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Uniform Modelling of Heat Production Costs in Single-Family and Multi-Family Houses

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Abstract. To ensure a fair and extensive comparison of different heating systems four representative buildings including their heat demand for space heating and domestic hot water were defined. A model for the heat production costs has been developed based on existing methods like the VDI 2067 part 1 [1] and the simplified approach for the calculation of the "Levelised Cost of Heat" (LCoH) of the IEA SHC Task 54 "Price Cost reduction in solar thermal systems" [2]. The developed model includes the costs of purchase, installation, operation, maintenance and disposal and was implemented in an EXCEL calculation tool which enables the calculation of the total life cycle costs (LCC), the levelized cost of heat (LCoH) and the CO2 emissions over the lifetime of the system.

Keywords: Life Cycle Costs (LCC), Levelized Cost of Heat (LCoH), Heat Production Costs, Heat Demand

1. Introduction

The provision of heat for residential buildings has a significant impact on the sustainability of the energy supply and represents an immense cost factor. To optimize the heat supply regarding the current climate policy objectives, various technologies and their combinations are available, which focus in particular on the use of renewable energy sources. But especially for the use of renewable energies, which must cover 65% of the heat supply of residential buildings in Germany from 2024, the requirements of planners, decision-makers and users as well as the overall socially responsible parties are very high with regard to the sustainability of the systems used and the costs. Due to insufficient knowledge and development of the existing methods for life cycle and cost analysis as well as the lack of models and data for this purpose, these cannot currently be assessed in a comparable manner.

For the ecological and economic evaluation of systems and components for heat supply in residential buildings, a multitude of influencing factors over the life cycle play a role. The project "Efficient Heating", initiated by Fraunhofer ISE, Fraunhofer IBP and the Institute for Building Energetics, Thermal Engineering and Energy Storage (IGTE) at the University of Stuttgart and carried out jointly with representatives of the heating, real estate and planning industries, aims to understand the underlying complex interrelationships between the different factors. On international level the IEA SHC Task 71 "Life Cycle and Cost Assessment for Heating and Cooling Technologies" aims to harmonise methods for the life cycle and cost assessment for heating and cooling technologies.

The reliability of the data regarding the basic materials used, manufacturing techniques, installation, maintenance and end of life is to be supported by data collection directly from the industry, among others. In addition to the exemplary comparison of alternative materials, components and manufacturing processes, the influence of a variable lifetime energy yield shall be considered. The investigations are to be carried out at the level of building integration and, for selected questions, also in the economic context. To improve data availability and decision support, the environmental and cost information generated in the project will be made available to potential users to enable them to select ecologically and economically advantageous variants.

2 Defined buildings, Heat demands and heating technologies

For the comparison of different heating technologies well defined heat demands are required. To fulfil this requirement and cover a large share of the residential market in Germany four buildings including the corresponding heat demand for space heating and domestic hot water preparation were defined:

- Single family house stock (SFHs)
- Single family house new building (SFHnb)
- Multi-family house stock (MFHs)
- Multi-family house new building (MFHnb)

The IWU building typology, which is also the basis of the European building database TABULA, was used to define the buildings that are considered as representative as possible, particularly for the existing buildings (see Figure 1).

Figure 1. *Typology of the German residential building stock [3]*

Table 1 summarizes the major information about the four defined buildings.

Table 1. *Relevant information about the four defined buildings; *excluding circulation losses*

	living area in m²	**Residents in no.**	**Domestic hot water load in kWh/(m² yr)**	**Space heating load in kWh/(m² yr)**	**Max. supply temperature in °C**
SFHs	140	3	10.2	157	55
SFHnb	140	3	10.2	45	35
MFHs	908	20	11.8*	148	55
MFHnb	908	20	11.8*	43	35

Within the project “Efficient heating” it was agreed to compare altogether 10 heating technologies, see Table 2. These heating systems are simulated in the simulation environment Polysun. The results of the simulation as gas and electricity consumption are input into the cost calculation.

Table 2. *Heating technologies to be evaluated within the project “Efficient heating”*

Heating technology	**Justification***
Gas heating	Gas heating is used as a reference as it is currently the most widespread technology
Air-to-water heat pump	The air-to-water heat pump has the largest market share of newly installed heating systems after the gas boiler

Solar thermal combined system with gas condensing boiler	The solar thermal combined system with gas condensing boiler is represented by two of the industry partners
Solar thermal combination system with air-to-water heat pump	The solar thermal combination system with air-to-water heat pump is a purely renewable heating system that makes a significant contribution to saving electricity, particularly in summer and during the transitional period, thus reducing the load on the grids
Brine-to-water heat pump with PVT collector as heat source	The brine-to-water heat pump with PVT collector as heat source is represented by two of the industry partners
Air-to-water heat pump with gas condensing boiler	The air-to-water heat pump with gas condensing boiler is an important heating technology, particularly for existing buildings and refurbishments.
PV direct heating	PV direct heating is represented by one industry partner
Pellet heating	Pellet heating has the largest market share among biomass heating systems.
Geothermal heat pump	The geothermal heat pump is another important application of climate-neutral heat pump technology.
Fuel cell	The fuel cell also represents an important application of climate-neutral heat pump technology.

* For the German heating market

3 Life Cycle Costs

Life cycle costs (LCC) are the costs incurred during the service life of a product, from purchase to installation, operation, maintenance and disposal. As part of the "Efficient heating" project, the life cycle costs of the heating system are described using equation (1).

$$LCC_Z = \sum_{k=1}^{K}\left\{\sum_{t=0}^{T}\left(\frac{I_{k,t}}{(1+r)^t}\right) + \sum_{t=0}^{T}\left(\frac{M_{k,t}}{(1+r)^t}\right) + \sum_{t=0}^{T}\left(\frac{D_{k,t}}{(1+r)^t}\right) - \frac{RV_{k,T}}{(1+r)^T} - \sum_{t=0}^{T}\left(\frac{S_{k,t}}{(1+r)^t}\right)\right\} + \sum_{b=1}^{B}\left\{\sum_{t=1}^{T}\left(\frac{O_{b,t}}{(1+r)^t}\right)\right\} \quad (1)$$

LCC_Z	Life Cycle Cost of heating technology Z in €
K	Quantity of all components of heating technology Z
T	Period of observation in years
$I_{k,t}$	Investment costs of component k in the period t in €
$M_{k,t}$	Maintenance costs of component k in period t in €, M_(k,0)=0 €
$D_{k,t}$	Deinstallation and disposal costs of component k in period t in €, D_(k,0)=0 €
$RV_{k,T}$	Residual value of component k at the end of the period of observation T in €
$S_{k,t}$	Subsidies for the component k in the period t in €
B	Quantity of energy sources supplying heating technology Z

$O_{b,t}$	Operating costs less compensation caused by the operation of the technology with the energy source b in the period t in €
r	Real interest rate in % p.a.

The annual values ($I_{k,t}$, $M_{k,t}$, $D_{k,t}$, $S_{k,t}$, $O_{b,t}$, and r) can be specified either in constant values or in annually adjusted values. All costs and prices are specified and calculated with VAT in order to be able to comply with a VAT exemption as it applies to PV modules in Germany.

The system boundaries for the calculation are the boiler room, the distribution system and the radiators or heating surfaces are not part of the system under consideration.

3.1 Investment costs

The investment costs of the heating system can be incurred once upon purchase or in installments over several years and include the purchase of the components (heat generator, storage tank, pumps, hydraulics, heat transfer medium, etc.) and the installation of the heating system. In addition, the investment costs include the costs incurred for the construction measures required to operate the heating system. These include the costs for necessary electrical or gas connections, flue gas systems, boreholes for geothermal probes, excavation costs for ground collectors, concrete bases for the outdoor unit of air heat pumps, etc., unless these are already included in the installation costs. If other components are saved by installing the heating system, e.g. roof tiles - in the case of in-roof collectors, the costs of the respective components can be credited.

3.2 Maintenance costs

The maintenance and repair costs include the necessary investments for the repair of the heat generator or other components as well as the replacement of smaller components such as pumps, expansion vessels or the replacement of heat transfer media. They also include the costs arising from the maintenance of the system by a service technician, chimney sweep costs, etc.

3.3 Disposal costs

The disposal costs include the dismantling of the plant and the landfill costs. Any profits from scrap recycling are credited.

3.4 Residual value

The residual value of the heating system is calculated according to [1] with a linear depreciation of the initial investment I0 according to equation (2).

$$RV = I_0 \frac{T - t}{T} \tag{2}$$

While the initial investment is given from the investment costs and the subsidies according to equation (1).

3.5 Subsidies

The subsidy can be paid once when the system is purchased, but also at any other time during the period under consideration and spread over several years as an investment subsidy or as tax savings.

3.6 Operating costs

The operating costs include fuel costs (oil, gas, biomass, H_2, electricity, etc.) as well as the electricity costs for operating the heat generators, pumps, controls and other consumers, if any. The operating costs also include the CO_2 costs and any other charges. If electricity is also generated by the heating system, for example by PV and PVT systems as well as fuel cells and CHP units, and this is either used by the system itself or fed into the grid, it reduces the operating costs in line with the procurement costs or feed-in tariffs.

3.7 Real interest rate

The real interest rate is calculated from the nominal interest rate and the yearly inflation I according to equation (3).

$$r = \frac{r_{nominal} - i}{1 + i} \tag{3}$$

with:

$r_{nominal}$	%/a	Nominalzins
i	%/a	Inflation

The yearly quatities (rnominal i) can be either used as constant values or in yearly adjustable values.

4 Levelisised Cost of Heat

The levelised cost of heat (LCoH) are describing the costs per kWh heat (end energy) (€/kWh) and are calculated according to equation (4).

$$LCoH = \frac{LCC}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}} \tag{4}$$

with:

LCoH	€/kWh	Levelised cost of heat
E_t	kWh	End energy used for domestic hot water and space heating

The annual final energy Et for space heating and domestic hot water is determined on the basis of the space heating load profiles and the hot water demand of the reference buildings defined above.

5 Summary and Outlook

In the German project "Efficient heating", four different buildings (Single family house stock and newly build, multi-family house stock and newly build) have been defined and the basic approach of a uniform modeling of the heat generation costs in single and multi-family houses was developed. This includes all costs from purchase to installation, operation, maintenance and disposal of the heating system. In addition, parameters such as subsidies, CO2 taxes, etc. are included to enable an economic perspective.

In the further course of the project, the individual summands of the approach described in equation (1) are parameterized in detail. The final model is then used to calculate the heat production costs for the following generic heating systems on the basis of detailed price research and system simulations.

- Gas heating
- Air-to-water heat pump
- Solar thermal combined system with gas condensing boiler
- Solar thermal combination system with air-to-water heat pump
- Brine-to-water heat pump with PVT collector as heat source
- Air-to-water heat pump with gas condensing boiler
- PV direct heating
- Pellet heating
- Geothermal heat pump
- Fuel cell

Aspects related to ecological assessment of the heating technologies can be found [4].

Data availability statement

The submission is not based on data.

Underlying and related material

There is no other material apart from the listed references available which supports our findings.

Author contributions

Stephan Fischer: Conceptualization, Methodology, Resources, Writing - Original Draft, Funding acquisition **Karl-Anders Weiß:** Conceptualization, Writing - Review & Editing, Supervision, Project administration, Funding acquisition **Björn Nienborg:** Methodology, Resources, Writing - Original Draft, Writing - Review & Editing **Katrin Lenz:** Writing - Review & Editing

Competing interests

The authors declare that they have no competing interests.

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