SEVENTH FRAMEWORK PROGRAMME OF THE EUROPEAN COMMUNITY
(EC GRANT AGREEMENT N° 288819)

INTELLIGENT SERVICES FOR ENERGY-EFFICIENT DESIGN AND LIFE CYCLE SIMULATION

Deliverable D1.1:

State of the Art and Gap Analysis for Energy Performance Assessment

Responsible Authors:

Miha Kavcic, Costas Balaras, Gudni Gudnason, Romy Guruz, Jens Kaiser,
Peter Katranuschkov, Tuomas Laine, Tobias Mansperger, Theodora Pappou

Co-Authors:

Boštjan Černe, Amin Zahedi

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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 **objective** of WP1 of ISES is to (1) perform analyses of user roles, existing information resources and anticipated usage scenarios and needs, (2) develop typical use cases that shall be used as baseline for all subsequent RTD work and, (3) provide objective specification of the requirements regarding a) ICT-related energy and CO_2 emissions modelling, and b) the interoperability needs for efficient application of advanced simulation methods. This deliverable performs a survey of existing ICT resources for energy and CO_2 performance assessment. Gaps are identified and their possible impacts on the ISES platform are discussed. The functionalities of state-of-the-art tools to be used in ISES are also analysed. Not addressed are issues already identified within the EU project 260088 HESMOS with regard to the building life cycle process and the use of architectural BIM-CAD and BIM-FM tools. These issues are covered in the HESMOS Deliverable D1.1 (Bort et al. 2011). Hence, the attention is specifically on weather and climate data, user behaviour and user comfort, product components and catalogues and stochastic considerations which are not in the focus of HESMOS.

This deliverable covers the overall work performed in WP1 within Task T1.1 Gap Analysis. In order to better prepare the focused detailed work in the WPs 2-6, a broad horizontal study of the relevant aspects has been first performed, which is reflected by the content and the extended title of the deliverable.

The deliverable report is structured into nine parts:

Part 1 gives a brief introduction, motivating the performed study, aligning it with the use case scenarios developed in Task 1.2 and documented in Deliverable D1.2, and explaining the overall structuring of the report.

Parts 2-7 provide the core of the report, analysing the various resources that need to be considered on the ISES Virtual Lab for achieving comprehensive probabilistic energy and CO2 performance assessment.

Part 8 outlines the state-of-the-art in energy-related ICT methods and tools, focussing specifically on the tools intended for ISES.

Finally, in **Part 9** a synthesis of the findings and achieved goals is done.

An extensive bibliography and a listing of used acronyms and abbreviations rounds up the report.

All partners were involved in the work and each partner has contributed from their expert viewpoint as follows:

- **TRI**: Lead, all subtasks from contractor and operator point of view with focus especially on component development;
- **TUD**: Product catalogues; stochastic approach, material and climate data, ICT tools, structure and editing of the report;
- **LAP**: Product catalogues, end user perspective
- **NMI**: User behaviour and user comfort, stochastic methods
- **NOA**: Consideration of site and primary energy, sources weather and climate data, user behaviour and user comfort, building materials, elements and systems
- **OG**: Life Cycle Processes (facility management, client and operator view), user behaviour
- **SOF**: Software methods and tools
- **UL**: Software methods and tools.

A delay of about 1.5 months in the finalisation of the deliverable report was caused by difficulties in coordinating and structuring all partner contributions in the first phase of the project (month 1-6).

1. Introduction

Due to the emphasis on energy efficiency in buildings, the commitment for reducing greenhouse gase (GHG) emissions and the market need for building renovations, numerous different solutions have emerged in the building construction market. On December, 16th 2002 the European Parliament and Council adopted Directive 2002/91 on the energy performance of buildings (EPBD), which is the main legislative instrument for improving the energy efficiency of the European building stock. EPBD mandated that by 2006 all EU Member States bring into force national laws, regulations and administrative provisions for setting minimum requirements on the energy performance of new and existing buildings that are subject to major renovations, and for energy performance certification (EPC) of buildings. Its rules and guidelines require a substantial increase in building envelope thermal insulation, which has an impact both to the thermal performance of the building envelope and to the technical characteristics of the thermal insulation materials. To achieve that, new and more comprehensive methods for building energy and carbon emissions (e.g. CO_2) performance assessment are needed.

Energy efficiency of buildings – status

33% of all energy in the EU is used for transport

26% of all energy in the EU is used by industry

41% of all energy in the EU is used by buildings

Figure 1: About 2/3 of energy consumption in buildings is used for heating and cooling. Source: Eurostat http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Consumption_of_energy

The ISES projects aims to contribute to these higher goals by developing a Virtual Energy Laboratory that will provide for detailed energy performance studies taking into account the stochastic nature of the involved resources and processes. This will be achieved through development and integration of a number of ICT building blocks utilising the computational power provided by today's Cloud Computing technique. However, in order to provide a sound basis and appropriate modularisation of the ISES ICT platform, at first the relevant information and processing aspects regarding building energy analyses and simulations have to be studied in broader terms. This is the major purpose of the project deliverable D1.1, whose findings are documented in this report.

At the outset, the question that needs to be answered is which phases of a facility life cycle have to be looked at. It is generally recognised that the most critical phases to control in order to affect the actual energy consumption through the whole building life cycle are early design and operation (see Figure 2). Early design focuses especially in the initial spatial layouts, according to client's intent and building envelope design. It may also include initial heating, ventilation and air-conditioning (HVAC) system selection and definition of main electromechanical systems service areas. During operation, monitoring and analysing of energy efficiency are important tools to bring actual energy consumption closer to the optimum performance and also to react on the changes in the use of the building. Most decisive, thereby, is the first operation phase where systems are adjusted to actual as-built, environmental and behavioural conditions.

The importance of early building design is growing as new regulations emerge to meet the requirements for reaching nearly zero energy building (nZEB) by the end of the decade, in accordance to the EU EPBD recast (2010/31/EC). Therefore, this is the main usage scenario targeted by the ISES project. Energy efficient solutions typically need involvement of multi-discipline expertise and this can be achieved by using collaborative, *team based holistic working methods*. This is a goal that is also well aligned with the ISES objectives. Moreover, it allows following the cost optimality principle of the directive's nZEB regulations.

There are new collaborative processes and contracting methods, like Integrated Project Delivery (IPD), which emphasize team working. IPD is using the benefits of building information modelling (BIM) in a collaborative environment. All project stakeholders work for the same goal and participate in each other's work. Information exchange between teams works naturally because of the close integration of teams. The information collection is also more efficient, since it is only done once and then shared with other teams immediately (Eastman et al. 2011). Due to these considerations, the use of standardised BIM as basis is a preset requirement in ISES, which is not further discussed against other options in this report.

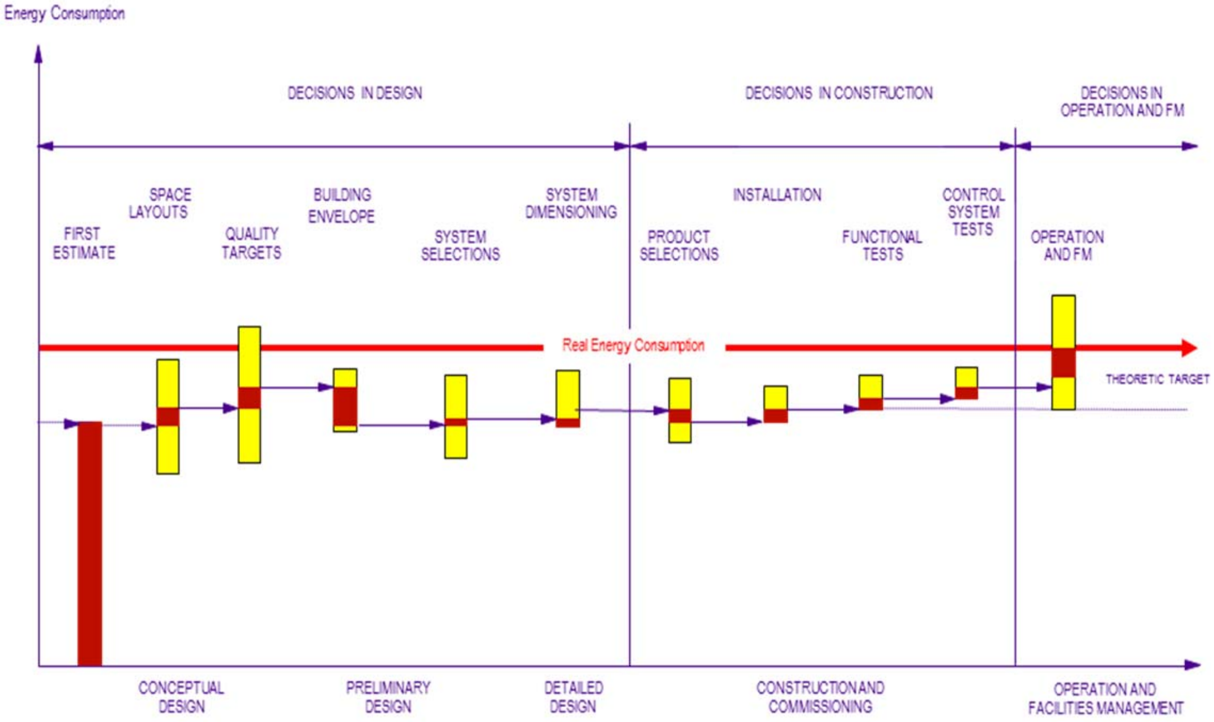

Figure 2: Building process energy and life cycle management. (Hänninen, 2011)

However, the ISES Description of Work (ISES 2011) and more comprehensively the ISES Deliverable D1.2 "Use Case Scenarios and Requirements Specification" (Guruz et al. 2012) define two more major scenarios that should be targeted by the ISES platform along with early design. These are:

(1) The development of product components, and

(2) Refurbishment and retrofitting of existing facilities.

The first of these scenarios is, on more local scope, equally important to early design with regard to energy related decision making. It addresses the perspective of providers of prefabricated elements and HVAC equipment, which are both highly relevant with regard to building energy efficiency. In the context of ISES, in first place prefabricated façade elements for the building envelope are the primary target. The second scenario is to some extent similar to the design scenario but addresses another important business case – the efficient use and energy performance improvement of the existing building stock.

Figure 3 adapted from ISES Deliverable D1.2 (Guruz et al. 2012) shows a general view of the two principal life cycles addressed in ISES, i.e. component product development and the building's life cycle, highlighting the targeted main usage scenarios and presenting in concise form the *information and computational targets and needs* for successful performance of these scenarios. Preliminary analyses showed that for all scenarios principally the same information resources and computational tools are needed, although in detail there are of course various differences to be taken into account. The information issues to be considered comprise energy consumption (target), as well as weather and climate data, user behaviour, user comfort, building elements and materials and providers' digital product libraries (input). The computational resources that are directly relevant to the ISES goals are energy simulation, CFD analysis and stochastic analysis tools*).

These aspects are separately discussed in the following chapters.

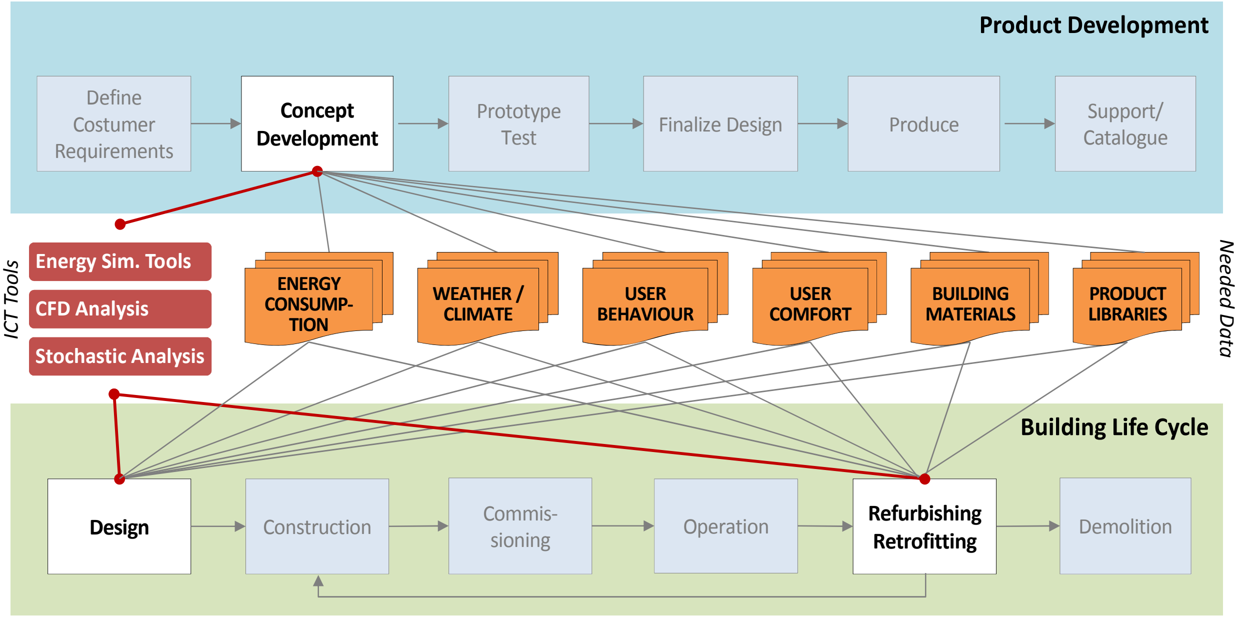

Figure 3: Energy aspects related to the focused ISES scenarios

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*) Various other relevant ICT tools are included in the ISES Description of Work , such as an nD Navigator for pre- and post-processing and for visualisation of energy simulation results, various Virtual Lab Management Tools, BIM management tools, Cloud-enabling facilities etc. However, all these tools are not directly related to building energy assessment, but only indirectly support the process. Therefore, they are not a target of discussion in this report. Such tools and services will be specifically referenced in the ISES Deliverable D2.2 „Architecture and Components of the Virtual Lab Platform“.

2. Energy Consumption

Basically, energy consumption is considered in two ways: (1) as final energy consumption, and (2) as primary energy consumption.

Final energy consumption, i.e. at the site of a building (also known as **site energy**), is commonly available from either measured or monitored or calculated data. This includes the energy supplied to the technical systems of a building through the system boundary to cover the different end uses of the building for HVAC, domestic or service hot water, lighting, appliances etc. or to produce electricity. It has to be considered also whether renewable energy produced on site can be used as part of the site energy. The net delivered energy to the building is defined as the delivered energy minus exported energy, both expressed per energy ware. A balance of the delivered and exported energy ware can be performed only if the same primary energy factors and/or CO_2 coefficients apply to the delivered and exported amounts of that energy ware (EN 15217, 2007).

Final (site) energy consumption is of practical interest to a building owner, since this information is directly related to the building's direct operational cost. It is necessary to differentiate between thermal and electrical energy consumption in order to derive appropriate energy performance indicators.

The **primary energy**, i.e. the **source energy** that has not been subjected to any conversion or transformation process (e.g. power plant), is used to produce the energy delivered to the building. It includes both non-renewable energy and renewable energy. It is possible to convert to primary energy using national average or even local conversion factors. In this case it is possible to estimate the actual energy consumption of different fuels that may be used for generating electricity (e.g. coal, natural gas, oil, etc.). Use of primary energy is of greater relevance to policy makers and is necessary for calculating the environmental impact and CO_2 emissions of a building's energy consumption.

According to the European Standard EN 15217 (2007), energy performance indicators can represent: a) primary energy, b) CO_2 emissions, c) net delivered energy weighted by any other parameter defined by national energy policy (e.g. delivered energy, or cost). These may be complemented by any other indicators. That sets some kind of priority and allows for sufficient flexibility to have it tailored to specific needs and even national or market priorities. However, while indicators are clearly defined, they are not readily available for integrated BIM-based*) building and component design and are usually calculated independently and input manually into specialised energy tools.

Conversion factors for calculating the primary energy consumption from the estimated or measured final energy consumption depends on the fuel and the fuel mix for generating electricity. This implies that there may be available *different national or even regional conversion factors* that may even depend on the time of day (e.g. using a different fuel mix in power plant to meet electrical loads during the day or the use of renewable energy sources for power generation in a national or regional power network). This kind of information is also not readily available. Accordingly, national averages are commonly used for calculating the primary energy consumption for different fuels. As an

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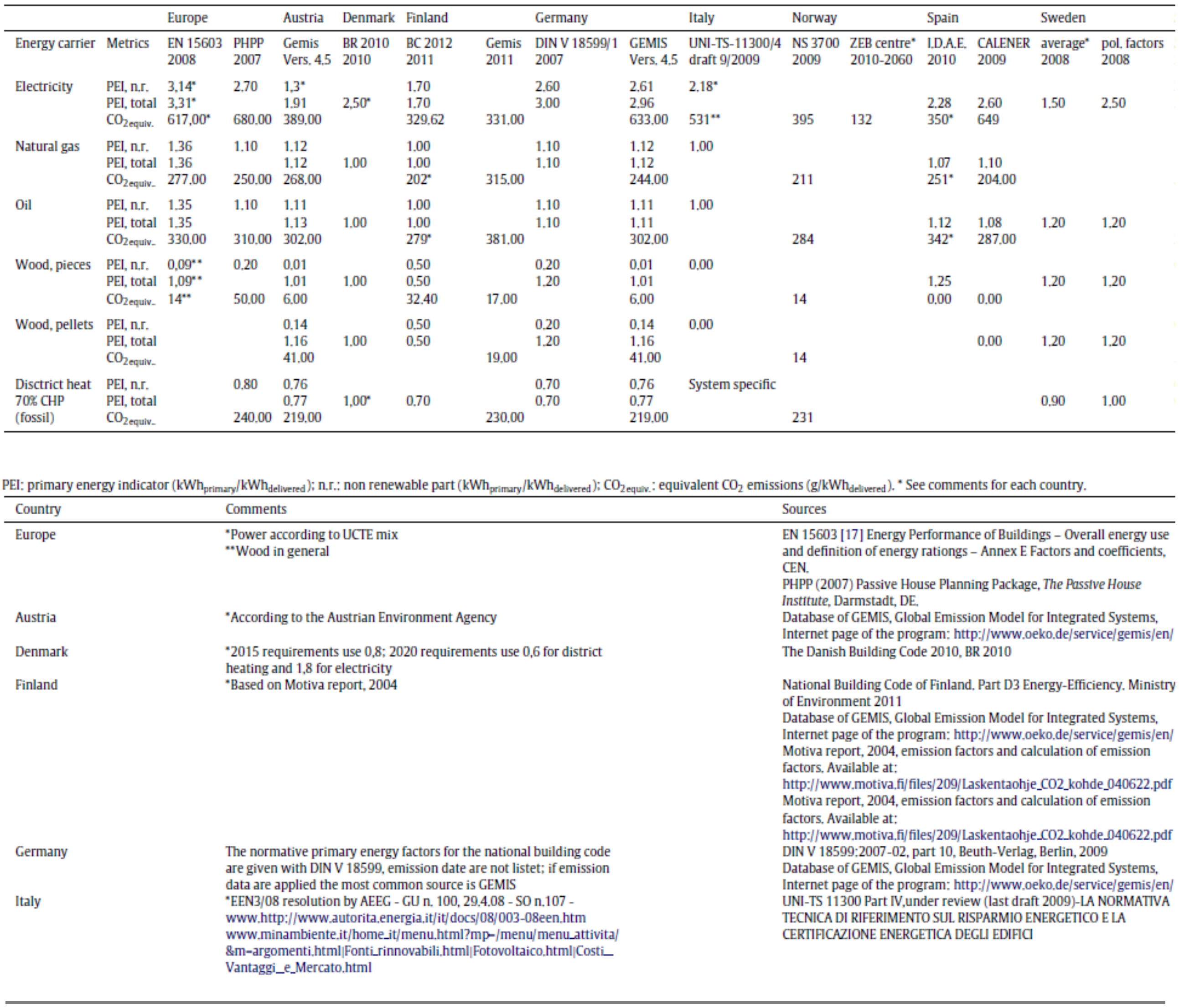
*) BIM = Building Information Modelling is a new working paradigm in Architecture, Engineering, and Construction and Facilities Management (AEC/FM), expedited internationally by the BuildingSMART Alliance (cf. Eastman et al. 2011)

example, the following table shows the different conversion factors used in various European countries (Sartori et al. 2012).

Table 1: Energy conversion factors in selected European countries (source: Sartori et al. 2012)



		Europe		Austria	Denmark	Finland		Germany		Italy	Norway		Spain		Sweden	
Energy carrier	Metrics	EN 15603 2008	PHPP 2007	Gemis Vers. 4.5	BR 2010 2010	BC 2012 2011	Gemis 2011	DIN V 18599/1 2007	GEMIS Vers. 4.5	UNI-TS-11300/4 draft 9/2009	NS 3700 2009	ZEB centre* 2010-2060	I.D.A.E. 2010	CALENER 2009	average* 2008	pol. factors 2008
Electricity	PEI, n.r.	3,14*	2.70	1,3*		1.70		2.60	2.61	2.18*						
	PEI, total	3,31*		1.91	2,50*	1.70		3.00	2.96				2.28	2.60	1.50	2.50
	$CO_{2equiv.}$	617,00*	680.00	389.00		329.62	331.00		633.00	531**	395	132	350*	649		
Natural gas	PEI, n.r.	1.36	1.10	1.12		1.00		1.10	1.12	1.00						
	PEI, total	1.36		1.12	1.00	1.00		1.10	1.12				1.07	1.10		
	$CO_{2equiv.}$	277.00	250.00	268.00		202*	315.00		244.00		211		251*	204.00		
Oil	PEI, n.r.	1.35	1.10	1.11		1.00		1.10	1.11	1.00						
	PEI, total	1.35		1.13	1.00	1.00		1.10	1.11				1.12	1.08	1.20	1.20
	$CO_{2equiv.}$	330.00	310.00	302.00		279*	381.00		302.00		284		342*	287.00		
Wood, pieces	PEI, n.r.	0,09**	0.20	0.01		0.50		0.20	0.01	0.00						
	PEI, total	1,09**		1.01	1.00	0.50		1.20	1.01				1.25		1.20	1.20
	$CO_{2equiv.}$	14**	50.00	6.00		32.40	17.00		6.00		14		0.00	0.00		
Wood, pellets	PEI, n.r.			0.14		0.50		0.20	0.14	0.00						
	PEI, total			1.16	1.00	0.50		1.20	1.16					0.00	1.20	1.20
	$CO_{2equiv.}$			41.00			19.00		41.00		14					
Disctrict heat 70% CHP (fossil)	PEI, n.r.		0.80	0.76				0.70	0.76	System specific						
	PEI, total			0.77	1,00*	0.70		0.70	0.77						0.90	1.00
	$CO_{2equiv.}$		240.00	219.00			230.00		219.00		231					

PEI: primary energy indicator ($kWh_{primary}/kWh_{delivered}$); n.r.: non renewable part ($kWh_{primary}/kWh_{delivered}$); $CO_{2equiv.}$: equivalent CO_2 emissions ($g/kWh_{delivered}$). * See comments for each country.

Country	Comments	Sources
Europe	*Power according to UCTE mix **Wood in general	EN 15603 [17] Energy Performance of Buildings – Overall energy use and definition of energy rationgs – Annex E Factors and coefficients, CEN. PHPP (2007) Passive House Planning Package, *The Passive House Institute*, Darmstadt, DE.
Austria	*According to the Austrian Environment Agency	Database of GEMIS, Global Emission Model for Integrated Systems, Internet page of the program: http://www.oeko.de/service/gemis/en/
Denmark	*2015 requirements use 0,8; 2020 requirements use 0,6 for district heating and 1,8 for electricity	The Danish Building Code 2010, BR 2010
Finland	*Based on Motiva report, 2004	National Building Code of Finland. Part D3 Energy-Efficiency. Ministry of Environment 2011 Database of GEMIS, Global Emission Model for Integrated Systems, Internet page of the program: http://www.oeko.de/service/gemis/en/ Motiva report, 2004, emission factors and calculation of emission factors. Available at: http://www.motiva.fi/files/209/Laskentaohje_CO2_kohde_040622.pdf Motiva report, 2004, emission factors and calculation of emission factors. Available at: http://www.motiva.fi/files/209/Laskentaohje_CO2_kohde_040622.pdf
Germany	The normative primary energy factors for the national building code are given with DIN V 18599, emission date are not listet; if emission data are applied the most common source is GEMIS	DIN V 18599:2007-02, part 10, Beuth-Verlag, Berlin, 2009 Database of GEMIS, Global Emission Model for Integrated Systems, Internet page of the program: http://www.oeko.de/service/gemis/en/
Italy	*EEN3/08 resolution by AEEG - GU n. 100, 29.4.08 - SO n.107 - www.http://www.autorita.energia.it/it/docs/08/003-08een.htm www.minambiente.it/home_it/menu.html?mp=/menu/menu_attivita/&m=argomenti.html|Fonti_rinnovabili.html|Fotovoltaico.html|Costi__Vantaggi__e_Mercato.html	UNI-TS 11300 Part IV,under review (last draft 2009)-LA NORMATIVA TECNICA DI RIFERIMENTO SUL RISPARMIO ENERGETICO E LA CERTIFICAZIONE ENERGETICA DEGLI EDIFICI

Typically, national conversion factors are specific to a country and may significantly vary for other countries. This is an issue that needs careful consideration in facility design and operational decision making.

3. Weather and Climate Data

The difference between weather and climate is a measure of time. Weather is what conditions of the atmosphere are over a short period of time, and climate is how the atmosphere "behaves" over relatively long periods of time (www.nasa.gov).

Accordingly, weather data refers to the state of the atmosphere with respect to a specific parameter (temperature, wind, cloudiness, moisture, pressure, etc.) at a given point in time (e.g., high temperature for a given day). Climatic data refers to "average" weather conditions for a given location over a long period of time, for example, the average high temperature for a given date (www.weather.gov/glossary/).

The need for appropriate climatic data for long term prediction of the annual energy performance of buildings (e.g. thermal comfort conditions, heating and cooling loads) with relatively low computational time has led to the development of the so-called Test Reference Years (TRYs) a term mainly used in Europe or Typical Meteorological Years (TMYs) a term mainly used in the USA. TRYs are commonly composed of hourly values for a one year period (12 typical meteorological months) rather than extreme conditions of actual (measured) weather data. A comprehensive overview of various weather data sets and methodologies is available in (Crawley, 1998) and (Forejt et al. 2006.).

The thermal performance of buildings and other renewable energy sources (RES) systems, for example, solar thermal and photovoltaic systems, does not depend solely on global radiation and air temperature, but also on other meteorological parameters like diffuse solar radiation, relative humidity, wind velocity etc.

Building simulation software require comprehensive **TRYs** that provide a standard for **hourly data** (8760 hourly records) of solar radiation and other meteorological parameters for a period of one year, representing climatic conditions considered to be typical over a long time-period (e.g. 10, 20 or 30 years). TRY data have natural diurnal and seasonal variations and represent a year of typical climatic conditions for a location, preserving the main local weather characteristics, for example, typical cold or hot conditions, but consistent with the local long-term averages. However, TRYs should not be used to predict weather for a particular period of time, nor is it an appropriate basis for evaluating real-time energy production or efficiencies for building design applications or RES systems (Wilcox & Marion, 2008).

Several methodologies for the generation of TRYs based on measured weather data have been reported in literature. Most of them promote the idea of using sequences of real measured data to compose a TRY, for example, the Sandia National Laboratories method and its modification known as the TMY2 method (Marion & Urban, 1995) and TMY3 (Wilcox & Marion, 2008), the Danish method (DRY, 1995), the Festa and Ratto method (Festa & Ratto, 1993) and the European ISO 15927–4 method (EN ISO 15927-4, 2005).

Measured data around the world are typically available from a limited number of weather stations where complete weather (meteorological) stations are installed for routine (continuous) measurements. The National Climatic Data Centre (NCDC) provides access to the World Data Centre (www.ncdc.noaa.gov/oa/ncdc.html) that archives all publicly available meteorological data from around the world. In addition, actual hourly and daily historical weather data for numerous locations around the world are available from Weather Bank from the corresponding National Weather Service reporting stations (www.weatherbank.com/archive.html).

Measured data is a valuable resource but can only be used in the vicinity of a weather station. Otherwise, the data has to be interpolated between different weather stations. However, depending on the location of the building to be simulated, local conditions may be distinctly different. For example, urban conditions are distinctly different from a weather station that may be located near or at an airport.

Access to weather data and the means to interpolate between different locations for a specific building site, is available through commercial software known as **Meteonorm**. It allows for a reliable calculation of solar radiation, temperature and additional meteorological parameters at any site in the world, based on over 8300 weather stations. It also generates input data to numerous simulation software, for example, DOE-2 and eQuest, EnergyPlus, TRNSYS etc. Datasets are also available for a typical year with minute, 10 minute, hourly, daily or monthly values, representing an average year.

Specific format data are also available for different tools, for example weather data for DOE-2 (http://doe2.com/index_Wth.html), more than 2100 locations in the EnergyPlus weather format (http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm) and TMY-3 weather files for TRNSYS. In addition, several software tools have automatic design day calculations for sizing, including, for example, dry bulb temperature, dew point temperature or relative humidity (Crawley et al. 2008).

In order to derive more typical **weather patterns** than either a single representative year or a group of selected months from different years that are statistically evaluated to be representative, ASHRAE developed a set of weather data known as Weather Year for Energy Calculations - WYEC. The available database includes hourly weather data for 77 locations in the United States and Canada. ASHRAE also developed similar information for several international locations (International Weather for Energy Calculations) that includes hourly weather data for 227 locations throughout the world.

The specific weather data parameters and even the desirable time step depends on the simulation or calculation tool to be used and the methodology that these tools are based on, and of course availability of suitable local weather data. At present, there is little harmonisation and standardisation available for the industry practice.

In Europe, transposition of the European Directive 2002/91/EC on the energy performance of buildings (**EPBD**) has initiated wide-spread efforts to develop and use official software to meet national requirements and comply with relevant European standards (EN ISO 13790, 2008). According to the European standard it is possible to follow three different calculation methods:

(1) a fully prescribed monthly quasi-steady-state;

(2) a fully prescribed simple hourly dynamic;

(3) calculation procedures for detailed (e.g. hourly) dynamic simulation methods.

However, a significant gap is the limited availability of national TRYs or other suitable hourly data for each country. For example, in Greece the calculation engine of the standard national software is based on the monthly quasi-steady-state calculation providing acceptable results on an annual basis, which is sufficient for assessing the annual energy performance of buildings and issuing an energy performance certificate. Accordingly, the Greek national technical guidelines have been prepared to meet the practical input requirements of the software. The weather data necessary for the calculations have been prepared for the four national climatic zones and 62 Hellenic cities (TOTEE 20701-3/2010, 2010). The relevant data provide information for the design conditions and mean monthly data (temperature, heating degree days and cooling degree hours, relative and specific humidity, wind speed, horizontal solar radiation and calculation procedures for tilted surfaces, ground and water temperature). Over Europe, the methods of using weather data and the availability of such data varies considerably, which provides difficulties in establishing a common approach.

However, the development of **stochastic weather data** provides an opportunity to produce synthetic data representative of future climatic conditions that may influence more comprehensive lifecycle energy consumption analyses (de Wilde & Coley, 2012). The lack of detailed or non-appropriate weather data may lead to inaccurate analysis results and may even result in incorrect sizing of HVAC systems, misleading assessments of energy savings, or improper selection of design options (Williamson et al., 2009). Unfortunately, availability of hourly data that account of the influence of climate change in the future is limited. A simple approach to account for future climate changes is the so-called *delta-method*: start from a simple hourly weather file and apply a uniform monthly change (e.g. increase or decrease) of each parameter directly to the variable, over a monthly period. A more realistic approach to produce design weather data for building thermal simulations that accounts for future changes to climate is the so-called "morphing" method (Belcher et al., 2005). However, this method generates only one year of data for a given time period in the future, so there is some uncertainty in the projection. In addition, it requires the use of a climate model and the morphing technique relies on the baseline recorded weather being from the same time period as the baseline in the climate model. Meteonorm (http://meteonorm.com) generates hourly weather data using stochastic and physical processes that may also account for climate change if historical monthly averages that are normally used as inputs are replaced with results from a General Circulation Model (Robert & Kummert, 2012). An alternative form of future hourly climate data can be produced using stochastic weather generators. The UK Climate Impacts Programme (UKCIP) produced in 2009 an on-line user interface that allows generation of hourly synthesised weather data for any decade up to 2080 at any location in the UK (UKCIP, 2009). However, there are still difficulties with the use of available weather data that is too far away from the building location to be representative of the climate at the mesoscale level and the building's microclimate, where temperature and wind variations could far exceed those at the mesoscale.

In order to circumvent the difficulties related to the lack of standardisation and the still under-developed stochastic approaches regarding weather and climate data, in ISES the structure and content of climate data necessary to run building simulations will be based on the specification developed in the EU HESMOS project (Grunewald & Kaiser, 2011). In this context, climate data is understood as the collection of climate elements related to a single unique geographical location (primary location) as a function of time. The related single unique geographical location represents typically:

(1) a city,
(2) a special place inside/nearby a city (e.g. airport),
(3) a special landmark (e.g. top of a mountain).

The climate dataset of a single unique geographical location will be used as representative climate dataset for other geographical locations nearby or a region around the primary location with similar climate and geographical conditions.

Climate elements are the outdoor air temperature, the relative outdoor air humidity, the overall solar radiation on a horizontal plane, the direct/diffuse solar radiation on a horizontal plane, the wind direction and wind velocity, the precipitation and cloudiness etc. The values of climate elements are based on time series of measurements in combination with statistical post processing or simulations, as e.g. provided by the middle German regional climate information system reKIS (www.rekis.org).

In general, climate data sets will be divided into two main parts:

- *Part 1 – Meta-data delineating one or more climate data sets,* which contains the geographical location, owner information, the type of use etc.
- *Part 2 – data tuples of various climate elements representing a climate dataset.*

A climate data set can contain more than one sub data sets.

4. User Behaviour

Over the last few years there has been great improvement in building performance simulation software and many aspects of the design of facilities are now accurately modelled by the simulation software such as the building envelope including detailed information about building elements, building systems and material properties. However, there are some aspects of the building design that are still much less detailed (Bourgeois, 2005; Tabak, 2008). These aspects relate to the **actual use** of the designed facility and how the building occupants interact with the building. They become critical design parameters as the energy performance of the building envelope has enhanced through better understanding of the building physics, new technologies and building materials that have enabled designers to reach energy performance well beyond passive house standards in the design of zero energy buildings.

With improved energy performance of the building envelope and better control and optimization of HVAC systems, functional use of the building and occupant dynamic behaviour and interaction with the building systems play an increasing role in achieving better energy efficiency in buildings and at the same time, achieving efficient healthy indoor environment for the building occupants.

Case studies of residential buildings (Marteinsson & Gudnason, 2010) have shown that about 25% of the total energy use can be attributed to the occupant activities and behaviour in the building. The energy demand depends on many factors, e.g. social status and income, lifestyle, cultural background and individual preferences, settings for temperature, humidity, personal comfort. Many of the processes that individuals perform within buildings are highly unpredictable and fuzzy in terms of how occupants perceive indoor conditions like comfort and what actions are taken to control the indoor environment.

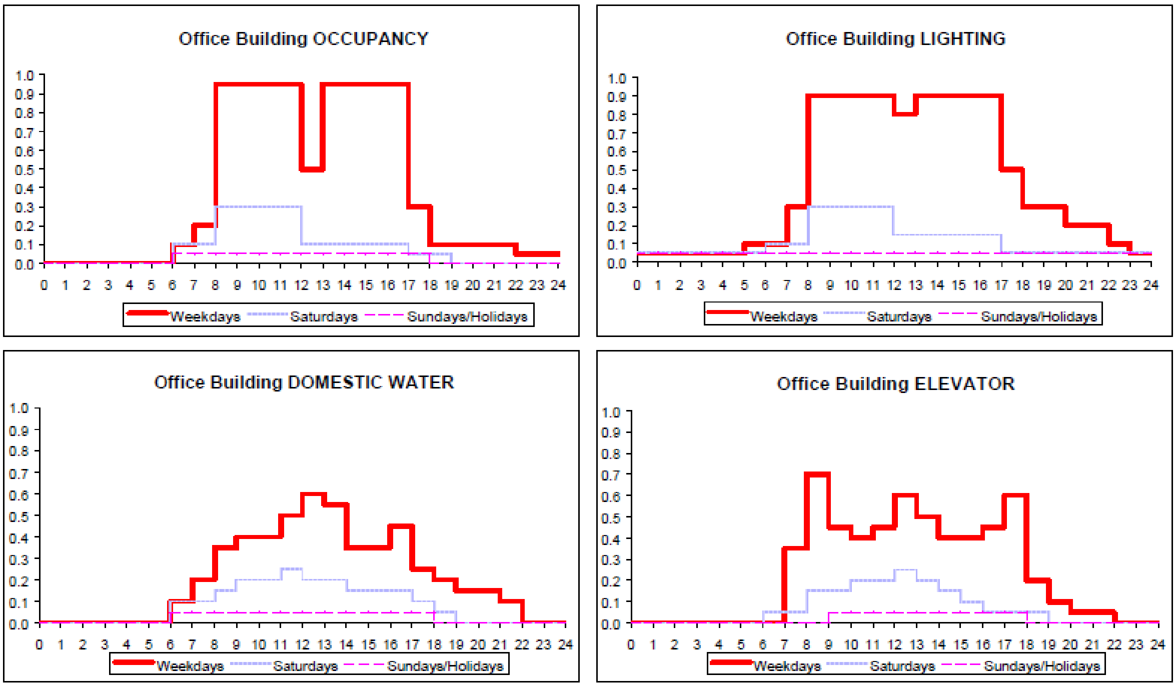
Actual **building occupancy and occupant behaviour remain critical factors** that are difficult to predict or modulate, thus mandating the need of proper controls. For specific buildings, user behaviour needs to be carefully considered to allow proper optimization of the building design to meet the peculiarities of actual users (Hoes et al., 2009). In addition, occupant perception of indoor environmental quality remains a determinant factor that is influenced by various parameters and needs to be also taken into account although it is difficult to accurately predict. The implementation of user profiles in building simulation is therefore necessary in order to improve the accuracy of building energy consumption and approach real building energy performance.

Occupancy has a direct impact on the building's energy consumption since it determines the number of operating hours and the use of systems (i.e. heating, cooling, mechanical ventilation, domestic hot water, lighting and other equipment or appliances) during the day and week.

Different end use buildings have distinctly different operating hours. Non-residential and residential buildings are the main two categories, although within non-residential buildings there may also be distinct differences. For example, hospitals have relatively high-energy consumption due to the demanding indoor environmental quality conditions (e.g. high space heating, cooling and ventilation loads) and availability of hot water and steam, continuous 24hour operation throughout the year for the majority of the facilities, high use of medical equipment etc. Similarly, hotels exhibit high-energy consumption that is mainly due to space air-conditioning, cooking and high domestic hot water needs, with 24hour operation, although seasonal operation may distinctively differentiate their operational characteristics (e.g. compared against annual operation). On the other hand, schools have lower energy consumption since they do not operate during summer and have limited operating hours during the day, are equipped with simple heating systems or limited air-conditioning and mechanical ventilation.

The modelling of occupancy and user behaviour in buildings has been an active research topic for more than a decade now and various calculation methods and modelling approaches have been proposed that provide input to existing building performance simulation software or as computational algorithms that can be integrated into existing simulation software or as standalone simulation tools. Case studies have demonstrated significant reduction in total energy demand using occupant behavioural modelling in whole building performance simulation (Bourgeois et al., 2004).

Early studies that focused on **spatio-temporal occupancy** have resulted in development of temporal diversity profiles or diversity factors*) to account for presence of users in the buildings and the effect they have on internal heat gains and activity based energy demand. The density of people and their activity influences internal heat gains, in terms of number of people present in a space (for multi-zone analysis) or the building (single-zone) and heat gains from use of artificial lighting, equipment and appliances. In addition, occupancy also unavoidably controls the energy demand stemming from use of equipment (plug loads), lighting, domestic hot-water and heating, cooling, ventilation for maintaining a comfortable indoor environment and air quality.



Office Building

OCCUPANCY	Midnight		2a	3a	4a	5a	6a	7a	8a	9a	10a	11a	12p	1p	2p	3p	4p	5p	6p	7p	8p	9p	10p	Midnight
Weekdays	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.20	0.95	0.95	0.95	0.95	0.50	0.95	0.95	0.95	0.95	0.30	0.10	0.10	0.10	0.10	0.05	0.05
Saturdays	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.30	0.30	0.30	0.30	0.10	0.10	0.10	0.10	0.10	0.05	0.05	0.00	0.00	0.00	0.00	0.00
Sundays/Holidays	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00

LIGHTING	Midnight		2a	3a	4a	5a	6a	7a	8a	9a	10a	11a	12p	1p	2p	3p	4p	5p	6p	7p	8p	9p	10p	Midnight
Weekdays	0.05	0.05	0.05	0.05	0.05	0.10	0.10	0.30	0.90	0.90	0.90	0.90	0.80	0.90	0.90	0.90	0.90	0.50	0.30	0.30	0.20	0.20	0.10	0.05
Saturdays	0.05	0.05	0.05	0.05	0.05	0.05	0.10	0.10	0.30	0.30	0.30	0.30	0.15	0.15	0.15	0.15	0.15	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Sundays/Holidays	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

DOMESTIC WATER	Midnight		2a	3a	4a	5a	6a	7a	8a	9a	10a	11a	12p	1p	2p	3p	4p	5p	6p	7p	8p	9p	10p	Midnight
Weekdays	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.20	0.35	0.40	0.40	0.50	0.60	0.55	0.35	0.35	0.45	0.25	0.20	0.15	0.15	0.10	0.00	0.00
Saturdays	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.15	0.20	0.20	0.25	0.20	0.20	0.15	0.15	0.15	0.10	0.05	0.00	0.00	0.00	0.00	0.00
Sundays/Holidays	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00

ELEVATOR	Midnight		2a	3a	4a	5a	6a	7a	8a	9a	10a	11a	12p	1p	2p	3p	4p	5p	6p	7p	8p	9p	10p	Midnight
Weekdays	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.70	0.45	0.40	0.45	0.60	0.50	0.40	0.40	0.45	0.60	0.20	0.10	0.05	0.05	0.00	0.00
Saturdays	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.15	0.15	0.20	0.20	0.25	0.20	0.15	0.10	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00
Sundays/Holidays	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00

Figure 4: Typical office building schedule profiles (source: eQUEST Training Workbook – Hirsch, 2004)

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*) Diversity profiles or diversity factors (Bourgeois et al., 2006) have been widely used for estimating spatio-temporal occupancy in building performance simulation, presented as 24 hour daily, weekly or monthly schedules. Diversity factors are fractional numbers, percentages of a user defined maximum loads where load variability and power management features are represented by three types of load profiles for weekdays, weekends and holidays.

More recent studies recognized some limitations of the method and aimed to gain more detailed understanding of building occupant behavioural aspects to more realistically model behaviour of building occupants and how they interacts with the building and the building's systems. Thus, while many of the earlier studies were focused on the effect of limited number of variables on energy consumption, later studies quantify and predict the total energy impact of occupant behaviour more accurately in whole-building energy simulations. Moreover latest methods further integrate building space layout and the underlying business processes and organisational structure in analysing building energy performance. However, stochastic prediction methods that can provide for improved probability and accuracy of the data are still rarely used, mainly in academic studies.

Development of more specific **user profiles** is necessary for better building simulations. However, such profiles strongly depend on the target of application (purpose of the calculation – design of new building, refurbishment of an existing building, energy audit), the specific requirements of the tool to be used, the methodology that these tools are based on, and the building end use. Accordingly, one can define a constant average value, or monthly, daily and even hourly values.

Based on European standards (e.g. EN ISO 13790, 2008 and EN 15251, 2007) and available international literature (ASHRAE 2011), series of user profiles have been developed in order to represent the behaviour of occupants. The main goal is to define **typical profiles** that can expedite the process of defining input data in a consistent manner. In some cases, when there are distinctly different profiles (e.g. intermittent occupancy, heating or cooling) or specific end use buildings, it may be necessary to perform additional analysis and even require an end use monitoring (for existing buildings) in order to properly enhance the typical profiles. However, one needs to maintain a balance between accuracy, transparency, robustness and reproducibility.

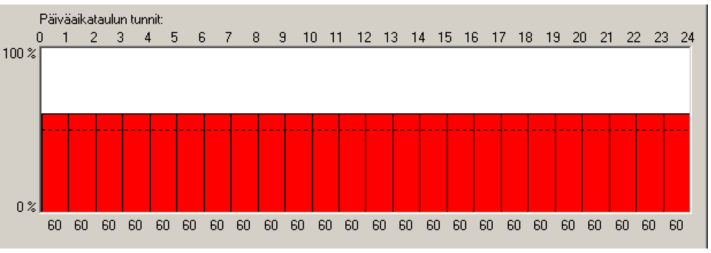
Table 2: Overall spatio-temporal occupancy for various building types

Building Type	**Building or Thermal Zone End Use**	**Operating Hours**	**Operating Days per Week**	**Annual Operating Months**
Residential	House, apartment buildings	18	7	12
Office	Office rooms	10	5	12
Education	Elementary school classrooms	8	5	9 (Sept.-May)
	High school / university classrooms and auditoriums	13	5	10 (Sept.-June)
Hospital	Hospital rooms	24	7	12
	Patient rooms	24	7	12
	Operating rooms	8	5	12
	Waiting rooms	8	5	12

The following user profiles for the operation days of the above given types of buildings have been compiled from energy consulting experience in real projects performed by Granlund, Finland. They document occupancy percentage against the time of the day, taking into account different end use spaces (zones) within those buildings.

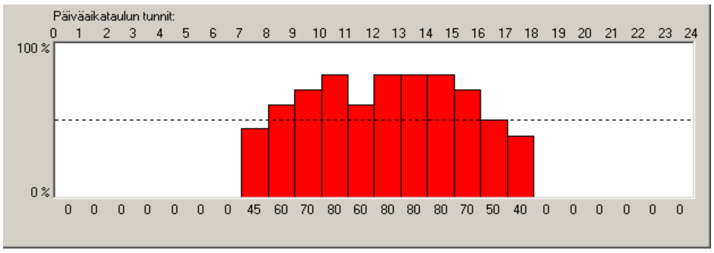
Residential buildings

House, apartment building

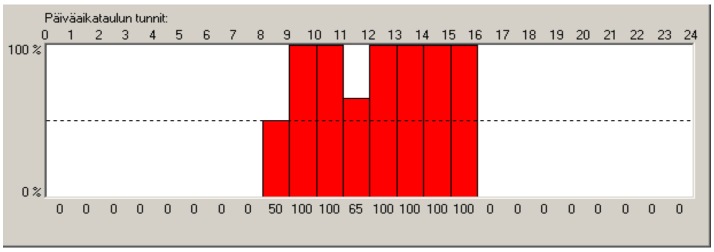


Office building

Office rooms

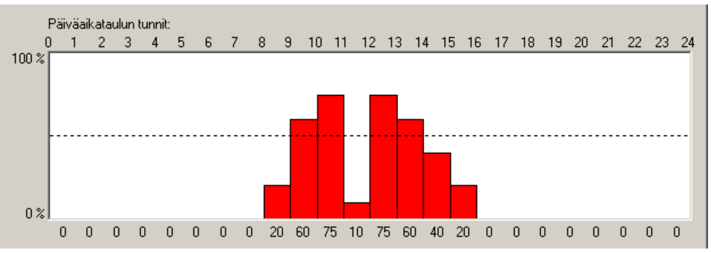


Meeting rooms

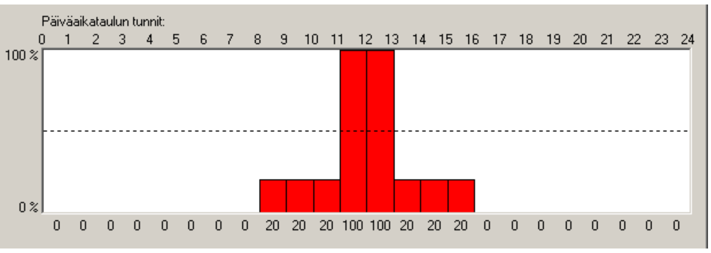


Education

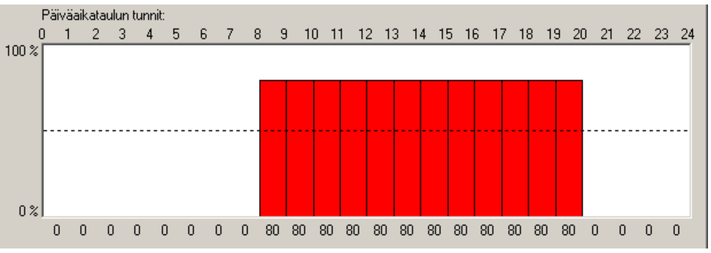
Elementary school classrooms



Dining areas

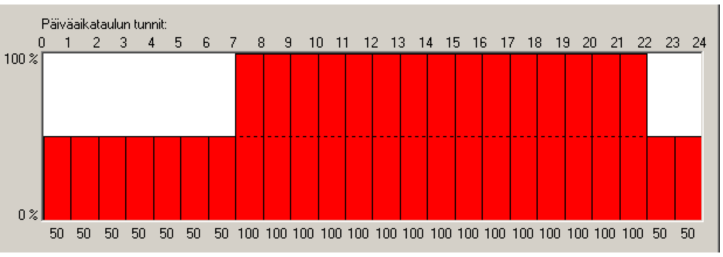


High school / university classrooms and auditoriums

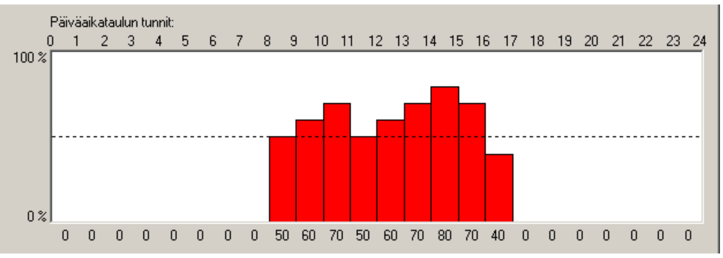


Hospitals

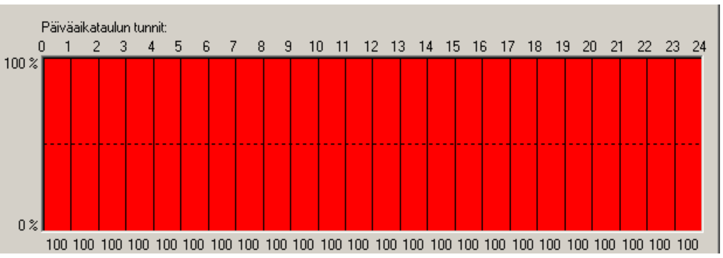
Patient rooms



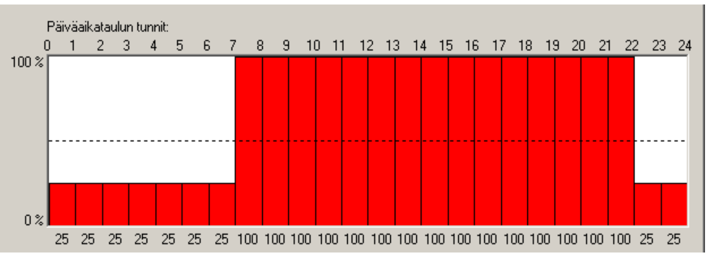
Doctor’s office



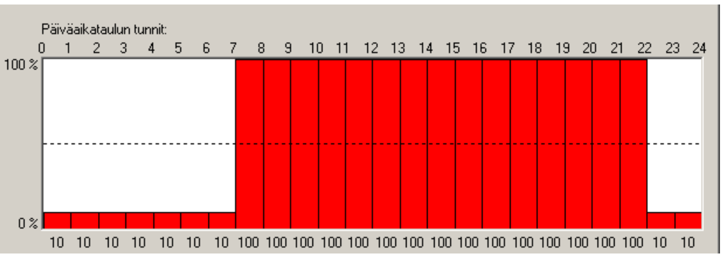
Chancellery and nurse office



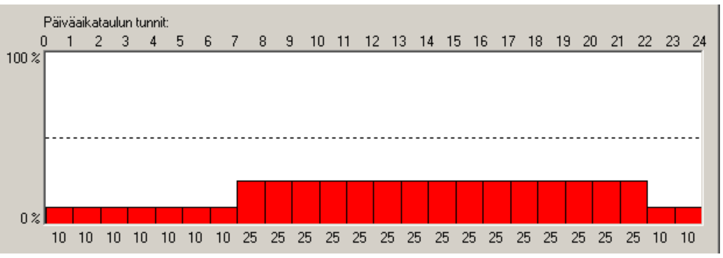
Circulation



Kitchen



Storages and restrooms



5. User Comfort

Total indoor user comfort is achieved by addressing various parameters and needs, including: (1) thermal comfort, (2) air ventilation, (3) visual comfort and indoor lighting, (4) hot water, as well as (5) the influence of heat gains due to occupancy, lighting, equipment and appliances. All these aspects play important role for the accuracy and reliability of energy simulations and decision making and should be taken into account in advanced building energy design.

Thermal comfort is defined as the conditions in which a person would prefer neither warmer nor cooler surroundings. It is a rather complex concept, since it depends on various influencing parameters and it is the combination of these parameters that creates the end result of comfort. Depending on the building end use and functions in its various spaces, indoor environment conditions may vary significantly, since occupant needs can be different.

The parameters that influence overall comfort are grouped into three general categories, namely: (1) *Physical Parameters,* which include the air temperature of the environment (dry bulb), the mean radiant temperature of the indoor wall surfaces, the relative humidity of the air, the relative air velocity of the indoor air, the atmospheric pressure, the color of the surrounding environment, odors, light intensity, and noise levels; (2) *Organic Parameters,* which include age, gender and national characteristics of the occupants; and (3) *External Parameters,* which include human activity levels (related to the metabolism), type of clothing, and social conditions. Among them, the most important parameters influencing thermal comfort are: Dry bulb temperature, Relative humidity, Air velocity, Barometric pressure, Clothing, and Activity.

Many different combinations of the above variables can achieve thermal comfort. In all cases, it is the end result that we are interested in achieving, which means that, it is the combined effect of these parameters on the human body that is important. The positive or negative effect of one parameter on comfort may be enhanced or counterbalanced by the change of another parameter.

Table 3: Typical indoor thermal conditions for various building types (EN 15251:2007)

Building Type	**Building or Thermal Zone End Use**	**Temperature [°C]**		**Rel. Humidity [%]**	
		Winter	**Summer**	**Winter**	**Summer**
Residential	House, apartment buildings	20	26	40	45
Office	Office rooms	20	26	35	45
Education	School / High school classrooms	20	26	35	45
Hospital	Hospital rooms	22	26	35	50
	Patient rooms	22	25	35	50
	Operating rooms	18	20	35	55
	Waiting rooms	20	26	35	50
General circulation areas and common use spaces		18	26	35	50

Air ventilation plays a dominant role in achieving and maintaining comfort conditions and acceptable indoor environmental quality in any environment. Ventilation supplies the necessary amounts of fresh air, either by: (1) *Natural ventilation* (the outdoor air enters into the space and the indoor air exits from the space as a result of physical process, e.g. wind and temperature differences, depending on the prevailing outdoor, i.e. variability of wind velocity and direction, and indoor conditions, and thus there is limited control); (2) *Mechanical ventilation* (the outdoor air is supplied and the indoor air is exhausted by mechanical means using fans and ductwork in order to control the air flow can be controlled in terms of quantity, velocity, quality and thermal conditions, at the expense of higher energy consumption); and (3) *Hybrid ventilation* (the outdoor air supply is primarily based on natural ventilation assisted with simple fans to enhance the effectiveness and control the air flow rates, at a minimal energy cost).

The quantity of outdoor air that needs to be brought into the space is determined by national and international standards, depending on the function of the space. The air movement into the space must be handled with care, since there is a direct influence of air velocity on occupant thermal comfort. Outdoor air quality will influence indoor conditions, thus one needs to exercise caution when using untreated outdoor air, especially in areas where outdoor air may be heavily polluted with particulate and gaseous contaminants. Health standards may impose limits on the use of untreated outdoor air, which as a result, limits the effectiveness of natural ventilation techniques and influence comfort conditions in naturally ventilated buildings.

Mechanical ventilation and air conditioning systems can be used to clean the outdoor air at the expense of increased energy consumption and operational cost of the building. The filtering system should be well maintained, to prohibit adverse effects for the growth of microorganisms which can even be fatal. Increasing the ventilated air to maintain acceptable indoor air quality means more fresh outdoor air has to be conditioned, thus increasing the energy cost. The importance of ventilation, both as an indoor environmental quality issue and as the single largest heat loss / gain component, makes ventilation the most important design challenge for HVAC systems.

The minimum amount of fresh outdoor air depends on the building end use, the number of occupants and the generation of indoor pollution and can be estimated based on European standards (e.g. EN 15251, 2007) and available international literature (e.g. ASHRAE, 2010). In general, the minimum requirements for different end use buildings should satisfy the minimum requirements per person (m^3/h/person), according to the maximum occupancy (person/m^2 net occupiable floor area).

Table 4: Typical outdoor air requirements for various building types (EN 15251:2007)

Building Type	**Building or Thermal Zone End Use**	**Estimated Occupancy** [Person/100 m^2]	**Outdoor Air Requirements** [m^3/h/person]	**Outdoor Air Requirements** [m^3/h/m^2]
Residential	House, apartment buildings	5	15	0.75
Office	Office rooms	10	30	3.00
Education	School / High school classrooms	50	22	11.00
Hospital	Hospital rooms	30	35	10.50
	Patient rooms	22	25	5.50
	Operating rooms	20	150	30.00
	Waiting rooms	55	45	24.75

Proper **indoor light** is necessary to satisfy visual comfort conditions depending on the building end use and the indoor functions of specific spaces, minimizing visual discomfort and/or fatigue. In terms of energy consumption, the minimum luminous efficacy for general space lighting should be about 55 lm/W. The European standard (EN 12464.1:2011, Light and lighting - Lighting of work places – Pt.1: Indoor work places) specifies lighting requirements for humans in indoor work places, which meet the needs for visual comfort and performance. Lighting systems may consume significant energy and may also contribute to internal heat loads, depending on the type of lamp and the number of units.

An average installed lighting power per unit floor area (W/m^2) for satisfying the minimum illuminance (lx) for general space lighting (installed at a height of 2.6 m) can be calculated according to the recommended values for different end uses according to the European standard (EN 15193:2007, Energy performance of buildings - Energy requirements for lighting). This standard specifies the calculation methodology for the evaluation of the amount of energy used for indoor lighting inside the building and provides a numeric indicator for lighting energy requirements. Parasitic powers not included in the luminaire are excluded.

Table 5: Typical lighting parameters for various types of buildings (EN 15193:2007)

Building Type	Building or Thermal Zone End Use	Minimum Illuminance [lux]	Installed Lighting [W/m^2]	Measured reference height [m]
Residential	House, apartment buildings	200	6.4	0.8
Office	Office rooms	500	16.0	0.8
Education	Elementary school classrooms	300	9.6	0.8
	High school / university classrooms and auditoriums	500	16.0	0.8
Hospital	Hospital rooms	300	9.6	0.8
	Patient rooms	100	3.2	0.8
	Operating rooms	1000	32	0.8
	Waiting rooms	300	9.6	0.8

Sanitary hot water (**SHW**) in commercial buildings and domestic hot water (**DHW**) in residential buildings may also contribute to the heating loads of a building. The biggest consumers of SHW are hotels, hospitals and university residences. Common heat production units include electrical heating (e.g. electric resistance hot water boilers) or fuel heating (e.g. direct gas fired or combined with central oil- or gas-fired boilers). Solar thermal collectors are the most commonly used RES. However, studies on hot water consumption in commercial buildings are not common yet (Rankin & Rousseau, 2006).

Domestic hot water (DHW) demand depends on the building end use and user behavior. The European standard EN 15316-3-1 (Domestic Hot Water systems - Characterization of Needs - tapping requirements) defines hot water needs and includes four methods for calculating the energy needs of the delivered domestic hot water:

(1) Energy need related to tapping programs; use of one or more 24-hour cycles that define a number of domestic hot water draw-off needs. For single-family dwellings the standard provides specific tapping patterns.

(2) Energy need related to volume needs, depending on the floor area of the building, temperature of the (cold) inlet water, specified temperature of DHW at the tapping point. Specific fixed factors describe the relation between floor area and required volume, for different end use buildings.

(3) Energy need linear with floor area, using a specific domestic hot water demand per day based on a water delivery temperature (e.g. of 60°C) and a cold water supply temperature (e.g. of 10°C), depending on the floor area of the building, Specific fixed factors describe the relation between floor area and required energy, for different end use buildings.

(4) Energy need from tabulated values for different building types or functions, depending on the end use of the building, type of activity carried out within the building, use of a zone within a building where more than one activity is carried out, class of activity, such as the category of a hotel (number of stars) or the class of catering establishment. The floor area of the building is also required.

Two other standards treat distribution (EN 15316-3-2 - Domestic Hot Water Systems - Distribution) and generation systems (EN 15316-3-3 - Domestic Hot Water Systems – Generation).

Average hourly patterns for DHW are illustrated in the following figure taken from (ASHRAE, 2011). However, the structure and lifestyle of a typical family (variations in family size, age of family members, presence and age of children, hot-water use volume and temperature, and other factors) cause hot-water consumption demand patterns to fluctuate widely in both magnitude and time distribution.

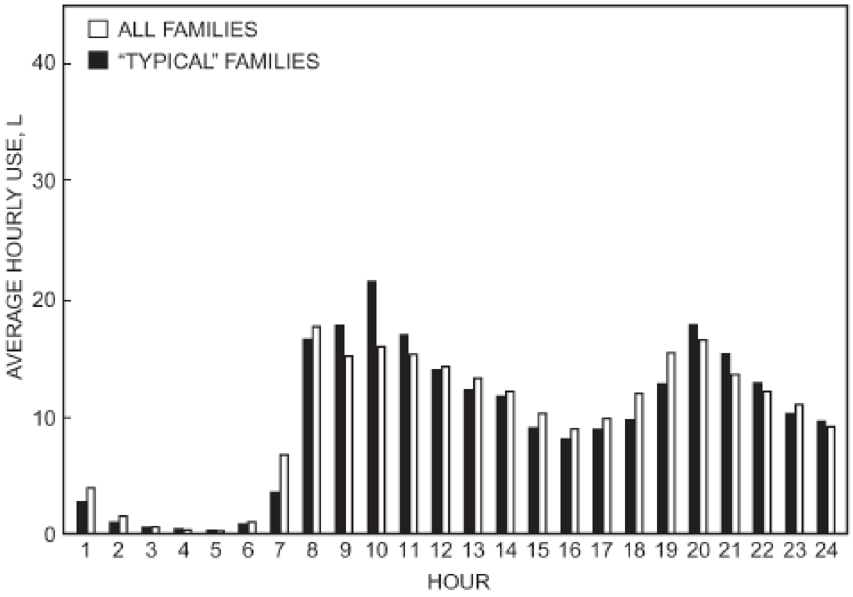


Figure 5: Residential Average Hourly Hot-Water Use (source: ASHRAE, 2011)

Typical daily DHW consumption per person and annual energy consumption are estimated based on European standards (e.g. EN 15316-3-1:2008 for some end use buildings) and available international literature (ASHRAE, 2011). The calculations are based on hot water temperature of 45°C and limited to the floor area that corresponds to the spaces with hot water consumption (i.e. not the entire floor area of the building, for example, circulation corridors, staircases).

Table 6: Typical hot water consumption at 45°C for various building types

Building Type	**Building or Thermal Zone End Use**	**Daily Hot Water Consumption**		**Annual Hot Water Consumption**	
		[Lt/person/day]	[Lt/m^2/day]	[m^3/bed/yr]	[m^3/m^2/yr]
Residential	House, apartment buildings	50	--	27.38*	--
Hospital	Hospital (< 500 patient beds)	80	--	29.2	--
	Hospital (> 500 patient beds)	120	--	43.9	--

* = per bedroom.

SHW is low for office buildings. The calculations for SHW demand and energy consumption may be performed using a typical hourly SHW consumption profile as illustrated in the following figure. However, typical water main temperature profiles are required for each specific building location.

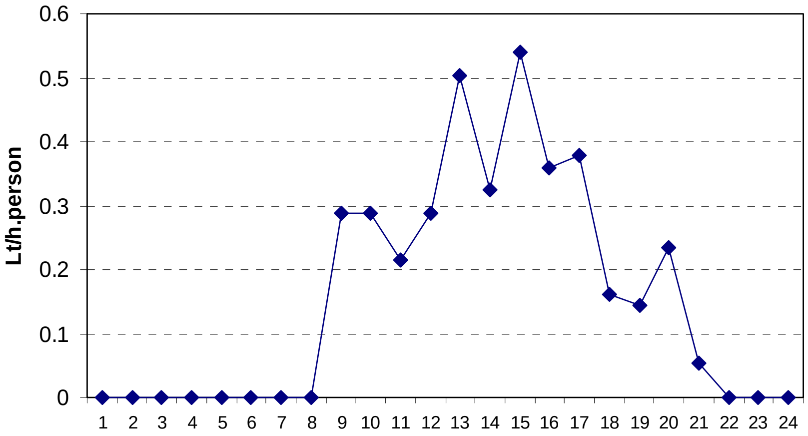


Figure 6: Typical SHW profile in office buildings

Finally, **internal heat gains** (occupants, lighting, equipment and appliances) may contribute significantly to loads for some end use buildings with a high number of occupancy and concentration of lights and equipment. The internal gains from occupants introduce both sensible and latent loads. The sensible heat transfer rate is the result of temperature variations, while the latent load is a result of the moisture variations from the desirable conditions. Heat gains from lighting and commonly from equipment, are limited to sensible heat gains.

Internal heat gains reduce the heating loads in winter and increase the cooling load in summer. To avoid oversizing, internal heat gains should be properly adjusted by a proper diversity factor. These adjustments to internal heat gains are necessary in order to account for the fact that instantaneous heat output from all internal sources (i.e. occupants, lighting, equipment and appliances) are usually less than the maximum output. The instantaneous loads are reduced for factors such as on-off cycles, occupancy schedules, and duty cycles and reduced power input. The diversity factors may also follow a certain profile, e.g. time series of different diversity factor profiles.

For residential buildings, the diversity factor for lighting is usually 0.1 in order to adjust the installed lighting for the average use of lighting throughout the operational day. For non-residential buildings, the operating time of lights depends on the availability of daylight and control systems, while the specific heat gains are a function of the type of lamps and fixture, the height of the space and the location of the lights, and the use of recessed lights if there is an exhaust system.

Occupancy may also contribute significantly to internal heat gains, when there is a large concentration of people in a space or building. The amount of heat generated and released primarily depends on indoor conditions and on the activity level of the person. A diversity factor can account for the average number of occupancy in the space or building in order to account for the number of people present during the operational day. For detailed calculations, may use a certain profile, e.g. time series of different occupancy depending on the end use of the building and the time of a typical operational day. However, this is still insufficiently investigated, especially with regard to its stochasticity.

Typical average heat dissipation from people, taking into account the corresponding average type of activity for the different end use buildings and average diversity factor (occupancy coefficient), are estimated based on European standards (EN ISO 13790, 2008; EN 13779, 2008). The following table includes the average thermal heat dissipation per unit floor area (W/m^2) and the average occupancy coefficient that represents the percentage of people present in the spaces (estimated in relation to the operation of the building, depending on its end use) during an average operational day.

Table 7: Average thermal heat dissipation and occupancy diversity factors for various types of buildings

Building Type	Building or Thermal Zone End Use	Thermal heat dissipation per person [W/person]	Thermal heat dissipation per unit floor area [W/m^2]	Average Diversity Factor
Residential	House, apartment buildings	80	4	0.75
Office	Office rooms	80	8	0.30
Education	Elementary school classrooms	80	40	0.16 – 0.18
	High school / university classrooms and auditoriums	80	40	0.32
Hospital	Hospital rooms	90	27	1.00
	Patient rooms	70	15	0.75
	Operating rooms	90	0	0.24
	Waiting rooms	80	44	0.24

Appliances and electrical **equipment** also release heat into the space. Normally, not all of the equipment installed in a building would be in use simultaneously, and for that reason a diversity factor should be applied to the full load heat gain as well. This internal heat source is significant in non-residential buildings (e.g. offices) as a result of the increased usage of computers and other communication and electronic office equipment.

Typical average installed rated power of equipment and average diversity factor for the different end use buildings, are estimated based on European standard (EN ISO 13790, 2008). The following table includes the average rated power of electrical equipment and appliances per unit floor area (W/m^2), the average diversity factor, along with the corresponding average diversified rated power and the average utilization factor that represents the percentage of actual operating time of the building and thus of the equipment, during an average operational day.

Table 8: Nominal and diversified rated power of el. equipment for various types of buildings

Building Type	Building or Thermal Zone End Use	Rated Power [W/m^2]	Average Diversity Factor	Diversified Rated Power [W/m^2]	Average Utilization Factor
Residential	House, apartment buildings	4	0.5	2	0.75
Office	Office rooms	15	0.3	4.5	0.30
Education	Elementary school classrooms	5	0.15	0.75	0.16 - 0.18
	High school / university classrooms and auditoriums	5	0.15	0.75	0.32
Hospital	Hospital rooms	15	0.5	7.5	1.00
	Patient rooms	8	0.5	4	0.75
	Operating rooms	20	0.5	10	0.24
	Waiting rooms	0	0	0	0.24

6. Building Systems, Elements and Materials

The role of **building systems** has grown from simply providing heating to living and working spaces to the use of mechanical cooling and ventilation systems for more comfortable year round indoor environment. Indoor humidity control may be necessary in some locations, while more elaborate control of outdoor and indoor contaminants and odours, have become an integral element of proper indoor environmental quality for achieving thermal and acoustical comfort and air quality. Heating, Ventilation and Air-Conditioning - **HVAC systems** include boilers, chillers, air-handling units, fan-coils, cooling towers, pumps, pipes, fans, ducts, diffusers and a wide variety of secondary systems or even renewable energy systems (e.g. solar thermal collectors, photovoltaics) and other electromechanical installations (e.g. lighting, motors, vertical transportation). For some building types, e.g. supermarkets, HVAC installations may also include refrigeration equipment (HVAC&R).

The **building envelope** determines the heating and cooling loads. Technically speaking, all problems related to the optimization of indoor environment can be handled with the available technology and there is a variety of available building services and systems. The limiting parameter is the energy consumption of conventional mechanical systems and associated equipment first cost and operational energy cost. Accordingly, the first step is to reduce the energy demand of the building that will allow the selection of smaller capacity and energy-efficient equipment, with lower operational energy. As buildings become more energy-efficient and more environmentally friendly building materials are used for the construction of buildings, it becomes more important to also account for the *embodied energy* of mechanical equipment and systems. The lower a material's embodied energy, the lower the amount of energy required to produce it and the lower its environmental impact. However, embodied energy data availability is limited and usually available for building construction materials, and very few include data on some particular mechanical systems and none comprehensively. In addition, there is usually no inventory of carbon and energy available for HVAC&R industry in national statistics (Chen & Zhang, 2011).

Building Information Modelling (**BIM**) is a new design trend with emerging applications in architectural and HVAC design. Ideally, accurate exchange of information of equipment and components is necessary, including during early design, for example, performance and approximate cost information in order to evaluate system equipment alternatives (ASHRAE, 2010). At later design stages, specific dimensions, and mounting details are required for preparation of drawings and construction documents. During functional testing and operation, records of actual performance and maintenance are required.

An open standard approach is under development for integrating facility management handover using the Cobie2 eXtensible Markup Language (XML) spreadsheet to BIM (Knight et al. 2010). When the graphical model is used to perform analysis, either an integrated analytical modelling tool within the BIM software runs the analysis, or the information in the model is exported out of the physical model in a file format that the analytical modelling software accepts, for example, IFC or gbXML (Dong et al., 2007). However, BIM-based work in the domain is still in an early stage. Many gaps need to be filled by projects like ISES, HESMOS, REViSITE and the ICT4E2B Forum (EeB, 2011) to enable seamless interoperable performance of ICT tools and platforms.

The work in ISES focuses specifically on the role of the building envelope in an effort to minimize the building's heating and cooling loads. The special emphasis is on the use of prefabricated façade elements that can be flexibly applied in various alternative configurations. Important in that regard is the consideration of detailed element construction, the respectively needed material data and the glazing.

Indeed, each opaque part of the envelope of a space is a combination of different **material layers**. In the ISES context the construction elements of project partner TRIMO containing several layers of different materials will be applied as practical proof of concept. These layer structures have to be assembled to façade elements and provided for integration in building simulation software so that all relevant parts from the product catalogue of TRIMO are available for design and simulation tasks.

The structure and content of **material data** which is necessary to prepare and process building simulations will be adopted from the HESMOS project. It will be largely identical to the description given in (Grunewald & Kaiser, 2011).

In the current time there are no general data repositories or special standardized data protocols for information exchange of physical data of construction material between software applications available on the market. There are different resources as stand-alone data pools mainly managed by academic and research organisations and available via the internet for manual research work or integration in software tools. These resources provide information in a quality which is appropriate for use in building simulation tasks with focus on energy related topics on general level. Examples are the 'baubook.at' database (Energieinstitut Vorarlberg and baubook GmbH, 2012), the MASEA database (Häupl & Plagge, 2007) and the NIST database (Zarr, 2006).

If issues related to building physics and building climatology like moisture transport have to be examined, partially different material data on a more detailed level are necessary to be linked in a simulation model. The material database of TUD-IBK contains a large number of such data used in ICT tools focused on building physics and energy simulations (Nicolai, 2011).

In parallel to the material resources mentioned above, material data inside market leading CAD software applications mainly for calculating investment costs of construction elements like walls, roofs and ceilings exists. Such material databases are integrated in specialised CAD or energy related software applications (see e.g. Nemetschek, 2012). However, they need to be adequately mapped to the available more comprehensive material descriptions to enable interoperability with energy simulation tools.

According to this situation, several issues need attention to provide for streamlined interaction. These include:

- Providing the right material data to the requesting applications
- Providing data in the required quality and units
- Defining interfaces and services to access this data
- Matching data from different sources to a unified format.

To fill in these gaps TUD-IBK have developed an in-house-standard to exchange material data from in house material laboratory to different software applications used for building simulation and building physics analysis during the last few years. The description for a large number of building materials is formulated in a hierarchical structure using XML (Nicolai, 2011).

The information content is divided into three main parts: (1) Material name and material category, (2) Constant scalar values, and (3) Functional relationships.

However, while thermal insulation is used to reduce heat losses through the opaque elements of the building envelope (i.e. walls and slabs), **transparent elements** like windows, skylights, clerestories etc. are used to allow for outdoor visual access and daylight that reduces the use of electrical lighting, in order to provide greater visual comfort and a more pleasant indoor environment. Commercially available **glazings** have different U-values*) and optical properties that will impact the

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*) E.g. clear single glazing: $6.1<U<6.3$ W/m^2.C, and double glazing: $2.5<U<3.2$ W/m^2.C.

heat losses and direct solar gains. To further improve the thermal performance of multi-glazed windows, the gap between two layers is filled with a low conductivity gas (i.e. argon, krypton, xenon). Evacuated glazings may further reduce heat losses by eliminating gaseous conduction and convection between two glass sheets. Radiative heat transfer is also minimized by using transparent low emittance coatings on internal side of the glass sheets. The thermal and optical properties of the fenestration assembly (i.e. framing, glazing, dividers) also influence the overall performance of the fenestration (e.g. thermal breaks, infiltration). Proper solar control (movable or fixed devices) on the building fenestration is essential to block, reduce or reflect direct and diffuse solar and visible radiation on the building fenestration in order to minimize cooling loads and regulate excessive direct solar gains.

In the past, tinted glasses have been used as stand-alone products or as the basis for the application of reflective coatings and low emissivity coatings. The disadvantage of tinted windows is that they absorb solar radiation and become very warm, with temperatures up to 50 °C. Some of this heat is then radiated towards the interior spaces, causing thermal discomfort. On the other hand, they also reduce outside viewing and indoor daylight levels. Visibly reflective coatings on tinted glasses expand both performance and aesthetic options (different colour appearance). Low emittance coatings can enhance performance and thermal efficiency while maintaining the original look of the glass. Spectrally selective glazings are of interest in hot climates while low emissivity coatings are more suitable for cold climates. Spectrally selective glazings have different performance for different wavelengths. They are transparent to visible light wavelengths while they reflect back unwanted infrared wavelengths. Chromogenic glazing like electro-chromic and thermo-chromic coatings on glazing, change electrostatically their optical transmissivity, depending on the incident solar radiation, outdoor temperature, previous hour space-conditioning load, or indoor daylight levels. Glazing properties change by applying a very small electrical voltage across the electro chromic coating. This is a very promising technology, but the cost is still relatively high.

Last but not least, in addition to the energy use for the operation of a building, there is considerable energy consumption for the building construction and embodied energy for the production of building materials. While the energy consumption during the construction process is very hard to determine and could be a research topic of its own, the estimation of the embodied energy of building materials is a matter of using proper databases to estimate it. Using a BIM Model, the quantities of all materials used for the building envelope can be easily summed up. Databases are available with relevant information on energy consumption per unit quantity of the various typical building materials and many building element manufacturers provide such figures in product data sheets. A good example for such a database is “Oekobau.dat” published by the German ministry for traffic, construction and urban development*). It is a building material database which currently includes about 950 datasheets of different materials in XML-format. Amongst others, these datasheets include primary energy (split in all relevant components), secondary fuels and global warming potential (GWP). However, once again, agreement about data structures and interoperability with other software tools is a gap of primary concern.

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*) http://www.nachhaltigesbauen.de/baustoff-und-gebaeudedaten/oekobaudat.html

7. Product Libraries

When modelling product data and design knowledge, two very different pieces of information appear: (1) the information which refers to the project's *host product* (the constructed facility), and (2) the information which refers to the autonomous *components* which are used in the host product. While some problems are common (e.g., how to model technical information), several ones are different, such as the origin of the information, the structuring of the information and the access to the information.

Product information holds many types of data including code conformance certificates for design decisions, values for building simulations, best practice installation instructions for construction, usage guidelines for maintenance, as well as data regarding demolition and recycling. Typically, this heterogeneous data is collated in the product catalogues of manufacturers and suppliers. In earlier times, these catalogues were in paper form. This has two major drawbacks. Firstly, it hinders the building designers to identify potential products because the manual process of searching for the suitable product in different types of catalogue requires a lot of time, knowledge and interpretation. Secondly, the different, highly inhomogeneous structuring of the catalogues (different languages, different ways to describe the technical details of a product component, even within the same company) has often been the source of errors in the later operation of the building. With the help of **electronic product catalogues** sources of error like inaccuracies and laborious transcription processes, but also the inefficiency of the manual processes should disappear (Amor et al. 2004). What is needed is (1) the harmonization of catalogue data representations, and (2) the interoperability of catalogue and building model data. The challenge in this regard relates to the interpretation of the content of the exchange. Standardised **product libraries** are the approach that should be used to solve the problem. BuildingSMART describes the issue in the following way: "*One definition that seems to be shared amongst several projects is that they see a 'product library' as some kind of a 'resource' containing a number of pre-defined products/objects with relevant properties and information attached to them The information about each object may or may not also include a graphical representation, i.e. a 3D symbol*." (Stangeland, 2011)

In the context of ISES product libraries are understood as digital machine readable specifications of manufacturer products used as components in a complex host product. They can play a very important role:

(1) For the seamless inclusion of the information about prefabricated product components and equipment (façade elements, doors, windows, various HVAC components) in the BIM of a built facility;

(2) For decision support in early design, i.e. for suggestion of reliable off-the-shelve alternative energy related design solutions when data about element construction and materials have not yet been decided by the architect.

The basic principles for the management of product information in product libraries are as follows:

- A product library comprises a hierarchy of product classes
- The properties are associated with classes
- The meaning of property values is given by the property definitions.

In the AEC/FM industry, the change from paper-based product catalogues to electronic and online systems is continually expanding. Due to their importance for the digital exchange process, many product ontologies have been developed over the last years. The industry starts to use national-based systems of high complexity (cf. Amor et al. 2004); at the same time classification and standardization organizations have developed their national and international support systems. Some are domain-specific (vertical), others are domain spanning (horizontal). Quite often they are both overlapping and unrelated.

Currently, a user can more quickly identify products by following the classification hierarchy and in many cases he can access online digital documents representing design details, installation guides, certificates etc., which may be copied into a project's information store. However, electronic catalogues still reproduce the standard of the paper catalogues, which requires human interpretation and manual transcription of the information from the catalogue to other tools. The parameterized information about a product that is finally decisive as to whether or not it will be selected for a project must still be manually interpreted. Interoperability of catalogue, design and analysis tools is largely missing.

To cope with this issue, major **standardisation efforts** have been undertaken on international level. Noteworthy here are especially (1) STEP/PLib and (2) IFC/IFD.

STEP (ISO 10303) is the international STandard for the Exchange of Product model data. It provides a general methodology for the development of information models for the data exchange and sharing in various technical domains. These information models are developed using the standardised high level modelling language EXPRESS (ISO 10303-11) and can be exchanged via so called STEP physical files (ISO 10303-21) or shared in common database repositories using the standardised data access interface SDAI (ISO 10303-22). Standardised conversion of the data to XML is also provided. STEP models provide descriptions of the physical and formal aspects of a product using a set of standardised resources such as geometry and topology resources, measure units, materials etc. (STEP Parts 41 ff.). On that basis, a number of Application Models for different industry domains and business processes have been developed. Most detailed STEP models are available in the automotive industry. AEC/FM is not supported by STEP but provides its own information modelling standard, IFC (ISO 16739). Nevertheless, as many building components and equipment are produced by the manufacturing industries, especially the STEP related part libraries (PLib) can be of interest in the ISES context.

PLib, officially the ISO 13584 Standard series "Parts Library", defines a model and an exchange format for digital libraries of technical components. The objective of the standard is to provide a mechanism capable of transferring parts library data, independent of any application. PLIB specifies the structure of a library system that provides an unambiguous representation and exchange of computer interpretable parts library information. It thus can provide for productivity increase (as the components are not modelled several times), quality increase (as the data models are guaranteed by the supplier of the library) and product data storage / exchange efficiency (as in product data a component is only represented by a reference).

Attributes in PLib are used to characterize any kind of property of any kind of entity that belongs within the problem area of the products computer model. Three levels of attributes are distinguished:

- *Level 1* - Attributes are characteristics of a part whose value can be inferred from the part identifier.
- *Level 2* - Attributes are characteristics of a part once the part is chosen, i.e. attributes that are specific to the instance of a part. A Level 2 attribute may itself be a part.
- *Level 3* - Attributes may also be a structured list, thus allowing higher-level assembled parts. There is no structure or rules to ensure that all manufacturers use the same attributes to identify properties of similar products.

Unlike STEP Application Protocols or IFC that specify models for data exchange and sharing, PLIB offers a model for creating dictionaries of components. PLIB implementations are typically manufacturer specific; therefore, it makes it difficult to compare products from different manufacturers unless they have the same terminology and provide implementations of the same context parameters. In PLIB, the context knowledge necessary to evaluate performance of products is embedded within the catalogue.

PLib is fully interoperable with STEP. PLib library component representations may be defined as STEP data. In STEP product data, PLib components may be represented by simple references. However, use of PLib with IFC is hardly attempted in today's CAD and specialised AEC/FM software tools.

IFC, the Industry Foundation Classes for AEC/FM (ISO 16739), are an international standard for the representation of construction information suitable for transfer between applications. It facilitates the exchange and sharing of information between the different applications used by the various stakeholders in the lifecycle of the facility. Thus, the IFC specification provides the AEC/FM standard for BIM, which is similar in its essence to the STEP standard, but is better aligned with the specific characteristics of the construction industry. IFC is developed and maintained by the buildingSMART Alliance (formerly the International Alliance for Interoperability). The current implementation level is named IFC 2x4 (publicly announced as IFC4) and was released in October 2011.

Similar to STEP, IFC information modelling is done using EXPRESS (ISO 10303-11). In IFC, specified classes are structured into several levels from common resources used throughout a project to domain specific resources used for a particular process within a construction project. Classes are not defined for every conceivable product type within a constructed entity, but represent generic categories of element (e.g., wall, beam, space), which can be categorized to provide a unique specification of the actual type of element. To this extent there are very few attributes associated with a class, which could be used to transfer information relevant to a manufacturer. However, the IFC incorporate a mechanism called Property Sets (PSets), which allow information publishers to dynamically allocate new properties to an object they wish to describe. The assumption is that groups of interested parties will agree a common set of these properties sufficient for the transfer of information within their field. Indeed, a large number of these commonly agreed properties are listed in the IFC specification. PSets have many of the disadvantages of the attributes in PLib in that there is no specification of the semantics of PSet information outside that published in the IFC distribution.

IFD, the **I**nternational **F**ramework for **D**ictionaries (ISO 12006-3), is a reference library with terminology and ontologies assisting in identifying the type of information being exchanged. It supports IFC by providing a dictionary that describes the objects and specifying what properties, values and units they can have (buildingSMART 2012).

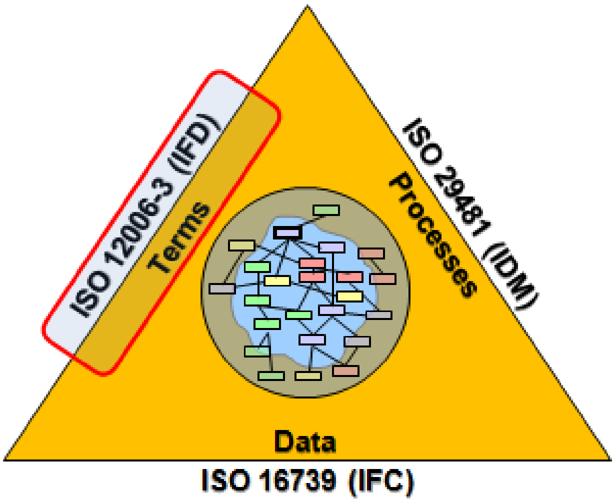

Figure 7: The integrated IFC-IFD-IDM Framework (source: BuildingSMART)

In its essence, IFD provides a mechanism that allows for creation of multilingual dictionaries or ontologies. Thus, it provides a flexible and robust method of linking existing databases with construction information to an IFC-based Building Information Model (BIM).

The IFD library is being developed in two streams: content and technology. Content in the IFD is of two types:

(1) *Naming Concepts*
A concept is a thing that can be distinguished from other things. A concept may have several labels or one name can be used as a label for several concepts. All concepts are assigned a Globally Unique ID (GUID). IFD separates the names and languages from the concept itself, it is not a mapping of words in one language to words in another language, but a mechanism where the concept itself is a separate thing, only connected to the words describing it through relationships.

(2) *Characteristics* (synonyms, acronyms, definitions and lexemes)
Characteristics or properties are concepts that are described using a description. Characteristics are concepts that cannot be defined using other concepts. Subjects are concepts being defined and characteristics are concepts that define. Characteristics contain values when instantiated in a relationship. Concepts are related to other concepts through relationships. Relationships are collected into contexts based on how and where they came from. Concepts can relate to other concepts in multiple contexts.

Figure 8 below shows an example of the naming concept (left) and the M:N relationships between concepts in IFD (right). The left diagram shows the Norwegian word “dør”, which in a normal dictionary is translated to “door” in English. By studying the concept we find that in Norwegian we refer to the door with its frame, while door in English only refers to the door-leaf. The Norwegian dør should therefore be translated to door set. In IFD this is achieved by separating the concept itself from the names and descriptions used to name and describe it. The right diagram shows the tackling of multiple relationship cardinalities. As the image shows a 'beam' is not just a 'beam' but also a word used to describe multiple concepts. In any computer related exchange of information it is essential to capture the different concepts hidden behind all those different versions of the word 'beam'. Because of the internal relationships between concepts in IFD it is possible to translate a specialized concept into a more generalized one.

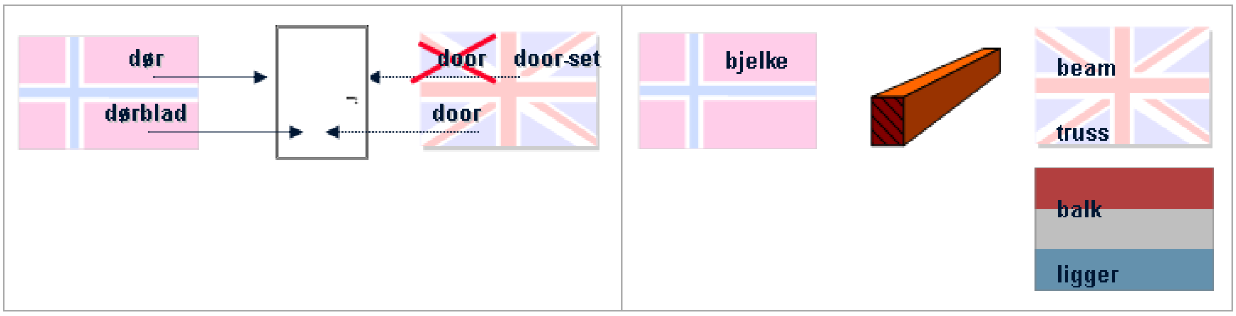

Figure 8: Examples for the representation of semantics in IFD

The following figure illustrates how a concept (window) can be described by a set of characteristics in IFD. The relationship between a concept and its characteristic can also be captured in a context allowing the relationship between the particular use of a concept and its properties in that use to be captured within a given context.

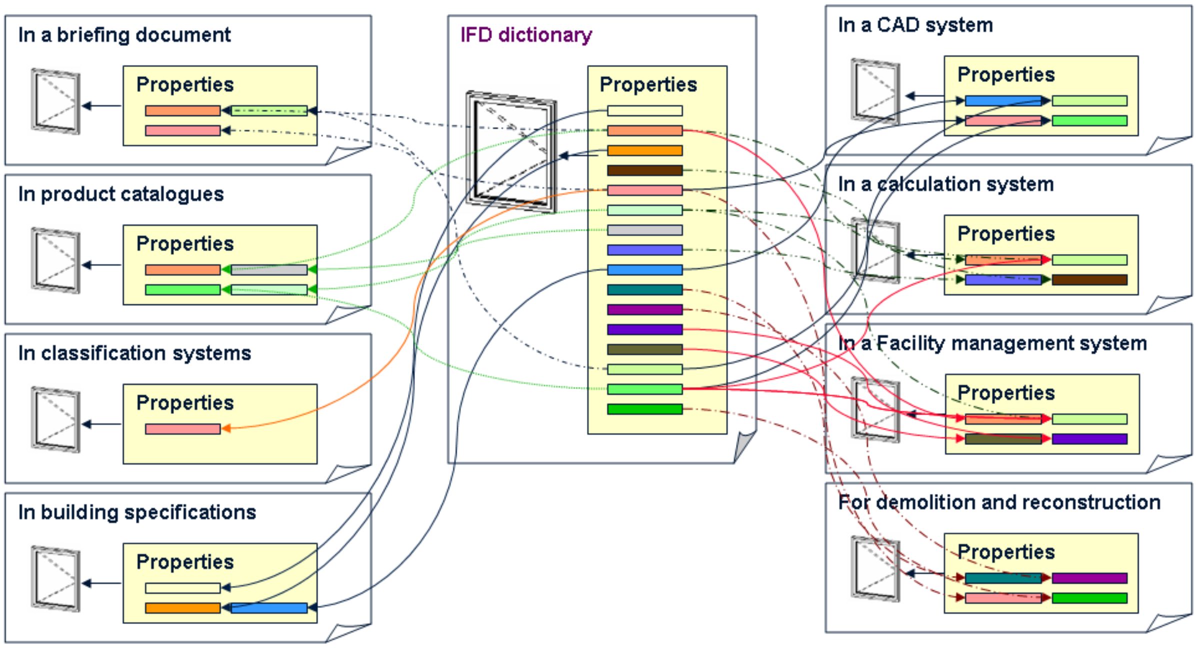

Figure 9: Example of how a "window" may be used in multiple contexts in IFD

In spite of the progress in the last years, with regard to ISES several **gaps** in state-of-the-art specification and use of product libraries can be identified:

- *eeCatalogues*
  In order to use product catalogues for detailed energy calculations, specific energy related data is needed. However, current available catalogues lack energy-relevant digital specifications enabling direct use in simulation software
- *Level of Detail*
  Link to BIM exists but is on relatively coarse level, there are limited capabilities for assignment of groups (e.g. all heated rooms on the ground floor or all elements of the north facade) or parts (alternatives of certain parameters of catalogue elements enabling the varying of the elements themselves in a continuous simulation chain)
- *Mapping to BIM*
  IFD mapping is 1:1; however, in many cases a M:N mapping is needed.
- *Interdisciplinary issues*
  Lack of harmonisation between the description of machine parts (HVAC equipment) and building parts (building elements)
- *Use of Catalogues in CAD*
  IFC provides several mechanisms for that purpose, but they are yet weakly supported by current software tools
- *Use of Catalogues in energy simulations*
  Missing embedding / integration of catalogue data with design templates*).

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*) A promising attempt in that regard is currently undertaken in the HESMOS project (Grunewald et al. 2012); this will be continued and extended in ISES.

8. Software Methods and Tools for Building Energy and CO_2 Analysis and Performance Assessment

8.1 Overview

A building's heating, cooling, lighting, and equipment systems all interact with each other, the building envelope and the building site in a multitude of complex ways. Integrating all of the variables into an energy efficient design can be a daunting task without the assistance of design analysis and simulation tools. Hundreds of such tools for a broad spectrum of tasks have been developed, enhanced and are in use throughout the word over the past decades (Crawley et al., 2008). Many of them have gained international recognition and market acceptability. Free and license tools include databases, spread sheets, component and systems analyses, and whole-building energy performance simulation programs. They require different levels of expertise, target different users and audiences and feature different input/output requirements and computer platforms.

In general, building energy tools can be typed in three major categories with several subcategories as follows (cf. DOE 2011):

- Whole-Building Analysis
  - Energy Simulation
  - Load Calculation
  - Renewable Energy
  - Retrofit Analysis
  - Sustainability / Green Buildings
- Materials, Components, Equipment, and Systems
  - Envelope Systems
  - HVAC Equipment and Systems
  - Lighting Systems
- Other Applications
  - CFD Analysis
  - Indoor Air Quality
  - Multi-building Facilities
  - Utility Evaluation etc.

In the context of ISES, most important of these are Energy Simulation, Sustainability, CFD Analysis and the use of stochastic variables and/or stochastic methods in energy and CO_2 performance analyses and simulations.

The table below provides a compiled overview of 40 current tools related to energy simulation, CFD analysis and sustainability based on data from (DOE 2011). Whilst functionality, quality, user friendliness, origin and scope of these tools differ in a broad range, it is nevertheless obvious that there is no lack of ICT support for various energy related studies to date. However, despite the great progress in the area in the last decade, there are several gaps that still need to be overcome. This includes:

- The weak integration with general-purpose design (CAxx) and FM software
- The lack of common energy models that can support the interoperability among the specialised tools
- The weak support of ICT standards such as SOA and cloud computing, even though national and international energy related standards are duly supported
- The weak web integration (most tools being stand-alone desktop systems providing little or no web-enabled services)
- The weak support of BIM / IFC.

Table 9: Overview of current energy simulation, CFD analysis and green building ICT tools

Tool	Keywords / targeted application areas /	Country
AEPS System Planning	Renewable energy system, modelling, simulation, energy usage, system performance, financial analysis, solar, wind, hydro, behaviour characteristics, usage profiles, on-grid, off-grid, residential, commercial, system sizing, utility rate plans, utility costs, energy savings	USA
AnTherm	Thermal heat bridges, heat flow, steady state, 2D, 3D, transfer coefficients, thermal conductance, visualization, simulation, EPBD, temperature distribution, vapour transfer, vapour diffusion, avoiding moisture and mould, energy performance, linear and point thermal transmittance, vapour pressure, surface condensation, thermal comfort	Austria
Apache	Thermal design, thermal analysis, energy simulation, dynamic simulation, system simulation	UK
Autodesk Green Building Studio	BIM, interoperability, energy performance, DOE-2, EnergyPlus and CAD integration	USA
BSim	Building simulation, energy, daylight, thermal and moisture analysis, indoor climate	Denmark
BuildingAdvice	Whole building analysis, energy simulation, renewable energy, retrofit analysis, sustainability/green buildings	USA
BUS++	Energy performance, ventilation, air flow, indoor air quality, noise level	Finland
COMSOL	Multiphysics, simulations, heat transfer, finite element analyses	USA
CYPE - Building Services	Building services, single model, energy simulation, sizing, HVAC, plumbing, sewage, electricity, solar, analysis of acoustic behaviour	Spain
Czech National Calculation Tool	EPBD, Energy Performance Certificate, Delivered energy, Energy Demand Calculation	Czech Republic
Delphin	Coupled heat, air and moisture transport, porous materials, building envelope	Germany
DesignBuilder	Building energy simulation, visualisation, CO_2 emissions, solar shading, natural ventilation, daylighting, comfort studies, CFD, HVAC simulation, pre-design, early-stage design, code compliance checking, hourly weather data, heating and cooling equipment sizing, EnergyPlus interface	UK
DeST	Building simulation, design process, building thermal properties, natural temperature, graphical interfaces, state space method, maximum load	China
DOE-2	Energy performance, design, retrofit, research, residential and commercial buildings	USA
ECOTECT	Environmental design, environmental analysis, conceptual design, validation, solar control, overshadowing, thermal design and analysis, heating and cooling loads, prevailing winds, natural and artificial lighting, life cycle assessment, life cycle costing, scheduling, geometric and statistical acoustic analysis	UK

ENER-WIN	Energy performance, load calculation, energy simulation, commercial buildings, daylighting, life-cycle cost	USA
EnergyPlus	Quasi standard energy simulation tool, includes load calculation, building performance, energy performance, heat balance, mass balance etc.	USA
ENERPASS	Energy performance, design, residential and small commercial buildings	Canada
eQUEST	Energy performance simulation, energy use analysis, conceptual design performance analysis, Energy and atmosphere credit analysis, life cycle costing, DOE 2 integration, LEED support	USA
ESP-r	Energy simulation, environmental performance, commercial buildings, residential buildings, visualisation, CFD analysis	UK
HAMLab	Heat, air and moisture simulation laboratory, hygrothermal model, PDE model, ODE model, building and systems simulation, MatLab and SimuLink support, optimization	Netherlands
HEED	Whole building simulation, energy efficient design, climate responsive design, energy costs, indoor air temperature	USA
ISE	Thermal model, building zone simulation, MatLab/SimuLink	Netherlands
Microflo	CFD, airflow, air quality, thermal performance	UK
PHPP	Energy balance, high-performance houses, passive houses	USA
Physibel	Heat transfer, mass transfer, radiation, convection, steady-state, transient, 2-D, 3-D	Belgium
PVcad	Photovoltaic, facade, yield, electrical	Germany
REM	Home energy rating systems, energy simulation, code compliance, weatherization, EPA Energy Star Home analysis, equipment sizing	USA
RIUSKA	Energy calculation, heat loss calculation, system comparison, dimensioning, 3D modelling, BIM	Finland
scSTREAM	CFD, ventilation, airflow, temperature distribution, humidity distribution, contaminant distribution, thermal comfort, air quality	USA
SIMBAD	Building and HVAC toolbox, transient simulation, control, integrated control, control performance, graphical simulation environment	France
TAS	CFD and thermal analyses, building dynamic thermal simulation, user comfort, energy simulation	UK
TEK-sjekk	Energy performance, indoor climate simulation, code compliance, load calculation, residential and non-residential buildings	Norway
TOP ENERGY	Energy efficiency optimization, simulation, variant comparison, visualisation of energy flows	Germany
TRNSYS	Energy simulation, load calculation, building performance simulation, renewable energy, emerging technologies	USA
VisualDOE	Energy efficiency, energy performance, energy simulation, design, retrofit, residential and commercial buildings, HVAC, DOE-2	USA

Even though only selected tools are shown in the table, clearly not the lack of tools but the lack of their interoperability and of standardised platforms is a R&D issue. This is especially important with regard to parallel, alternative studies including stochastic parameters as targeted in ISES. To achieve that, certain amount of re-engineering of available tools will be necessary. Therefore, ISES will rely on tools of the consortium partners and not on legacy, off-the-shelve tools. The following sections outline the intended methods and tools to be used and extended or newly developed in ISES.

8.2 Energy Simulation Tools in ISES

Simulation tools in ISES will be provided by the partners OG (RIUSKA, ROOMEX) and TUD-IBK (COND, THERAKLES, NANDRAD).

RIUSKA is an efficient and versatile comfort and energy simulation application. It uses a building's information model (BIM) to calculate the thermal conditions of a building and its spaces in different loading and weather conditions.

The RIUSKA application can be used for the following tasks:

- Ensuring compliance with the objectives
- Temperatures of premises in summer and winter
- Comparison of indoor climate quality levels
- Comparison of architectural solutions (windows, window protection, façade solutions)
- Comparison and dimensioning of systems
- Analysis of problematic spaces
- Energy consumption of buildings and building systems
- Projected consumption of maintenance

The application takes into account structures, massiveness, local weather, thermal loads, usage hours and so forth. It performs hourly calculations on, for example, annual energy consumption, temperatures in various spaces and their constancy as well as heating and cooling needs.

RIUSKA is based on many years of development at Granlund and the core of the tool, the internationally acclaimed DOE 2.1E simulation program.

ROOMEX is an easy-to-use BIM-based tool for spatial requirements management. It helps to define spatial requirements and create space groups from technical system service areas to cleaning areas, makes it possible to visually check the performance and verify it to requirements, supports decision-making by producing easy-to-understand visual reports, helps in managing different versions of BIM models and supports the use of BIM in other applications, such as energy simulation. ROOMEX is fully IFC compliant. A completely new version of the tool functioning as web service and interoperable in a SOA environment is currently being developed in the HESMOS project.

TUD-IBK tools provide analysis and simulation capabilities on three levels, i.e.:

- building element (COND)
- single zone (THERAKLES)
- multi-zone / whole building (NANDRAD).

The latter, currently still under development, is successor of the DELPHIN program listed in Table 9 with considerably extended capabilities. All these tools are re-engineered within the HESMOS and the ISES projects to provide for:

- Use as web services within a virtual energy lab environment
- BIM / IFC interoperability
- Pre- and post-processing via an independent web-based nD Navigator

Specific extensions in ISES will include, in addition to the enhancements of the computational model of NANDRAD, capabilities enabling cloud-based simultaneous computing of simulation alternatives. Table 10 below presents the functionality of the TUD-IBK simulation tools that will be applied in ISES.

Table 10: Functionality of TUD-IBK Simulation Tools (Source: Grunewald et al. 2012)
(Legend: ● available | ○ to be ready 12/2012 | – not applicable or not in scope)

Function / Result	Element	Room	Zone/Building
Space			
Air Temperature	–	●	●
Operative Temperature	–	●	●
(Relative) Air Humidity	–	●	●
CO_2	–	●	○
Air flow rates	–	●	○
Moisture transport in construction elements	●	–	–
Space envelope			
Layer structure	●	●	●
Layer material	●	●	●
Window Area	–	●	●
Thermal bridges	●	–	–
Window & Frame			
Glazing	–	●	●
Shading	–	●	●
HVAC – Heating			
Idealised System	–	●	●
Detailed System	–	○	○
HVAC – Cooling			
Idealised System	–	●	●
Detailed System	–	○	○
Lighting			
Idealised System	–	●	○
Detailed System	–	○	○

8.3 CFD Analysis

CFD software can be used for 3D simulation of building exterior atmospheric flows and interior natural ventilation flows. However, commercial CFD tools are usually general purpose CFD software, such as cfdesign (www.cfdesign.com). They are not specifically oriented to ventilation flows addressed to specialized CFD or HVAC engineers. Detailed 3D results of outdoor and indoor domain flow fields can be provided, so natural ventilation performance can be assessed with respect to the occupants' comfort. A validated CFD model is a powerful tool to carry out parametric studies or optimize the design of a ventilation system, to effectively replace costly experiments or limit their use to special constructions or conditions prohibiting their use in everyday design.

A lot of specialized preparatory work is required to simulate ventilation. Especially for the solution of the coupled indoor/outdoor flow problem, huge computing time is required. Validation against experimental data is mandatory. Solid knowledge of fluid mechanics and numerical techniques are required by the user.

Currently, no unified platform exists for everyday use in architectural and HVAC design providing detailed natural ventilation simulations. The efforts of engineers to optimize such systems are implemented by repetitively solving the direct problem which in the case of 3D calculations is extremely time-consuming.

CFD models are ranked very highly concerning the detailed analysis they perform and may be used with as much as complex domains. However, they are still time consuming and computationally expensive and their use requires expertise. CFD tools for the calculation of ventilation flows are provided by various vendors (see Table 9). However, these tools have to be combined with building energy simulation packages, as well as with architectural design and structural analysis software, so that compatibility and interoperability problems are often manifested in the data transfer between the different tools. The use of ICT tools from separate vendors significantly increases their cost; most of them use their own pre- and post-processors, which are generally incompatible with the data formats of others. In addition, more time and money are required for training and more personnel is involved in the use of separate tools.

The ISES CFD solver being developed by SOFiSTiK HELLAS will be integrated within a holistic architectural design and energy lab platform, suitable for everyday use in the design of buildings, and in general, of civil engineering constructions of any kind (buildings, atriums, stadiums, etc.). This will enable the designer not only to produce optimized natural ventilation systems, but also to fully take into account natural ventilation characteristics in the context of multidisciplinary building design from its early stages. In addition, since the analysis capabilities of ISES will extend to the outdoor flow field as well, in case of a new building, the design may concern the choice of building location and orientation or even the choice of the surrounding topography in order to create the prerequisites for enhanced natural ventilation in its interior. It will be coupled with a stochastic-based algorithm for the optimum design of some critical geometric parameters under consideration to achieve suitable natural ventilation, as required by the designer. To simulate 3D flows in affordable computing time, especially when used in the context of an optimization procedure, a HPC cloud framework will be exploited for the parallel processing of the software to be developed. The IFC model that will be the basis for data integration contains thorough definitions across all disciplines and life-cycle phases which will provide for the automated generation of much of the needed input data and will thus facilitate the fast creation of high quality error-free computational models.

8.4 Stochastic Analysis

8.4.1 General Principles and Considerations

In general terms, systems are termed “stochastic” or “deterministic” based on whether the system includes dynamic time-dependent properties or is static in the sense that no randomness or uncertainty is involved in reaching subsequent stages of the system from any given initial starting stage as it evolves over time. Numerical modelling methods are stochastic or deterministic based on the absence or presence of randomness in the system. An inherent characteristic of stochastic or probability-based models is that they deal with discrete state changes in the system that is triggered by random events which can occur at any possible moment in time or at discrete observation points (Evans, 1988).

Stochastic models can be broadly categorised into two groups:

- *Discrete Time Models*
  The system changes the random variable values only at discrete points in time and observations are selected for given moments in time that are evenly spaced along the time scale. The Discrete Time Model may be used for approximation of continuous systems by setting the time increment small compared to the total process time.
- *Continuous Time and Discrete Events Models*
  In these systems the time parameter is continuous at least conceptually and their random variable values evolve continuously over real time. Observations are made considering the changes in state of the system that take place at discrete time intervals subject to instantaneous happenings or events in the system.

In the current practice of building energy assessment energy consumption is most often determined by a *prescriptive approach* as detailed in national standards and regulations and thereby complying with set requirements. Similarly, design tools for calculation of energy consumption of buildings have been mostly focused on calculating energy loads for dimensioning of heating, cooling and air conditioning systems. Usually these tools are based on static (deterministic) calculation methods, applied at the later design stages of the building and leaving little opportunity for design optimisation in the energy efficiency of the design. However, with climate change and rising energy prices, the need to consider the total impact of buildings over its service life has grown (Hopfe, 2009). Over the last years many ICT tools have emerged that assist designers in energy and environmental performance assessment but these tools still use deterministic approaches where model output is fully predictable and repeatable in terms of the input parameters which are based on average or industry standard explicit values gained from experimental measurements and/or other observations over time (Kim et al. 2011). The problem is that thousands of possible input parameters do exist many of which need to be estimated or assigned by best educated guess or based on subjective judgement. Even though these parameters may be empirically verified to some extent, there are numerous conditions that present uncertainty in the definition of their values that may influence the output of the simulation and cause significant discrepancy between the designed and the actual energy performance of a building.

Hence, various **methods** have emerged to account for the variability in the input parameters space. One approach to model time-depended variability is by using *diversity temporal-profiles* (Fabi et al. 2011). One such profile is used for modelling occupant presence in the building during the simulation. In this case the diversity profile describes the presence of occupants, the corresponding casual heat gain and energy loads stemming from utility demands over a specific time period e.g. a 24 hour. Other types of diversity profiles provide fixed schedules of values that estimate the impact of variation in a given parameter. These can be applied to various situations such as infiltration, operation of lights etc.

Several efforts have aimed at improving on the deterministic schedule based, single value outcome approach by modelling some processes separately or by introducing computational algorithms and numerical approximations that integrate into the overall simulation procedure thereby improving the flexibility and adaptability of the model and its ability to handle variation in model parameters. (Light switch model by Reinhart, 2004, control strategies, different energy system types) etc.

In spite of these efforts, state-of-the-art simulations are still based on a number of basic assumptions about the simulation model and the influencing factors e.g. climate, building properties and occupant behaviour that cannot be realistically replicated and the associated uncertainties quantified. Many of the input parameters depend on discreetness, non-linearity, uncertainty or variability, and on many varying factors both dependent and independent of one another (Hopfe, 2009). In such cases, average values can only give a reasonable estimation of the actual values. Uncertainty, inaccuracy and errors in input parameters have raised concerns as they may propagate through the simulation model resulting in inaccuracy and uncertainty in the simulation output (Fabi et al. 2011). Hence, more realistic description of parameters is required, based on statistical uncertainty analyses, input parameter screening, weighing of parameter significance in the model and then further sensitivity analyses to evaluate and rank each parameter in order of sensitivity or impact on the simulation results.

Stochastic simulation has been studied by numerous researchers (cf. MacDonald, 2002; Hopfe, 2009; Jacob et al. 2011). General findings are in agreement that stochastic methods generate different results from traditional deterministic analyses methods and deliver more valuable design information and support a more robust decision-making process in design. Several methods have been analysed and are now generally categorized as *Internal* and *External* methods. External methods are consistent with the envisaged ISES Virtual Energy Lab where the simulation software is seen as “black box”. Internal methods, on the other hand, modify the underlying algorithms used by the simulation software. Thus, to adapt the model to a new project the computational algorithms need to be partially redefined (Jacob et al. 2011). A further distinguishing characteristic between the methods is that external methods require multiple simulations whereas internal methods only evaluate the model once.

Three different external methods have been identified that comply with the external definition depending on the number of random variables being analysed and the required simulations:

- *Differential Method* – analyses one random variable at a time to quantify the effect that each variable has on the simulation outcome – requires 2N +1 simulations
- *Factorial Method* –analyses a group of random variables simultaneously to quantify their combined effects on the simulation outcome - requires 2N simulations
- *Monte Carlo Method* – analyses all random variables at once to quantify the overall uncertainty in the simulation outcome. The number of simulations is not dependent on the number of random variables N but rather on the statistical accuracy required. Typically about 80 simulations are needed to obtain adequate results (MacDonald, 2002).

Especially the Monte Carlo sampling-based techniques have successfully and widely been deployed in the area of building energy performance simulation (Kim et al. 2011). The technique has proven suitable for integrating both *uncertainty* and *sensitivity* analyses with current deterministic simulation tools such as EnergyPlus, DOE-2,ESP-r etc.

Uncertainty analysis has the objective to assess and quantify the uncertainty in the model outcomes that derives from uncertainty in the input parameters whereby the method gives information on how reliable and confident the simulation outcome is (Hopfe, 2009; Eisenhower et al. 2010; Fabi et al. 2011).

Uncertainty analysis explores the mapping between uncertain output results Y(X) = [y1(X), y2(X), ... , YnY(X)] as a function of uncertain input parameters X=[x1, x2, ... , XnX] computing what is the uncertainty in Y(X) given the uncertainty in X (Helton, 2008). The uncertainty of input parameters X is expressed in terms of probability distributions, but can also be specified by samples of measured values, i.e. empirical probability distributions. Input parameters are expressed in terms of probability distributions D = [D, D2, ... , DnX] that characterize the uncertainty in input parameters x1, x2,..., xnX respectively. Distributions D are sampled accordingly to generate samples for variables X’ = [x’1, x’2, ... ,x’nX] resulting in a matrix of [xnS x xnX], i.e. sample size nS and number of variables nX. The matrix is propagated through the simulation model S times to determine the statistics of the mapping [X’i, Y(Xi)] i = 1,2 .. nS].

With many input parameters generating the probability distributions can present a major effort. Therefore, part of the analysis strategy is to do initial exploratory analyses using fairly basic definitions of probability distributions and identify the most important input parameters. Further definition on the identified input parameters distribution can then be done with a second analysis step using a refined probability distribution.

In the Monte Carlo sampling-based analysis it is assumed that input parameters are not related and independent of one another, i.e. there exists no correlation between them. Since this is not the case for many input parameters, e.g. moisture and temperature, outdoor and indoor temperature, there may be a need to induce a desired correlation structure onto the samples being generated. Specifically correlated variables should have correlation closed to their specified value and uncorrelated variables should have correlation close to zero (Helton, 2008).

However, generating stochastic samples for building simulation will always be a compromise between precision of the estimate of the population mean and the cost of doing simulation runs. In stochastic building energy simulation, which is an evaluation of a multi-dimensional parameter space that normally involves a very large number of stochastic variables, hundreds of simulation runs with a very large number of samples may be required. A sound sampling strategy is therefore a very important aspect of stochastic building energy simulation. The overall aim is to determine, appropriate sample sizes with as few elements as possible and an estimated sample mean with variance of insignificant value as it converges to the actual population mean.

While there do not exist any direct guidelines for establishing exact sample sizes, several researchers have compared the performance of different sampling methods and their efficiency pertaining to building simulation. Matala (2008) compared simple random sampling and Latin Hypercube sampling in order to finding optimized sample sizes. MacDonald (2009) examined the performance of several sampling methods; simple random (SRS), stratified (SS) and Latin Hypercube sampling (LHS) in application of typical building simulation problems. Burhenne et al. (2011) extended the work done by MacDonald by adding the analyses of a sampling method based on Sobol sequences. All these researchers have verified their work on several simulation models of different complexity. The results obtained by Burhanne summarize the findings. They showed that the sample size of 64 already converges to the mean using the SS, LHS and Sobol sequences methods, while the robustness (variation) was better for the SS and Sobol sequences methods, followed by LHS and seemingly the SRS showing the greatest variation and least robustness. The building simulation model showed that the Sobol sequences displayed the least variation followed by LHS and SS methods. Further the study showed that for these methods the mean converges very quickly to produce acceptable results for small sample sizes (see Figure 10).

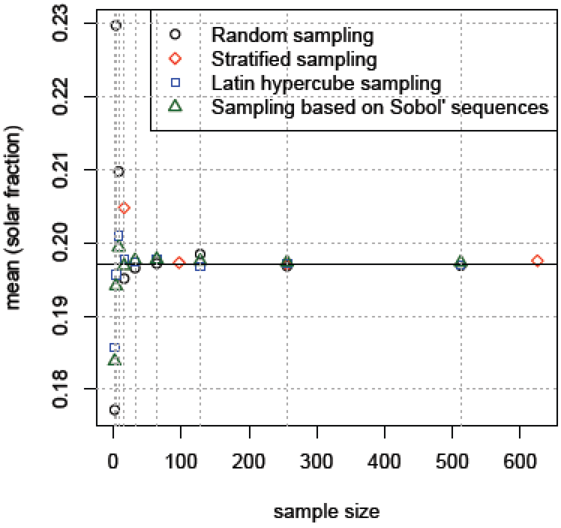

Figure 10: Comparative convergence of sampling methods (source: Burhenne et al. 2011)

The overall conclusion was that for the most of the analysed aspects the sampling based on Sobol sequences performs better than the other investigated sampling methods, but the performance of the different methods varies based on the number of input parameters and model properties.

Sobol sequences sampling and LHS have the fastest convergence to the mean as well as having the least variation producing more robust results. Burhenne et al. (2011) recommend using either sampling based on Sobol sequences or Latin Hypercube Sampling in Monte Carlo building simulations, especially when sample sizes are kept as small as possible to reduce computer cost.

There are no simple answers as to which method should be used and no single dominant approach has emerged. The simple Monte Carlo sampling method will always give dependable results given that the sample size is big enough. However it must be taken into account that stratified, Latin Hypercube and Sobol methods all eliminate or drastically reduce the problem with bias in the sample distribution which can be a drawback when considering the SPS method, especially for smaller sample sizes, in which case regions with clusters and gaps may affect the results from the simulation giving overemphasized values where clusters occur and non-consideration to regions where gaps appear in the sample distribution.

While uncertainty analysis can be performed on simulation models to assess uncertainties in the model outcome derived from uncertainties in the parameter input, **sensitivity analysis** can be applied to determine how sensitive model outcome is to changes in the model inputs. Sensitivity analysis allocates and quantifies the impact of model input parameters to the uncertainty of the model output factors or model performance indicators. It will therefore quantify the contribution of individual uncertain input parameter and thereby identify which input factors are more important when determining the uncertainty of the model outputs. The sensitivity analyses method is a powerful tool to illustrate the consequences of alternative assumptions about a given model and as such, an important method for checking the quality of the model as well as for checking the robustness and reliability of the model analysis. However, the application of sensitivity analysis strongly depends on the context and nature of the investigation. It can provide a general evaluation of the model precision when used for evaluating model performance indicators in alternative simulation scenarios or for detailed study in the significance and interaction of individual input parameters.

Various approaches to sensitivity analysis are reported in the literature. Widely recognised are two techniques: (1) the *Local Method* and (2) the *Global Method*. The Local Method focuses on “one parameter at a time” (OAT), while assuming no changes in the nominal values of other parameters (Hopfe, 2009; Eisenhower et al. 2010). It can be usefully applied when few parameters are studied. It is not recommended or justifiable unless the model under consideration can be proven to be linear between inputs and outputs (Saltelli et al. 2006). For many situations, changes in relatively few parameters have substantial influence on the output and the OAT method may prove helpful, given that strong correlation exists between the output and input values. However, normally many changes in input parameters will occur simultaneously and models cannot be assumed to be linear. In this case global sensitivity analysis should be used to address the entire output range while changing all input parameters simultaneously across their entire value range. By covering the whole input range global methods enable both investigating the relative impact of individual parameters as well as the total sensitivity in the output and selected performance indicators. Suggested methods such as the variance based method allow the concept of factors of importance to be evaluated. Making importance ranking possible in a rigours and easy implementation, they further enable the correct use of “model-free” sensitivity analysis approaches (Saltelli et al. 2006).

When dealing with models of large number of uncertain parameters it is beneficial to apply **screening methods** to the input parameter space. The objective of using screening methods is model simplification and/or reduction of the number of uncertain input parameters propagating through the model. The task is to identify the input parameter or a set of input parameters that have the least influence on the variability of the model outputs. These non-influential parameters can then be fixed at any given value of their range of uncertainty without reducing significantly the model output and without significant loss of information (Saltelli et al. 2006). Similarly, the most important parameters can also be identified which have the strongest effect on the output variability. This type of parameter screening is quite valuable in early phases of the analyses when computationally expensive models are being analysed.

There are many different methods available to do parameter screening. The OAT technique is the simplest and the least computationally demanding (Hopfe, 2009; Eisenhower et al. 2010). Using the OAT technique one parameter is varied at a time and the effect of each one measured with respect to the output metrics. The technique is fairly crude and least accurate but will give indication on how input parameters influence the output and their rank of importance. The approach used in the literature (cf. Ekström, 2005; Hopfe, 2009) is to vary the input parameter values in small intervals around the nominal value usually a fixed interval e.g. %5. Another frequently used technique is the Morris method, which computes the "elementary effect" determining whether the effect of input parameter xi on the output Y is negligible, linear and additive (Ekström, 2005). Global methods such as the variance methods for "model-free" measures can also provide parameter screening by observing the change in variance of output metrics as input parameters or a set of them are varied by fixed values over their range without effecting the output variance. Identifying such sets will in turn explain the unconditional variance by remaining parameters (cf. Saltelli et al. 2006). Saltelli also points out that for models which are expensive to evaluate the method proposed by Morris can be used as it requires smaller sample size.

Screening methods have been already efficiently applied in building energy performance simulation. Eisenhower et al. (2010) report several use cases where the screening method was used to reduce significantly the number of uncertain parameters in the model, e.g. Rahni (1997) effectively reduced the number of uncertain parameters to 23 out of the original 390 parameters.

8.4.2 Stochastic Modelling in ISES

In building component product development and in the design of facilities, almost all design parameters are subject to uncertainty. While uncertainty and sensitivity analysis techniques have been widely studied in the last years using different building models, simulation scenarios and number of uncertain parameters, there are fewer researchers that have tempted to model the whole building under uncertainty using over 1000 uncertain parameters when evaluating energy efficiency (cf. Eisenhower et al. 2010). Indeed, applying Monte Carlo uncertainty and sensitivity analysis to whole building simulation with over 1000 uncertain input parameters presents a major challenge, effort and costs associated with generating appropriate probability distributions for each and every uncertain parameter. In such cases, approximations and simplifications have to be carried out before the actual simulation is performed. Firstly, probability distributions based on limited empirical observations should be used and for simplicity reasons the same probability distributions should be applied over the entire parameter range, e.g. normal, log-normal or uniform distributions. Typically, if the distribution is not known beforehand and cannot be otherwise approximated, the uniform distribution should be used for all non-zero parameters and exponential distribution should be used for zero parameters. Input parameter values should be varied in small intervals around a nominal value, usually a fixed interval e.g. %5, 10%, 20%. Such methods can be appropriate as part of the analysis strategy, e.g. in initial exploratory analyses using fairly basic definitions of probability distributions to identify the most important input parameters, then followed by further steps to refine the probability distributions for the most important input parameters.

As uncertainty in input parameters definitively has effect in the building energy assessment, probability distributions of uncertain input parameters must be selected critically and carefully. Currently, weather and climate data is usually treated deterministically and modelled by characteristic profiles (Wilcox & Marion, 2008). Furthermore, although modelling of occupant behaviour in operational facilities has developed significantly in recent years and more realistic and sophisticated computational models have emerged, they still remain very specific and have yet to be integrated into mainstream simulation tools.

The solutions of ISES are focused on **three main scenarios** in the life-cycle of buildings and facilities:

(1) Development of new building components and products
(2) Design and engineering of new buildings and facilities
(3) Refurbishment and retrofitting of existing buildings and facilities

Each of these is characterized by different level of detail and accuracy in the available information that represents uncertainty in the energy performance simulation outcome.

Development of new building components and products

One of the important aspects of ISES is the evaluation of energy performance of new products in all their development stages by means of a virtual laboratory platform. In this way, new products can be evaluated for energy efficiency in a controlled environment taking into account varying load conditions and usage scenarios. Energy efficiency analyses can be performed by using several characteristic host products in which the virtual product is integrated. Host products can be representative of whole buildings of varying complexity to simple models characterizing the optimal product environment.

Under these conditions, uncertainties primarily relate to:

- The environment of the host product ⇨ geographic location
- The suitability of the host product ⇨ building typology and BIM used
- The external and internal loads ⇨ climate conditions, usage scenarios etc.

Design and engineering of new buildings and facilities

Design and engineering of new buildings can be broadly broken down into four main phases: feasibility study, conceptual design, preliminary design and detail design.

In the early stages of the design process the most critical factors are determined that are responsible for the total energy consumption throughout the life-cycle of the building. It is also the phase where the level of uncertainty is greatest and so are the possibilities to influence the design and optimize it for greatest energy efficiency. At the feasibility and conceptual stage, to begin with, only very generic information exists about the design, apart from client brief, site constraints and designer vision for the facility. As the design develops and spatial programs, structural systems and construction materials are being decided on, basic energy scenarios can be investigated including initial studies of energy subsystems (heating, cooling and ventilation). During these stages it is important to identify energy inefficiencies attributed to the design and highlight opportunities for improvement.

As the design proceeds into the preliminary and detail design stages, fundamental decisions are taken with regard to energy and environmental performance of the building throughout its service life. In these stages, more detailed and accurate energy analyses can be performed. Spaces are divided into zones with similar function that characterizes energy loads of the zone. However, while energy efficiency is one of the most critical factors that have to be taken into account, it is also very important to consider other factors in parallel such as indoor air quality, occupant health and comfort and other environmental factors that influence energy consumption.

Therefore, in performing energy studies to optimize the zone layout, construction, materials and building systems for energy efficiency, multi semi-stochastic analyses need to be carried out. To facilitate the process, pre-programmed solutions (or eeTemplates) for climate and zone loads need to be prepared to be able to model the building effectively.

Refurbishment and retrofitting of existing buildings and facilities

Buildings and facilities in need of refurbishment and retrofitting for energy efficiency and CO_2 emission reduction constitute the large majority of the existing building stock, many of which were built pre-dating any requirements for insulation to energy losses of the building envelope. In this context, the ISES Virtual Energy Lab foresees several scenarios for energy efficiency analyses in the operation phase of buildings and facilities:

- Optimization and configuration of building components and systems under different usage and climate scenarios
- Design and engineering of replacement products and systems into existing buildings and facilities where situations are both varied and non-optimal
- Design for refurbishment selecting optimal replacement products and analysing their properties.

In all scenarios, the adequate consideration of occupancy and the related consumption patterns are of high importance for the achievement of reliable simulation results. However, currently used occupancy profiles in most software tools are deterministic. They fail to capture the stochastic variations in actual building occupancy.

Stochastic occupancy profiles

In the research community, several stochastic approaches have been examined in the last years to model occupancy profiles including techniques like smoothing, regression and curve fitting, time-series analyses, artificial neural networks and principal component analysis (cf. Page et al. 2008; Widén & Wäckelgård, 2010; Wong et al. 2010; Zhun et al. 2011). A pioneering attempt to develop a stochastic occupancy model has been conducted by Wang et al. (2005). They examined the statistical properties of occupancy and vacancy in single person offices of a large office building by developing a probabilistic model to predict and simulate occupancy (see Figure 11). In this model, vacancy and occupancy intervals are considered separately. An exponential distribution was suggested to model vacancy intervals. This model was not validated for occupied intervals and a time-varying model was suggested instead. However, some intervals still did not pass the goodness of fit test.

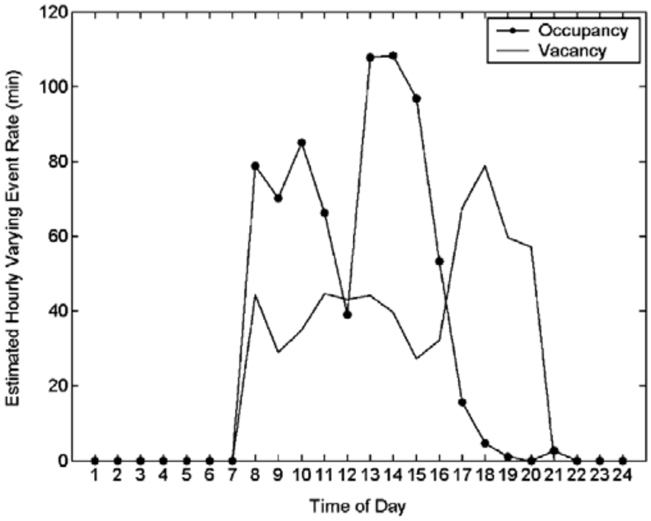

Figure 11: Estimated hourly varying occupancy and vacancy rate (variation among different offices)

Overall, it can be summarised that while many research efforts have been undertaken to include more accurate stochastic analyses in building energy performance assessment, practice ripeness is still barely reached. Over the years, the direction of research has shifted, replacing old approaches with newer and more efficient ones. Apparently due to their limited success, a number of old approaches have been outdated, including methods like state space and Kalman filter modelling or on-line load forecasting. However, the rapidly increasing power of computers and the possibility to use cloud computing is making it possible to apply more complicated solution techniques. There is a clear trend towards new, more sophisticated techniques. There is also a clear move towards hybrid methods, which combine two or more advanced techniques.

9. Conclusions

The main objective of ISES is to develop ICT building blocks to integrate, complement and empower existing tools for design and operation management to a Virtual Energy Lab. This will allow simulation, assessment and optimisation of the energy efficiency of built facilities and facility components in variations of real life scenarios before their realisation, acknowledging the stochastic nature of the involved information resources. To enable efficient implementation of the envisaged ISES platform, various aspects of the built facilities and their environment have to be studied and evaluated against this and other ISES objectives. This report looked into the most important and relevant aspects, discussing the state-of-the-art and the gaps with regard to ISES of:

(1) Various needed information resources for adequate and reliable building energy and CO_2 performance assessment, and

(2) Software methods and tools used in research and in industry practice.

The first included weather and climate data, user behaviour, user comfort, building systems, elements and materials, as well as libraries for digital specification of product components. The second included an overview of building energy tools available on the market, as well as specific considerations with regard to simulation tools, CFD analysis tools and stochastic analysis methods and tools to be used in ISES.

In this way, deliverable D1.1 achieves two goals:

(1) Substantiate the scope of the project

(2) Provide guidance for the RTD work packages WP 3-7 that have to deal in detail with many of the issues addressed in this report.

However, although a broad study of all relevant topics has been performed, additional studies will inevitably be necessary on specific issues when development work proceeds.

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Appendix I: Acronyms

AEC	Architecture, Engineering and Construction
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIM	Building Information Modelling
CAD	Computer Aided Design
CFD	Computational fluid dynamics
DHW	Domestic Hot Water
EPBD	Energy Performance of Buildings Directive of the European Union
FM	Facilities Management
GHG	Green House Gases
HESMOS	EU Project No 260088 "ICT Platform for Holistic Energy Efficiency Simulation and Lifecycle Management Of Public Use FacilitieS"
HPC	High Performance Computing
HVAC	Heating, Ventilation, Air Conditioning
ICT	Information and Communication Technology
ID	(unique) Identification
IFC	Industry Foundation Classes
IFD	International Framework for Dictionaries
IPD	Integrated Project Delivery
NIST	The National Institute of Standards and Technology of the USA
nZEB	Nearly Zero Energy Building
OAT	“One at a Time” sensitivity analysis methods
PLIB	Parts Library
RES	Renewable Energy Sources
SHW	Sanitary Hot Water
STEP	STandard for the Exchange of Product Data
TMY	Typical Meteorological Years
TRY	Test Reference Year
WYEC	Weather Year for Energy Calculations
XML	Extensible Mark-up Language
XSD	Extensible Mark-up Language Schema Definition