International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 0830

A SYSTEMATIC MULTI-CRITERIA ASSESSMENT INFRASTRUCTURE FOR RESIDENTIAL BUILDING HEATING TECHNOLOGIES IN CHINA

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ABSTRACT

China nowadays faces comprehensive challenges on supplying modern clean space heating to a majority of its citizens. Various building space heating technologies are implemented throughout north and south China. However, investors and policy makers are suffering from a lack of a systematic assessment tool to evaluate which heating technology to choose based on unique local conditions from techno-economic and environmental perspectives. This paper fulfills such research gap by proposing a multi-criteria assessment infrastructure to assist relative stakeholders evaluate potentials of different space heating technologies. The proposed infrastructure is multi-disciplinary and requires to handle a large amount of data from various sources, which can well reflect the feasibility of building space heating technologies systematically.

Keywords: residential building, space heating, multi-criteria infrastructure, system analysis, China

NONMENCLATURE

Abbreviations	
GSHP	Ground Source Heat Pump
ASHP	Air Source Heat Pump
SWHP	Surface Water Heat Pump
CHP	Combined Heat and Power
KPI	Key Performance Indicator
COP	Coefficient of Performance

1. INTRODUCTION

A great amount of energy input is required into residential building sector since China is undergoing fast urbanization process and promotion of life standard [1]. Generally in north China, there's a challenge to upgrade existing fossil fuel based high emission district heating systems into more sustainable heating systems. In south China, there's a lack of building space heating facilities. Meanwhile discussions on improvement solutions have been continuing. Various space heating technologies could be potential candidates to solve aforementioned problems, such as heat pumps, solar heaters, boilers or a combination of several technologies (hybrid systems). Currently in China, most of the existing renewable and sustainable space heating technology implementations are policy driven based on experts' endorsements as well as financial incentives. The policies are often universally applied to the whole country. Therefore, investors and policy makers are suffering from insufficient understanding of the feasibility of space heating technologies at different geolocations of China from systematic point of view. Neither is there a holistic and quantitative evaluation of technology implementation outcomes in long run [2]. In order to fill such research gaps, this paper established a systematic multi-criteria assessment infrastructure for various building space heating technologies, which can be applied into the following cases:

- How the current fossil-fuel based heating systems in existing buildings can be replaced or assisted by renewable heating technologies when reaching its lifespan or new regulations come into force.

Selection and peer-review under responsibility of the scientific committee of the 11th Int. Conf. on Applied Energy (ICAE2019).
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- How to choose efficient heating technologies for the existing buildings which lack space heating supply in spite of its heat demand.
- How the newly constructed buildings can be installed with the most efficient, affordable and clean heating systems, either in densely populated urban areas or remote sparse rural villages.

For all cases, system analysis is applied. With a system analysis model being built, critical system evaluation parameters/key performance indicators (KPI) are suggested to compare different space heating technologies quantitatively. Selection of KPIs should reflect technology primary energy use, economic affordability, environmental impact, geographical availability as well as other related desired benchmarks.

2. SYSTEM ANALYSIS IN RESIDENTIAL BUILDING SPACE HEATING

2.1 System boundary

System analysis is a set of different methods that help model builders optimize the system of interests [3]. Based on the philosophy of system thinking [4], system analysis aims at evaluate the reality of interest from multi-criteria, cross disciplinary perspectives to achieve sustainability as well as advise decision making process.

When applying system analysis into residential building space heating scenarios, heating technologies can be compared and evaluated at four different system boundary levels. The following contexts describes how system boundary can be defined, as well as how totally contrastive conclusions can be led to due to different choices of system boundaries.

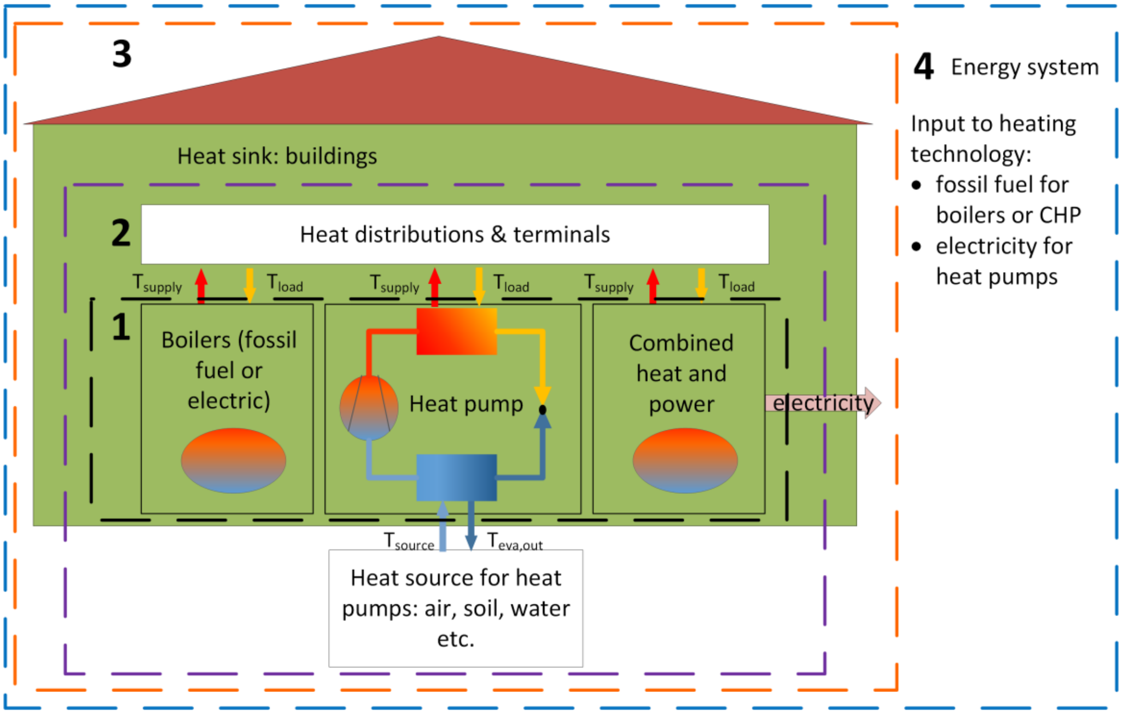

Fig 1 Building space heating system viewed from four different system boundaries

Represented by fig 1, the building space heating system can be viewed from four different system boundary levels as suggested by [5].

System boundary level one within the black dashed square represents the building space heating technology unit. It can be a boiler, a CHP or a heat pump. The sizing or capacity of such heating unit can be for a single-family house or for an entire building district. If it's a boiler or a CHP, system boundary one represents the basic combustion process of heat generation. If it's a heat pump unit, it represents the thermodynamics cycle and should comprise a compressor, a condenser, an evaporator as well as expansion devices. This boundary level calculates heating technology unit efficiency, which is the foundation for later on primary energy use calculation.

System boundary level two within the purple dashed square represents the heating system that contains the heating unit. System level two incorporates heat distribution networks as well as building indoor terminals. Furthermore, for heat pumps, such heating

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system should also include equipment in heat sources, such as air heat exchangers for air source heat pumps (ASHP), borehole heat exchangers, piping and liquid pumps for ground source heat pumps (GSHP) or water heat exchangers, piping and pumps for surface water heat pumps (SWHP). At this boundary level, heat source characteristics is very important for a successful implementation of heat pump system. Heat source temperature's geographical and seasonal distribution should be investigated in order to gain a comprehensive evaluation of heat pump operation boundary conditions. This boundary level calculates heating technology system efficiency, which includes energy behavior of liquid pumps and sometimes storage tanks.

System boundary level three within the orange dashed square contains the heat sink, which is the building or building district. At this boundary level, building properties are taken into consideration. Building envelope, building types and user behaviors all influence building heat demand. At this boundary level, when building heating peak demand is obtained, heating technology can be sized. The sizing of heating technology determines its capital expenditure. The annual building heating demand, however, is related to heating technology operation expenditure.

System boundary four within the blue dashed square considers the primary energy that fed into the energy system, which is important for heating technology environmental impacts. For boiler or CHP systems, primary energy used in China is usually coal. Therefore, coal mix should be investigated to obtain emission factors. For vapor compression cycle heat pumps, electricity mix should be investigated and fossil fuel electricity should be converted into primary energy to calculate related greenhouse gas emissions and air pollutants emissions.

2.2 System model complexity

After defining the system analysis boundary, a system multi-criteria evaluation model can be established. Modified from [6], building heating energy system model complexity relative to multi-criteria evaluation data availability can be represented by fig 2.

In fig 2, zone A is the area where rough estimation can be performed when only a limited amount of data is available. Zone B, on the other hand, deals with statistics when a large amount of data can be acquired. For example, machine learning methods could be used to predict building heating energy demand. Zone D is for complete building heating system analysis, with very detailed data such as building envelope materials, heat pump operation data, primary energy supply mix data etc. Such model is very data intensive and can consume a lot of computational resources.

In building heating energy system modelling, one can decide his/her own system complexity based on data availability, with a holistic consideration of how deep the system analyses should be targeting different stakholders.

3. MULTI-CRITERIA ASSESSMENT INFRASTRUCTURE

In building heating system modelling, the choice of different building heating systems should be investigated from techno-economic, environmental perspectives. Such multi-criteria assessment could reflect heating system advantages and disadvantages systematically and can provide insights for different stakeholders. Furthermore, when it comes to the choice of which heat pumps to use for building heating solutions, geographical

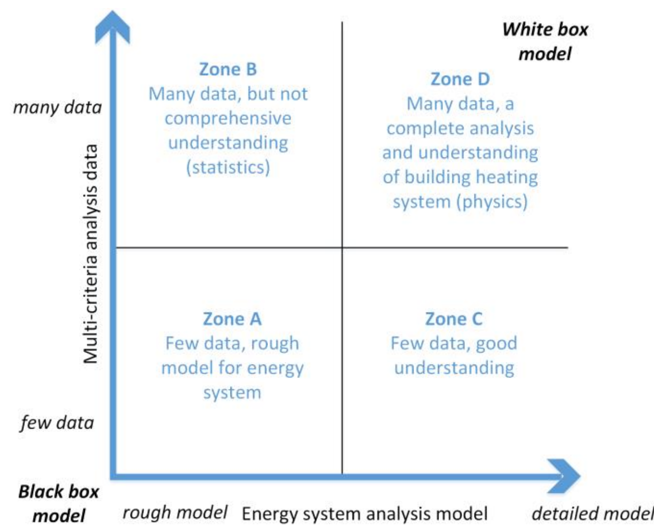

Fig 2 Building heating system model complexity

availability matters. Because application of ASHP, GSHP and SWHP is often geographically constrained. ASHP needs to consider outdoor air temperature fluctuation and humidity condition. GSHP should consider extractable heat for underground soils and rocks, as well as drilling conditions. SWHP need to evaluate water body temperature seasonal variation and water quality.

In this proposed multi-criteria assessment infrastructure, three steps are needed, data collection, data process and KPI calculation. Data collection manages heating technology operation data, price data, heat source data, building data etc. It's the most important and difficult step. The quality of obtained data determines calculation accuracy. Data processing establishes system analysis model and quantitatively calculates selected KPIs. Finally, KPIs can be visualized on

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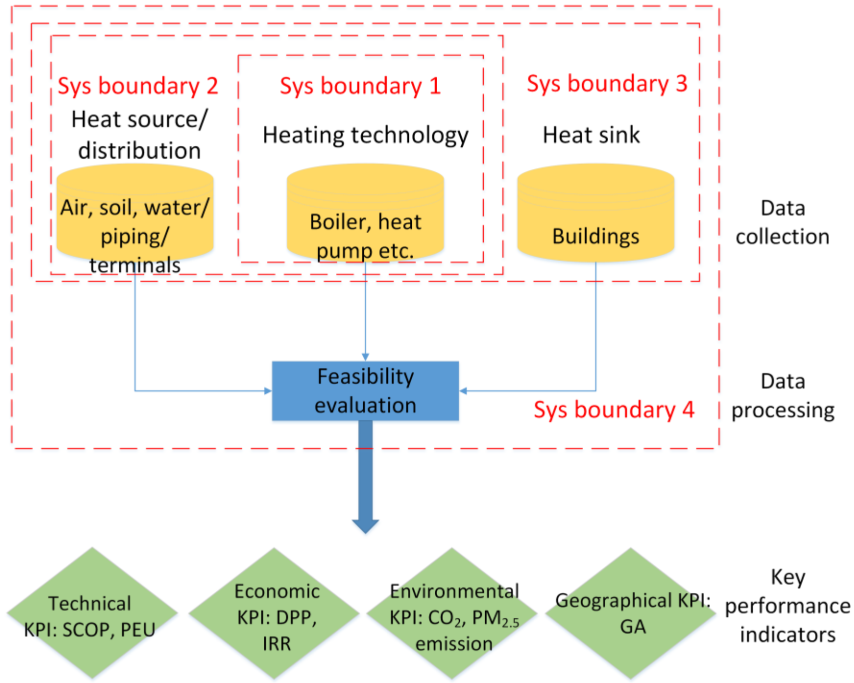

Fig 3 Multi-criteria assessment model infrasturcture

various result maps. Such model has been successfully implemented in case studies of different Chinese cities such as in [7].

4. CONCLUSIONS

In order to find the most proper building space heating solutions in various local conditions in China, this paper proposes a multi-criteria assessment model infrastructure, which can assist system modelling and help stakeholders quantitatively compare different building heating solutions. The infrastructure has been successfully implemented in case studies and shows its universality in building heating solutions in China.

The novelty of this infrastructure is that it not only evaluates heating technology technically, economically and environmentally, but also considers geographical or spatial availability in a dynamic modelling process. Spatial data determines heating technology feasibility, which expands the scope of evaluation.

The advantage of this infrastructure is its quantitative evaluation and innovative integration with spatial data. Such integration can help visualization of results which greatly facilities communicating research within and beyond the academy.

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