Development of protocol for sub-metering for ventilation models and verification for shopping centres

Matthias Haase*[1],

1 SINTEF Building and Infrastructure
Høyskoleringen 7b
Trondheim, Norway
**Corresponding author: Matthias.haase@sintef.no*

ABSTRACT

Shopping centres are complex buildings with specific needs. The use that different areas are put to affects energy consumption, whereas the different functional patterns and stakeholder groups influence energy use. They are also associated with specific requirements that make it relevant to consider different types of performance indicators.
The study investigates the energy conservation measures applicable for management, operation and use of shopping centres and aims to perform the measurements and verification of the energy savings of shopping centres. Its main focus was to track inefficient use and user implications in complex buildings (shopping centres) with focus on the ventilation. First, the main predictor variables and performance indicators associated with ventilation were identified.
A protocol for sub-metering of ventilation related energy consumption and flows (mainly electricity for fans, but also heating and cooling) was defined as necessary basis in order to be able to track inefficient use and user implications. User profiles were split into sub-categories, owners, tenants (shop owners, differentiating by size and type) and end-users (shopper, with appropriate differentiation) are three minimal differentiations.
Energy can be considered to follow function because energy in the end is used to meet requirements defined by the activities that take place in a shopping centre. In a SC, requirements are diversified by the type of tenants (shops, retail, restaurants, cafes, etc.), by the size of tenants rental space (stalls, retail units, independent anchor stores etc.), or by the type of spaces (common areas, offices, storage etc.). The different activities can be characterized by functional patterns for various groups; – opening hours for customers will differ from operational hours for technical services and lighting. Facility operation has to meet the requirements of staff before the shopping centre opens to the public. In shopping centres, many tasks are performed outside of opening hours which require maintaining health and safety for the workers. Examples are cleaning, sanitation, loading and re-stocking of goods. In relation to this, the ratio of full operation of HVAC and lighting vs. opening hours or service hours is one index that could be used as a performance indicator.
The proposed method provides a solid basis for validation and thus performance based economic models that were introduced in order to be able to quantify cost-effective refurbishment investments of ventilation systems and strategies. The results of key performance indicators provided valuable input in the decision making process for deep retrofitting plans. Different proposals for visualization of results (feedback to managers, tenants, customers) were investigated and are discussed.

KEYWORDS

Ventilation in renovated buildings; Controls and user interaction; Innovative ventilation concepts and combined systems;

1 INTRODUCTION

In the re-cast of the Energy Performance of Buildings Directive (EPBD) adopted in May 2010, a benchmarking mechanism for national energy performance requirements was introduced. The EPBD recast required the Commission to establish a comparative methodology by 30 June, 2011. Ecofys conducted a study in 2011 for European Council for an Energy Efficient Economy (eceee) to determine cost-optimal levels to be used by Member States for comparing and setting these requirements (B oermans et al. 2011). The report aimed to contribute to the ongoing discussion in Europe around the details of such a methodology by describing possible details on how to calculate cost optimal levels and pointing towards important factors and effects. This report gives suggestions regarding the implementation of the EU directive 2010/31/EU and disseminates the acquired information and knowledge. The revised Energy Performance in Buildings Directive (EPBD) 2010/31/EU calls for a calculation of the cost optimal energy standards and renovation standards. Cost optimal calculations can often be too short-sighted to deal with the urgent need for societal answers to the climate change challenges and can risk underestimating the potential for energy renovations in the building sector. The calculation should be informed by a long term cost effective figure of reaching a certain energy efficiency target which sufficiently contributes to mitigating climate change (EEB, 2010). Life-cycle costing based on net present value (NPV) provides a sound basis for the development of a common methodology for calculating cost-optimal levels of renovation.

Shopping centres are not interchangeable with other kinds of complex buildings, such as office blocks, hospitals or schools. The character of shopping centres, form, function, usage, and users has implications for energy use. To support the understanding of what causes the main inefficiencies in energy usage and how to develop the best solutions sets, a definition of shopping centres was developed, based on existing literature.

The definition chosen in this study describes a shopping centre as "*a formation of one or more retail buildings comprising units and 'communal' areas which are planned and managed as a single entity related in its location, size and type of shops to the trade area that it serves*" (Bointner et al. 2015).

The definition gives an indication of the main form and function in shopping centres. In addition, location, type of development, the size and the GLA, the type of anchor stores and the trip purpose are all aspects that have been used to indicate the needs that a shopping centre serves within social and physical context, these are presented in Table 1. Climate and regional differences have implications for retrofitting practice and the definition and supporting table present climatic and regional differences and are registered in the description of ten representative reference buildings (Bointner et al. 2015).

In general, the shopping centre industry is used to key performance indicators (KPIs). Example of KPI for a Shopping centre real estate company are: Total property return, Occupancy, Like-for-like, NRI (net rental income) and Growth in EPS (earnings per share). This work will identify the main predictor variables and performance indicators found in shopping centres in a context with user and occupant expectations and requirements. Form follows function to a large degree in shopping centres. However, the needs of retail activity and the requirements associated with the different stakeholders and their typical functional patterns actively influence shopping centre architecture and energy consumption (Haase et al. 2015; Woods et al. 2015).

2 METHOD

The paper develops performance indicators based on the technical functionality of shopping centre architecture, for example flexibility and universal design, in short meeting user needs. Subsequently, predictor variables and performance indicators associated with several aspects were examined.
The IPMVP Volume III focuses on energy savings in new constructions where Volume I mainly refers to retrofit constructions. The fundamental difference between M&V in new and retrofit construction is related to the baseline. The baseline in a retrofit project is usually the performance of the building or system prior to modification. This baseline physically exists and can therefore be measured and monitored before the changes are implemented. In new construction the baseline is usually strictly hypothetical; it does not physically exists, and therefore cannot be measured or monitored. A new construction baseline can be defined or characterized by code or regulations, common practice, or even the documented performance of similar constructed buildings.
Energy codes and standards can provide a convenient, clearly defined, and consistent baseline in order to ensure appropriateness. Whole building energy simulation tools in particular require high level of design detail for proper analytical rigor, requiring a fairly well-developed design of the building. M&V requires baselines that are consistent and repeatable, or that can at least be readily adjusted to allow performance comparisons on a broader scale.
An accurate determination of energy savings is a key condition for long term success of energy management projects. Energy savings are determined by comparing measured energy use before and after implementation of an energy saving measurements.
To perform these kinds of analysis, it is necessary to:
Identify the market segments and the segmentation of the current energy performance requirements (different requirements for different building types) where applicable; define and select a sufficient number of reference buildings that are characterised by their functionality, characteristics and regional conditions, including indoor and outdoor climate conditions; specify packages of energy saving- energy efficiency- and energy supply measures to be assessed; assess the corresponding energy-related investment costs, energy costs and other running costs of relevant packages applied to the selected reference buildings; use, when appropriate, the established reference buildings and relevant packages to identify, using the same methodology, cost-optimal energy performance requirements for building elements and technical building systems.

3 RESULTS

The results are divided into architectural, energy flows and protocol issues, discussed in the following sub-sections.

3.1 Architecture, typology and layout of shopping centres

Architecture encompasses technology, functionality and aesthetics. In this section, architectural form has been considered in context with user and occupant expectations and requirements to build a basis for energy performance indicators that relates to shopping centre form, layout, users requirements and cultural context. There are different types of shopping centres (see **Error! Reference source not found.**) and there is a typology associated with the usage that different areas in shopping centres are put to, functional patterns and stakeholder groups are associated with the areas. The different shopping centre types and typologies may vary according to for example size and use, for example it may be expected that speciality centres will have smaller circulation areas and less storage space than regional centres, and some centres do not have restaurants, staff rooms or atriums [2].

Table 1: Shopping Centre typology [2].

Location	Type of development	Size	GLA [m²]	Anchor store	Trip purpose
Town Centre Shopping/ urban	Neighbourhood centre/ community centre	Small shopping centres	5,000 – 19,999 m^2	Supermarket or hypermarket	Convenience shopping
	Speciality centre (market halls, historical buildings, other)		Usually 5,000 m^2 and above	Traditional markets, tourist shops	Leisure, convenience shopping
Out-of-Town Shopping/ suburban	Retail Park and Factory Outlets		5,000 – 30,000 m^2	None	Household shopping, Comparison shopping, leisure
	Regional centre	Medium/ large shopping centres	20,000 – 79,999 m^2	One or more department stores	Comparison shopping
	Super-regional centre	Very large shopping centres	80,000 m^2 and above	Several department stores, entertainment centres	Comparison shopping, leisure

Table 2: Typical Areas in Shopping Centres [2].

Typology	Main usage				Location			
					Common areas	**Shop/ retail areas**	**Behind the Scenes**	**Outdoors**
Common Areas	Circulation	Main horizontal circulation	Vertical circulation	Emergency exits	Main usage areas	Within retail units and stalls	None	Benches paths, play areas and other
	Entrance	Main entrance	Side entrance	From car park				
	Sanitary	Toilets	Child care					
	Parking	Entrance	Circulation	Parking				
Restaurants/ cafes/ Food courts	Entrance	Seating	Service	Food preparation	Atrium location	Food serving in-store and restaurants	Kitchens, prep, storage	Pavement cafes
Shops/ Retail/ Other	Entrance	Sales	Service	Staff rooms / storage	Atrium, corridors	Main retail areas	Storage, staff rooms	Temporary/ permanent stalls
Behind the Scenes	Entrance	Trolleys	Trucks		None	Storage, staff rooms and waste areas in some units	Main usage areas	Delivery waste storage
	Storage	Services	Waste					
	Technical rooms	Pathway	Shafts	Sanitary				
	Circulation	Horizontal circulation	Vertical circulation	Emergency exits				
Outdoors	Restaurants/ cafes	Entrance	Seating	Service	Benches, paths, play areas and other	Temporary or permanent retail units, or stalls	Delivery and waste storage	Main usage areas
	Parking	Circulation	Parking lot	Service				
	Leisure	Resting/ Recreation	Seating	Other				

	Delivery area	Containers

However, there are certain areas that may be considered standard for all shopping centres. Table 2 describes the five main areas in shopping centres, their usage and different locations within a centre and shows an overlap in usage, for example not all retail takes place in clearly defined retail units; some take place in common areas in temporary or permanent units. Restaurants, food courts and cafes may be found within retail units and on occasion stores may be found in restaurants and cafes. In addition, centres that offer leisure activities, or specialised functions like conference facilities, are typologies not covered in this overview. Typical examples which impose other usages include cinemas, bowling alleys, or swimming complexes. Hotels or apartments may also be located within shopping centres. For these typologies additional performance indicators apply which are not covered.
Table 2 offers insight in the broad range of activities which take place in shopping centres, giving customer satisfaction requires a broad range of services from shops, toilets and deliveries, to technical rooms, child minders, cafes and car parks. The range of activity requires a complex and flexible physical structure, one that allows for, amongst other things, changing retail, demographic and technical needs.

3.2 Energy use and flows in shopping centres

Shopping centres are complex buildings with specific needs. The use that different areas are put to affects energy consumption, whereas the different functional patterns and stakeholder groups influence energy use. They are also associated with specific requirements that make it relevant to consider different types of performance indicators.

In the scope of this analysis both ventilation indicators and requirements with a direct or an indirect effect on energy consumption in shopping centres are identified. When defining the relevance of performance indicators; legal requirements (i.e. for work environment), ownership or authority over parts of the centre, and cultural context also come into play.
As a result of the underlining complexity of performance requirements in SC, it may also be useful to distinguish between causes of energy use within a functional sub-division, meaning energy divided by the functions which it is used (by end use or supply system), and organizational sub-divisions of energy use distinguished by who pays for the energy and thus is related to billing practice, tenant agreements, and contracts with energy supply carrier companies.
The first three are mainly linked to the demand side and indicators that represent the requirements that can be found in norms, standards and the like. While different stakeholder groups, organisation and contextual aspects like climate and energy availability, also define the relevance of performance indicators, and suggest which priorities should be given when performance requirements are in conflict. The latter interest groups and contextual aspects also form billing practices, sub-metering and indicators for dividing the operational energy costs.

3.3 Protocol for sub-metering

Figure 1 illustrates a functional sub division of energy end use within a shopping centre. Starting with the energy supply and the technical services in place, the energy use associated with heating, cooling and electricity are structured by end use. The diagram is easiest to comprehend for centralized HVAC systems, but in principle the structure is the same for all installations localized in tenants' retail space. In a typical shopping centre there will exist several heating, or cooling loops and many electrical subdivisions (distribution boards) on top of various end uses of energy.

The illustrated processes are usually in the control of facility managers and technical staff. A multitude of performance indicators can be related to this structure. Some performance indicators are important in the design and commissioning of the systems, other are of use in the day-to-day running of the centre. Reading the diagram from left to right, the potential of increasing energy efficiency lies both in production, distribution and end-use.

Energy can be considered to follow function because energy in the end is used to meet requirements defined by the activities that take place in a shopping centre. In a SC, requirements are diversified by the type of tenants (shops, retail, restaurants, cafes, etc.), by the size of tenants rental space (stalls, retail units, independent anchor stores etc.), or by the type of spaces (common areas, offices, storage etc.). The different activities can be characterized by functional patterns for various groups; – opening hours for customers will differ from operational hours for technical services and lighting. Facility operation has to meet the requirements of staff before the shopping centre opens to the public. In shopping centres many tasks are performed outside of opening hours which require maintaining health and safety for the workers. Examples are cleaning, sanitation, loading and re-stocking of goods. In relation to this, the ratio of full operation of HVAC and lighting vs. opening hours or service hours is one index that could be used as a performance indicator.

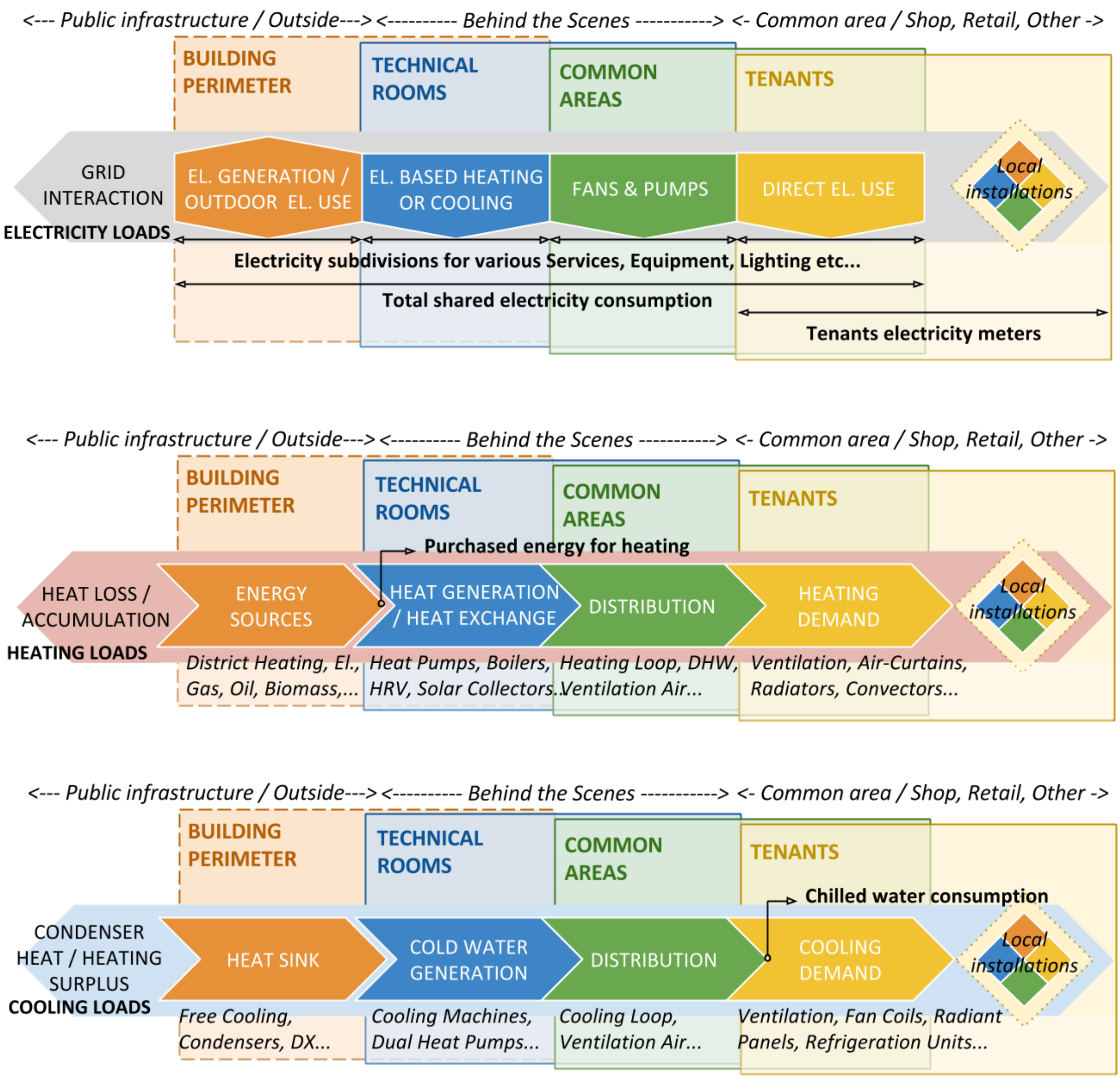

Figure 1 – Sub division of energy flows (electricity and thermal) associated with different end uses.

Therefore, six performance concepts are identified which form the structure of the next sections, all with contextual relevance to energy use and supply of energy in SC:
Concepts with functional element sub-division:

- Energy follows function
- Energy follows form
- Energy follows user needs

Concepts with organizational element sub-division:

- Energy follows stakeholders
- Energy follows organization
- Energy follows availability

The different concepts are explained in more detail in Haase and Skeie (2015).

3.4 The role of key performance indicators

In typical shopping centres the retail units are often heated, cooled and ventilated separately from the common areas. The same retail units are often also connected to the central spaces by large open doorways through which air, odours, light, and noise exchanges occur, effectively linking the different spaces. This limits the accuracy of heating, cooling and ventilation assessments. Key performance indicators based on floor area can be used, but it is challenging to meet performance requirements, to keep within accepted limits of comfort and meet retailer needs in such an open indoor environment, where different spaces inside the shopping centre are effectively linked.

Comfort needs, however, are also socially constructed. In the design process, operation, meetings between tenant associations and management, labour meetings performance indicators can be important quantitative statements to meet user needs with regard to comfort and ensure high energy performance. Also building code requirements related to work space specifications can have an influence on the design choices. Access to daylight for shop workers e.g. is of importance for those shops that do not have direct access to daylight due to its location within the shopping centre.

Organisational forms can be observed in Real estate companies, property companies, management companies, facilities companies (outsourcing or within the same owner company) and tenant associations. Contracts between those organisations and the indicators used in those agreements are often based on KPIs which offers potential for introducing energy intensity related KPIs.

Nowadays, it is a challenge to transform the current energy system into modular power generation in order to improve the quality and the reliability of the electricity supply. The renewable energies and efficient solutions can overcome the oversizing problem of the electrical infrastructure for meeting the energy demand peaks as well as the energy transmission losses. It is important to operate with KPIs that can help to distribute energy production within the centre. However, the incorporation of renewable system in shopping centres must take into account that some problems in the supply can appear given its dependence of the climate conditions as well as the affections in the quality of the grid since they can generate frequency and voltage fluctuations and outages. Furthermore, any interaction in the grid must consider the grid capacity for admit new compounds.

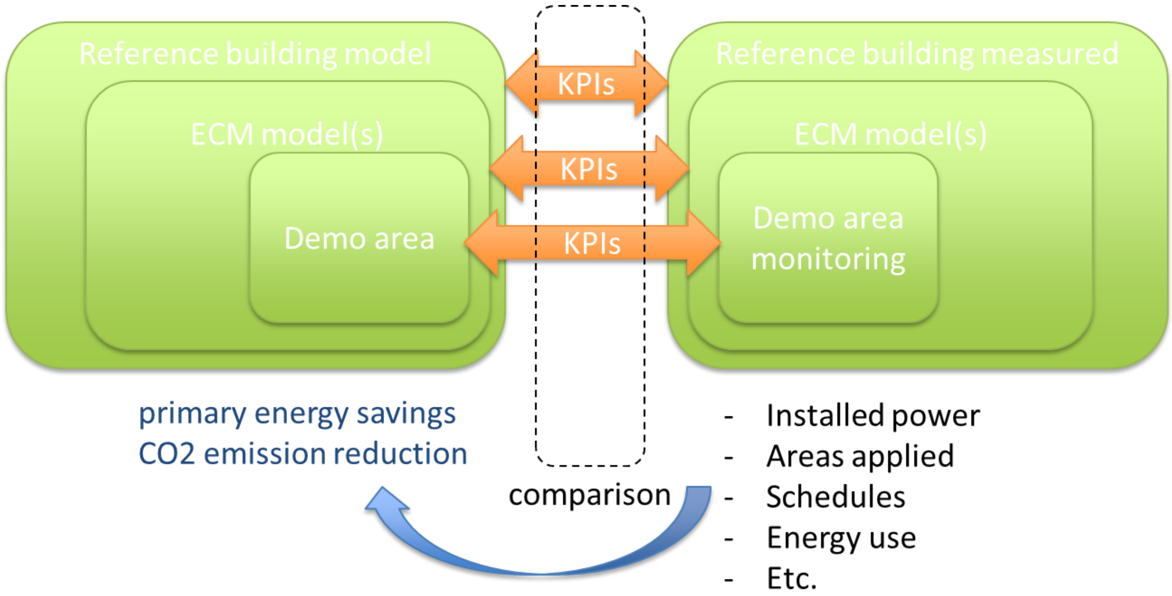

Figure 2 – Schematic description of procedure

The HVAC (heating, ventilating, and air conditioning) system is responsible for providing the thermal and hygienic needs of a shopping centre. An efficiently designed and operated building and HVAC system reduces the amount of energy needed to control hydrothermal conditions and air flow in a space. In addition to the passive solutions regarding thermal insulation, natural ventilation and solar gain controls there are specific solutions regarding the HVAC system, that promise to lead to energy savings. To reduce the consumption associated with HVAC the focus must be on:

- energy efficient equipment
- energy flux strategy
- equipment control and management.

<u>Energy efficient equipment and components</u>

The current equipment could be replaced with ones with greater efficiencies.
This is especially true when the existing systems are old, inefficient or malfunctioning. Some of the main predictor variables include:

- Efficiency of the heating system (boiler, Heat pumps, Combined heat and power (co- and tri-generation, Biomass boiler or District heating)
- Efficiency of air-conditioning systems (e.g., chillers);
- Efficiency of ventilation system
- Presence and efficiency of heat recovery systems;
- Performance parameters of economisers;
- Efficiency of auxiliary devices

The type of distribution system (radiant floor or ceiling, fan coils or primary air) should be also considered as a predictor variable with special attention to the efficiency of auxiliaries (e.g., fans, motors) and to the correct size of equipment and balance systems.

Energy flux strategy and recovery

The recovery factor of the heat waste recovery system and the performance of free cooling should be considered. Thermal layout is important because it influences which thermal synergies (e.g., thermal cascade) can be exploited. For instance, the existence of interconnections and the supply and return temperatures of the refrigeration and heating/cooling duct are important predictor variables.

Equipment control and management

Building system control and management strategies in shopping centres and retail buildings are crucial to ensure correct operation. The operation should therefore be regulated by a central unit (building management system – BMS) acquiring information from the field and deciding the best strategies to deliver the required conditions for each zone and tenant. Control strategies are very powerful predictor variables (on/off set points, temperature and rate set points etc.)

4 DISCUSSION

The shopping centre market has changed from a fairly homogeneous, mass consumption market to one that is fragmented according to for example taste and lifestyles, reflecting a diverse and changing society. Shopping centre architecture therefore needs to meet needs of consumers who are more sophisticated and demanding. During the rehabilitation process it is important to keep in mind the four main stakeholders groups, namely customers, management, tenants and community. An integrated design process is needed that takes into account the goal to develop future markets where good architecture contributes to low-energy use, attractive trading jobs and meeting spaces, and thereby supporting the activities of all four groups. For Energy conservation measures (ECM) this implies a specific set of procedures in order to be able to implement these concepts in a measurement and verification of demonstration areas:

1. Comparison of key performance indicators (KPIs) in reference building model with measured data (e.g. electricity bill, district heating bill)
2. Definition of KPIs for reference model
3. Deduction of KPIs from reference model for ECM model
4. Deduction of KPIs from ECM model for demonstration area (e.g. installed power, schedules, areas, etc.)
5. Use of new KPIs for demo area
6. Comparison of monitoring KPIs with KPIs in demo area
7. Use of same KPIs in similar areas within the ECM model
8. Comparison of monitoring KPIs with KPIs in ECM model
9. Comparison of KPIs in ECM model with KPIs in reference model
10. Calculation of KPIs (e.g. energy consumption divided into electricity, energy need for heating and cooling, ventilation) for whole shopping centre
11. Calculation of KPIs for whole shopping centre (e.g. primary energy savings, CO2 emission reduction, based on comparison with base case)

5 CONCLUSION

In the scope of this analysis both indicators and requirements with a direct or an indirect effect on energy consumption in shopping centres were identified. When defining the relevance of performance indicators; legal requirements (i.e. for work environment), ownership or authority over parts of the centre, and cultural context also come into play. Six performance concepts were identified which have contextual relevance to energy use and supply of energy in SC. As a result of the underlining complexity of performance requirements in SC, it may also be useful to distinguish between causes of energy use within a functional sub-division, meaning energy divided by the functions which it is used (by end use or supply system), and organizational sub-divisions of energy use distinguished by who pays for the energy and thus is related to billing practice, tenant agreements, and contracts with energy supply carrier companies.

A possible task for the future could be to identify if and how relevant energy performance indicators can be incorporated in contracts, or other forms of agreements between the stakeholders.

6 ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Community Seventh Framework Programme (FP7/2007-2013) under grant agreement n. 608678.

7 REFERENCES

Boermans, T., Bettgenhäuser, K., Hermelink,A. and Schimschar, S. Cost optimal building performance requirements, May 2011 © European Council for an Energy Efficient Economy, Commissioned by eceee with financial support from Eurima and the EuropeanClimate Foundation (ECF), access: http://www.ecofys.com/files/files/cost_optimality-eceeereport.pdf; access date: 24.06.2014

Bointner, R., Toleikyte, A., Woods, R., Atanasiu, B., De Ferrari, A., Farinea, C. and Noris, F. (2014), Deliverable 2.1 report - Shopping malls features in EU-28 + Norway, EU FP7 project CommONEnergy – Reconceptualizing Shopping Malls,

EPBD. 2010. Energy Performance in Buildings Directive 2008/0223, European Commission, Brussels, revised 2010. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF, access date: April 2015

Haase, M., Skeie, K.S., Woods, R., Mellegård, S., Schlanbusch, R.D., Homolka, S., Gantner, J., Schneider, S., Lam-Nang, F., (2015) Deliverable 2.3 report - Typical functional patterns and socio-cultural context, EU FP7 project CommONEnergy – Reconceptualizing Shopping Malls, , access date: April 2015

Haase, M., Antolin, J., Belleri, A., Interactions of retrofitted shopping centres with local energy grids, proceedings IEECB&SD conference (IEECB&SD2016), Frankfurt, Germany, 16-18 March 2016

IPMVP, International Performance Measurement & Verification Protocol - Concepts and Options for Determining Energy and Water Savings, Revised March 2002. DOE/GO-102002-1554, http://www.nrel.gov/docs/fy02osti/31505.pdf, access date: Feb 2017

Woods, R., Mellegård, S., Schlanbusch, R.D., Haase, M., Skeie, K.S., Deferrari, A., Cambronero Vazquez, M.V., Ampenberger, A., Bointner, R. (2015), Deliverable 2.2 report – Shopping mall inefficiencies, EU FP7 project CommONEnergy – Reconceptualizing Shopping Malls, , access date: April 2015