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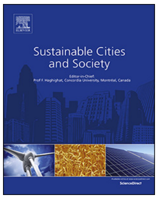

Energy storage key performance indicators for building application

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ABSTRACT

Energy storages are key elements for the design and operation of nearly-zero-energy buildings. They are necessary to properly manage the intermittency of energy supply and demand and for the efficient use of renewable energy sources. Several storage technologies (electrochemical, thermal, mechanical, etc.) to be applied at building scale are already available on the market or they are in the final stages of research and development. These technologies have heterogeneous features and performances; therefore, it is necessary to develop a procedure to compare different alternatives in order to carry out a techno-economical assessment. This paper summarizes the current status of energy storage systems at building scale and proposes a set of simplified Key Performance Indicators (KPIs), specifically identified to simplify the comparison of energy storage systems in the decision-making/designing phase and the assessment of technical solutions in the operational phase. The defined KPIs are finally applied to 10 case studies analyzed within the International Energy Agency Energy Conservation Through Energy Storage (IEA ECES) Annex 31 “Energy Storage with Energy Efficient Buildings and Districts”.

1. Introduction

The extensive efforts aimed at decreasing the use of fossil fuels, improving energy efficiency, and increasing renewable power generation – especially in developed countries – succeeded in reducing energy-related CO_2 emissions. According to the Renewables 2017 Global Status Report (REN21, 2017), for the third consecutive year, CO_2 emissions nearly flattened, rising by 0.2% in 2016. However, it should be pointed out that in 2015 the average concentration of CO_2 in the atmosphere was 399 ppm, which was 40% higher than the pre-industrial level (IEA, 2016) and the resulting climate change are affecting the world at an increasing pace. Meanwhile, the share of fossil fuels in final energy consumption remained dominant with a quota of 78.4%, while the contribution of all renewable resources was 19.3% in 2015. Among the renewable resources’ percentage, only 10.2% corresponds to new technologies, and the rest was the contribution of traditional biomass. Modern renewable energy resources, according to their use, can be broken into: 4.2% for renewable heat (biomass, geothermal, solar heat), 5.2% for renewable power (hydropower, wind, solar, biomass, geothermal) and 0.8% for biofuels used in transportation (Adib et al., 2016). This study indicates that the renewable energy sources are not utilized effectively in order to replace the fossil fuels.

The general dependence on fossil fuel can also be observed in the building sector, which consumes about 40% of the global energy resources (Aste, Adhikari, Compostella, & Del Pero, 2013). These statistics confirm the need for higher share of renewables in all sectors, especially in building sector. The strong political support of the last decades, together with the introduction of innovative technologies, reduced the price of renewable technologies (in particular for solar and wind) – in turn revolutionizing the renewable power market. In addition, the imposition of the nearly-zero energy standard for new constructions and buildings undergoing major renovation strongly fosters the integration of renewables (with particular reference to the PV technology) in the building sector (European Union, 2010).

There are challenges that accompany the opportunity to have more renewable energy penetration to meet the demanding targets. In fact, mismatch in supply and demand profiles of buildings, coupled with market-controlled cost profiles, lead to a complex energy system. For instance, the current instantaneous self-consumption of PV electricity in the residential sector is, on average, quite low (around 30%) (European Commission, 2015), due to the disparity between the energy consumption profile and the on-site renewable generation curve. Therefore, a considerable amount of energy/power has to be fed to or drawn from the grid.

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Nomenclature

ESS	Energy storage system
EPBD	Energy performance of buildings directive
EER	Energy efficiency ratio
nZEB	Nearly-zero-energy building
DoD	Depth of discharge
RES	Renewable energy sources
DHW	Domestic hot water
PCM	Phase change materials
CAES	Compressed air energy storage
C_t	Energy storage total capacity [kWh]
$C_{us\text{-}max}$	Energy storage maximum useful capacity [kWh]
C_r	Recharging energy [kWh]
CGE	Specific generation/purchasing cost of the energy sent to the storage [€/kWh]
CO_t	Total turn-key costs of the ESS [€]
CO_{OM}	O&M costs of the ESS [€]
CO_{DC}	Decommissioning cost of the ESS [€]
CO_{sav}	Expected cost saving generated by the use of the ESS [€]
$D_{c\text{-}min}$	Fastest charge duration [h]
$D_{d\text{-}min}$	Fastest discharge duration [h]
ED_t	Total energy demand for a certain purpose (heating, cooling, DHW) [kWh]
$ES_{r\text{-}D}$	Stored energy factor on the total energy demand [%]
$ES_{r\text{-}RES}$	Stored energy factor on the renewable energy production [%]
E_{sav}	Expected energy saving generated by the use of the ESS [kWh]
G_{RES}	Energy generated by RES in the building or group of buildings [kWh]
NC_t	Total number of equivalent working cycles during the expected lifetime of the ESS
NC_{RP}	Number of the measured/expected equivalent working cycles during the reference period
$P_{c\text{-}max}$	Maximum charging power [kW]
$P_{d\text{-}max}$	Maximum discharging power [kW]
SC_s	Specific cost of the ESS [€/kWh]
SC_{se}	Specific cost of the stored energy [€/kWh]
SD	Maximum self-discharge rate [%]
$SD_{average}$	Average self-discharge for each working cycle [%]
SMES	Supermagnetic energy storage
V_t	Volume of the ESS [m^3]
VD_t	Volume density of energy of the ESS [kWh/m^3]
W_t	Weight of the ESS [kg]
WD_t	Mass density of energy of the ESS [kWh/kg]
η_c	Efficiency of the charging phase [%]
η_d	Efficiency of the discharging phase [%]
$\eta_{c/d}$	Total charging/discharging efficiency or roundtrip efficiency [%]

Energy can be stored and retrieved at a later time, different place and maybe at different temperature levels, to bridge the gap between energy supply and demand. This is possible based on the thermodynamic laws of energy transformations between different energy forms, such as thermal, mechanical, chemical, and magnetic. The transformations and corresponding energy storage systems (ESS) can be classified according to the scheme shown in Fig. 1 (Dincer and Rosen, 2002).

There are several possibilities of integrating the above-mentioned energy storage technologies in buildings, according to the following main typologies:

- Passive short-term storage: Using the building's components for thermal energy storage in the form of sensible (Thieblemont, Haghighat, & Moreau, 2016; Thieblemont, Haghighat, Ooka, & Moreau, 2017) or latent heat storage (Bastani et al., 2015);
- Active short-term storage: Water tanks with or without PCMs (thermal latent/sensible), ice storages (thermal latent), batteries

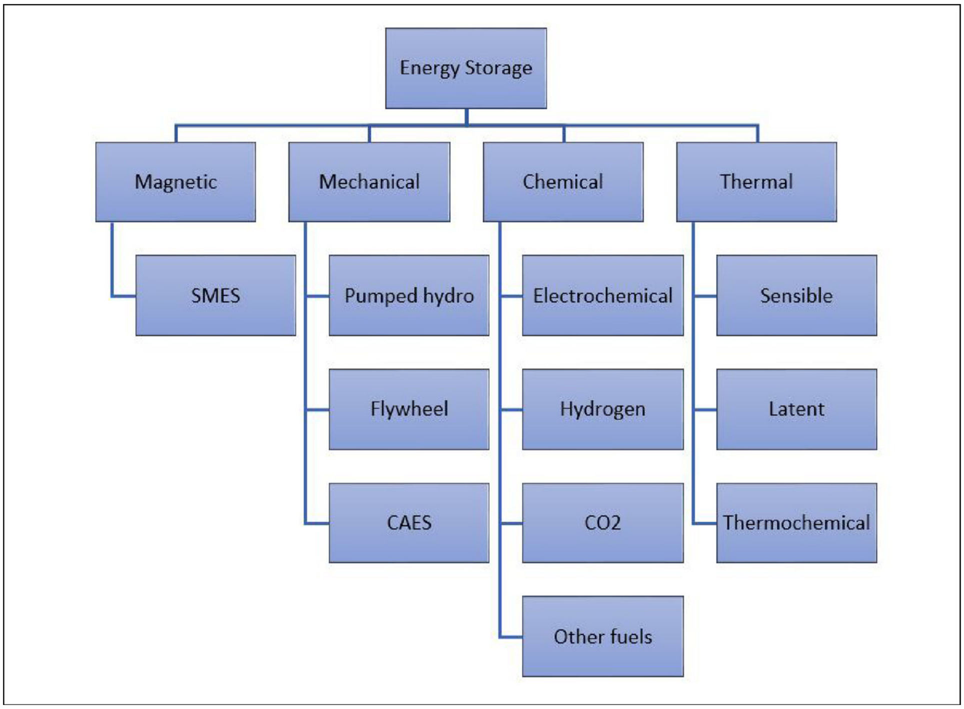

Fig. 1. Classification of the energy storage technologies currently available on the market, CAES:Compressed Air Energy Storage, SMES:Supermagnetic Energy Storage.