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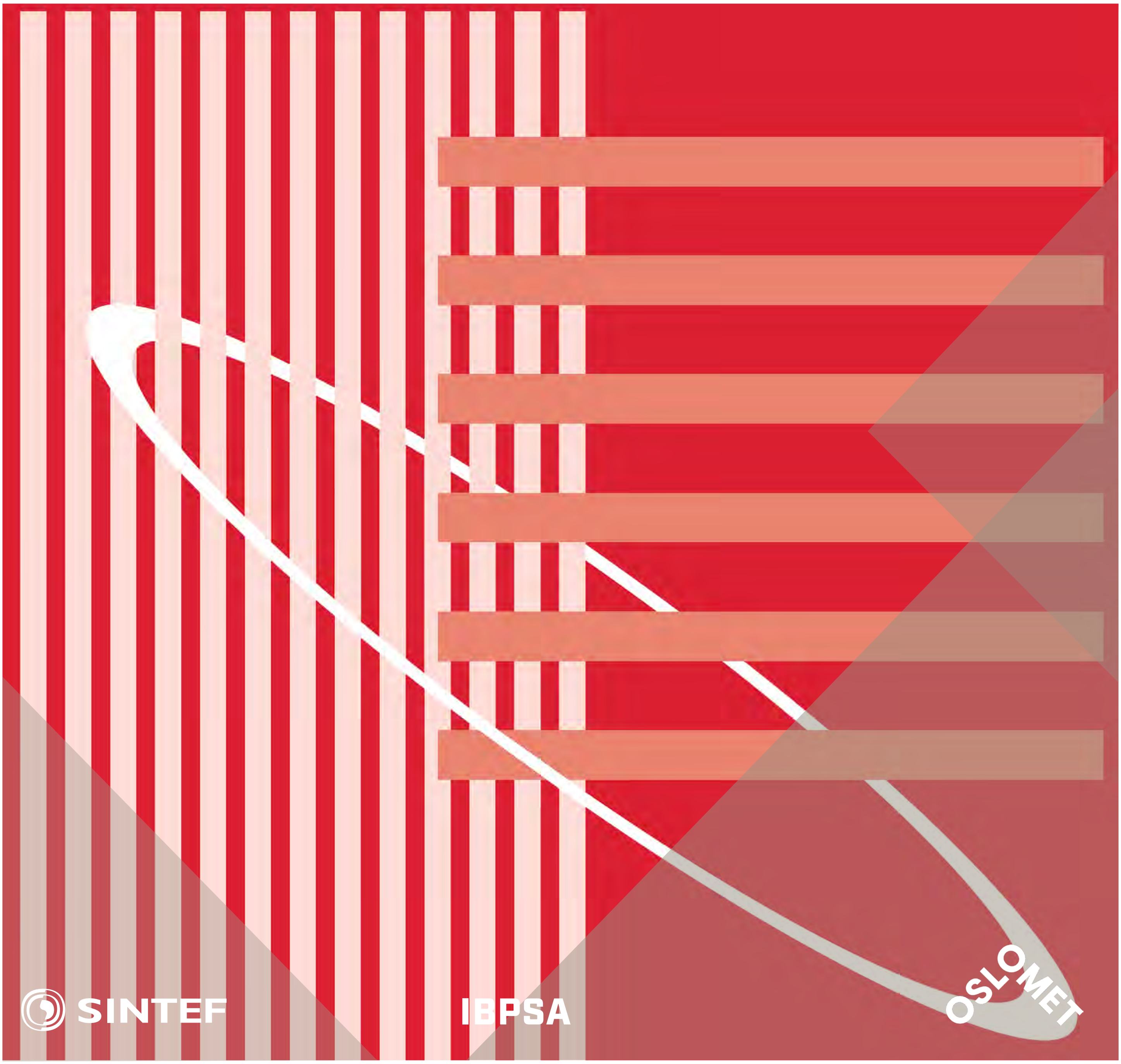

SINTEF Proceedings

Editors:
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Requirements for representative models for comfort and energy simulations in districts

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Abstract

The energy master planning process for districts requires an analysis of different scenarios, which include new construction to different levels of energy efficiency, major renovation of all or some buildings comprising building stock under consideration with Deep Energy Retrofit of these buildings, minor renovations with energy-related scope of work, or demolition of some old buildings. Such analysis requires building energy modeling. In this research work we collected models of representative buildings from several countries and compared them.

Different baselines and constraints were compared for different countries as Australia, Austria, Canada, Denmark, Finland, Germany, Norway, UK and USA and were put into context (cultural and economic) and pattern were developed. In typical districts in city centres the dominant commercial buildings are often heated, cooled, and ventilated. The same retail units are never connected to other buildings or spaces of activities. Still, large open doorways through which air, odours, light, and noise exchanges occur, effectively linking the different spaces, exist. The next step will be to develop a common approach to calibration of building models to existing energy use data available from metering and sub metering.

Introduction

Climate change challenge the ambitious goals that regulators have put in place by setting more and more aggressive building and community energy-related requirements based on the Sustainable Development Goals of the UN. The concept of Energy Master Planning (EMP) can help to initiate a better planning and implementation process to fulfill these goals. In the EU, reaching for the climate gas reduction goals of the Paris Agreement, stakeholders on all geographical and organizational levels from nations, regions, cities and communities are challenged. Following bottom-up approaches for energy planning on the neighborhood level is a promising attempt to reduce energy demand, increase efficiency and lower the carbon footprint in a multi-stakeholder approach.

In the context of the 2012 EU directive (EED 2012), several important measures have been adopted throughout the EU to improve energy efficiency. These include national long-term renovation strategies for the building stock in each EU country, mandatory energy efficiency certificates accompanying the sale and rental of buildings, the preparation of national energy efficiency action plans (NEEAPs) every three years, minimum energy efficiency standards and labelling for a variety of products, as well as obligation schemes for energy companies (to achieve yearly energy savings of 1.5% of annual sales to final consumers). However, Member States have yet to fully implement the Directive and additional support in building capacity and know-how is needed (EPBD 2018). Significant additional energy savings, reduced emissions, and increased energy security can be realized by considering holistic solutions for the heating, cooling and power needs of communities, on neighbourhood and district scale, comprising collections of buildings. As a result, considerable literature has become available including both guidance and assessment tools aimed at EMP at the neighbourhood and district level as e.g. campuses (DOE 2013; Huang et al. 2015; EnergyPlan 2019; BREEAM 2019; LEED 2019). But the existing guidance and tools do not seem to be fully solving the challenges. The energy planning consists in determining the optimal mix of energy sources to satisfy a given energy demand. The major difficulties of this issue lie in its multi scales aspect (temporal and geographical), but also in the necessity to consider the quantitative (economic, technical) but also qualitative (environmental impact, social criterion) criteria (Schiefelbein et al. 2017).

In order to be able to apply principles of a holistic approach to neighborhood and districts, often coined community energy planning in the literature, and to provide the necessary methods and instruments to master planners, decision makers, and stakeholders, it is essential to identify and frame the constraints that bound the options towards an optimized energy master planning solution (Sharp et al. 2020). Existing master planning guidance available indicates that identifying and establishing project goals is a critical first step (Jank, 2017).

In a new initiative of the European Commission, Positive Energy Districts are envisioned as "*are energy-efficient and energy-flexible urban areas or groups of connected buildings which produce net zero greenhouse gas* *emissions and actively manage an annual local or regional surplus production of renewable energy. They require integration of different systems and infrastructures and interaction between buildings, the users and the regional energy, mobility and ICT systems, while securing the energy supply and a good life for all in line with social, economic and environmental sustainability.*" (JPI UE 2020).

In many cities, the necessary legal and strategic frameworks for the realization of PED/PENs are not yet in place. Very often, there is also a lack of a planning culture in city administrations or the personnel resources available might be insufficient. In particular, the transformation of large (brownfield) areas to climate neutral city districts has a big potential for the development of PED/PENs but needs cooperation between administration, industry, and research. Especially in case of heterogeneous ownership structures, cooperative planning processes are indispensable. Far less common in EMP guidance and related literature is information on the identification of constraints that limit energy technology options and how stakeholders influence the decision-making process. Literature in this area mentions options analysis or prioritization, or optimization analysis (EED 2012; Jank, 2017; Fox 2016; Zhivov et al. 2014; Robinson et al. 2009), yet, options analysis or optimization is certainly influenced by project energy-related constraints. Sharp et al. (2020) compared EMP in several countries and analysed these constraints (Sharp et al. 20120). The results show that successful energy master planning is highly dependent on a thorough understanding of framing goals and constraints, both local and regional, and their associated limitations that will dictate the optimum master planning design. Haase and Baer (2020) pointed out that as more and more countries push to improve the efficiency, environmental impact, and the resilience of their buildings and neighbourhoods, the need for early and comprehensive energy master planning on neighbourhood and district level is critically important.

The development of districts requires a distinct understanding of the situation now as well as a vision of the future district to be able develop suitable pathways for this transition. In order to be able to do that a district needs to be modelled that consists of several buildings, sufficiently described so that the future district can actively manage their energy consumption and the energy flow between them and the wider energy system. The energy master planning process requires an analysis of different scenarios, which include new construction to different levels of energy efficiency, major renovation of all or some buildings comprising building stock under consideration with Deep Energy Retrofit of these buildings, minor renovations with energy-related scope of work, or demolition of some old buildings. Such analysis requires building energy modeling. In this research work we developed requirements for representative models of buildings and districts from several countries.

Methods

The paper develops new performance concepts for districts based on the technical functionality of district architecture, and on concepts with functional and organizational element sub-division.

The IPMVP Volume III focuses on energy savings in new constructions, whereas Volume I refers mainly to retrofit constructions. The fundamental difference between M&V in new and retrofit construction is related to the baseline (IPMVP 2002). 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 exist, 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 for buildings can provide a convenient, clearly defined, and consistent baseline to ensure appropriateness. Whole building energy simulation tools require high level of design detail for proper analytical rigor, requiring a well-developed design of each 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.

One of the first steps in energy master planning is to determine the framing constraints.

The imposed constraints are constraints that for the most part is relevant for individual buildings or facilities (e.g. requirements on maximum energy consumption, emissions or requirements on specific indoor climate parameters) but the imposed constraints can also apply to the entire district (e.g. local plans or national energy targets). The energy planner, owner or operator of the district could also choose to impose special voluntary operational constraints that are more restrictive than e.g. legislative constraints, e.g. 100% renewables, possibility for islanding for a certain length of time etc. Several constraints were divided into the following five categories (Sharp et al., 2020):

- Natural Locational Constraints – Resources and threats
- Distribution System & Storage Constraints
- Building and Facility Constraints
- Indoor Environment Constraints
- Building Equipment and District System Constraints

These constraints should ideally be specified so that direct implications for energy use can be deducted.

The natural constraints cover e.g. locational threats and resources. Locational threats deal with all natural threats that influence the possible choices of technologies or solutions and could be e.g. regional or local air quality, extreme temperatures or high winds. Locational resources deal with the availability of energy on-site or nearby. It covers both renewable energy sources for the location, e.g. wind, solar etc. and existing available energy infrastructure, e.g. power lines, gas pipes, district heating etc. Harnessing adequate amounts of energy from renewable energy sources usually requires quite a lot of space, e.g. it may be difficult to harness solar energy in big cities where roof or land area is not available and it may be difficult to utilize wind turbines since they require open spaces to be efficient. Therefore, the spatial possibilities are also part of the natural constraints. The constraints analysis shows the link between single building requirements and specific goals that a district might have set. In net zero energy districts e.g. the resources on the one hand have to meet the buildings energy use on the other hand. A miss-match is an important performance indicator.

Results

Architecture encompasses technology, functionality, and aesthetics in districts. However, architectural form has to be considered in context with functions, user and occupant expectations and requirements to build a basis for energy performance indicators that relates to the layout of the buildings in the district, users requirements and cultural context. There are different types of buildings (see Table 1) but there is not a stringent typology associated with the usage that different areas in districts are put to, functional patterns and stakeholder groups are associated with the areas. The different building types and typologies may vary according to for example location, size and use, for example it may be expected that districts in city centres will have smaller circulation areas and larger public spaces than residential districts, and some districts do not have restaurants, shops or parking areas.

However, there are certain areas within a district that may be considered standard for all districts. Table 1 describes the five main areas in districts, their usage and different locations within a centre and shows an overlap in usage, for example not all commercial activities 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, city centre districts that offer leisure activities, or specialised functions like meeting or 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 a district. For these typologies, additional performance indicators may apply.

Table 1: Five main functions in districts (plus outdoor spaces)

Function	Description	Building types
Residence		Single family Multy-family Apartment blocks
Commercial	Commercial activities	Office Shopping mall Shop Restaurants
Service	Public services	Schools Kindergarten Departmental Office
Cultural	Cultural activities	Museum Gallery Theatres Concert hall Sports facilities
Industry	Production sites	Office factory
Common areas	Public and private spaces Squares Parks Outdoor space	

Table 2 summarizes the differences in characteristics in Building Energy Use Limits by Country. There is a large variety of energy use limit characteristics in different countries. While some report site/end energy, others report primary energy, it is important to make efforts to streamline reporting matrices and calculation methods

Table 1. Typical end energy demand values for non-residential buildings according to EnEV 2012 (average values) in Germany and total net energy requrirements according to TEK17 [20] in Norway

Building usage	ENEV 2012		TEK17
	Heating / DHH	Electricity	Total net energy demand
	kWh/(m²a)	kWh/(m²a)	kWh/(m²a)
Middle class hotel	85	55	170
Restaurant	205	95	180
Cinema	55	80	180
Gyms	120	35	145
Multipurpose Convention Centers	240	40	180
Swimming pool (indoor)	385	105	145
Non-food commerce small	135	45	180
Shopping malls	70	75	180
Hospitals	175	80	225 (265)*
Office building (heating only)	105	35	115
Office building (heating/cooling)	110	85	115
Cultural building			130
Light industry/workshop			140 (160)*
School building			110
University/university college			125
Nursing home			195 (230)*
Kindergarten			135

* Numbers in parentheses are buildings with reduced possibility for heat recovery from ventilation

Table 2: Difference in Building Energy Use Limits by Country

Characteristics of building energy use limit	Country						
	Austria	Denmark	Finland	Norway	US	UK*	Germany
Energy use limit	Max heating site/end	Max total site/end	Max total primary	Max total net (site/end or primary?)	Max total site/end or primary	Max fossil, electric, total site	Total site & primary - reference bldg
Format of energy use limit	One number & simple equation	Simple equation	Numbers	Numbers	Numbers	Numbers	Simulation-reference bldg
Limit units (per year)	kWh/m2	kwh/m2 heated	kWh/m2	kwh/m2 heated	kBtu/ft2	kWh/m2	TBD
Limit required?	Required	Required	Required	Required	Voluntary	Voluntary	Required
How limit addresses building types	One equation for all	Two equations - 1. dwellings 2. commercial	Values for 7 types. No limit-hospitals/ others	Values for 12 types.	Values for 53 types.	Values for 10 types.	Reference building varies for every building
How limit varies within a building type	Varies - equation using volume/surface ratio	Varies - equation using building heated floor area	No variance	No variance	No variance	1-4 categories	
How limit addresses different climates	No variance	No variance	No variance	No variance	Numbers for 16 climates.	No variance	
How limit addresses different operations (e.g., operating hrs)	No variance	No variance	No variance	No variance	Multipliers for shifts.	Multipliers for shifts.	

Energy use and flows in complex districts

Complex districts consist of buildings and outdoor spaces with specific needs. The use that different buildings and 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 districts are identified. When defining the relevance of performance indicators; legal requirements (i.e. for work environment), ownership or authority over parts of the district (single buildings or a complex of buildings), and cultural context also come into play.

As a result of the underlining complexity of performance requirements in districts, 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, building owner and tenant agreements, and contracts with energy supply carrier companies.

The first three divisions 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.

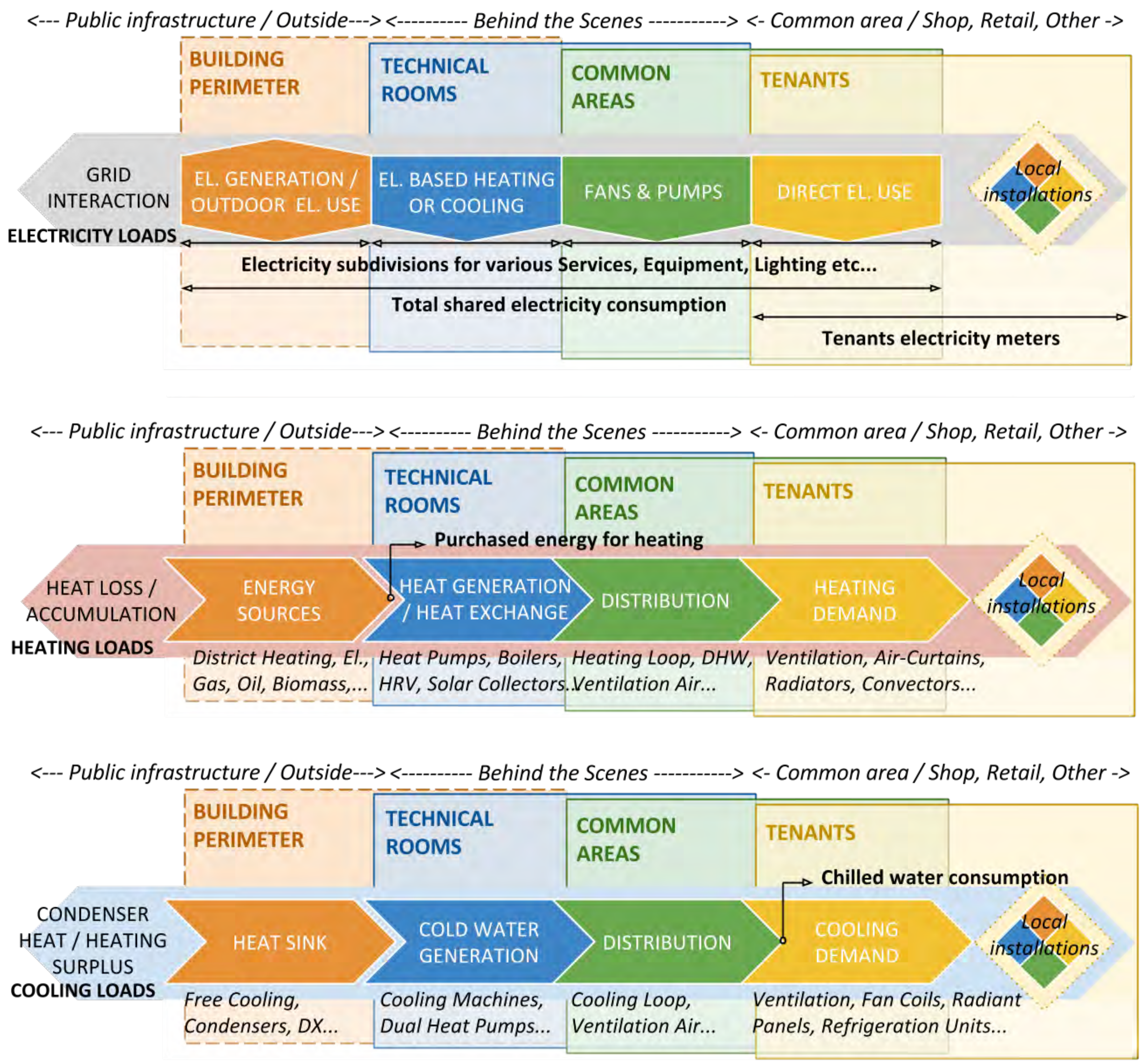

Figure 1 – Sub-division of energy flows (electricity and thermal) associated with different end uses.

Protocol for sub-metering

Figure 1 illustrates a functional sub-division of energy end use within a district. 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 systems, but in principle the structure is the same for all installations localized in private and public space. In a typical district, there will exist several heating, or cooling loops and many electrical subdivisions (distribution boards) on top of various end uses of energy. The different concepts are explained in more detail in Haase et al. (2015).

The illustrated processes are usually in the control of facility managers and technical staff of each building. Multi-owned districts often lack professional skilled workers. A multitude of performance indicators can be related to this structure. Some performance indicators are important in the design and commissioning of the systems, others are of use in the day-to-day running of the buildings. Reading the diagram from left to right, the potential of increasing energy efficiency lies both in production, distribution and end-use. Building performance simulation tools should take these into account and visualize them for their users.

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 district. In each district, requirements are diversified by the type of activities/functions (residences, commercial (shops, retail), service (schools, restaurants, cafes, etc.), by the sizes of tenants rental spaces, or by the type of spaces (public areas, offices, parking etc.). The different activities can be characterized by functional patterns for various groups; – opening hours for commercial buildings will differ from operational hours for technical services and lighting. Facility operation has to meet the requirements of staff in commercial and cultural or service buildings before they open to the public. In districts, many tasks are performed outside of opening hours which require maintaining health and safety for the workers. Examples are maintenance and cleaning, sanitation and supply infrastructures, mobility and transport. 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.

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 districts:

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

Discussion

In typical districts in city centres the dominant commercial buildings are often heated, cooled, and ventilated. The same retail units are never connected to other buildings or spaces of activities. Still, large open doorways through which air, odours, light, and noise exchanges occur, effectively linking the different spaces, exist. 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 commercial part of a district are effectively linked.

In the transformation process, operation, meetings between tenant associations and management, labour meetings performance indicators can be important quantitative statements to meet user needs regarding comfort and ensure high energy performance. Also building code requirements related to work-space specifications can have an influence on the design and transformation choices (Boermans et al. 2011). An active cooperation with various stakeholders is essential (Haase and Baer 2020). Access to daylight for workers e.g. is of importance for those buildings that do not have direct access to sufficient daylight due to its location within the district.

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 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 district. However, the incorporation of renewable system in districts 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.

Individual building computer-based energy models that are currently available for general use buildings are not sufficient and the need for a clear reporting structure of key performance indicators became evident. They need to be further customized to function as archetypes to predict energy use in districts and adapted to different climate conditions and energy use requirements. To be used for community planning, all prototype models must be fully parametrized for common modeling inputs in order to be able to build in energy efficiency measures.

The next step will be to develop a common approach to calibration of building models to existing energy use data available from metering and sub metering.

However, it is important to highlight that districts are not the simple sum about its buildings, but the set of all parties that make up the urban system such as buildings, mobility, public lighting, open spaces, water and waste management. Ideally, Energy Master planning of districts must be programmed according to a long-term vision together with all transformation measures and their possibly assessed impacts. In that sense, the energy policies can lead to various positive social, environmental, and economic impacts that can bring an added value for the choice of the alternative strategies. To facilitate the transformation process, the benefits that can be generated by the requalification measures and the different impacts that they can provide on the whole community must be considered (Ürge-Vorsatz et al. 2014; Bisello and Vettorato 2018).

Conclusion

The HVAC (heating, ventilating, and air conditioning) system is responsible for providing the thermal and hygienic needs of a building in a district. 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.

Energy efficient equipment and components

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 districts and group of buildings are crucial to ensure correct operation. The operation should therefore be regulated by a central unit (district management system – DMS) 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.). In the scope of this analysis both indicators and requirements with a direct or an indirect effect on energy consumption in districts were identified. When defining the relevance of performance indicators; legal requirements (i.e. for work environment), ownership or authority over parts of the district, and cultural context also come into play. Six performance concepts were identified which have contextual relevance to energy use and supply of energy in districts. As a result of the underlining complexity of performance requirements in districts, 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 is to identify if and how relevant energy performance indicators can be incorporated in contracts, or other forms of agreements between the stakeholders. Also, other energy use from sectors like mobility should be started to include. This could result in multiple benefits which could help to enhance the district master planning.

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