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New tool for planning district cooling systems

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ABSTRACT

INDIGO project focuses on the means for evaluating the performance, benefits and potential of District Cooling (DC) systems. The newly developed tool supports the optimal design of new DC systems, the assessment of existing DC systems' potential for performance/efficiency improvement and the comparison with building specific cooling systems. Life cycle analysis (LCA) framework is used for economic feasibility and climate impact assessment. The main input parameters are cooling demand, cooling production, distribution network characteristics and available resources. As an output, the tool yields primary energy consumption, greenhouse gas emissions and costs of the system. The defined potential district cooling system can be compared with building and space specific cooling systems delivering the same cooling service. The results are reported as a diverse set of key performance indicators (KPIs).

KEYWORDS

district cooling; energy planning; cooling systems; climate impact, life cycle assessment

INTRODUCTION

Heating and cooling in industry and buildings together account for approx. half of the European energy consumption. The share of cooling of the energy consumption is still relatively small, but it is growing in importance in both households and industry. Warming induced by climate change further contributes to this trend. On the other hand, ambitious climate change mitigation requires drastic reductions in energy use. In November 2016 the Commission proposed an update to the Energy Efficiency Directive including a new 30% energy efficiency target for 2030. In June 2018 the Commission, the Parliament and the Council reached a political agreement which includes a binding energy efficiency target for the EU for 2030 of 32.5%, with a clause for an upwards revision by 2023 [1]. District cooling (DC) can increase the cooling system efficiency by 5 to 10 times compared to on-site cooling systems [2]. It therefore offers a promising way of improving the energy efficiency, and reducing greenhouse gas emissions of cooling systems.

The goal of project INDIGO is to provide tools supporting design, planning and operation of DC systems. The project covers all the parts of the system; generation, distribution, storage, and demand. Within INDIGO, an open-source planning tool focused on the design phase of a DC system, has been developed. The purpose of the tool is to support the design and planning of new DC systems, and the assessment of existing DC systems' potential for

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performance/efficiency improvement. [3, 4, 5]. A limited background review shows that in addition to INDIGO, there is a number of ongoing projects with a similar topic. [6, 7]

In the frames of CoolHeating project a tool has been developed for small modular district heating and cooling project, mainly meant for non-experts in district heating technology, e.g. decision-makers in municipalities. Tool focuses on economic aspects of the system and does not include any energy related calculations. Main input consists of investment and financing, operational costs, revenues and economic parameters. The results include assets, liabilities and equities, incomes, a balance sheet, cash-flow and profitability. [8]

E2District project aims to develop and demonstrate a novel cloud enabled management framework for DHC systems, which will deliver energy cost savings through intelligent adaptive DHC control and optimisation methods. A scalable District Operation System will integrate all key control, optimisation, diagnostics and prosumer engagement modules into a cloud-enabled DHC management platform. [9]

The FLEXYNETS project proposes a district heating and cooling solution based on decentralized reversible heat pumps (HPs). The network is operated at neutral temperature, about 15–25 °C, lowering thermal losses, facilitating the integration of low temperature waste heat, and giving rise to a reversible network, able to provide heating and cooling on the same pipes. In this way, the same network can provide contemporary heating and cooling. GIS Software Tool for Designing Networks is being developed. The software tool is GIS based and developed for Danish towns. The analysis is based on steady state conditions for fixed temperature levels. [10]

The H-Disnet project develops solutions for capturing the major part of available waste/excess (temperatures less than 60 °C) heat with thermo-chemical systems. Excess heat is transformed to thermo-chemical potential by the use of desiccant brine solutions. It will be applied to form an intelligent district network with thermal, electric and gas networks. The modelling of H-DisNet technology for simulation provides the basis for control strategies, large network examination and potential assessment. On this basis, smart control strategies and a network identification tool are developed. [11]

HotMaps project will produce a web-based GIS toolbox for analysing heating and cooling demand as well as supply options on a local, regional and national levels. The source code produced during the development of Hotmaps will be accessible on the open source platform GitHub. Main features will be to identify location of heating and cooling demand and potential supply on a map (EU28) with renewable and industrial excess potential highlighted, to estimate potential district heating options for a selected area, to estimate and compare costs of individual heating vs. district heating and to compare the results with national plans for de-carbonisation. [12]

InDeal project will offer an innovative platform that will impose an adequate distribution of heating and cooling among the buildings in the network. A number of innovative modules have been integrated in an advanced automated Decision Support System (DSS) including artificial intelligent metering devices, energy demand prediction of the network, data-driven short-term weather forecasting, energy storage monitoring and modelling, energy harvesting, web-based control platform along with solutions for minimising heat losses. [13]

The OPTi project will deliver methodologies and tools that will enable accurate modelling, analysis and control of current and envisioned DHC systems. The methodology will be deployed both on a complete system level, and on the level of a building(s). The DHC system will be a subject to dynamic control, and will treat thermal energy as a resource to be controlled for DHC towards saving energy and reducing peak loads. OPTi's framework is composed of digital twin of a DHC system as the cornerstone, to evaluate new approaches for operating and optimizing the control of a DHC system. OPTi framework integrates different models in a co-simulation approach. [14]

PLANHEAT project aims to develop a tool for mapping, planning and simulating a local energy demand and supply to investigate future scenarios, potential identification of an existing network and describe benefits from energetic, economic and environmental points of view. Tool will be easy-to-use, open-source and free. Potential mapping includes demand estimation (degree hours for cooling and heating), database for retrofitting and energy efficiency measures, models for current and future energy demand estimation, available energy sources and industrial excess heating and cooling. GIS based platform will be developed to visualize both demand and supply (potential). [15]

In STORM project a generic district heating and cooling (DHC) network controller will be developed with the ambition to increase the use of waste heat and renewable energy sources in the DHC network. The self-learning control techniques will be used instead of model-based control approaches. It will make the controller easy to implement in different configuration and generations of DHC networks. The STORM controller includes modules for forecasting, planning and dispatching heating and cooling management actions. The control strategies benefit the whole energy chain, spanning from energy generation and distribution to end-user consumption. [16]

The THERMOS project aims to provide the methods, data, and tools (free and open source) to enable more sophisticated thermal energy system planning rapidly and cheaply. The THERMOS Tool is a map-driven open-source web-based application tailored to the real world requirements of energy planners to make heat network planning faster and more efficient. [17]

The aim of THERMOSS is to define a set of retrofitting heating and cooling packages based on cutting-edge, high-potential, market-ready technologies that are connected together in an open ICT platform for smart energy management at building and district-level. It employs DIMOSIM, an integrated simulation tool for the analysis of feasibility, conception and operation of district energy systems. The tool is meant for the development, test and analysis of the optimisation of concepts and operation of district energy systems. [18]

District Heating Assessment Tool (DHAT) is a tool for performing economic feasibility studies for establishing district heating compared to individual heating, and can be adjusted to local conditions globally. The model can be used by heat planners showing the economic and environmental benefits and costs of district heating. The DHAT Tool can be used by heat planners to calculate the economic feasibility of establishing district heating in areas currently supplied by individual heating. The tool is based on Danish technical data and price projections can be adjusted, making it easy to use in different countries. The model is a MS Excel based tool with no hidden data or VBA code – the user is free to modify all data inputs and variables – for easy access and quick overview of the model. [19]

The project INDIGO focuses on district cooling by improving system planning, operation and control making them more efficient, intelligent and economic. As part of the project, an open source planning tool for evaluating alternative district cooling system configurations, building and space-specific cooling systems is developed [20]. This tool is different from any other existing, as far as we are aware. The tool evaluates energy efficiency, economic performance and life cycle greenhouse gas emissions. User can quickly define an arbitrary system supported by pre-defined sets of input data. The tool then automatically generates an optimisation model representing the defined system and solves it, providing results for a representative year of operation. The model includes available resources, energy production and storage, cooling supply and distribution network. Finally, the results are processed to provide the user useful visualisations and set of key performance indicators. Further details are provided in the following. In addition, method, implementation and use cases of the planning tool are described in detail in project deliverable D5.2 [21].

PLANNING TOOL OVERVIEW

The planning tool enables comprehensive analysis of cooling systems. It can be used to compare potential benefits of DC over building or space specific cooling systems, or to investigate different configurations of these systems. It generates an energy system model representing the system and providing input for energy, economic and emission related analyses. All main parts of a cooling system are included in the analysis. Calculation of emissions is based on the life cycle assessment (LCA) framework [22, 23]. The scope, main components and their categorisation are presented in Figure 1.

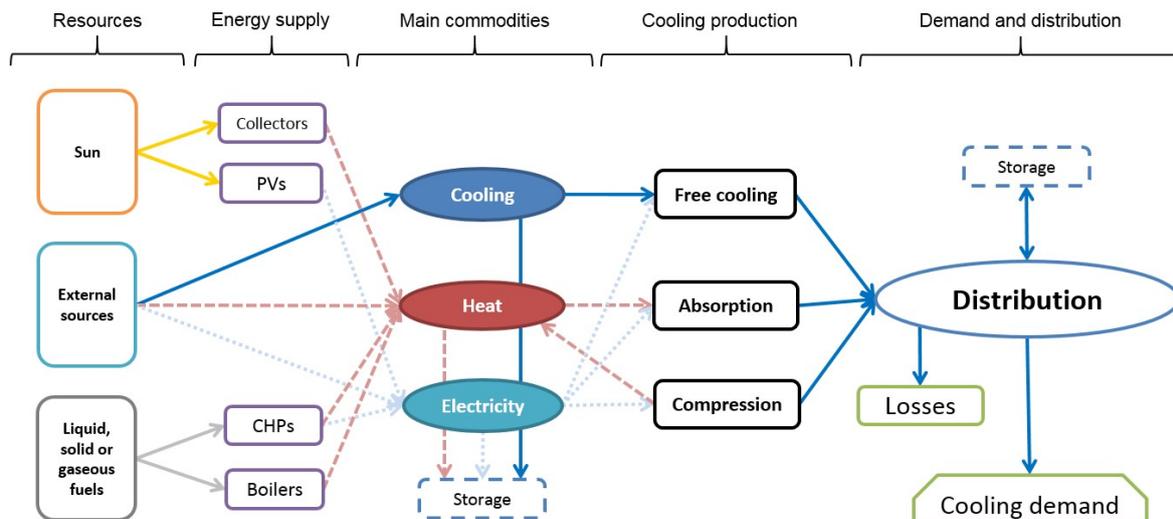


Figure 1. Structure and elements of the energy system model representing a cooling system.

IMPLEMENTATION

The program has been implemented using Python 3.4. The main supporting packages used are PySide (for Qt-based GUI), oemof (for modelling the cooling systems) and matplotlib (for visualisations within the tool).

The calculation algorithms and the data structures used in analysing the cooling systems have been implemented as classes. The interface for defining, modifying and utilising these classes has been defined into a single class (class System). This interface can also be used outside the planning tool independently.

MODEL GENERATION

A dynamic generation of a defined cooling system based on user input is at the core of the planning tool. This process is enabled by the oemof library. The resulting optimization is a linear programming (LP) model with a reasonably short solving time also with free, publicly available solvers such as CBC (Coin-or branch and cut) solver recommended by the oemof community.

In the oemof framework, an energy system consists of sources, sinks, transformers and buses between the first three with energy storages also available as dynamic elements. Sources are where the primary energy to run the system is drawn (e.g. fuels, electric grid) while the sinks represent cooling demand itself, and electric grid or heating system for possible surplus production. Transformers are components representing energy conversion units. They can be e.g. CHP units or electric chillers. These units are operated to supply the required cooling demand. Energy storages can be connected to the busses to store the corresponding commodity such as electricity or district cooling. The same structure can be seen in Figure 1.

The model generation process proceeds in following steps:

- 1) The cooling demand is defined; For a DC system, it is the sum of cooling demands of every connected consumer and the distribution losses. For a building or space specific cooling system, it is the defined cooling demand.
- 2) All the buses between sinks, sources, transformers and possible energy storages are defined. Some of these buses might be left unused if no components are connected.
- 3) Sources (i.e. resources) are generated and connected to the respective busses. A variable cost is defined for each source if needed.
- 4) A set of (possibly) defined energy supply units are generated as transformers. Each of the transformers have a connected input (resource) and one or more outputs (heat, electricity) with capacities and conversion efficiencies defined.
- 5) The energy supply units or external sources are connected to defined cooling production units. Similar to energy supply units, cooling production units have capacities and efficiencies defined. However, they all produce only cooling.
- 6) Possible storage units for electricity, heating and cooling (produced or external) may be defined according to the specifications given by the user.
- 7) The sinks are generated including cooling demand, distribution network losses, an electric grid for surplus electricity sold and a heating system connection for surplus heat sold.

Concerning the sinks, the cooling demand and losses need to be fulfilled (i.e. they are fixed). The connections for surplus production are open with a negative cost (revenue) defined. One special sink is defined for the pump electricity consumption if a distribution network exists. While the planning tool does not include a network simulation model, a simplified calculation algorithm has been implemented that returns the hourly electricity consumption based on design pressure loss (i.e. pressure loss at peak cooling demand) and cooling demand.

ANALYSIS

The analysis of the defined cooling systems consists of three main parts; energy analysis, economic analysis and emission analysis. The emission analysis takes into account both the

operation and the embedded emissions. The three analysis carried out are summarized in Table 1 below with their respective input

Table 1. Types of analysis summarised.

Type of analysis	Energy analysis	Economic analysis	Emission analysis
Description	The energy flows between defined components of a cooling system, based on results of the optimisation model.	Operational costs based on results of the optimisation and investments needed for the defined system combined.	Total emission of the specified system based on operation of the system and the system specification calculated.
Input data	System definition, commodity prices, cooling demand.	System definition, commodity prices, specific investment costs, length of analysis (years)	System definition, specific emissions (operational and for equipment/materials), component lifetime.
Results	Energy flows between components	Total costs, cumulative costs with and without revenues included.	Operational and embedded emissions.

The overall analysis process is visualised in Figure 2.

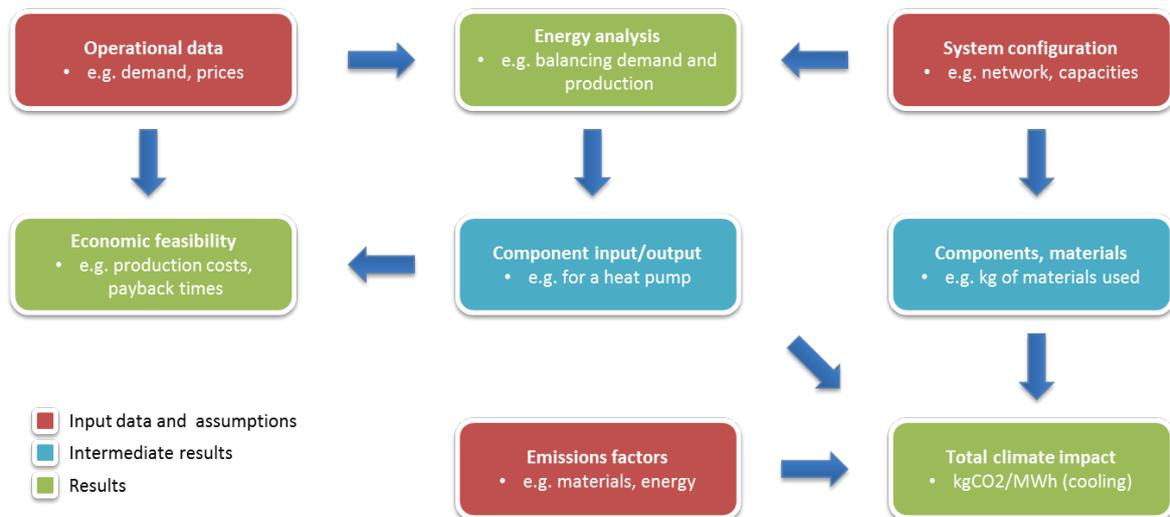


Figure 2. Overall description of the analysis to be carried out.

The analysis starts from the top right corner of Figure 2; by defining the system being investigated and preparing the required input data. Then, by solving the generated optimization model the energy flows within the system are found out. Using both information on the system components (investment) and their energy consumption (operational costs), the economic feasibility can be studied. Energy consumption and component specification are also used to calculate the life cycle climate impact (measured as greenhouse gas (GHG) emissions) of the system. The life cycle assessment covers both the operational phase and the production of components, i.e. materials used. The embedded emissions are technology specific with different values used for small and large units. The operational emissions are

calculated using location specific data, e.g. average specific emission factor of electricity for a specific country.

The results of the analyses are visualized and combined into a set of selected key performance indicators (KPIs). Possibly the most interesting indicators are price of cooling (€/MWh) and specific emissions (kgCO₂/MWh).

TYPICAL TASKS

While the cooling system analysis is not detailed enough to be used directly in design process or e.g. to optimise the operation of a real, existing system, the results are highly useful in the planning process as input for feasibility studies.



Figure 3. Examples from GUI of planning tool.

The tool includes all the main components of a cooling system, but still it is relatively easy to use. This means that different configurations can be defined quickly and compared. The economic and emission analyses are carried in long-term, enabling development of costs for different commodities to be taken into account.

In GUI of planning tool (see Figure 3 for exemplar illustration) user can easily perform GIS based model construction and system component parameterisation and create model files for optimisation in several scenarios. Furthermore, user can run DC scenarios and analyse results from optimisation, operative time series and KPIs, in several graphs and tables. User can compare different scenarios or perform sensitivity analysis subject to component (producers, supply units or storages) capacity. More detailed description of user's options can be examined from [21].

The potential users for the tool include communities that want to include energy planning related to cooling demand in e.g. city planning, master planners developing e.g. a specific area or consultants producing feasibility studies. Energy utilities can also make use of the tool should they want to quickly study a specific system with different alternative cooling solutions before assessing a system in more detail e.g. before a possible tendering or design process.

CONCLUSION

An open-source planning tool focusing on the design phase of a DC system has been developed within the project INDIGO. The purpose of the tool is to support the design and planning of new DC systems, and the assessment of existing DC systems' potential for performance/efficiency improvement.

The tool is implemented in Python with the main supporting libraries being PySide (for GUI), oemof (for energy system modelling) and matplotlib (for visualisation of results). The tool is available as open-source within GPL 3.0 license.

The aim of the tool is to be easy to setup, configure and use - enabling feasibility study type investigation of an arbitrary cooling system. The built-in model generation provides a simple LP model for the defined system. While not being 100 % accurate, the method still provides reasonable input e.g. for a feasibility study. As setting up different kinds of systems is easy, the user can try out and compare different configurations and find out how the defined system performs with different input assumptions.

The tool analyses the defined system from energy, economic and emission point of view. The energy analysis consists of building and solving the LP model providing information on the energy flows between all the main components within a cooling system. Economic analysis uses this input as well as investment cost

The LCA data in the model is generic by nature and it is therefore appropriate for screening studies and simplified LCAs but for more specific assessment the user is encouraged to replace the model data with more specific data representing the exact system analysed, particularly data on processes that most affect the results.

The results are visualised and a set of KPIs are calculated. These KPIs combine the results of the energy, economic and emission analyses, e.g. as specific emissions for cooling supplied.

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NOMENCLATURE

DC	District cooling
GHG	Greenhouse gases
GIS	Geographic information system
GUI	Graphical user interface
KPI	Key performance indicator
LCA	Life cycle analysis
LP	Linear programming

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