TOWARDS INTEGRATION OF ENERGY STORAGE SYSTEMS FOR CARBON NEUTRAL BUILDINGS: A REVIEW OF MULTI-CRITERIA DECISION MAKING APPROACHES

Xiaoshu Lü[1,2], Tao Lu[1], Pekka Tervola[1]

[1]*Department of Electrical Engineering and Energy Technology*

University of Vaasa, Finland

[1]*Department of Civil Engineering, Aalto University,* Finland

Vaasan yliopisto
UNIVERSITY OF VAASA

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Background

Europe's energy crisis is escalating and so are the costs

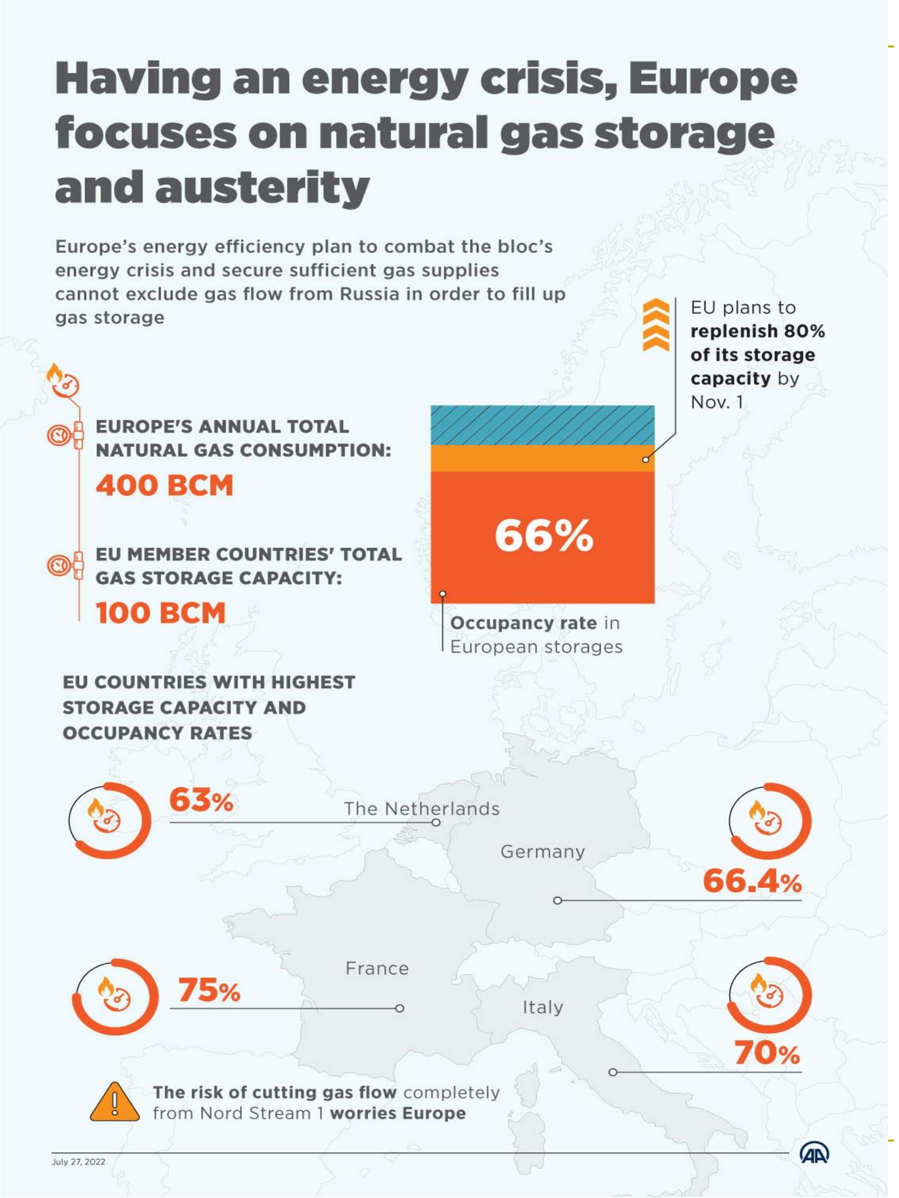
- Europe's energy crisis due to Russia has forced governments and users to spend billions to prevent soaring prices
- Natural gas prices have increased 550% and hit €274 per MWh, which exceeded the peak prices during the last crises in 1970s, 1980s, and 2000s according to IEA (International Energy Agency)
- Europe's energy crisis creates concerns that the EU could run short of gas this winter, despite a great effort to fill storages

Source: London (CNN Business) September 6, 2022

Background

Europe focuses on storage to alleviate energy crisis

- The EU's current gas storage capacity has reached approximately 100 billion m^3. The continent purchases on average 155 billion m^3 of natural gas from Russia but consumes more than 400 billion m^3
- Storage systems, e.g. filled in the summers and used in the winter when demand is high, play an important role in the security of supply and in offering flexibility to the European energy.



- https://www.aa.com.tr/en/economy/europe-focuses-on-storage-to-alleviate-energy-crisis/2646855

Background

The EU carbon neutral goal and energy crisis

- Renewable energy and energy efficiency are the two pillars for decarbonization strategy
- Storage is emerging as the third and perhaps the most important pillar now
- The EU planed 120-billion euros to eliminate dependence on Russian fossil fuel.
- The EU targeted 45% renewables by 2030 vs previously planned goal 40%
- European Association for Storage of Energy estimated the EU needs triple storage capacity by 2030, equivalently to 14 GW yearly installation for 8 years. In a market, installation is < 1 GW during 2021
- IEA estimated capacity expansion by 35 times this decade

Source: https://www.energy-storage.news/europe-needs-a-massive-rollout-of-energy-storage/

Background

Current energy storage types

- Pumped hydroelectric power plant, solid and flow batteries, flywheels, compressed air energy storage systems, thermal energy storage (TES), hydrogen, biomethane, synthesis gas are mostly discussed and used, with the most common being pumped hydro and lithium batteries. Pumped hydro accounts for 90% global electricity storage capacity

- Hydropower requires specific geographic places and may entail environmental impacts. Lithium batteries have short lifespan and cause environmental harm due to the mining of raw materials, such as lithium and cobalt

- All forms of energy storage are required with coherent strategy to enable renewable energy intakes

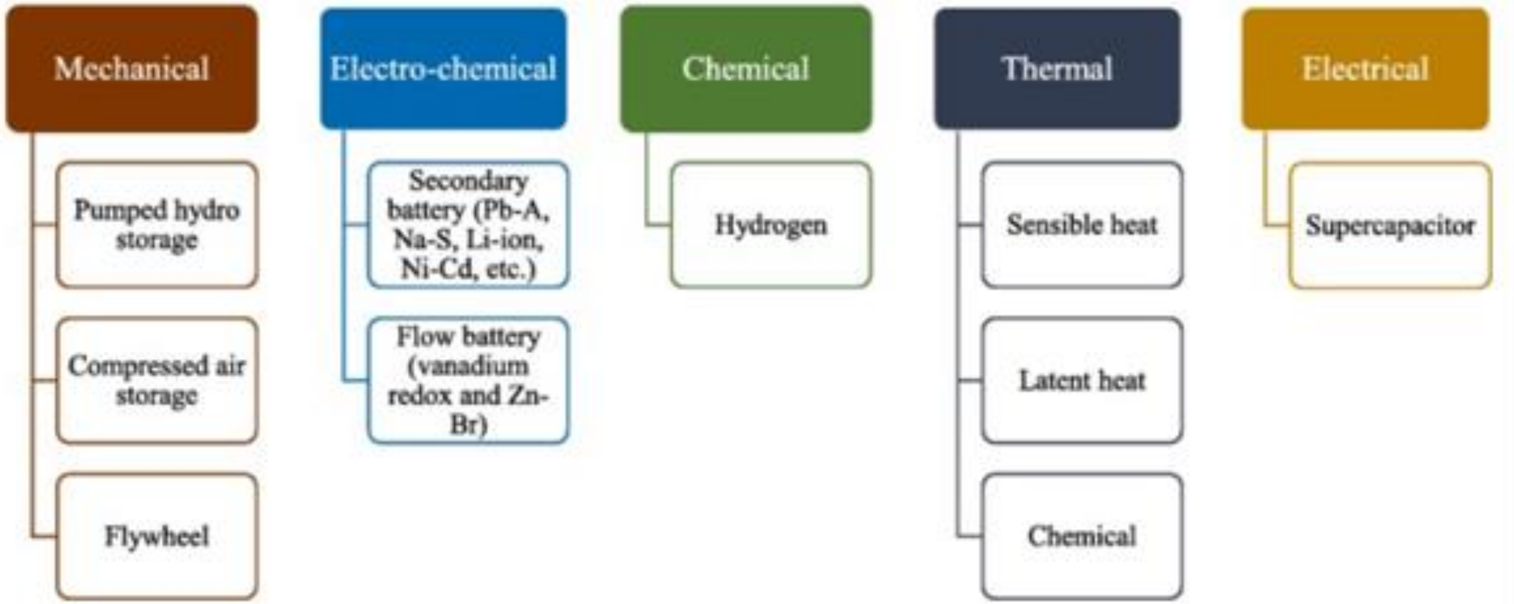
- Large-scale adoption of energy storage presents challenges from technologies, economics and policy

Background

Current building energy storage status

- Globally, buildings account for over 30% energy and 40% carbon emissions
- In the EU, over 75% space heating and other heating use in buildings comes from fossil fuel which is projected to increase in the coming years
- Given that 18.2 GW of new solar power was installed in 2020, an 11% improvement over the 16.2 GW deployed in 2019, the rapid growth of renewable energy sources (RESs) do not coincide with current energy consumption . The discrepancy between the demand and supply is caused by the intermittency of RES, for example, PV systems predominantly produce during daytimes and summers whilst the largest demands appear during the evenings and winters
- Thermal energy storage (TES) is a key to solve such a challenge for the large-scale deployment of RES

Overview of energy storage systems (ESS)

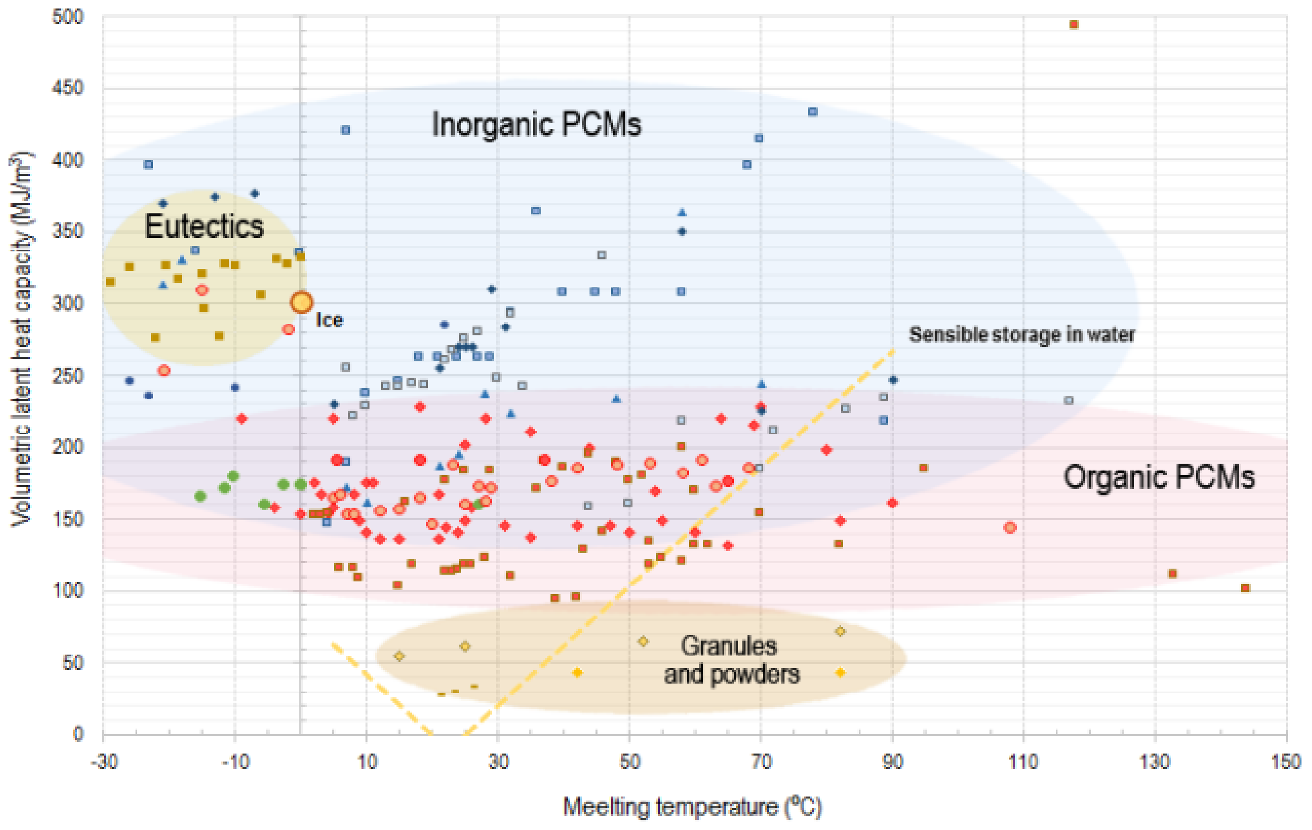


- In building applications, thermal energy storage (TES) is the most commonly used technology
- TES design parameters: energy density and capacity, charging and discharging time, depth of discharge, round trip efficiency etc, at material level.
- At the building level, heat transfer between the material and the fluid for example (compatibility to container material, reversible cycles, thermal losses, flexibility and modularity) are the important design parameters

https://www.statista.com

Applications of thermal energy storage (TES) to buildings Material level

- TES consists of sensible, latent heat and thermochemical energy technologies
- Sensible heat storage uses a high thermal mass without phase change
- Latent heat storage uses phase change materials (PCMs) due to their high storage capacities
- Building PCMs are generally categorised as organic compounds (e.g. paraffins and fatty acids), inorganic compounds (e.g. salt hydrates and metals) and eutectics

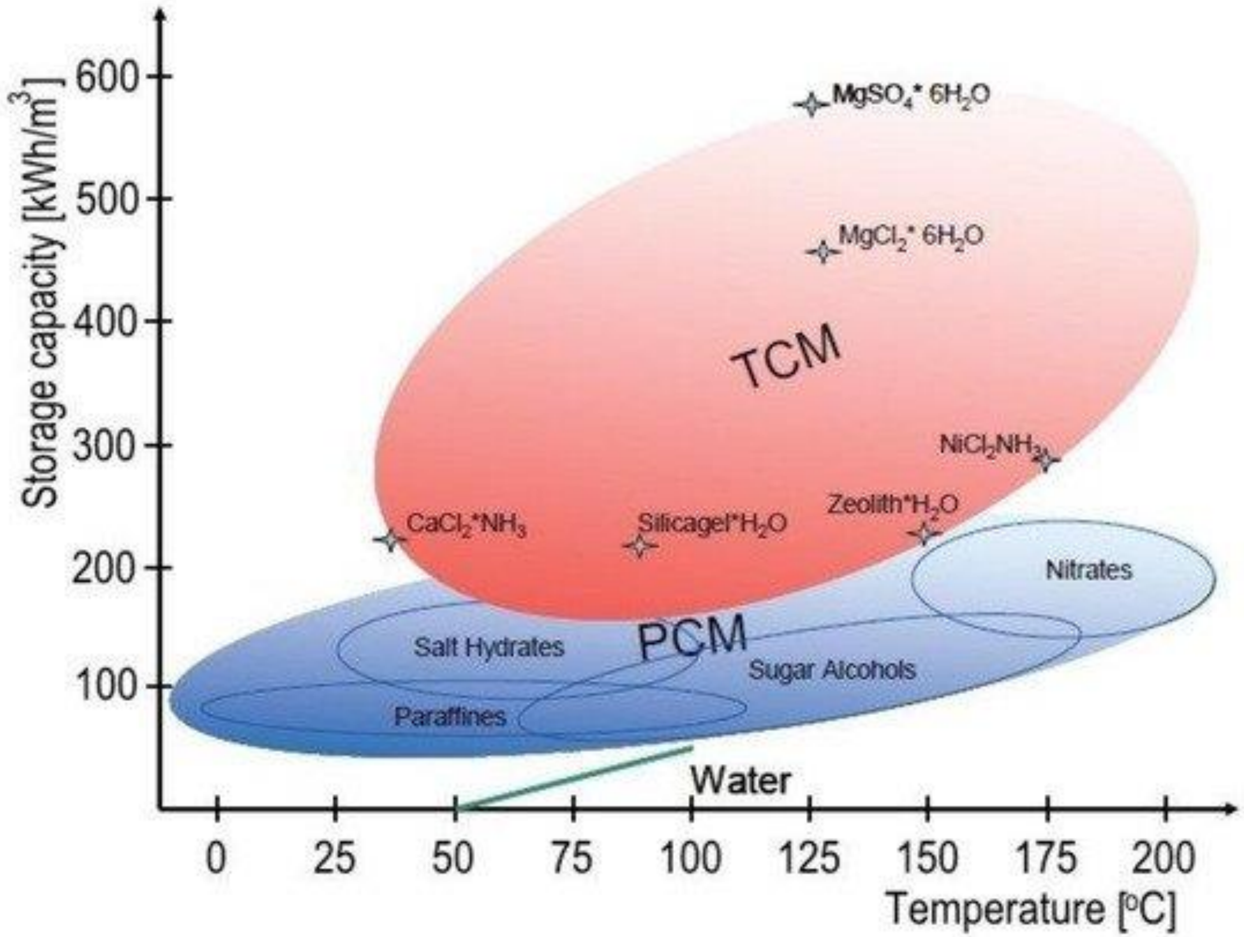


Applications of thermal energy storage (TES) to buildings
Material level

- Thermalchemical storage material (TCM) stores and releases heat through chemical reactions

- TCM has a high storage density and high cycling stability

- TCM applications to buildings are not common due to the costs

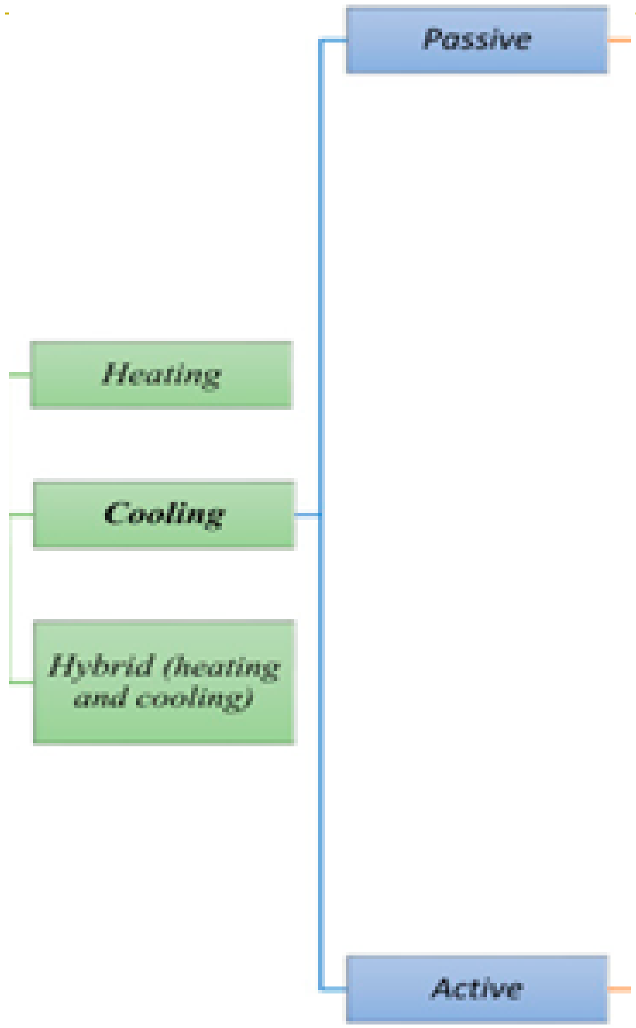


A comparison of working temperatures for PCM and TCM applications

Applications of thermal energy storage (TES) to buildings Building level

- Applications of TES to buildings involve identifying opportunities for a renewable and decarbonization purposes

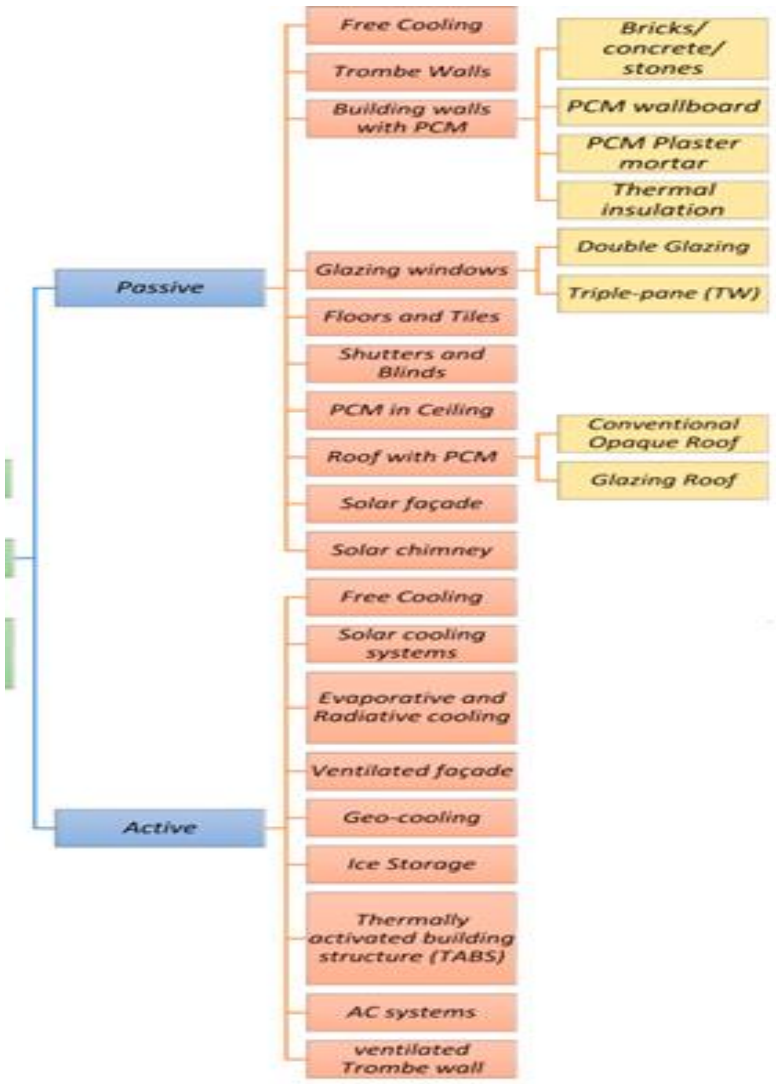
- Broadly speaking, there are two TES integration systems: passive and active systems



Applications of thermal energy storage (TES) to buildings Building level

- Passive systems: TES is embedded into the building construction systems, such as building envelops of walls, floors, and roofs, fenestration, and other systems in such way that its operation does not need auxiliary equipment

- Active systems: TES requires some additional energy for mechanically assisted equipment to enable the operation



Applications of thermal energy storage (TES) to buildings
Building level

Besides technologies, other criteria regarding economics, environment, etc, are needed to satisfy

Technical
Maximal Power Pmax [kW]
Specific Energy [kWh/kg]
Specific Power [kW/kg]
Energy Density [kWh/m3]
Power Density [kW/m3]
Minimal Charge/Discharge Time [h, min]
Depth of Discharge [%]
State of Charge [%]
Round trip efficiency η [%]

Social
Human rights
Human health and safety

Economic
Maximum number of cycle [-]
Energetic investment cost [e/kWh]
Power investment cost [e/kW]
Cost over the life-time [e/kWh]

Environmental
Lifetime Energy Efficiency
Lifecycle GHG Emissions
Supply Chain Criticality
Material intensity
Recyclability
Envrionmental health

Multi-criteria decision making (MCDM)

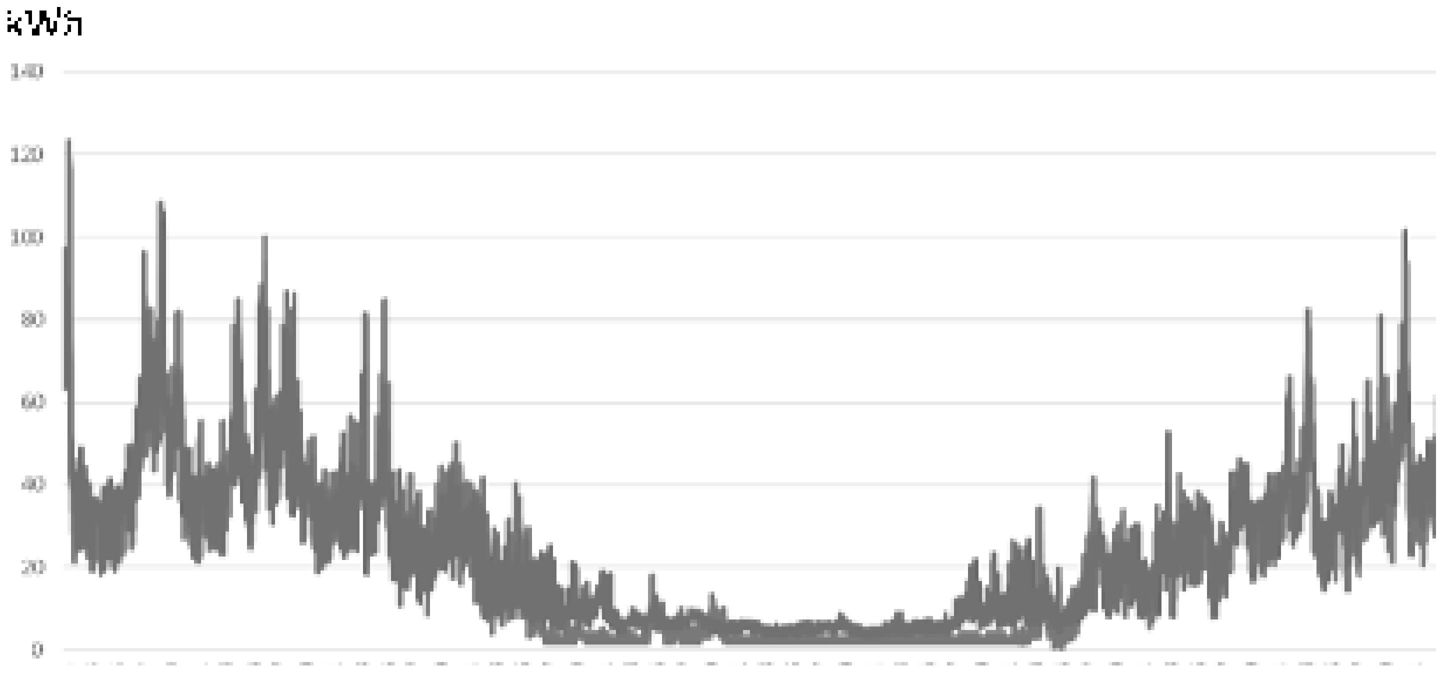
- MCDM is particular useful for complex decision problems involving multiple and conflicting objectives and criteria. It provides means to compare options by assessing trade-offs between different options
- There are a few MCDM software tools: HOMER (Hybrid Optimization of Multiple Energy Resources, developed at National renewable energy laboratory, USA) and iHOGA (Improved Hybrid Optimization by Genetic Algorithm, developed at University of Zaragoza, Spain)
- Building level applications include optimisation of RES generation and ESS (TES+batteries) in terms of techno-economical and environmental factors using software
- Material level applications include selection of PCMs based on materials' thermophysical properties, costs, and risk criteria

Case study

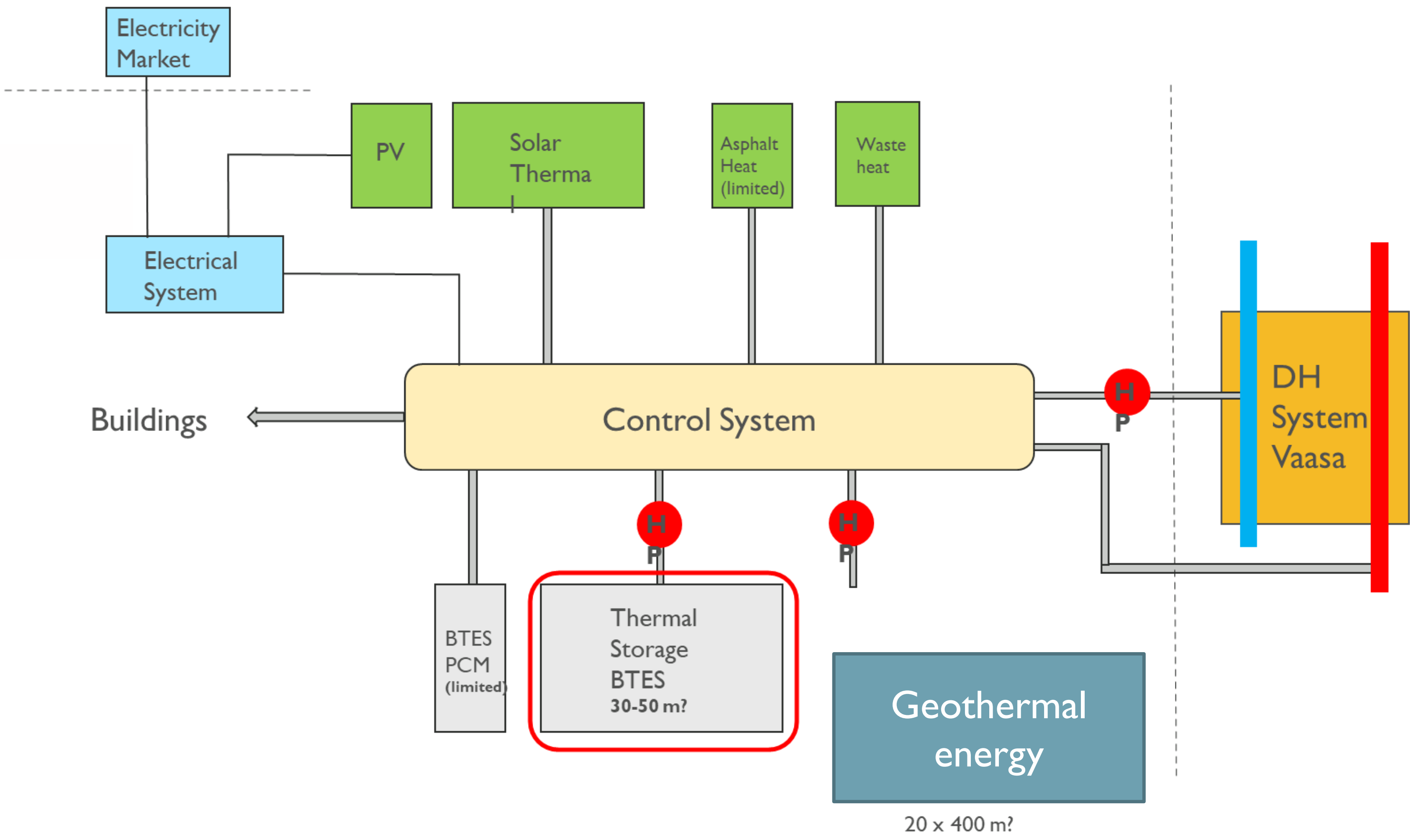
- The case study aims to synthesize the review and to conceptually illustrate MCDM applied to TES investigation for carbon neutral buildings
- We focus on the conceptual illustration of MCDM
- The case study buildings belong to university campus
- We investigate different implementation scenarios for achieving zero carbon campus through upgrading campus' infrastructure systems

Load patterns

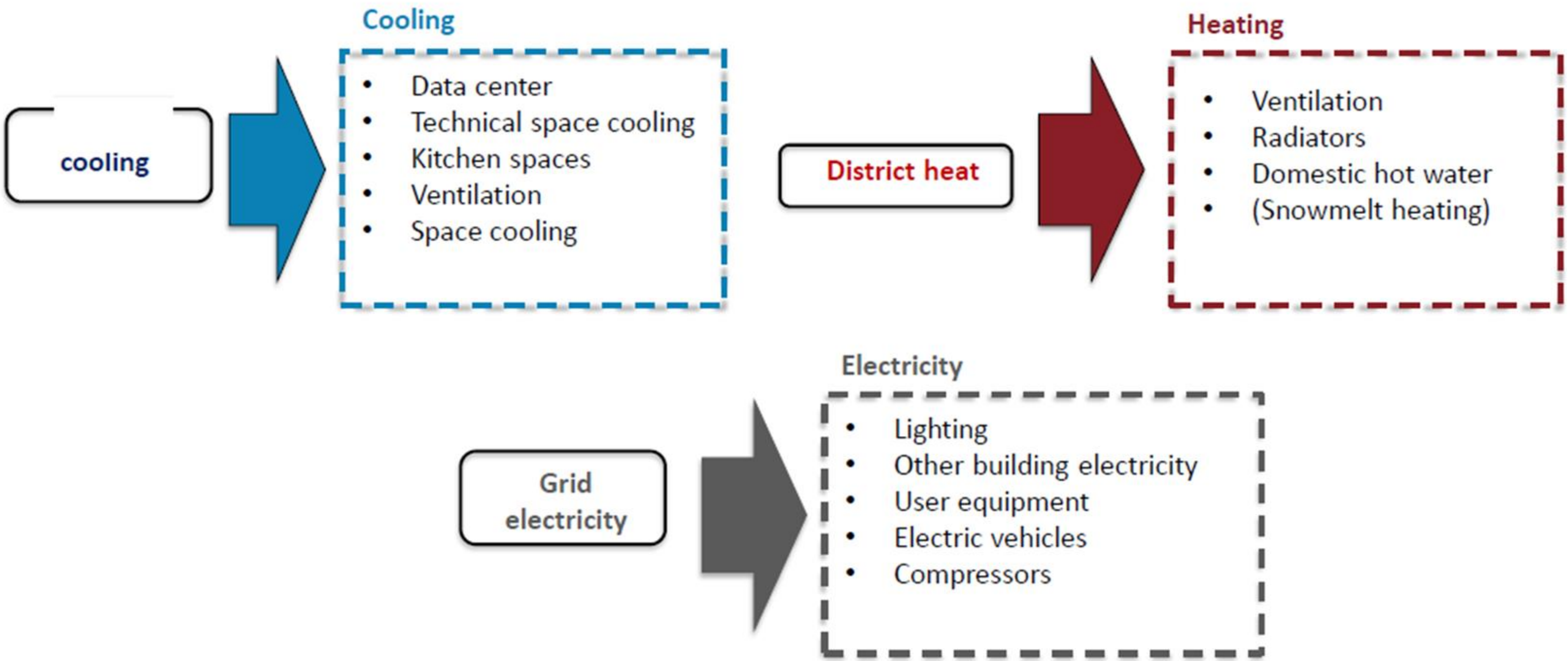
Collected building energy datasets on campus were used to calibrate and validate load model



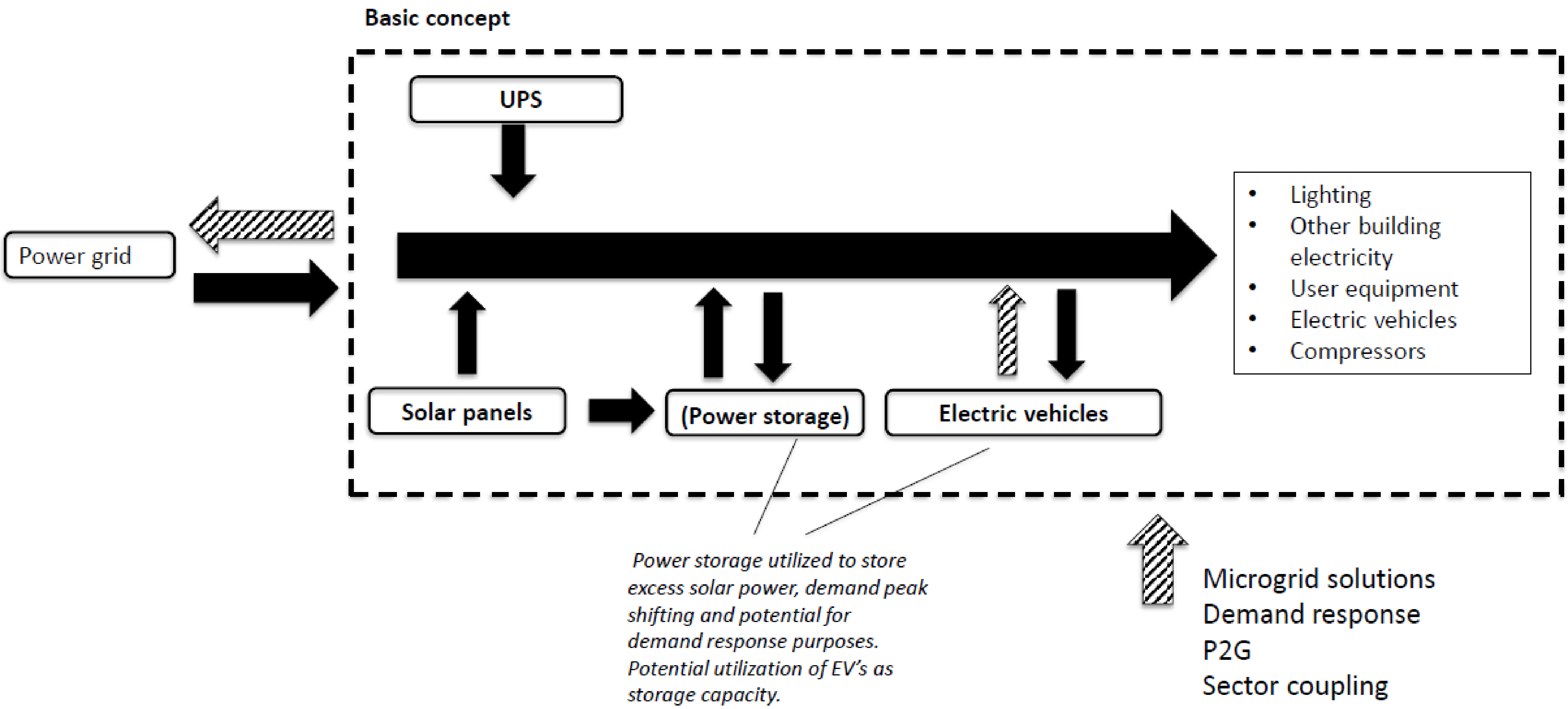
Energy system plan



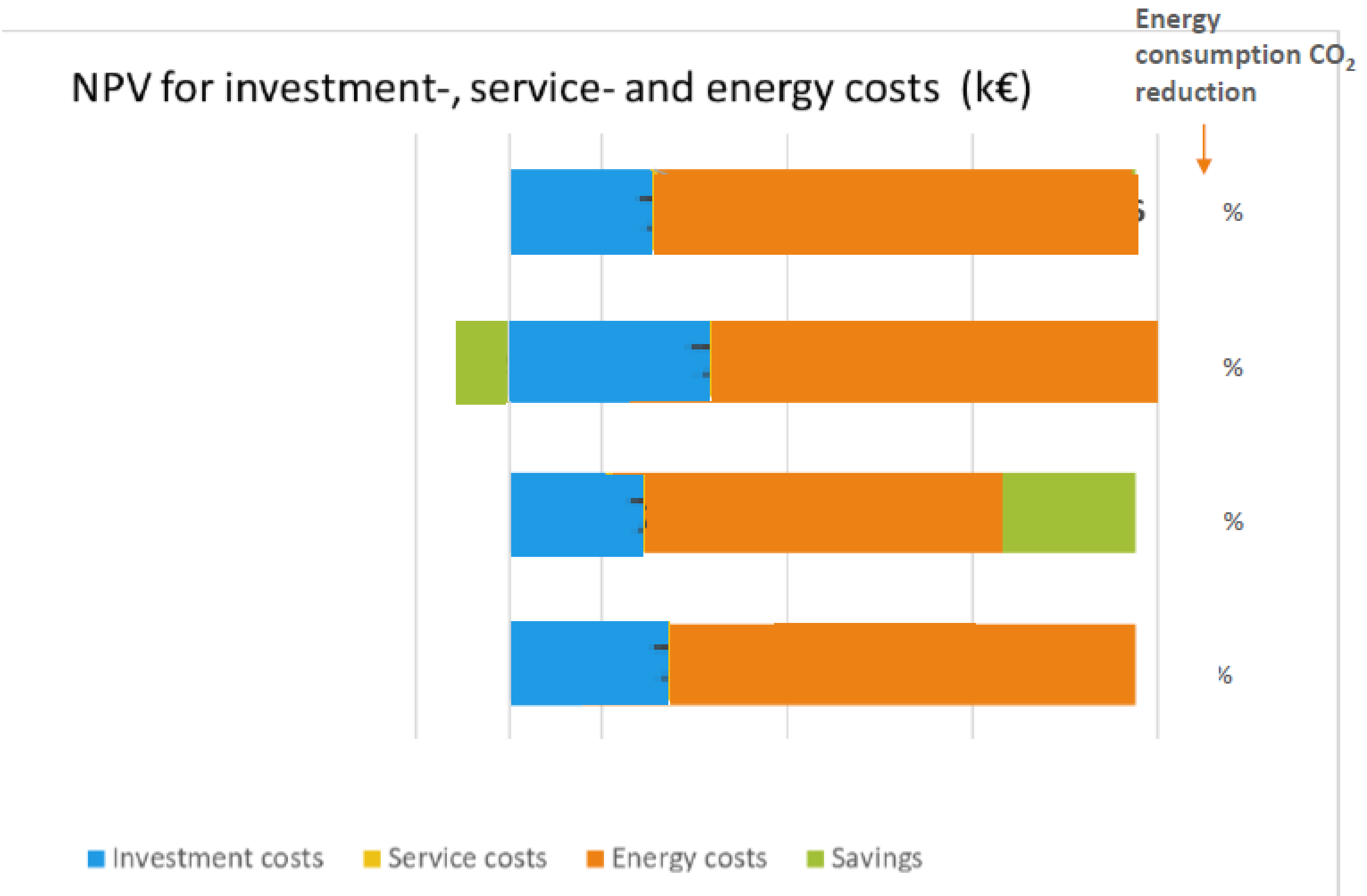
MCDM analysis



MCDM analysis



MCDM analysis results



Conclusions

- A literature review of MCDM for energy storage selection within the building sector is conducted
- MCDM is an interdisciplinary approach that has been increasingly employed in applications of wide-scale renewable energy deployment in buildings at different scales, ranging from single buildings, districts to cities
- MCDM is very useful in planning low carbon energy systems

References

[1] M.M. Rahman, A.O. Oni, E. Gemechu, A. Kumar, Assessment of energy storage technologies: A review, Energy Conversion and Management, 223, (2020), 113295.

[2] K.P. Kampouris, V. Drosou, C. Karytsas, M. Karagiorgas, Energy storage systems review and case study in the residential sector, Earth and Environmental Science 410 (2020) 012033 doi:10.1088/1755-1315/410/1/012033.

[3] L.F. Cabeza, Thermal energy storage, in A. Sayigh (Eds.), Comprehensive Renewable Energy, vol. 3, Elsevier, Oxford (2012), pp. 211-253.

[4] R. Tamme, T. Bauer, E. Hahne, Heat Storage Media, Ullmann's Encylopedia of Industrial Chemistry, Wiley-VCH Verlag GmbH & Co. KGaA, 2009

[5] A. Mavrigiannaki, E. Ampatzi, Latent heat storage in building elements: A systematic review on properties and contextual performance factors, Renewable and Sustainable Energy Reviews, Elsevier, 60(C), (2016), 852-866.

[6] M.M.A. Khan, R. Saidur, F.A. Al-Sulaimana, A review for phase change materials (PCMs) in solar absorption refrigeration systems, Renew. Sustain. Energy Rev. *76*, (2017), 105–137.

[7] M. Schmidt, M. Linder, A Novel Thermochemical Long Term Storage Concept: Balance of Renewable Electricity and Heat Demand in Buildings, Front. Energy Res., 17 (Sec. Process and Energy Systems Engineering) (2020), https://doi.org/10.3389/fenrg.2020.00137.

[8] K. Faraj, M. Khaled, J. Faraj, F. Hachem, C. Castelain, Phase change material thermal energy storage systems for cooling applications in buildings: A review, Renewable and Sustainable Energy Reviews, 119, (2020), 109579, https://doi.org/10.1016/j.rser.2019.109579.

[9] L. Navarro, A. de Gracia, S. Colclough, M. Browne, S. J. McCormack, P. Griffiths, L.F. Cabeza, 2016. Thermal energy storage in building integrated thermal systems: A review. Part 1. active storage systems, Renewable Energy, 88(C), (2016), 526-547.

[10] L. Navarro, A. de Gracia, D. Niall, A. Castell, M. Browne, S. J. McCormack, P. Griffiths, L.F. Cabeza. Thermal energy storage in building integrated thermal systems: a review. Part 2. Integration as passive system, Renewable Energy, 85, (2016),1334-1356.

[11] L.C Chow, J.K Zhong, J.E Beam, Thermal conductivity enhancement for phase change storage media, International Communications in Heat and Mass Transfer, 23 (1), 1996, 91-100. https://doi.org/10.1016/0735-1933(95)00087-9.

[[12] T.Balezentis, D. Streimikiene, I. Siksnelyte-Butkiene, Energy storage selection for sustainable energy development: The multi-criteria utility analysis based on the ideal solutions and integer geometric programming for coordination degree, Environmental Impact Assessment Review, 91, (2021), 106675.

[13] H.Sharma, E. Monnier, G. Mandil, P. Zwolinski, S. Colasson, Comparison of environmental assessment methodology in hybrid energy system simulation software, Procedia CIRP, 80, (2019), 221-227. https://doi.org/10.1016/j.procir.2019.01.007.

[14] A. Vallati, S. Grignaffini, M. Romagna, A New Method to Energy Saving in a Micro Grid, Sustainability, 7 (10), (2015) 13904-13919, https://doi.org/10.3390/su71013904.

[15] M.A.M. Khan,Y.L. Go, Design, optimization and safety assessment of energy storage: A case study of large-scale solar in Malaysia, Energy Storage, 3, (2021), e221.

[16] A. Ijadi Maghsoodi, S. Soudian, L. Martínez, E. Herrera-Viedma, E.K. Zavadskas, A phase change material selection using the interval-valued target-based BWM-CoCoMULTIMOORA approach: a case-study on interior building applications, Appl Soft Comput, 95 (2020), 106508.

[17] T. Mukhamet, S. Kobeyev, A. Nadeem, S.A. Memon, Ranking PCMs for building façade applications using multi-criteria decision-making tools combined with energy simulations, Energy, 215 (B), 2021, 119102. https://doi.org/10.1016/j.energy.2020.119102.

[18] C.L. Hwang, K. Yoon, K. Multiple Attribute Decision Making: Methods and Applications. New York: Springer-Verlag, 1981.


Thank you for your attention
Contact: Xiaoshu.Lu@aalto.fi