figure 13: eKPI chart "energy" in nD Navigator for comparing different alternatives

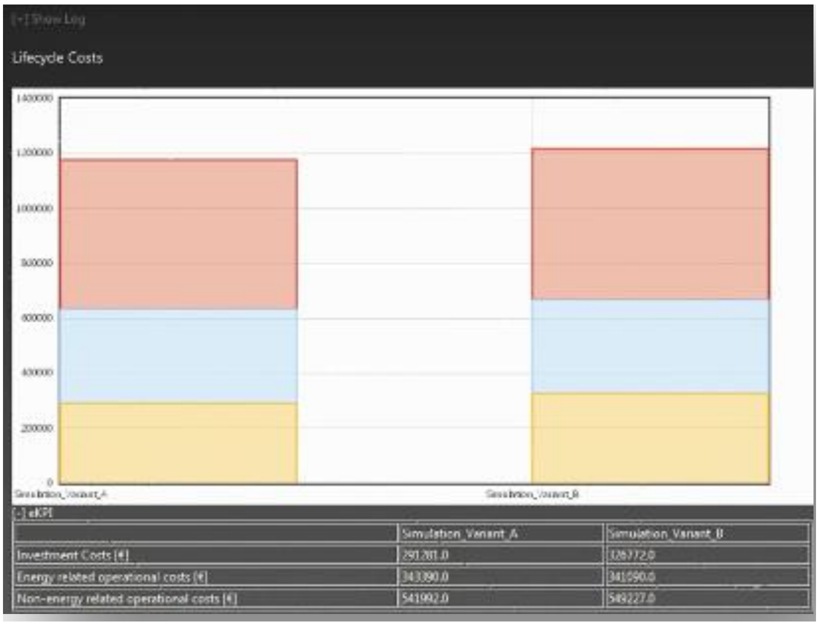


Figure 14: eKPI chart "life cycle costs" in nD Navigator for comparing different alternatives

1.2.2 Operation Phase (Use Case 2) / Retrofitting and Refurbishment Phase (Use Case 3)

Requirements management with WebROOMEX and RIUSKA

WebROOMEX as part of the HESMOS IVEL FM module allows the continuous monitoring of indoor conditions in the building. This enables the FM team to check wether client requirements are met even under changing external conditions or during the implementation of energy saving measures. During the operational phase, information can be browsed and visualised by colour coded floor plans with WebROOMEX. On the GUI user requirements such as minimum / maximum temperatures, air flow rates as well as the internal loads per room can be displayed and assigned to floor spaces according to DIN 277 and to certain HVAC zones.

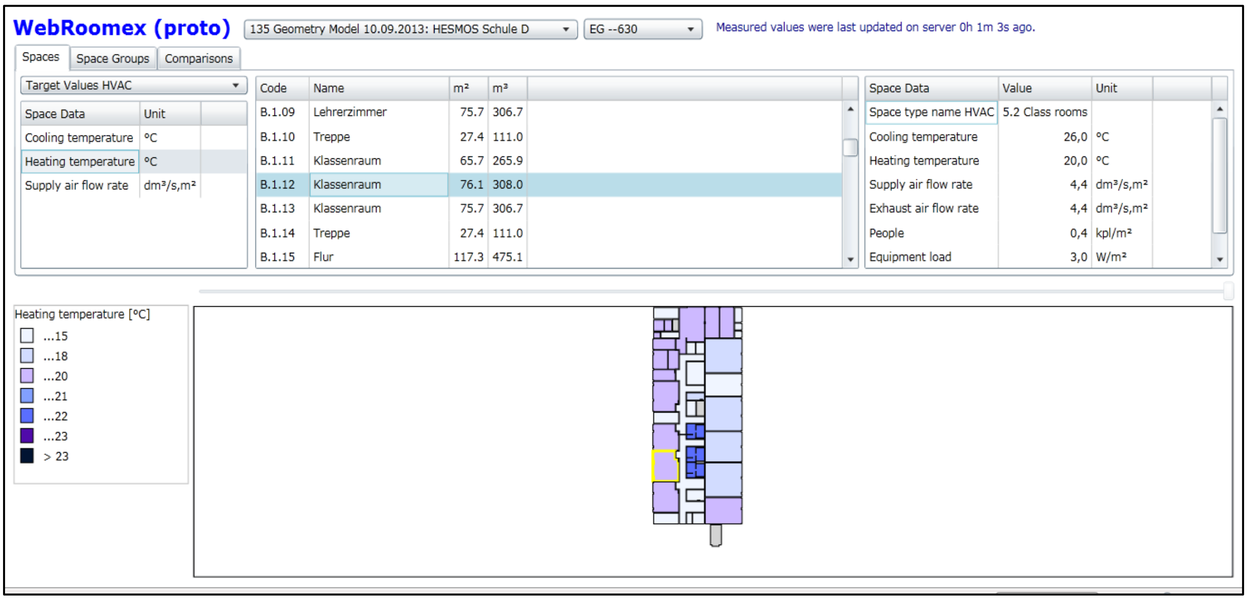


Figure 15: Requirements stored in WebRoomEX thermal comfort monitoring

Using the "comparison" functionality, target values, simulation values and measured values can be compared. For these comparisons, a shared data base to store multiple simulation results was developed and the sensor data of BAS can be accessed through Intelligent Access Services (IAS).

The IAS response will deliver measured values for the specific rooms in the IFC file (IfcSpace "name") within the requested time interval to easily detect deviations. On the basis of these analyses, the FM team can localise inefficiencies in thermal comfort and develop optimisation measures.

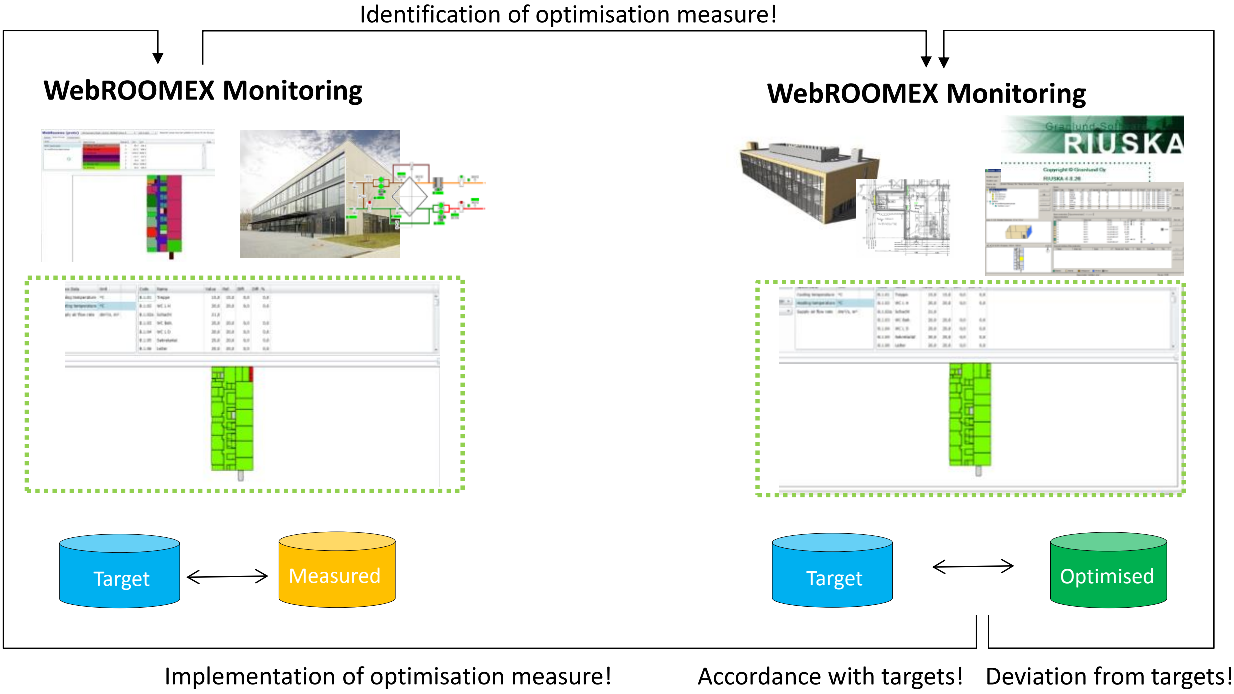


Figure 16: Guidance through the WebRoomEX thermal comfort monitoring scenario

The energy manager can then verify these measures with a RIUSKA energy simulation on the basis of an energy-enhanced Building Information Model (eeBIM). For preparation of building operation optimisations the original eeBIM from the design phase should be updated to comply with the alterations made during construction and commissioning to an as-built building model. Due to the fact that energy use data, measured weather data and other operating data which closely represents the current operation of the building is available in the as-built eeBIM, optimisation measures can be verified by energy simulations.

Web based monitoring / analyses / optimisation with Granlund Manager Metrix and RIUSKA

Using the Granlund Manager Metrix web interface, the FM team can monitor the performance of ventilation equipment and avoid non-load operation as well as unsatisfactory heat recovery efficiency. For this purpose, sensor data obtained from BAS with regards to ventilation equipment - supply and exhaust air temperatures, status of ventilation fans and heat recovery units as well as outdoor temperatures - are utilised by Granlund Manager Metrix. The Granlund Manager Metrix web interface is divided in three levels which contain differing levels of detail for fast and intuitive access to relevant information.

Figure 17: System performance monitoring with Granlund Manager Metrix

On the 1rst level of the graphical User Interface (GUI), a performance metric is published comparing measured values of the ventilation equipment against pre-determined target values for the entire building. If this metric is between 90 and 100 %, the ventilation equipment is functioning well. If it is between 80 and 90 % it is functioning satisfactorily, but if it is less than 80 %, a detailed analysis is necessary to identify the reasons for this weak performance and develop optimisation measures. This performance metric is calculated as the average of two indicators which are identified as most important in influencing the ventilation system performance. The first indicator is time schedule efficiency to monitor if the ventilation system is running according to the predefined optimal time schedule to avoid non-load operations. The second indicator is heat recovery efficiency to monitor if the heat recovery unit is functioning according to the manufacturers specification. Furthermore, a trend view is generated for the past three years, the past twelve months and the past 30 days. In addition an overview is presented - worst equipment view – which displays the ventilation systems that do not function satisfactorily. The causes for unsatisfactory performance of the ventilation systems can be analysed on the 2nd level of the web interface. Here time schedule efficiency and heat recovery efficiency of ventilation systems can be studied independently in greater detail. On the 3rd level of the web interface, time schedule efficiency and heat recovery efficiency can be evaluated using time series plots. In these plots, the target value is always represented as a zero line enabling the FM team to easily detect when the ventilation system is running longer than expected or the heat recovery coefficient cannot be met due to exhaust air flow rates being lower than supply air flow rates, leakages in the ventilation pipes, pressure losses which cause a higher ventilation equipment power or an obsolete heat plate exchanger.

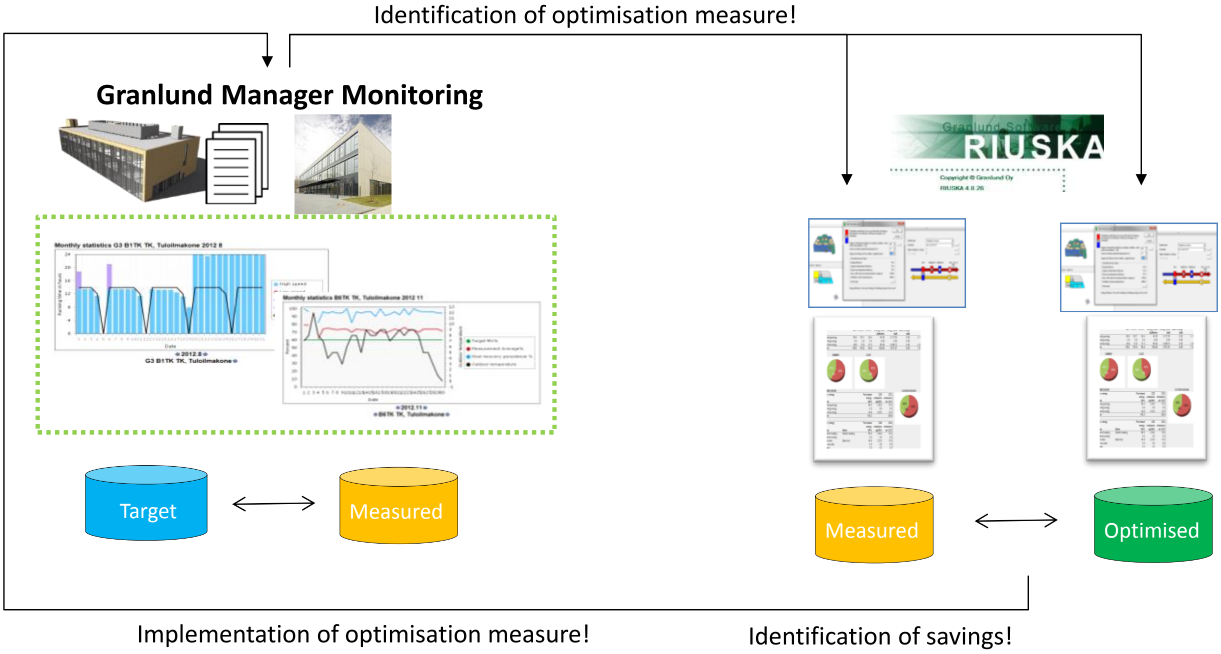


Figure 18: Guidance through the Granlund Manager system performance monitoring scenario

On the basis of these analyses, the FM team can localise performance problems and can develop energy conservation measures (ECM) e.g. optimise the time schedule of the ventilation equipment or optimise heat recovery efficiency issues such as air flow rates [m^3/h] are too high, exhaust air flow rate is lower than supply air flow rate (leakages), higher fan performance and because of this higher electricity demand (pressure loss) or very high or very low air velocities. These ECM can be verified by energy simulations with RIUSKA. RIUSKA energy simulation with its new reporting functionalities provides transparent reports of energy consumption segmented in heating, hot water, cooling, ventilation, lighting and equipment electricity, energy costs as well as CO_2 emissions and verifies the effectiveness of energy optimisation strategies.

2 Methodology to Record Evidence on Benefits and Costs

To validate the implementation of the IVEL on two pilot projects, Building Information Models (BIM) were created according to required model standards based on the design and construction documents in Allplan. The administrative building “Finance Centre Kassel” is used to validate the simulation and decision-making capabilities during the design and tendering phase of PPP projects.

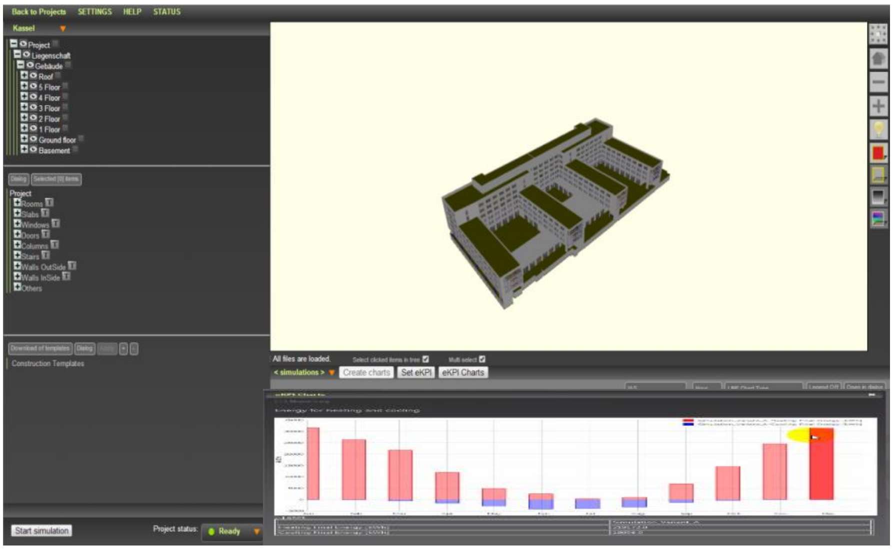


Figure 19: Comparison of design alternatives regarding energy-related eKPIs

For the school building “Alfons-Kern-School Pforzheim” a SQL data base with web access was installed to collect the required sensor data for thermal comfort monitoring with WebRoomEX and system-performance monitoring with Granlund Manager Metrix.

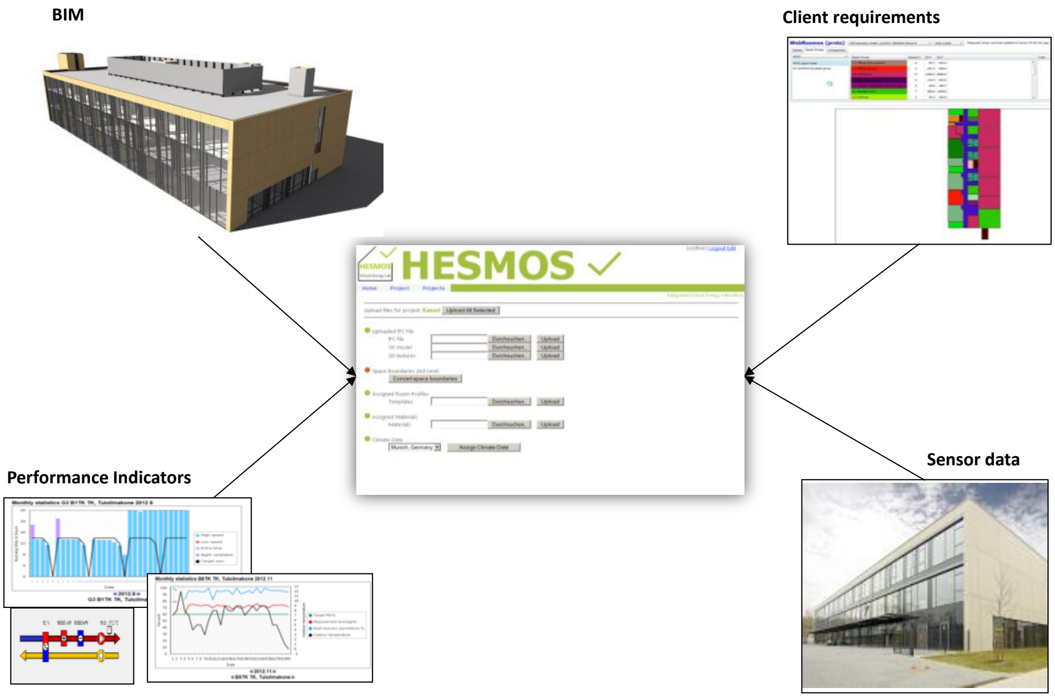


Figure 20: Thermal comfort and system performance monitoring during operational phase

2.1 Methodology to report benefits of process optimisation

The methodologies used to validate process optimisation are described in this chapter. Process optimisation means increasing process quality while reducing process time and process costs. For that purpose, the current working processes had been analysed in WP 01: Gap Analysis, Use Case Scenarios and Requirements Specification (Bort et. al 2011). With this analysis, gaps in current practise for an integrated process had been identified and use case scenarios of the integrated processes as well as the required data exchange over the whole building life cycle had been defined and documented with the Information Delivery Manual (IDM) Methodology (ISO 29481-1). In this deliverable, the conventional processes performed on the pilot projects are compared to the standardised processes supported by HESMOS IVEL for simulation as well as decision-making during design and for monitoring as well as optimisation during operational phase. The chosen parameters for this target-performance analysis of processes are "reduction in process time" which influences process costs and "optimised process quality" which influences employee satisfaction. Within a process report comparing the current processes and the HESMOS processes, the added value as well as the percentages of time savings is documented.

2.1.1 Process time

To analyse and document the performance parameter "reduction in process time" the duration of the different phases of the current processes had been analysed and based on the implementation of the IVEL on the pilot projects an expert survey by the project participants was performed. By evaluating the manmonth spent in the different phases differentiated by the project participants - project coordinator, architect, HVAC planner, building physicist, cost estimator and FM coordinator - time savings were identified and are documented in the process optimisation report in chapter 3.1.1 of this deliverable.

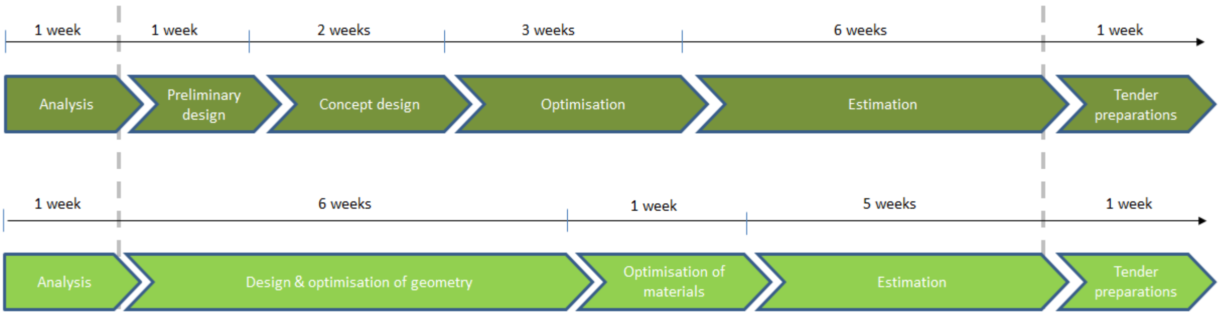


Figure 21: Process optimisation during design and tendering compared to current processes

During the operational phase the time needed for monthly, quarterly and yearly reporting as well as the analysis of optimisation measures was analysed as it is currently done and compared to the capabilities from the HEMOS IVEL.

2.1.2 Process quality

To analyse and document the performance parameter "optimised process quality" the process quality was evaluated by experts of the different process phases over the whole life cycle and the changes in the level of maturity was documented according to the Capability Maturity Model (CMM) of the National Building Information Model Standard developed by the NBIMS initiative. The CMM has been developed for users to evaluate their business practices, locate their current position and identify optimisation and development potential.

The following areas of interest are taking into consideration:

- **Data richness:** Identifies the completeness of the Building Information Model.
- **Life cycle views:** Refer to the phase of project and identifying how many phases are covered by the BIM. This category has high cost reduction, high value implication, based on the elimination of duplicative data gathering.
- **Roles or disciplines:** Refer to the players involved in the different business processes. Disciplines are often involved in more than one view as either a provider or a consumer of information, to eliminate that this data has to be re-created.
- **Business process:** Defines how business is accomplished. If the data and information is gathered as part of the business process then data gathering is no cost requirement.
- **Timelines / Responses:** While some information is more static; accuracy may be critical in emergency situations. The closer to accurate real time information you can be the better quality the decisions that are made.
- **Delivery method:** Data delivery is critical to success. If data is only available on one machine, than sharing cannot occur rather than by e-Mail or hard copy. In a structured network environment if information is centrally stored or accessible than some sharing will occur. If the model is a system oriented architecture (SOA) in a web enabled environment, information will be available in a controlled environment to the appropriate players.
- **Graphical information:** Graphics help paint a clearer picture to all involved. As standards are applied then information can begin to flow as the provider and receiver must have the same standards in place.
- **Spatial capability:** Understanding where something is in space is significant to many information interfaces and the richness of information.
- **Information accuracy:** Having a way to ensure that information remains accurate is only possible through some mathematical truth capability.
- **Interoperability:** Ultimate goal to ensure interoperability of information. There are many ways to achieve this, however the most effective is to use a standards based approach to ensure that information is a form that it can be shared and products are available that can read that standard of information.

Table 1: Capability Maturity Model Metrix

Maturity Level	Data Richness	Life-cycle Views	Roles Or Disciplines	Business process	Delivery Method	Timeliness/ Response	Graphical Information	Spacial capability	Information Accuracy	Interoperability/ IFC Support
1	Basic core data	No complete project phase	No single role fully supported	Business processes not defined	Single point access from workstation	Most response info manually re-enterd	Preliminary text, no technical graphics	Not spatially located	Manual load of information	No interoperability
2	Expanded data set	Planning & Design	Only one role supported	Few business processes designed	Single point access with control over access	Most response info manually re-enterd but awareness how to obtain	2D, no interaction with information, as-designed	Basic spacial location	Some electronic validation	Some interoperability
3	Enhanced data set	Add construction supply	Two roles partially supported	Some business processes designed to collect information	Network access with basic password control	Data calls not in BIM but most other data was	2D, non-intelligent and not object oriented, as designed	Spatially located	Electronic calculation of space	Some machine to machine flow of information
4	Data plus some information	Includes construction supply	Two roles fully supported	Most business processes designed to collect information	Network access with full control	Limited response info available	2D, intelligent, as designed	Located with limited info sharing	Electronic identification of internal spaces	Limited info transfer between products from the same vendor
5	Data plus expanded information	Includes construction supply and fabrication	Design fully supported	All business processes designed	Limited web environment	Most response info available	2D, intelligent, as built	Spacially located with Metadata	Electronic identification of many spaces and items, some items entered manually	Most info transfer between products typically from the same vendor
6	Data with limited authorative information	Add limited operation and warranty	Design and construction fully supported	All business processes designed but few maintaining	Full web environment, some access control	All response info available	2D, intelligent, as built and current	Spacially located with full info sharing	All internal and external spaces identified electronically	Full info transfer and information interoperability is the norm.
7	Data with mostly authorative information	Includes operation and warranty	Design, construction fully supported and operations partially supported	All business processes designed, some maintaining information	Full web environment, role based access manually controlled	All response info from BIM, primary source of accurate data	3D object based with intelligence	Part of a limited GIS	Internal spaces computed electronically and some outside information	Limited IFC use for interoperability
8	Completly authorative information	Add financal	Design, construction and operations fully supported	All business processes designed, all capable of maintaining information	Web enabled environment, secure	Limited real time access from BIM	3D object based and process to keep them current	Part of a more complete GIS	Units calculated electronically and reported	Expanded IFC use for interoperability
9	Limited Knowledge Management	Full facility life cycle collection	Full facility life cycle collection	All business processes designed, some maintain data	Netcentric web environment, SOA, roles manually	Full real time access from BIM	4D - add time	Integrated into a complete GIS	All internal and external areas computed and some metrics to track	IFC use is the norm, but not exclusively used to attain interoperability
10	Full Knowledge Management	Analysis on the entire ecosystem	Internal and external roles supported	All business processes designed, all maintain data in real time	Netcentric web environment, SOA	Real time access with live feeds to sensors	nD - Time & Costs	Integrated into a GIS with full info flow	All spaces calculated automatically and metrics used to ensure information	IFC's fully implemented and used for interoperability

2.2 Methodology to report benefits of building optimisation

For reporting of building optimisation energy related Key Performance Indicators (eKPI) have been defined in Deliverable 9.1: "Requirements synthesis and energy-related key performance indicators" (Bort et al. 2011) and the calculation methods have been developed in Deliverable 5.2: "HESMOS enhancements of energy simulation tools" (Grunewald et al. 2011). These eKPIs comprise the categories ecological, socio-cultural and economical quality as well as the eKPI for final energy, greenhouse gas emissions, thermal comfort, investment and operational costs also addressed in sustainability certificates. For validation of the **design and tendering use case,** different façade alternatives are compared regarding final energy for heating and cooling, CO_2 emissions, temperature profiles, and temperature over- and under runs as well as life cycle costs in the nD Navigator charts to identify the alternative with the best cost-quality ratio.

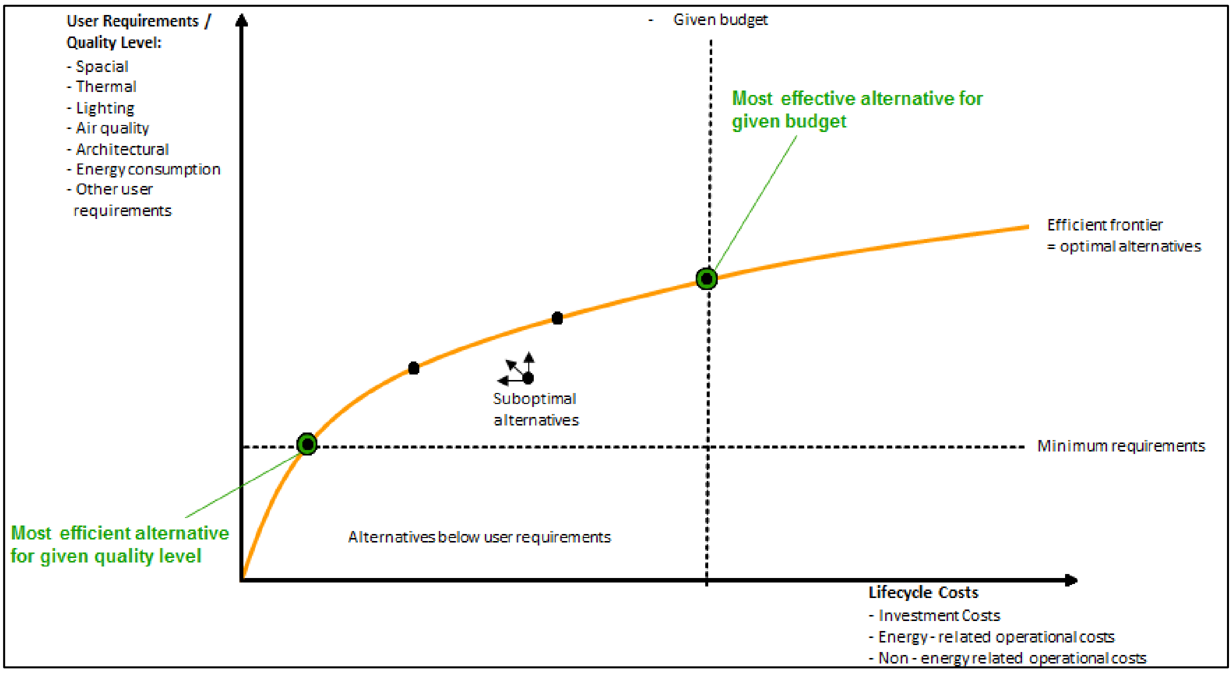


Figure 22: Comparing design alternatives

For the **operation phase** indicators which have the most impact on energy savings were identified to be among others the running hours of ventilation equipment, the heat recovery of ventilation equipment as well as the adjustment of temperature settings (heating and ventilation) and can be monitored in the FM module of the HESMOS IVEL. But performing energy saving optimisations should never affect thermal comfort of the tenant which can also be proven in the FM module of the HESMOS IVEL. To document the quality of the building during operational phase and to reliably determine actual savings for final energy, costs and greenhouse gases by an energy conservation measure a Measurement & Verification (M&V) plan according to the International Performance and Verification Protocol (IPMVP) has to be set up.

In this deliverable "optimisations in building quality" as well as "optimisations in costs" are identified during the validation process on the pilot projects.

2.2.1 Quality

To identify the design concept of the building envelope which meets best the quality requirements of the client and for documentation of energy, greenhouse gas emission savings as well as thermal comfort optimisation during the **design and tendering phase**, different alternatives have to be prepared for thermal simulations. For that purpose construction types with the building physical properties can be chosen from the HESMOS IVEL data base or can easily be created on the graphical user interface to start thermal simulations. Net energy for heating and cooling is simulated for the whole building based on transmission and ventilation losses as well as solar and internal gains. Within the post-processing view the simulation results are prepared regarding eKPI for decision-making and different energy concepts can be analysed by choosing the combustibles from the IVEL data base. Additionally, the different alternatives can be compared if they meet min. / max. indoor temperatures according to the European standard EN 15251 and the alternative which meets best the thermal comfort conditions while saving energy can be identified.

For evaluation and documentation of energy and greenhouse gas emission savings during the **operation phase** and the **optimisation phase** (retrofitting and refurbishment) a Measurement & Verification (M&V) plan has to be developed for the pilot school building according to the following steps:

1) Choose the **M&V Option**. There are four generic approaches for conducting M&V defined within the International Performance Measurement and Verification Protocol (IPMVP) as Option A, B, C and D.

Table 2: M&V Options by the IPMVP

IPMVP Option		How savings are calculated	Typical applications
A. Retrofit Isolation: Key Parameter Measurement	Savings are determined by field measurement of the key performance parameter(s) which define the energy use of the ECM's affected system(s) and/or the success of the project. Parameters not selected for field measurement are estimated. Estimates can based on historical data, manufacturer's specifications, or engineering judgment. Documentation of the source or justification of the estimated parameter is required.	Engineering calculation of baseline and reporting period energy from: short-term or continuous measurements of key operating parameter(s); and estimated values.	A lighting retrofit where power draw is the key performance parameter that is measured periodically. Estimate operating hours of the lights based on facility schedules and occupant behavior.
B. Retrofit Isolation: All Parameter Measurement	Savings are determined by field measurement of the energy use of the ECM-affected system.	Short-term or continuous measurements of baseline and reporting period energy, and/or engineering computations using measurements of proxies of energy use.	Application of a variable speed drive and controls to a motor to adjust pump flow. Measure electric power in the baseline and reporting period with a kW meter installed on the electrical supply to the motor, which reads the power every minute.
C. Whole Facility	Savings are determined by measuring energy use at the whole facility or sub-facility level. Continuous measurements of the entire facility's energy use are taken throughout the reporting period.	Analysis of whole facility baseline and reporting period (utility) meter data.	Multifaceted energy management program affecting many systems in a facility. Measure energy use with the gas and electric utility meters for a twelve month baseline period and throughout the reporting period.
D. Calibrated Simulation	Savings are determined through simulation of the energy use of the whole facility, or of a sub-facility. Simulation routines are demonstrated to adequately model actual energy performance measured in the facility. This Option usually requires considerable skill in calibrated simulation.	Energy use simulation, calibrated with hourly or monthly utility billing data. (Energy end use metering may be used to help refine input data.)	Multifaceted energy management program affecting many systems in a facility but where no meter existed in the baseline period. Energy use measurements, after installation of gas and electric meters, are used to calibrate a simulation. Baseline energy use, determined using the calibrated simulation, is compared to a simulation of reporting period energy use.

2) Define the **Measurement Boundary**. The measurement boundary can be the facility boundary or the boundary of the energy conservation measure (e.g. if you want to analyse energy savings by optimising the performance of the ventilation equipment).
3) Identify **Key Parameters** which affect the system performance and energy efficiency of the HVAC equipment and install sensors.
4) Define the **Operating Cycle** the monitoring should be done which depends on the chosen option as well as the desired level of accuracy.
5) Measure **Baseline Data** to determine actual performance and document expected performance (operation and manufacturer data).
6) Develop an **Energy Model** and run the simulation for the calibrated **Baseline Energy Model**.
7) Repeat the simulation process with the **Energy Conservation Measure (ECM)** implemented in the **Post-Installation Energy Model**.
8) Determine **savings** by subtracting the post-installation simulation results from the baseline results using either actual weather data and facility operation conditions or typical conditions and weather data.

For continouus **thermal comfort monitoring** the room temperatures are measured, because it is not possible to measure the operative temperature in the centre of the room, 60 cm above the floor such as specified in EN 15251. For monitoring purposes with WebRoomEX as well as simulations of optimisation measures with RIUSKA the as build model was already prepared with the min. / max. temperature as well as the air flow requirements and internal loads and sensor data from the data base of the building is provided via web access.

2.2.2 Costs

Already in an **early design**, with **life cycle costing (LCC)** different alternatives can be compared regarding the investment, energy-related and non-energy related operational costs and optimisation potential can be identified. Most important that the LCC results are evaluated together with the ecological value of a design concept as well as the thermal comfort conditions to develop a sustainable design. For that purpose, life cycle costs of different building shell alternatives are calculated in the post-processing of simulation results and visualised in the nD Navigator. Investment costs are calculated by the areas of the elements of the building shell from the IFC model and the assigned construction types which include a cost figure key value. For the estimation of energy-related costs the simulations results are processed regarding final energy. For different energy concepts the IVEL user can choose combustibles with energy price and basic charge from IVEL data base or can input the prices after request from energy supplier. For non-energy-related operational costs such as cleaning the areas for the windows and building shell are derived from the IFC model and key figures for cleaning can be inputted in the post-processing e.g. as values from the calculation according to the German Sustainability Standard or according to data from own building management data base. Finally, the net present value of the life cycle costs is calculated to be able to compare the different alternatives.

Based on the M&V plan established for the **operation** as well as the **retrofitting and refurbishment** phases, the continuous monitoring results and the analysis of optimisation measures, the energy-related costs can be estimated and optimised. Cost savings are determined and documented by applying the appropriate price schedule in the following equation:

Cost Savings = $C_b - C_r$

Where:

C_b = Cost of the baseline energy

C_r = Cost of the reporting period energy

Costs should be determined by applying the same price schedule in computing both Cb and Cr. When the conditions of the reporting period are used as the basis for reporting energy savings (i.e. avoided energy use), the price schedule of the reporting period is normally used to compute "avoided cost."

2.3 Methodology to document implementation costs

For implementation of the IVEL on a project, both for the design and tendering as well as the operation phase, the core platform which integrates all the information via web services is provided by TU Dresden's Institute of Construction Informatics. For cost documentation, it was documented what is needed additional to the IVEL core platform for the different use cases and with which costs, the implementation team has to calculate.

For implementation on the HESMOS pilot projects Nemetschek Allplan CAD was used to create the models, the NANDRAD solver from TU Dresden's Institute of Building Climatology for simulations and the nD Navigator for eeBIM preparations and visualisation of eKPI. If the project team wants to use other IFC based software tools which are already implemented in the company, it is also possible, but may require some additional adaption work.

For monitoring of the thermal comfort and system performance a SQL server base needs to be installed in the building which records the sensor data and a DSL router to transfer the data by user request to the IVEL. From technical point of view, it is possible to monitor system performance with in depth sensor data, but the costs are for most projects too high to be feasible. It has been identified that the following factors have a big impact on energy savings.

- Reduction of ventilation running hours
- Adjustment of temperature settings (heating and ventilation)
- Improvement of heat recovery system (existing or new)

On that basis a minimum data set of measured sensor data has been defined which must be delivered for thermal comfort with WebRoomEX as well as system performance monitoring with Granlund Manager Metrix from the FM module of the HESMOS IVEL as follows:

- Room temperatures
- Supply air temperatures of the ventilation equipment
- Exhaust air temperatures of the ventilation equipment
- Outdoor air temperatures
- Status of the supply fans
- Staus of the heat recovery unit

The costs for the SQL server, the DSL router as well as the necessary sensors are documented in chapter 3.2.3 of this deliverable.

3 Benefits and Costs of pilot projects

3.1 Process optimisation

3.1.1 Design and tendering phase (Use Case 1)

The reference for identification of process optimisation in chapter 3.1.1 of this deliverable was the working method used for design and tendering for the Kassel project with decentralised data coordination between the integrated project team. After implementation of the HESMOS IVEL, every project has access to the IVEL from everywhere where internet access is available, can work in a collaborative environment and provide their data centrally linked to the model for simulations, estimations and decision-making. To document building process optimisation potential the different working methods were compared by the project participants and time savings as well as a development in the maturity level according to the NBIMS standard (from 1 to 10 with 1 being the least mature and 10 being the most mature) were identified.

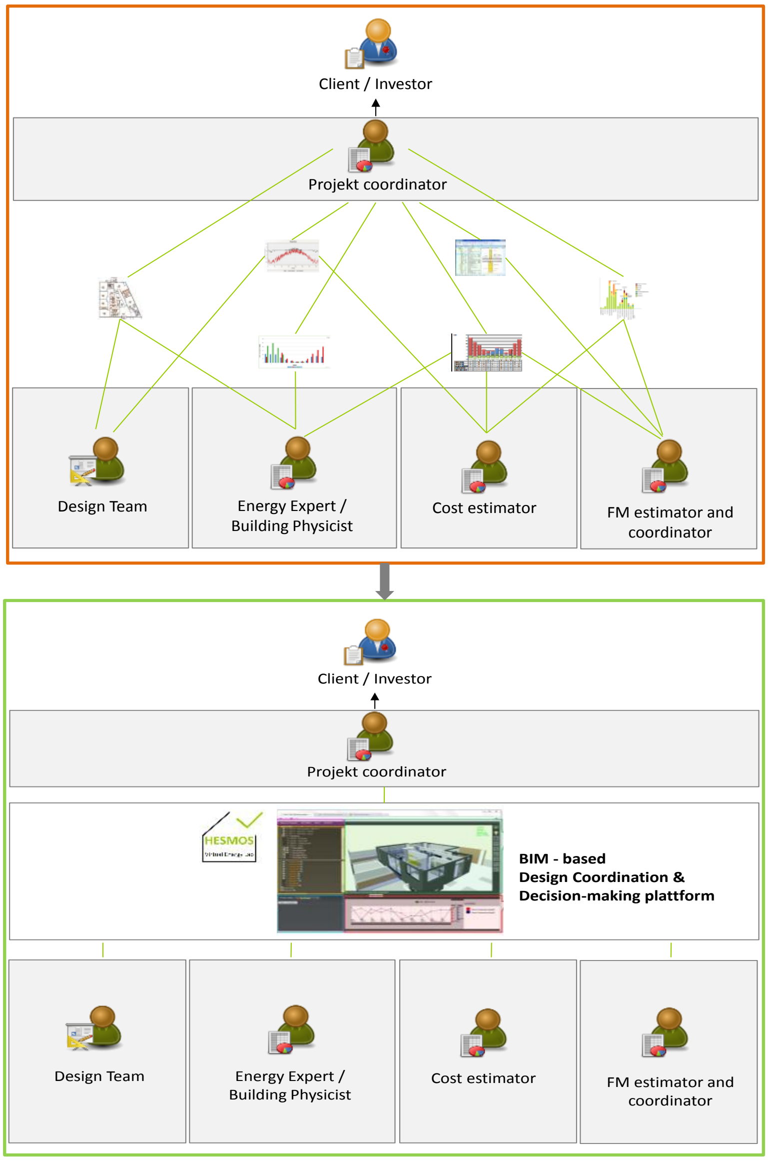


Figure 23: Coordination of the integrated design team

Compared to state of the art method where an energy consultant uses information from 2D drawings, specifications or other project data available to independently create the input for the energy simulation program, with the HESMOS BIM based energy modeling more alternatives can be analysed regarding energy-related Key Performance indicators and the alternative with the best cost-quality ratio can be identified. To show the capabilities of the HESMOS IVEL on the Finance Center, different design alternatives are compared and documented in chapter 3.1.2 of this deliverable.

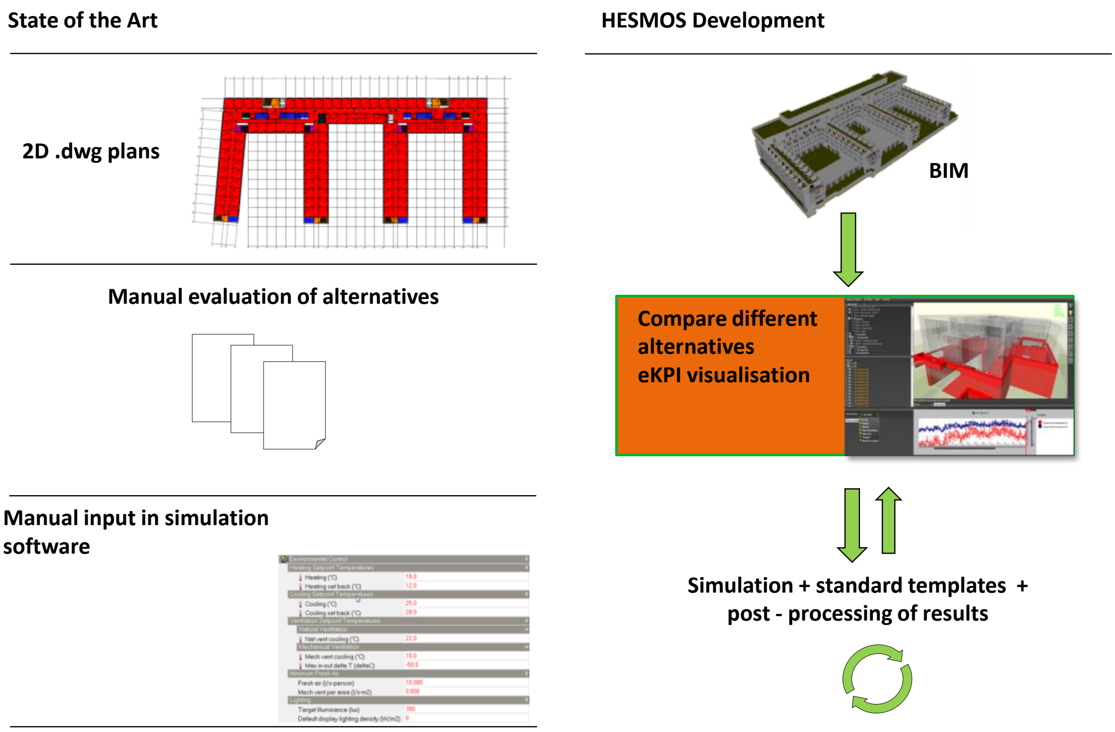


Figure 24: Comparison of state of the art and HESMOS developments during design and tendering

Table 3: Benefits – process optimisation – design and tendering

Criteria	AS IS Process	TO BE Process	Optimisation
Project coordinator			
Time	Coordination decentralised.	Coordination with central data model.	• Time savings because information is more easily managed, accessed, and shared.
	Manual verification of compliance with client requirements.	Automated verification of compliance with client requirements with editable standard requirements assigned to the rooms in the model.	• Time savings through automated target – performance comparison.
	Manual preparation of results for tendering documents.	Simulation results are processed regarding energy – related Key Performance Indicators.	• Time savings for preparing data for documentation and decision – making.
			Time savings = 30 %

Criteria	AS IS Process	TO BE Process	Optimisation
Quality	Sample testing of comfort conditions e.g. the worst room in the building.	Complete analysis of every room for compliance with the requirements.	• Increase of quality because of complete analysis and avoidance of deviations.
			Data richness from 1 to 10
	Work with specialised tools; excel exchange of data and results.	Work based on exchange requirements over the whole life cycle facilitate the project coordinator his tasks.	• All life cycle phases are covered and information exchange is ensured.
			Life cycle view from 2 to 9
	Coordination per project.	Standardised processes and data exchange.	• Standardisation leads to more effective completion of tasks and reduces the coordination effort.
			Business processes from 1 to 8
	Coordination decentralised via E-Mails.	Coordination centralised via Integrated Virtual Energy Lab.	• Proof that all data is taken into account and everybody of the project team has access to check the results.
			Delivery method from 1 to 9
	Manual not standardised evaluation of results from the project participants.	Automated, standardised target performance comparison and visualisation in the nD Navigator.	• Increase of quality of processes for the project coordinator because of transparent evaluation possibilities.
	2D plans and documentation for the presentation of the offer to the client.	3D model / eKPI in nD Navigator for transparent presentation to the client.	• Transparency in communication with the client. • Fewer requests for revisions, because the details can be discussed more efficiently upfront with the client.
			Graphical information from 4 to 10
Design Team			
Time	2D Design meetings / coordination.	3D design meetings / coordination.	• Time increase because model creation in an earlier phase. • Time savings through more effective communication in the design team.
	Separate change of layouts, views and sections.	Change of layouts, views and sections in one step.	• Time savings through flexible reaction on change requests.
			Time Savings = 0 %

Criteria	AS IS Process	TO BE Process	Optimisation
Quality	Work on 2D plans and exchange by e.g. dwg and exchange of results detached of the plans.	Collaborative work on the model.	• Increase of quality because of the web environment, where all project partners have access to.
			Delivery method from 1 to 9
	Identification of clashes by manually comparing layouts and views.	Identification of clashes in the 3D Model.	• Increase in quality through optimised design coordination.
			Graphical information from 4 to 10
Building physicist			
Time	Separate model creation for a specific part.	Existing BIM model basis for simulations.	• Time savings through reuse instead of rework.
	Manual input of requirements in the simulation software.	Library of pre-defined construction templates allow to create more alternatives.	• Time savings to create alternatives for simulations.
			Time savings = 32 %
Quality	Manual assignment of qualities.	Qualities assigned in the 3D model and types mapped.	• Avoidance of transmission errors.
			Data richness from 1 to 10
	QTO from 2D plans. Analyse the concept on simulation results.	QTO from the model. Transparent comparison of more alternatives.	• Increase in quality through transparency and comparison of alternatives.
			Graphical information from 4 to 10
	Manual input and results not spatially located only as a report.	Longitude and latitude of the building are used as basis for simulations and simulation results are assigned to rooms.	• Increase in quality because spatially located results and visual identification of optimisation potential.
			Spatial capability from 2 to 6
	Optimisation based on experiences and rule of thumbs.	Detailed thermal simulations of the whole building and possibilities to analyse more alternatives.	• Increase of quality through accuracy and realistic results.
			Information accuracy from 1 to 9
	Data has to be manually created in the simulation tool.	IFC used for interoperability and as basis for an open platform.	• Increase in interoperability through the use of IFC as exchange format.
			Interoperability from 1 to 9

Criteria	AS IS Process	TO BE Process	Optimisation
Estimation department			
Time	Manual assignment of qualities from the elem. specs (2D plan).	Qualities defined by the architect defined in the 3D model.	• Time savings for assigning qualities. No rework needed.
	Manual QTO as basis for cost estimation.	QTO from the 3D model.	• Time savings for Quantity Take Off.
			Time savings = 20 %
Quality	Manual assignment of qualities.	Qualities assigned in the 3D model.	• Avoidance of transmission errors.
			Data richness from 1 to 10
	QTO from 2D plans.	QTO and estimation with visualisation in the model.	• Increase in quality through transparency.
			Graphical information from 4 to 10
	Manual QTO	Precise QTO. Verification of quantities with 3D model.	• Increase in accuracy.
			Information accuracy from 1 to 9
	Quantities have to be manually entered in estimation software.	IFC used for interopera-bility between design and estimation.	• Increase in interoperability through the use of IFC as exchange format.
			Interoperability from 1 to 9
FM coordinator			
Time	Manual QTO of specific operation relevant areas e.g. for cleaning	Automatic QTO for operation relevant areas.	• Time savings because additional QTO is no longer necessary.
	Manual estimation of energy costs.	Energy costs from simulation and post-processing of results.	• Time savings by post-processing of simulation results regarding eKPIs.
			Time savings = 22 %
Quality	Manual assignment of qualities.	Qualities assigned in the 3D model.	• Avoidance of transmission errors.
			Data richness from 1 to 10
	Decision-making based on experiences.	Decision-making based on transparent prepa-ration of alternatives.	• Transparent comparison of alternatives.
			Graphical information from 4 to 10
	Manual QTO	Precise QTO from 3D Model.	• Increase in accuracy.
			Information accuracy from 1 to 9
	Quantities and simulation results have to be manually entered in LCC analysis.	IFC used for interoperability between design, estimation, simulation and FM.	• Increase in interoperability through the use of IFC as exchange format.
			Interoperability from 1 to 9

3.1.2 Commissioning and operation phase (Use Case 2)

The reference for identification of process optimisation in chapter 3.2.1 of this deliverable was the state of the art approach where no BIM is available, meter data has to be manually collected and prepared in Excel reports for reporting and the system performance can be only analysed on the technical interface of the Building Automation System (BAS). After implementation of the HESMOS IVEL remote access to real time sensor data from the SQL data base of the building is provided by a web service and visualised for web-based thermal comfort and system performance monitoring. Implementing the HESMOS energy-enhanced BIM approach all necessary data (space types, ventilation zones, client requirements and internal loads) are available for thermal comfort monitoring with WebRoomEX in the operation phase. In the colour coded floor plans as a view of the BIM, deviations from client requirements or necessary adjustments in temperature settings can be localised, optimisation measures developed and verified with a BIM-based energy simulation. The capabilities of the remote web-based system performance monitoring with the HESMOS IVEL based on easy to track performance matrixes are compared to the former approach where a very technical analysis on the BAS interface on site is necessary.

Compared to state of the art method where data is collected and distributed between the technician, secretary and the facility manager, data has to be technically analysed on site on the BAS interface and data has to be recollected to create an energy model for simulations, with the HESMOS IVEL the facility manager can continuously monitor the system performance and thermal comfort, identify and localise deviations and can immediately react to optimise the building operation. These optimisations in energy consumption and thermal comfort of the pilot building are documented in chapter 3.2.2 of this deliverable in a M&V plan according to the IPMVP.

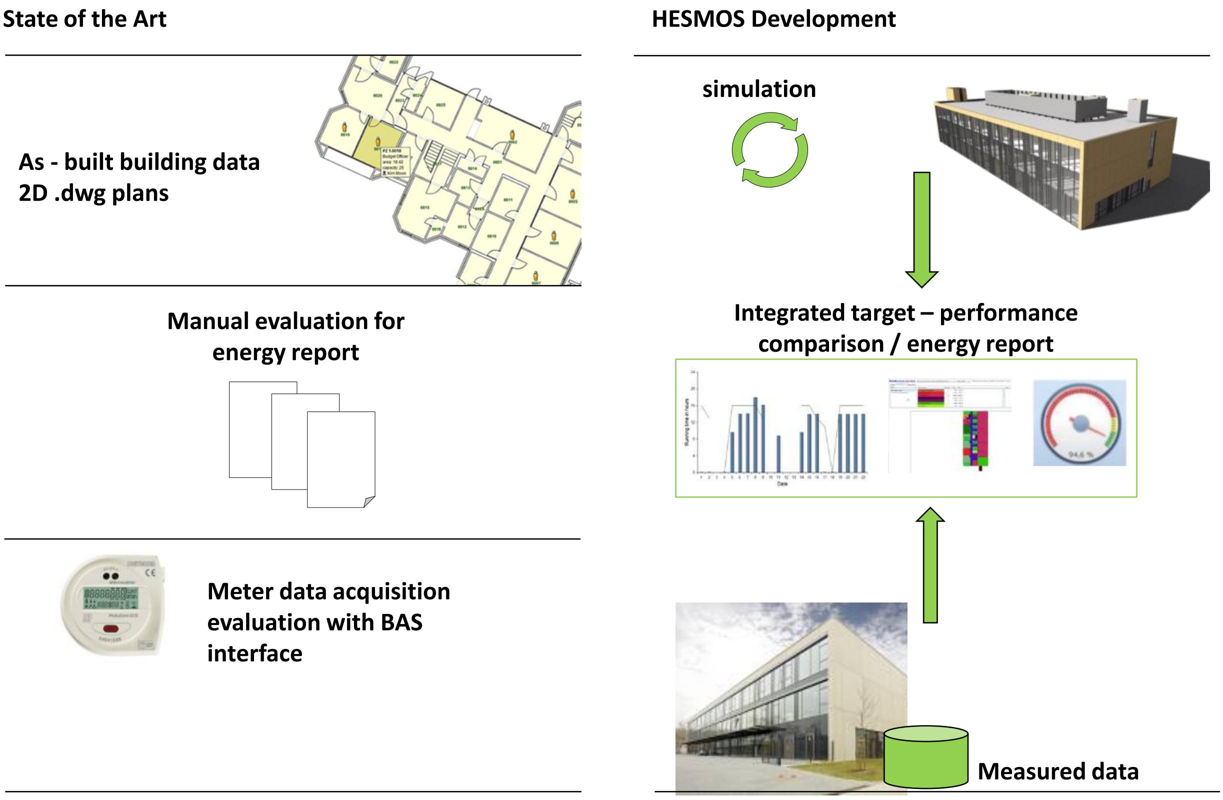


Figure 25: Comparison of state of the art and HESMOS developments during operation phase

Table 4: Benefits - process optimisation - operation

Criteria	AS IS Process	TO BE Process	Optimisation
Building Manager			
Time	Manual sensor data reading and evaluation on site.	Remote access and analyses of sensor data for monitoring of operational parameters.	• Time savings for travels and presence on site.
	Manual target – performance comparison.	Automated target – performance comparison, location in the model.	• Time savings because of a shorter validation process where necessary data is available on a shared data base and can be compared anytime via web from anywhere.
	Manual preparation of data in Excel tables.	Automated reports for system performance of ventilation systems.	• Time savings and reduced effort for the energy management process and reporting.
			Time savings = 15 %
Quality	Manual exchange between the different life cycle phases.	Integrated data exchange between the life cycle phases.	• Optimise quality by continuous up-dating of the data during the life cycle phases.
			Life cycle views from 2 to 9
	Task completion per project. No standardised business processes and data exchange defined.	Business processes for design and tendering, commissioning and operation as well as retrofitting and refur-bishment defined.	• Standardisation of processes and data exchange reduces risks of inconsistent data.
			Business processes from 1 to 8
	Sample testing of compliance with comfort conditions and system performance.	Continuous testing of compliance with comfort conditions and system performance.	• Increase of quality, because a real-time overview for every room and system is provided.
			Timeline and responses from 2 to 10
	Manual technical evaluation of the ventilation equipment on the BAS interface on site.	System performance evaluation of ventilation equipment based on processed performance indicators.	• Increase in quality, because of a transparent overview to identify deviations.
			Graphical information from 4 to 10
	Partial tracking of temperature deviations on the BAS interface.	Ontology to locate the sensor data from BAS systems to the rooms in the BIM.	• Increase quality because the locate deviations in the BIM.
			spatial capability from 2 to 6

Criteria	AS IS Process	TO BE Process	Optimisation
Energy Manager			
Time	Manual collection of data for analysis.	Optimisation simulations on the basis of the energy-enhanced Building Information Model.	• Time savings to find the required information for analyses of optimisation measures.
			Time savings = 20 %
Quality	Collection of data for simulations of different sources.	One single source of truth – the updated energy-enhanced Building Information Model (eeBIM).	• Increase of quality because of up-to-date consistent data.
			Data richness from 1 to 10
	Sample verification of optimisation measure based on experiences or partial simulations. No standardised reporting.	Verification of optimisation measure with simulations of the whole building based on standardised reporting and comparison capabilities.	• Increase of quality because of standard graphical reporting of results and standardised comparison capabilities.
			Graphical information from 4 to 10
	Decision of optimisation measures based on experiences or partly simulations.	Decision on consistent actual simulation results, measured data, and processed graphics at any time	• Increase of quality through accuracy and realistic results.
			Information accuracy from 1 to 9
	Data has to be manually created in the simulation tool.	IFC used for interoperability and as basis for an open platform.	• Increase in interoperability through the use of IFC as exchange format.
			Interoperability from 1 to 9

3.2 Building optimisation

3.2.1 Design and tendering phase (Use Case 1)

To document the building optimisation potential of the HESMOS IVEL during early design phase by easily creating and comparing different building shell alternatives, the basic design of the pilot project “Finance Center Kassel” was analysed regarding energy-related Key Performance Indicators (eKPI). This pilot building is an administrative building in Kassel at the location: Longitude / Latitude 51° 19' 0" N / 9° 30' 0" E, Height above NN = 142,30. Besides the location, the orientation is important for thermal simulations.

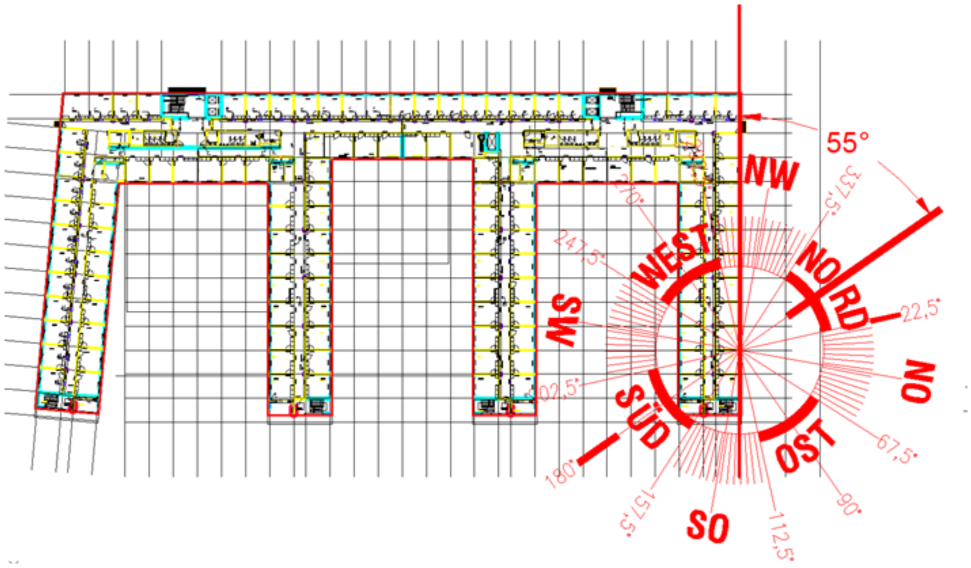


Figure 26: Orientation of the building

The basic design has 840 rooms, a gross floor area of about 26.400 m² and a gross volume of 91.200 m³. It comprises a thermal insulation composite system with 120 mm of insulation, ventilated aluminum covers between the windows with 100 mm of insulation and sun protection cases with 60 mm of insulation. The windows and transom – mullion façade was planned as 2 pane glasses. For the basic reference design the space templates for office buildings from the HESMOS IVEL data base were adapted to the specific client requirements, the construction templates were created using the materials and cost key figures from the HESMOS IVEL data base as well as for weather data the test reference year for the location Kassel from German weather service was selected. Because of the limitation of the zones that can be simulated and the large number of rooms, simulations were started for a representative part of the building of the basic design and for different alternatives of the building shell e.g. adapting the thickness of the insulation in the construction templates and the impacts on the eKPIs final energy, greenhouse gas emissions, thermal comfort as well as life cycle costs were analysed. The alternatives are the following:

- **Alternative 1**
  Increase the wall insulation from 120 mm to 200 mm

- **Alternative 2**
  Increase the insulation of the roof from 160 mm to 360 mm

- **Alternative 3**
  Implement 3 pane glass windows (incl. respective frames) instead of 2 pane glass windows

The nD Navigator chart shows the comparison of the energy simulation results for the representative part of the building and in the following Excel table the final energy savings and the CO_2 reduction was projected for the whole building based on the building shell areas.

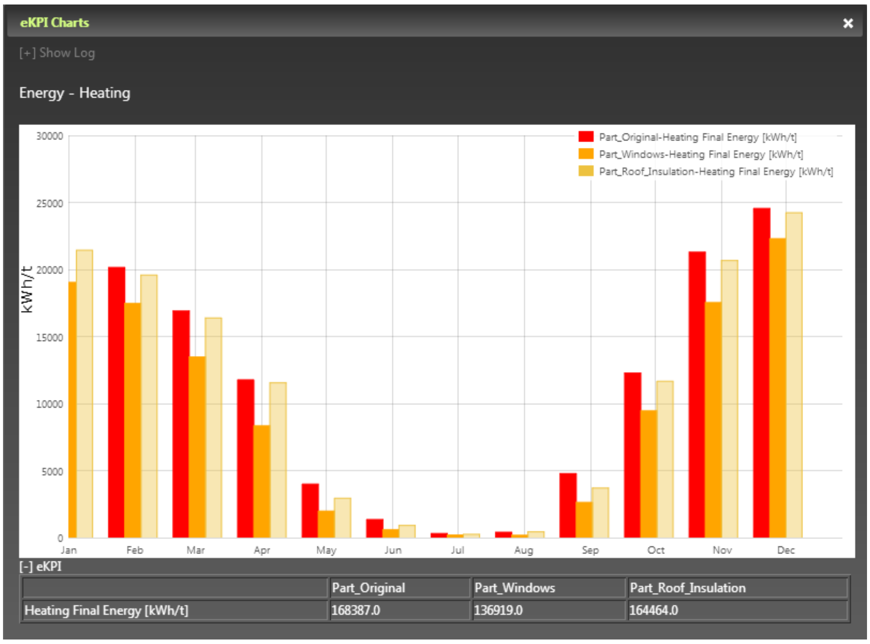


Figure 27: Comparison of alternatives in the nD Navigator

Table 5: Comparison of alternatives – energy savings

	Building shell area of represent-ative part [m²]	Final energy heating of represent-ative part [kWh]	Savings of represent-ative part [kWh]	Building shell area of the whole building [m²]	Savings of the whole building [kWh]	Savings of CO2 [t]
Baseline AS IS façade	-	168.387	-	-	-	-
Alternative 1 Increase of wall insulation from 120 to 200 mm	473,99 *1) (total: 756,30)	164.378	-4.009	6.056	-51.221,55	11
Alternative 2 Increase of roof insulation from 160 to 360 mm	443,16	164.464	-3.923	3.572	-31.620,53	7
Alternative 3 Implement 3 instead of 2 pane glass windows	556,40	136.919	-31.486	4.213	-238.272,26	52

*1) Note that the simulation solver uses inner dimensions of the room so that the façade area in front of the concrete core ceiling (horizontal) and in front of the inner walls (vertical) is not taken into account, but has an effect on energy savings when increasing the insulation.

According to the projected simulation results energy and CO_2 can be saved while meeting the thermal comfort conditions. In addition, for decision-making the different results can be compared with the HESMOS IVEL regarding their life cycle costs as net present value of investment and energy costs for heating and cooling. Cost key figures were included in the eeConstruction Templates to analyse if the additional investment costs would have been feasible. For the investment costs of the building shell of the baseline the costs for the outdoor walls, roof and windows were taken from the original estimation. For alternative 1 – increase of wall insulation - additional investment costs of +1,80 €/cm/m² which results in 14,40 €/m², for alternative 2 – increase in roof insulation - additional investment costs of +1,25€ /cm/m² which results in 25 €/m² and for alternative 3 – implementation of 3 pane glass windows – additional investment costs of 147 €/m² were taken into account.

Table 6: Comparison of alternatives – cost savings

Building shell	**Additional investment costs of the whole building [€]**	**Investment costs of the whole building [€]**	**Life Cycle Costs (investment, energy) of the whole building** Energy price increase = 4 % Discount rate = 4 % (5,5 %) **[€]**
Baseline AS IS façade	-	2.516.036	5.123.446 (4.620.511)
Alternative 1 Increase of wall insulation from 120 mm to 200 mm	87.206	2.603.242	5.115.144 (4.630.632)
Alternative 2 Increase of roof insulation from 160 mm to 360 mm	87.500	2.603.536	5.153.213 (4.661.414)
Alternative 3 Implement 3 pane glass windows instead of 2 pane glass windows	619.311	3.135.347	5.306.817 (4.887.969)

3.2.2 Commissioning and operation phase (Use Case 2)

To monitor system performance of the ventilation equipment, in detail the time schedule efficiency and heat recovery efficiency, Granlund Manager Metrix has been installed at the pilot project "Alfons-Kern-School". To document the energy, CO_2 and cost optimisation a Measurement and Verification (M&V) plan was developed according to the International Performance Measurement and Verification Protocol (IPMVP).

M&V plan

1) Choose the **M&V Option**

   Option D, to perform a calibrated simulation has been chosen, because the optimisation potential has recently been identified and there is no data at the moment for the reporting period. That is why a calibrated simulation is used to predict energy and CO_2 savings of the future improvement of the ventilation equipment.

2) Define the **Measurement Boundary**

   For measurement boundary to report energy and CO_2 savings the ventilation equipment has been chosen, because it has been identified during the research, that the optimisation of time schedule efficiency as well as the heat recovery efficiency have a big impact on savings.

3) Identify **Key Parameters**

   The following key parameters which affect the performance have been identified to be the improvement of the heat recovery system and the reduction in ventilation running hours, so for that purpose web access to the following sensors was provided:

   <u>Heat recovery efficiency</u>

   - Supply air temperature sensors
   - Exhaust air temperature sensors
   - Outdoor air temperature sensors
   - Status of the heat recovery unit

   <u>Time schedule efficiency</u>

   - Status of the supply air fan

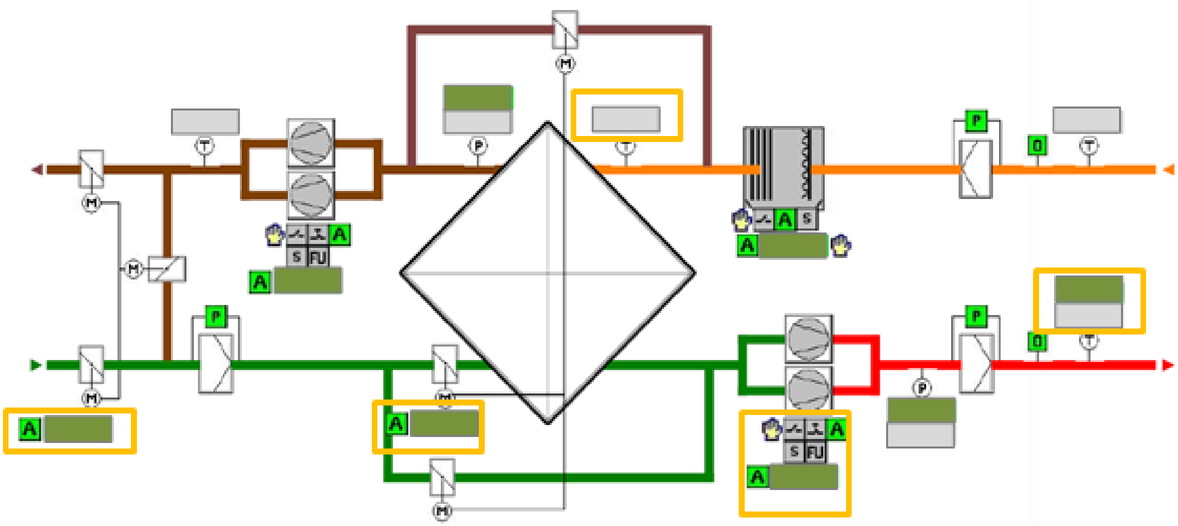


Figure 28: Key parameters – minimum data set for system performance monitoring

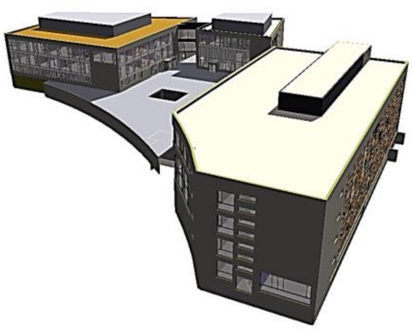
4) Define the **Operating Cycle**

   For the optimisation simulation a whole year is taken into account. For the measurement of the heat recovery efficiency the winter month are of most interest.

5) Measure **Baseline Data** and document **Expected Performance**

The following temperatures supply air temperature, exhaust air temperature, outdoor air temperature were recorded for the past three years. Additional data of the status of the heat recovery unit and the ventilation fans is recorded on the SQL data base since July 2013 and can be monitored with Granlund Manager Metrix.

For monitoring of expected performance – time schedule efficiency and heat recovery efficiency – the optimal time schedule has been defined according to the usage of the building and the heat recovery coefficient according to the manufacturer specification; these manufacturer specifications are the maximum heat recovery efficiency. As minimum heat recovery coefficient we used 0,75.

<table>
<tr><td>
</td><td>
</td></tr>
<tr><td>Building A
<u>Optimal time schedule</u>
Mo-Thur: 05:00 a.m. – 06:00 p.m.
Fr: 06:00 a.m. – 06:00 p.m.
Sa: 08:00 a.m. – 06:00 p.m.

<u>Heat recovery coefficient</u>
winter: 0,83, summer: 0,73</td><td rowspan="3">Building D
<u>Optimal time schedule</u>
Mo-Thur: 05:00 a.m. – 06:00 p.m.
Fr: 06:00 a.m. – 06:00 p.m.
Sa: 08:00 a.m. – 06:00 p.m.

Mo-Sa: 24 hours (because of the use of hazardous materials in the paint shop)

<u>Heat recovery coefficient</u>
winter: 0,83, summer: 0,79</td></tr>
<tr><td>Building B
<u>Optimal time schedule</u>
Mo-Wed: 05:00 a.m. – 08:00 p.m.
Thur: 05:00 a.m. – 10:00 p.m.
Fr: 05:00 a.m. – 08:00 p.m.

<u>Heat recovery coefficient</u>
winter: 0,83, summer: 0,73</td></tr>
<tr><td>Building C
<u>Optimal time schedule</u>
Mo-Thur: 05:00 a.m. – 09:00 p.m.
Fr: 05:00 a.m. – 06:00 p.m.
Sa: 07:00 a.m. – 06:00 p.m.

<u>Heat recovery coefficient</u>
winter: 0,91, summer: 0,79</td></tr>
</table>

Figure 29: Optimal time schedule and heat recovery coefficients of the pilot buildings

6) Develop an **Energy Model** and run the simulation for the **calibrated Baseline Energy Model**.

An energy model has been developed within RIUSKA for the simulation of the current situation in building D of the school building. The IFC was enriched in DesktopROOMEX with the client requirements – minimum/maximum temperatures, air flow rates etc. – as well as the ventilation zones and was imported to RIUSKA as basis for the simulation cases. Parameters for the ventilation equipment – heat recovery and time schedules - were set for every ventilation zone according to the measured data with Granlund Manager Metrix to create a calibrated energy model. Construction types for the outer walls, inner walls, baseplate, roof, intermediate floors/ceilings, windows and doors of the as build situation were assigned in the construction library of RIUSKA.

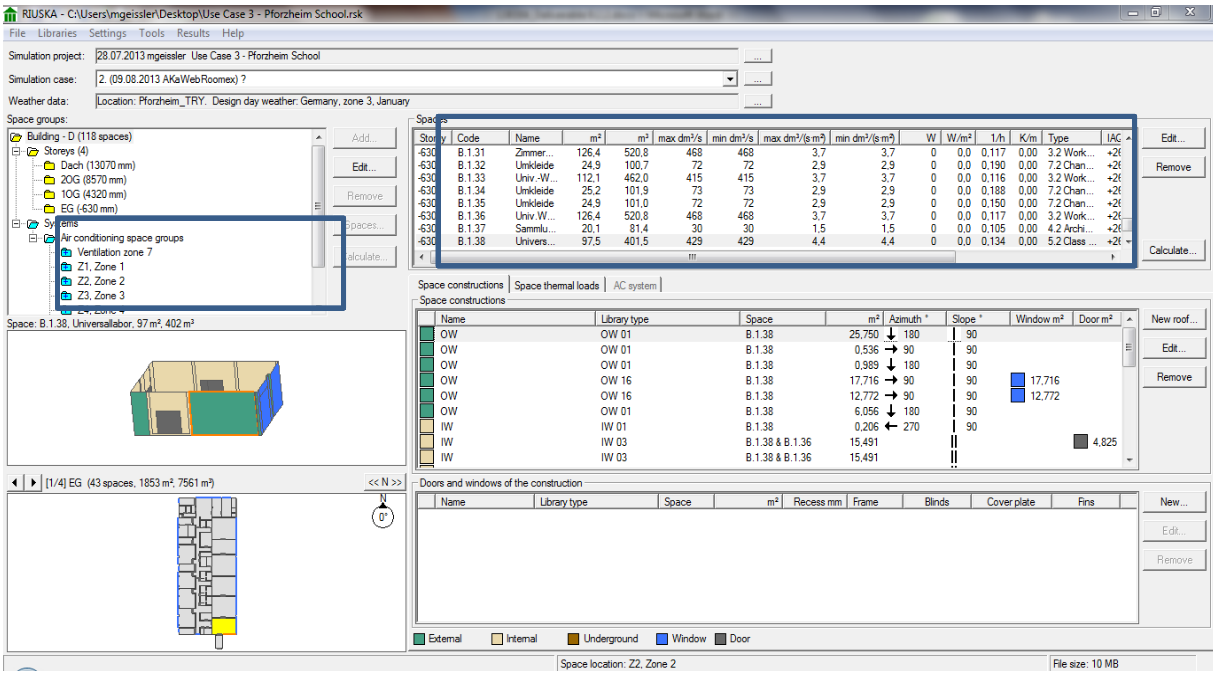


Figure 30: RIUSKA simulation prepared for the school building

7) Repeat the simulation process with the Energy Conservation Measure (ECM) implemented in the **Post-Installation Energy Model**.

   It has been identified that the exhaust air flow rates are lower than the supply air flow rates which affects the heat recovery efficiency. For documentation of energy and CO_2 savings another simulation case was created in RIUSKA, were the heat recovery efficiency was improved from the current 60 % to the minimum heat recovery efficiency of 75 %.

8) Determine savings by **substracting the post-installation simulation results** from the **baseline results** using either actual weather data and facility operation conditions or typical conditions and weather data.

   In the HESMOS monitoring case, with the new RIUSKA reporting possibilities presented in D6.1: “Enhancement of the energy-related tools for the lifecycle use of eeBIM” (Forns-Samso et al., 2011) energy savings can be documented in a comparison report such as shown for the simulations of the Pforzheim building.

Description of the simulation:
1. Use Case 3 - Pforzheim School & 2. Use Case 3 - Pforzheim School - Alternative

ANNUAL ENERGY NEED

Simulation 1	MWh	kWh/m²	kWh/m³
Heating energy	256	45,8	11,3
Cooling energy	71	12,7	3,1
-HVAC, other electricity	89	15,9	3,9
-Lighting electricity	125	22,4	5,5
-Equipment electricity	131	23,5	5,8

Simulation 2	MWh	kWh/m²	kWh/m³
Heating energy	198	35,5	8,7
Cooling energy	71	12,7	3,1
-HVAC, other electricity	89	15,9	3,9
-Lighting electricity	125	22,4	5,5
-Equipment electricity	131	23,5	5,8

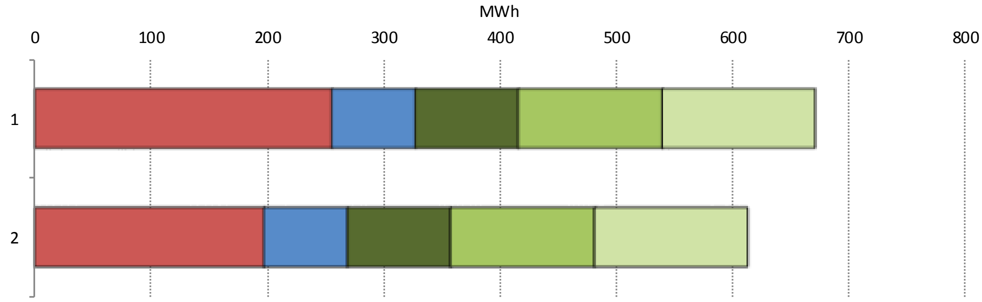


Figure 31: RIUSKA energy need comparison

Simulated heating energy (before optimisation)

Annual energy need for heating = 256 MWh/a
Purchased energy for heating = 309,04 MWh/a

Within the DOE-2 simulation engine of RIUSKA there was only weather data from other German locations available and climate data from the weather station could not be imported in the simulation. Because of this, weather data from the test reference year 2010 was converted and imported into RIUSKA and had to be calibrated to the actual year with the climate factor 0,96 (based on the correction of the weather data published by the German Weather Service and the location of the test reference year climate station): 309,04 MWh / 0,96 = 321,91 MWh/a

Measured heating energy (before optimisation)

Actual measured district heating (01.01.2012-31.12.2012) = 236,33 MWh/a
Climate correction factor = 1,16
Corrected data = 236,33 x 1,16 = 274,14 MWh/a

Comparing simulated and measured data (before optimisation)

A comparison between the simulated and the measured data shows that the performance of the building is better than the expecations which are based on the simulation results. This is the case because the advanced HVAC system and the BAS miminimse the energy consumption of the building based on the actual user behavior. In order to adjust the simulated data accordingly a correction factor is required.

The actual corrected energy consumption of the building was 274,14 MWh in 2012, according to the simulation the expected energy consumption of the building was 321,91 MWh in 2012. Based on this information the simulation values can be calibrated using the following factor:

f = 274,14 MWh / 321,91 MWh = 0,85

Simulated heating energy (after optimisation of the heat recovery unit)

Annual energy need for heating = 198 MWh/a

Purchased energy for heating = 239,7 MWh/a

It was assumed that after the optimisation measures the building will again perform better than the simulation results suggest. For taking this into account, the simulation results after the optimisation are multiplied with the correction factor f= 0,85 to predict the measured consumption after the optimisation measure.

239,7 MWh/a x 0,85 = 203,75 MWh/a

Determine savings

Energy savings: 274,14 MWh/a – 203,75 MWh/a = 70 MWh/a = 15 t CO_2/a

Besides the system performance monitoring it is important to monitor the thermal comfort conditions in the room. If deviations are identified, optimisation measures can be verified with WebRoomEX. For those purposes the structured client requirements and the internal loads as shown in the following tables are ready for target-performance comparisons in the IFC BIM.

Table 7: Client requirements

Group Nr. DIN 277	Type DIN 277	Minimum Temperature [°C]	Maximum Temperature [°C]	Air flow rates [m3/h]
2.1	Offices (one person)	17 °C / 20 °C	26 °C	390
	Offices (group)	17 °C / 20 °C	26 °C	910
3.2	Workshops	18 °C	26 °C	1.690
3,9	Special workrooms	18 °C	26 °C	-
	Special workrooms	18 °C	26 °C	910
4.1	Storage room	15 °C	26 °C	390
4.2	Archives	15 °C	26 °C	-
4.9	Other storage rooms	15 °C	26 °C	-
5.2	Class rooms	17 °C / 20 °C	26 °C	1.040
5.3	Special classrooms	17 °C / 20 °C	26 °C	1.170
6.1	Medical examination rooms	20°C	26 °C	390
7.1	Sanitary rooms	20°C	26 °C	260
7.2	Changing rooms	22°C	26 °C	260
8.1	Rooms for waste water, water, gas	15°C	if outdoor ≥ 32°C then (outdoor-6°K) else 26°C	-
8.4	Electrical supplies	5 °C	"-"	-
8.5	Telecommunication equipment	10 °C	"-"	-
8.9	Other operating equipment	15°C	"-"	-
9.1	Halls and corridors	15°C	"-"	-
	Assembly hall	17 °C / 20 °C	"-"	-
9.2	Stairs	15 °C	"-"	-

Table 8: Internal loads

Group Nr. DIN 277	Type DIN 277	People 80 W/P	Equipment		Lighting		
		[W/m²]	[Wh/m²,d]	[W/m²]	[W/m²]	Pcs.	W
2.1	Offices (one person)	7	42	4	16	4	98
	Offices (group)	14	8	1	18,1	12	98
3.2	Workshops	11	280	31	9,3	12	98
3,9	Special workrooms (cleaning)	0	0	0	7,4	2	49
	Special workrooms (paintshop)	3	108	10	16,3	12	98
4.1	Storage room	0	0	0	6	5	98
4.2	Archives	0	0	0	4,7	2	49
4.9	Other storage rooms	0	0	0	9,7	2	98
5.2	Class rooms	31	20	3	12,1	8	98
5.3	Special classrooms	19	20	3	12,6	11	98
6.1	Medical examination rooms	10	35	3	16,5	4	101,5
7.1	Sanitary rooms	0	0	0	17,9	4	52
7.2	Changing rooms	0	0	0	16,8	7	60
8.1	Rooms for waste water, water, gas	0	0	0	9,8	2	98
8.4	Electrical supplies	0	0	0	4,8	1	49
8.5	Telecommuni-cation equipment	0	0	0	4,9	1	49
8.9	Other operating equipment	0	0	0	10,6	9	98
9.1	Halls and corridors	0	0	0	6,2	14	52
	Assembly hall	0	0	0	5,2	10	52
9.2	Stairs	0	0	0	5,4	3	49

WebRoomEX has been implemented in the pilot school building and is continuously used for monitoring of thermal comfort conditions as well as indoor air quality (CO_2 and humidity).

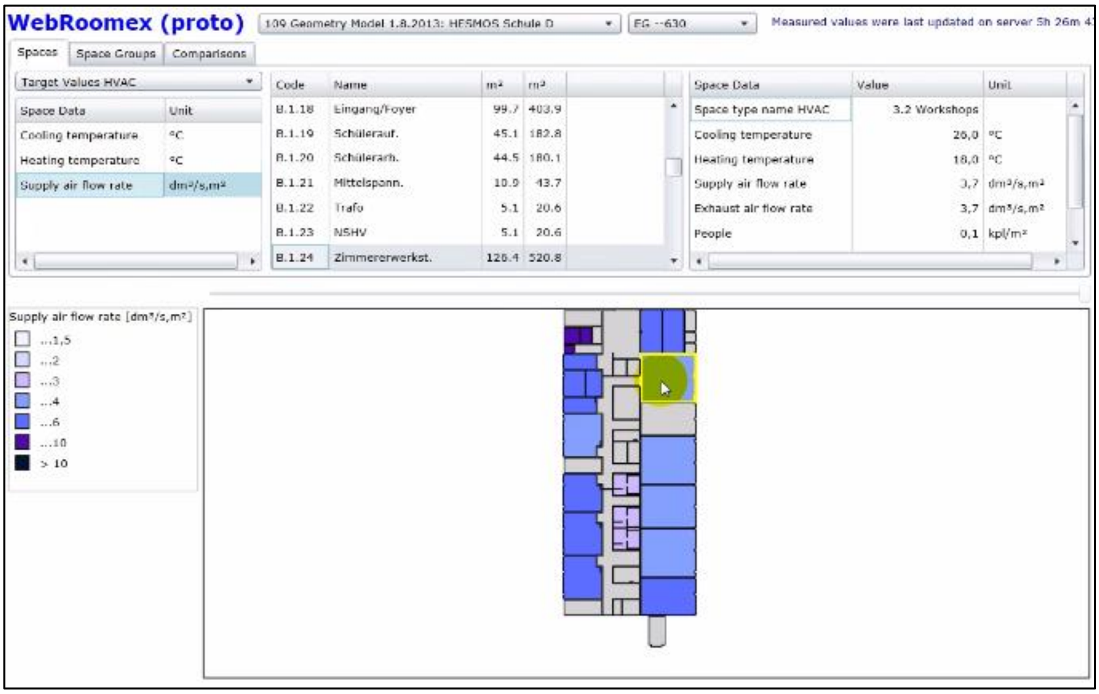


Figure 32: Web access to client requirements and internal loads with WebRoomEX

In the comparison graphs the building manager can easily identify by comparing target with measured sensor data on the web interface if a room is too hot (red) or too cold (blue). In the case of the pilot project, in room B.0.38 universal laboratory, optimisation potential has been identified like shown in the WebRoomEX screen shot below.

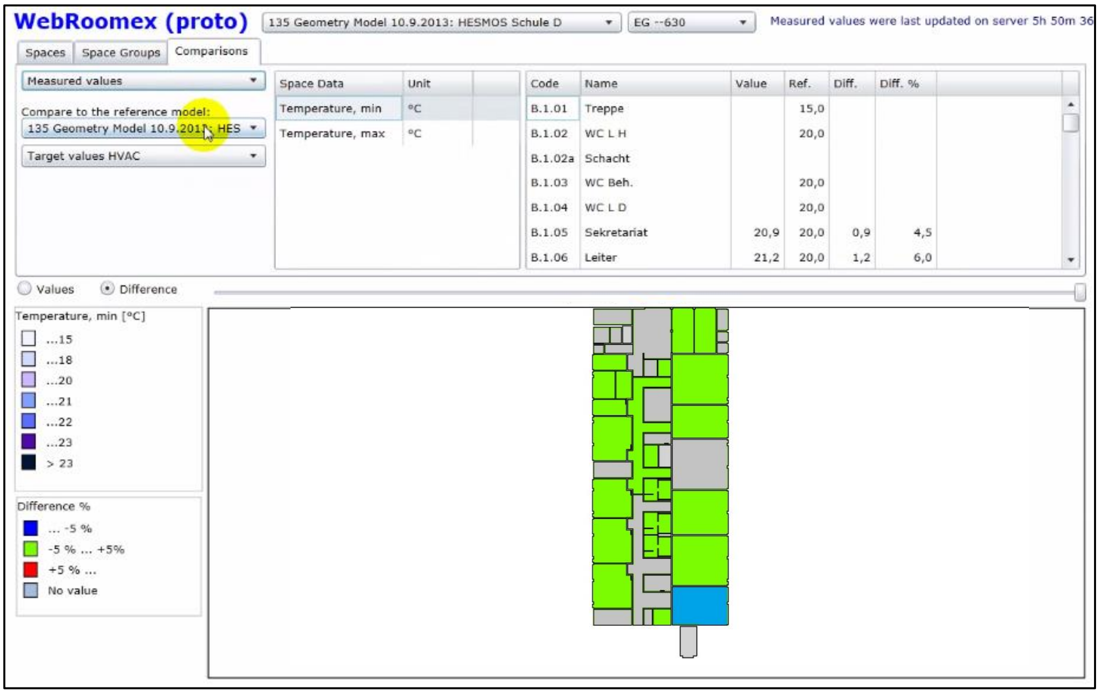


Figure 33: Comparison of measured data with targets on WebRoomEX interface

Deviations from targets can be easily identified and localised in the IFC-BIM and optimisation measures can be implemented in advance. In case of the pilot project the FM team developed an optimisation measure by additional inside fiber glass insulation of the elevator shaft and a double leaf steel door (with an U value of 2,3 W/(m^{2}xK)).

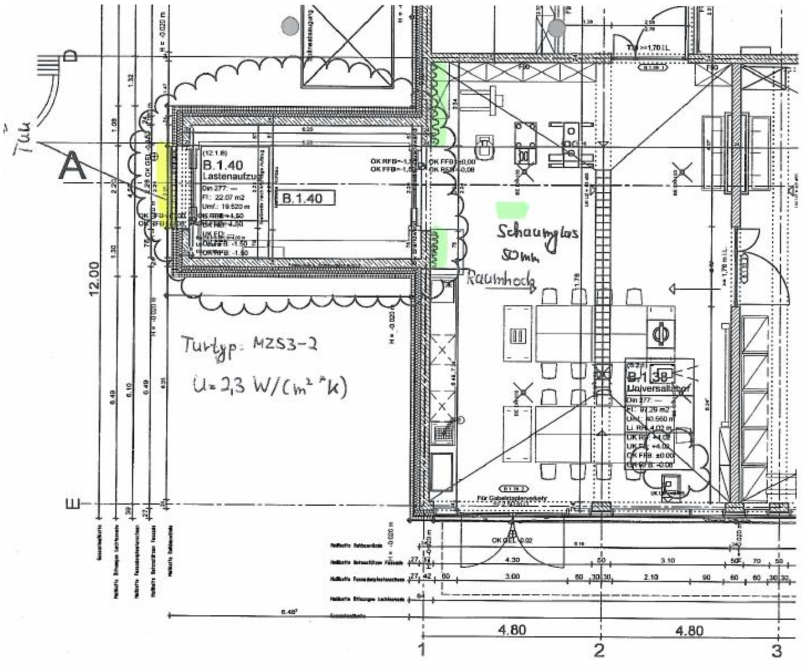


Figure 34: Measures to optimise thermal comfort

This optimisation measure has been verified by a RIUSKA simulation and visualised in WebRoomEX, that the client requirements are again met.

After the installation of CO_2 sensors (ppm CO_2 measurement of the air) in the classrooms and humidity sensors in the workshops to monitor thermal comfort conditions as well as to control the ventilation equipment, besides improved comfort conditions, 25 % of the electrical power was additionally saved.

4 Summary: Benefits and Costs

4.1 Process optimisation through implementation of the HESMOS IVEL

In summary, after implementation of the HESMOS IVEL for the design and tendering phase, the integrated project team needs 68 man days less compared to the conventional approach which saves 3,4 man month x 12.000 €/man month (AHO) = 40.800 € of labour costs.

During operation phase about 20 man days can be saved for monitoring and reporting by the building manager and about 10 man days can be saved for energy optimisation by the energy manager. In summary, about 0,75 man month x 7.200 €/man month = 5.400 €/a of labour costs can be saved which means for 30 years 162.000 €.

To document the optimisation in process quality all benefits were summarised in the Interactive Capability Maturity Matrix (I-CMM) of the National Building Information Modelling standard. After implementing the HESMOS IVEL the maturity developed from "not certified" to "platinum" because of e.g. the consistent data / information management, the nD Navigation, real time access to sensor data, an open platform which guarantees interoperability etc.

TODAY:	November 9, 2013		
© NIBS 2012	The Interactive BIM Capability Maturity Model		
Area of Interest	**Weighted Importance**	***Choose your perceived maturity level***	***Credit***
Data Richness	84%	Full Knowledge Management	*8,4*
Life-cycle Views	84%	Full Facility Life-cycle Collection	*7,6*
Change Management	90%	Full Optimization	*9,0*
Roles or Disciplines	90%	Internal and External Roles Supported	*9,0*
Business Process	91%	All BP Collect & Maintain Info	*7,3*
Timeliness/ Response	91%	Real Time Access w/ Live Feeds	*9,1*
Delivery Method	92%	Netcentric SOA Based CAC Access	*8,3*
Graphical Information	93%	nD - Time & Cost	*9,3*
Spatial Capability	94%	Part of a limited GIS	*6,6*
Information Accuracy	95%	Comp GT w/Limited Metrics	*8,6*
Interoperability/ IFC Support	96%	Most Info Uses IFC's For Interoperability	*8,6*
	National Institute of BUILDING SCIENCES Facilities Information Council National BIM Standard	**Credit Sum**	**91,7**
		Maturity Level	*Platinum*

ADMINISTRATION	Points Required for Certification Levels		
	Low	**High**	
	40	*49,9*	*Minimum BIM*
	50	*59,9*	*Minimum BIM*
	60	69,9	**Certified**
	70	79,9	**Silver**
	80	89,9	**Gold**
	90	100	*Platinum*

Figure 35: Interactive Capability Maturity Matrix (I-CMM) – Maturity reached with HESMOS IVEL

4.2 Building optimisation through implementation of the HESMOS IVEL

Because of the sustainability assessment during the design phase the alternative with the best cost-quality can be chosen. During the operational phase, because of the optimisation of the heat recovery efficiency 70 MWh/a x 80 Cent/MWh = 56 €/a can be saved which leads to 3.266 € for 30 years by estimated price increase of 4 %. In addition, the thermal comfort and indoor air quality can be optimised in case that deviations occur.

4.3 Costs for implementation of the HESMOS IVEL

For implementation of the HESMOS IVEL on a project, the core platform with model management, template management and post-processing, will be provided as open source.

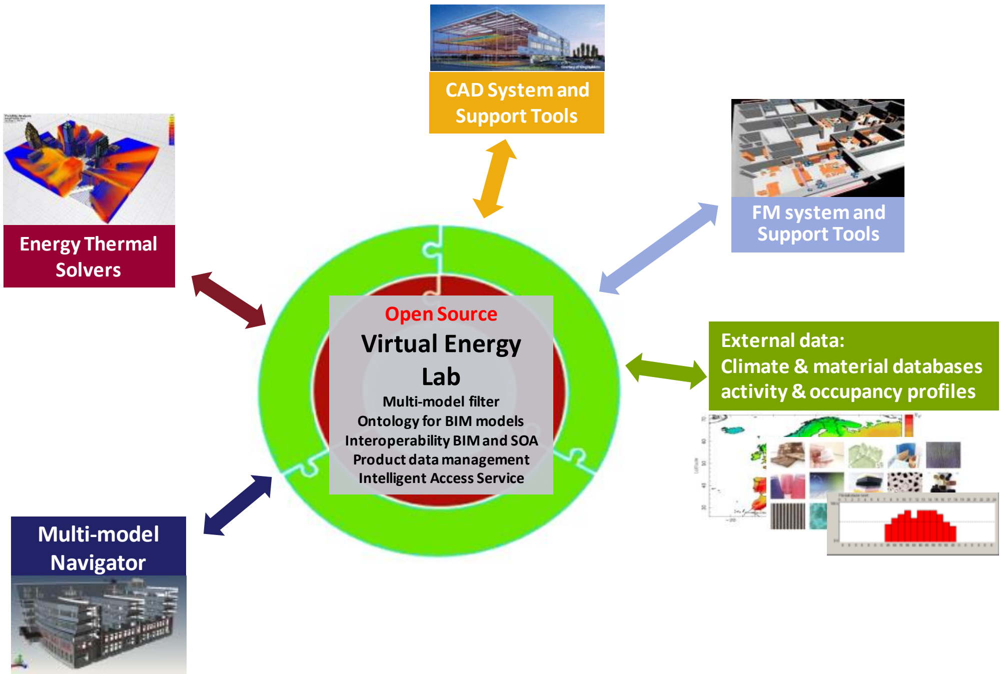


Figure 36: HESMOS Integrated Virtual Energy Laboratory

Software

<u>CAD</u>
A CAD system is needed to create the model and to export the IFC and X3D which are the basis for simulations and decision-making during the design and tendering phase. In HESMOS Allplan CAD from Nemetschek was used with license costs of 6.295 €.

<u>Simulation software</u>
NANDRAD: available for non-commercial use for free and it is in further development. For commercial use another simulation software can be integrated in the IFC based simulation and alternative comparison process.
RIUSKA: 2.800 € per license (but this is only a one time investment).

<u>nD Navigator</u>
The nD Navigator the web-based user interface to prepare the model for simulations and for the visualisation of the simulation results according to energy-related Key Performance Indicators, is still in prototype phase and investment costs cannot be published in this deliverable.

<u>WebRoomEX</u>
No costs, because WebRoomEX is still in the prototype phase

<u>Granlund Manager Metrix</u>
100 €/Air Handling Unit

Hardware

Server

To host the IVEL platform as hardware a server with costs of about 2.500 € is needed.

SQL data base and DSL Router

For monitoring of the thermal comfort in the rooms and system performance of the ventilation equipment a SQL server and a DSL router were installed in the building to record and transfer the data by user request to the IVEL. The investment costs for them were about 2.600 €.

Sensors

To equip a building in the size of our pilot school building (Building A, B, C, D) with sensors, the costs which occur are summarised for the data set of sensors used in the FM module of the IVEL. In addition, for the concept design of the BAS, costs of about 2.000 € were estimated.

Number of monitored buildings	4
Number of AHU equipment	4
Data points room temperature	50
Data points combined temperature / CO_2 level	89
Data points combined temperature / humidity	36

Figure 37: Number of sensors in Pforzheim school

In the following table the hardware costs for the sensors which are used for the HESMOS monitoring are summarized. They are between 18.240 € if only temperature sensors are used to 43.790 if combined temperature and CO_2 sensors are used.

Table 9: Hardware costs for sensors

Sensors	Cost per sensor	Sum sensor costs
Weather measurements [°C/%]		
outdoor temperature / humidity	550,00 €	1.650,00 €
Room temperature / humidity and CO2 sensors [°C, %, ppm CO2]		
room temperarture	50,00 €	8.750,00 €
combined room temperature and humidity	+(147,00 €)	+ (25.725 €)
combined room temperature and CO2	+(196,00 €)	+ (34.300,00 €)
Control cabinet		
DDC (e.g. for BACnet)		600,00 €
Input modules, analog (4 channel, 0-10 V)	121,00 €	5.324,00 €
Terminal blocks	1,50 €	262,50 €
Status of the ventilation fan / heat recovery unit [% per AHU]		
Control cabinet		
Input modules, analog (4 channel, 0-10 V)	121,00 €	121,00 €
Terminal blocks	1,50 €	6,00 €
Supply and exhaust temperature sensors [°C per AHU]		
Supply temperature	84,00 €	336,00 €
Exhaust temperature	84,00 €	336,00 €
Control cabinet		
DDC (e.g. for BACnet)		600,00 €
Input modules, analog (4 channel, 0-10 V)	121,00 €	242,00 €
Terminal blocks	1,50 €	12,00 €
SUM (only temperature sensors)		18.239,50 €
SUM (with combined temperature and humidity sensors)		35.214,50 €
SUM (with combined temperature and CO2 sensors)		43.789,50 €

Additional costs occur for the cables of about 900 €, for the installation about 2.700 € and for the definition of the data point of about 30 €/data point x 315 data points = 9.450 € in the Building Automation System management software and the establishment of a trend of about 30 €/data point x 315 data points = 9.450 € to record the data on the SQL data server.

Training

For training of the project team consisting of about 7 people for one day to apply the HESMOS platform and its components (nD Navigator, WebRoomEX, Granlund Manager Metrix) about 4.000 € training costs are estimated.

These costs are only one time investment costs and they will pay off fast because of the process optimisation as well as the savings which will occur in building operation.

5 Conclusions

This Deliverable report presented an overview of the benefits achieved by implementing the new capabilities of the HESMOS IVEL on BAM Deutschland's two pilot projects during design and tendering as well as operation phase. As a basis to understand the use case scenarios, the HESMOS IVEL and its capabilities were described step by step during both life cycle phases. For the design phase the HESMOS IVEL supports decision-making among different building shell design alternatives in the nD Navigator. During operation phase, sensor data from Building Automation Systems is monitored regarding system performance of ventilation equipment with Granlund Manager Metrix as well as thermal comfort conditions with WebRoomEX. As a result, target-performance comparisons to compare simulation results and measured data under the same external conditions can be realised; variances can easily be identified and immediately resolved. The FM team can also benefit from the described functionalities for identification and implementation of retrofitting and refurbishment measures.

To identify the benefits on the pilot project, the project participants evaluated the optimisation potential compared to their current working processes on the pilot project "Finance Centre Kassel" for design and tendering and "Alfons-Kern-School" during building operation. The actual man hours were documented and compared to the man hours which will be spent in such a project with the capabilities of HESMOS. In addition the project participants evaluate the optimisation of the process quality and the improvement of quality was quantified / documented according to the National Building Information Modelling standard.

For documentation of the optimisation of the building, a sustainability assessment was used to compare different alternatives regarding energy-related Key Performance Indicators to find the alternative with the best cost-quality ratio. During operational phase a Measurement and Verification plan according to the International Performance Measurement and Verification Protocol was set up, as basis for monitoring of the system performance and thermal comfort conditions as well as for documentation of the savings or saving potential.

After implementation on the pilot projects, it can be concluded that the HESMOS IVEL, contribute to the optimisation of the processes regarding time and quality, as well as the optimisation of the building itself with respect to environmental quality, comfort level and costs. Because of coordination with a central data model, the automated verification of compliance with client requirements, the transparent decision-making capabilities regarding eKPI as well as the standardisation of processes and data exchange, about 3,4 man month which means about 40.800 € of labour costs can be saved during design and tendering phase. The biggest savings are estimated for the building physicist and the project coordinator. During operational phase the facility manager has remote access to sensor data by web services visualised in the model or as performance metrics which saves about 0,5 man month per year of time through the reduction in travels and presence on site, a shorter validation process, the comparison anytime via web as well as a reduced effort for energy management process and reporting. Because an up-to-date eeBIM model was created by the project team during the design phase and updated during the construction and commissioning phases, with all required information, the energy manager can save about 0,25 man month per year of his time for analyses of optimisation measures. In summary, about 0,75 man month x 7.200 €/man month = 5.400 €/a of labour costs can be saved which means for 30 years 162.000 €.

The process quality has been evaluated by experts of the different life cycle phases and the capabilities have been documented in the Interactive Capability Maturity Matrix (I-CMM) from the National Building Information Model Standard. Because the HESMOS transparent, consistent and standardised eeBIM approach leads to a development in the maturity levels in the following categories - data richness, life cycle views, roles and disciplines, business processes, timelines / responses, delivery method, graphical information, spatial capability, information accuracy as well as interoperability - the highest standard “platinum” can be achieved.

The design scenario applied in this deliverable showed that the application of the HESMOS methodology on the pilot project can be used to quickly provide energy simulations from eeBIM models. Because of this easy and fast creation of different building shell alternatives the alternative with the cost-quality ratio can be identified in an early stage of a project.

Granlund Manager Metrix which is implemented in BAMs pilot school building is used to monitor the system performance of ventilation equipment and to identify inefficiencies of heat recovery or operating time schedules. The influencing factors as well as the energy saving potential of about 70 MWh/a which was identified in a BIM-based RIUSKA simulation when improving the heat recovery were documented in the M&V plan. Additionally, with WebRoomEX, deviations from agreed thermal conditions could be in-time localised and the thermal quality was optimised by improving the thermal insulation of the building. The optimisation of thermal comfort was documented during the pilot project by conducting RIUSKA simulations with actual operational data and verified in the color-coded floor plans from the model. Risks of thermal comfort deviations are minimised and as a result penalties from the client can be avoided.

Because of more efficient processes and improved environmental and indoor quality of buildings, the costs for implementation of the HESMOS IVEL – software, hardware and training costs – will be redeemed relative quickly. In the HESMOS Workshops first hosted by Obermeyer, second hosted by buildingSMART and third hosted by BAM, the IVEL use case scenarios were presented to a public audience to obtain further valuable feedback on the benefits.

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Appendix I: Aronyms and Abbreviations

AHO	**A**usschuss der Verbände und Kammern der Ingenieure und Architekten für die **Ho**norarordnung - Committee of the Associations and Chambers of Engineers and Architects for Fee Regulations
AHU	**A**ir **H**andling **U**nit
BAS	**B**uilding **A**utomation **S**ystem
BIM	**B**uilding **I**nformation **M**odel, **B**uilding **I**nformation **M**odeling
ECM	**E**nergy **C**onservation **M**easure
eeBIM	**e**nergy-**e**nhanced **B**uilding **I**nformation **M**odel
eKPI	**e**nergy-related **K**ey **P**erformance **I**ndicators
FM	**F**acility **M**anagement
GUI	**G**raphical **U**ser **I**nterface
HESMOS	**H**olistic **E**nergy Efficiency **S**imulation and Life Cycle **M**anagement **O**f Public Use Facilitie**S**
I-CMM	**I**nteractive **C**apability **M**aturity **M**atrix
IDM	**I**nformation **D**elivery **M**anual
IFC	**I**ndustry **F**oundation **C**lasses
IPMVP	**I**nternational **P**erformance **M**easurement and **V**erification **P**rotocol
IVEL	**I**ntegrated **V**irtual **E**nergy **L**aboratory
LCC	**L**ife **C**ycle **C**osting
M&V	**M**easurement & **V**erification
NBIMS	**N**ational **B**uilding **I**nformation **M**odel **S**tandard
SOA	**S**ervice **O**riented **A**rchitecture