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Fit4Micro

Deliverable 5.1

Report on 4 use case definitions for system development and evaluations

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History of Changes

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1. Executive summary

The objective of this deliverable is the identification of promising heating and cooling applications for the micro gas turbine (mGT) systems under development in the project Fit4Micro. To this end simulated load profiles of five different building applications are evaluated in terms of achievable full load hours. It turns out that a substantial number of full load hours, required for economic feasibility of such a technology (4000 hs were selected, as for other types of CHP), occurs only in large existing buildings in central northern European climates. A high demand of domestic hot water (e.g. in hospitals, hotels, retirement homes) supports the feasibility of an mGT system. The average consumption indicates that the electricity production of the mGT can be used onsite to a large extent.

With regard to cooling by combining the mGT with a thermally driven chiller (e.g. adsorption chiller), it turns out that it is unlikely to reach sufficient operating hours for a profitable system merely for the air conditioning of buildings. If process cooling in a suitable temperature (>5°C) range is required during a significant share of the year, this solution may become interesting in terms of economics.

The following four use cases have been defined for system development and evaluation in the project:

- Existing (1990s) multi-family house in Helsinki, Finland
- Existing (1990s) office building in Strasburg, France
- Old existing health building in Potsdam, Germany
- Old existing lodging building in Potsdam, Germany

2. Objective

The objective of WP5.1 of the project Fit4Micro and this corresponding deliverable is the identification of use cases (applications) in which the implementation of a micro gas turbine (mGT) – possibly in combination with an electric heat pump, a thermally driven chiller (TDC, in this case an adsorption chiller) and/or photovoltaics – seems generally promising in terms of system layout, economics and ecological aspects.

3. Methodology

To meet the objective described above, the applications were split into two major groups which were studied separately in the following:

- buildings and their respective heating and/or cooling demand, to be studied for all variants of mGT-system configurations
- industrial/commercial (manufacturing) processes which require cooling as potential applications for the combination of a mGT with a TDC

The assessment of these applications with regard to their suitability for the mGT-systems requires the definition of evaluation criteria, which is also done in this chapter.

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3.1. Characteristics of applications

3.1.1. Heating and cooling of buildings

In a first step, simulated generic load profiles for the heating and cooling demand of five building applications were studied, in order to identify promising options for the technology under study. Two sources of load profiles were considered for this purpose.

3.1.1.1. Load files for three European reference locations

In the project Speicher-LCA[1] detailed multi-zone building models for small to medium size multi-family houses and office buildings were created in Trnsys[2]. Helsinki (Finland), Strasbourg (France) and Athens (Greece) were fixed as reference locations and the respective average climates were generated in hourly resolution with the software Meteonorm[3]. A single building geometry was defined for each application independently of the location. The definition of the building physics relied on the average data collected in the Tabula database[4]. Four building standards were implemented: average 90s construction standards of all locations and a highly efficient building (corresponding to construction years after 2010). Which building standard was actually simulated in which location is documented in Table 1. The output of the simulations are hourly load profiles for heating and cooling, a DHW profile was generated separately. No electricity profile is available for these applications.

Table 1: Allocation of building standards to studied locations.

Location	90s Athens	90s Strasbourg	90s Helsinki	High Efficiency
Athens	x	x	x	X
Strasbourg		X	x	x
Helsinki			x	x

Figure 1 illustrates the implemented building geometries and lists some of their key specifications:

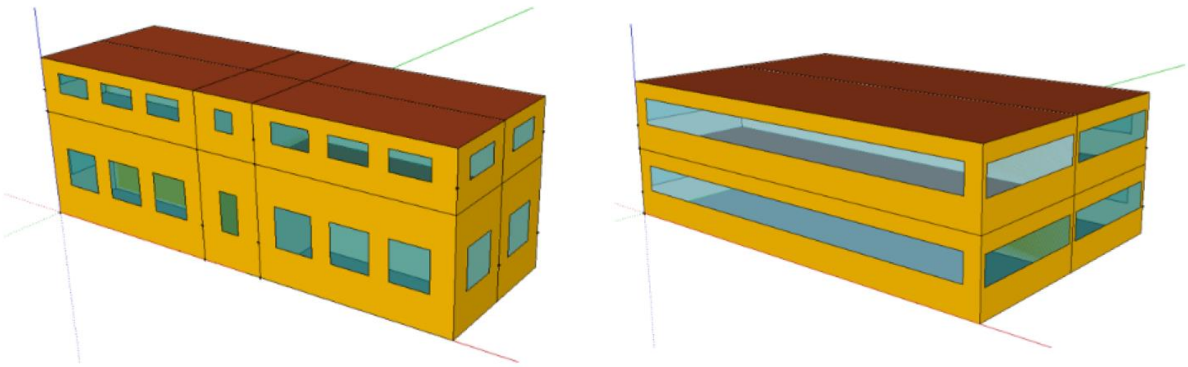

Figure 1: Geometries of the studied buildings; left: multi family house with 555m², right: office building with 520m²

[1] See: https://www.ise.fraunhofer.de/en/research-projects/speicher-lca.html and/or https://doi.org/10.2314/KXP:1696848008
[2] See: http://www.trnsys.com/
[3] See: https://meteonorm.com/en/meteonorm-version-8
[4] https://webtool.building-typology.eu/

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3.1.1.2. Load files for additional non-residential applications

To achieve the relatively high operation hours required by the evaluation criteria (see chapter 3.2), two additional applications were included in the study. These are health (e.g. hospitals, retirement homes) and lodging buildings, as they are known to have a relatively high and constant hot water demand over the year. Since little information is available on the typical configurations of these buildings over Europe and variability is high in each group, data for average buildings of these categories, gathered in the German project "EnOB:dataNWG[5]", in combination with average climate data for Potsdam (Germany) was used to generate the load profiles for heating, hot water, cooling and electricity in the software synPro[6].

Table 2: Heated area of average German buildings according to EnOB:dataNWG

Application	Before 19779	1979-2009	After 2009
Health	3828m²	2550m²	2253m²
Lodging	765m²	826m²	2252m²

Processes

To complement the demand profiles of buildings, characteristics of the cooling demand of various processes were derived from a short literature review. It is based on two studies on the cooling demand in Germany, which rely on various further sources.

- Report "Refrigeration technology in Germany – Characteristics of typical applications"[7]
- "Guidelines for energy audits for cooling systems"[8]

3.2. Evaluation criteria

According to a rule of thumb, combined heat and power (CHP) plants should reach a minimum number of 4000 full load hours (FLH) per year in order to supply heat and electric power economically. Evidently, this value depends on the specific boundary conditions of the respective application. If the installation shall also serve as backup in the case of power outages, much lower operating hours are acceptable. For the generic identification of promising applications, this value is adopted also for the mGT, which is a special type of CHP. Since the heat demand for space heating is highly dependent on the ambient temperature, the actual demand hours should be significantly higher to achieve 4000 FLH per year.

The procedure to determine the required area of a building type to reach 4000 FLH for the nominal capacity of the mGT (30kW) is illustrated in Figure 2: an annual heat load duration curve is scaled with the aim to reach 4000 FLH for a heating capacity of 30kW. The scaling factor (in case of the shown example 2.2) is then used to determine the required building area of the studied building type. As large buildings have a lower A/V-ratio[9] and thus lower specific thermal losses, the nominal heating demand is not linearly proportional to the heated surface. In Figure 6 in the Annex a correlation between heated building area and required peak heating power is derived. This equation is used. For the example profile shown in Figure 2 the building area

[5] https://datanwg.de/forschungsdatenbank/
[6] https://synpro-lastprofile.de/
[7] https://www.umsicht.fraunhofer.de/content/dam/umsicht/de/dokumente/referenzen/flexkaelte/Kältetechnik_in_Deutschland-Steckbriefe_zu_Kälteanwendungen.pdf
[8] https://www.klimaaktiv.at/dam/jcr:af481c17-4045-4b9e-95ed-a41111c57d90/Kälteleitfaden_2020_barrierefrei.pdf
[9] A/V-ratio: outer surface to volume ratio

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therefore needs to be adapted by a factor of $2.2^{1.17} = 2.52$. It must be highlighted that this approach does not account for variations in the building geometry, among other factors. Therefore, the results can only be considered as indicative.

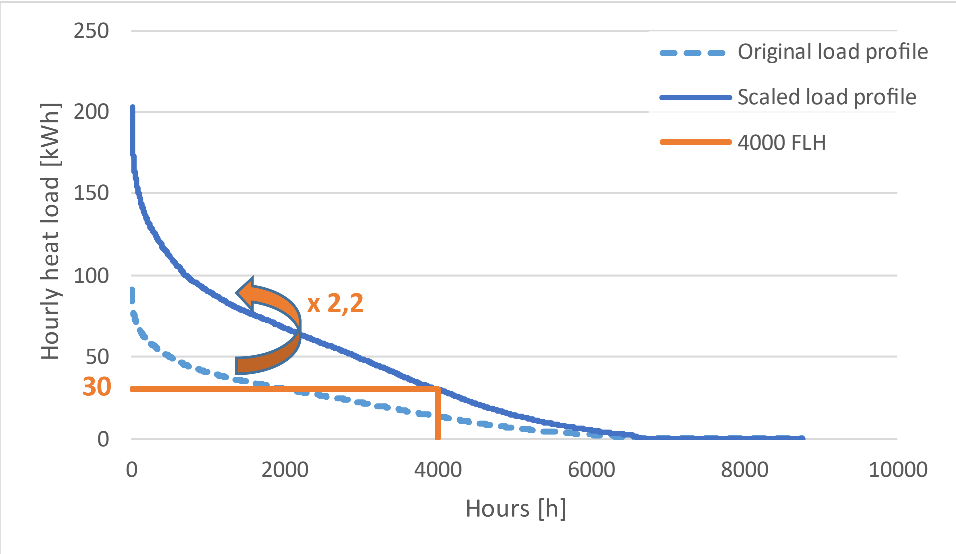

Figure 2: Annual heat load duration curve of an example building scaled to 30kW at 4000FLH

The average electricity consumption evidently is also a relevant information when evaluating the feasibility of mGT which produces heat and electricity simultaneously.

Practice has also shown that a significant number of operating hours is also essential for the economic viability of thermally driven chillers. Realized commercial projects typically also have operating hours above 3000-4000 hours, so this range shall serve as threshold where a TDC shall be combined with the mGT. Additionally, the required supply temperature must be considered to identify suitable applications for TDC, which use water as refrigerant. Therefore, only applications with cooling demand above 5°C are considered.

4. Results

4.1. Buildings

Figure 3 contains an overview on the key characteristics of the buildings studied in different locations over Europe (more comprehensive information can be found in Table 3 in the Annex of this document). Decisive for the evaluation of the suitability for a mGT-system are the heating hours (space heating only) and the heat demand hours (including domestic hot water, DHW). Since the DHW demand in office building is very low (and frequently covered by decentralized electric heaters) it is neglected in this evaluation. For the MFH there is a DHW demand during slightly over 4000 hours, so all of the MFH meet the threshold if the DHW demand is considered. Yet, since the average power for DHW preparation during hours of demand is 2.5kW only, the mere supply of DHW is not feasible for the mGT in this capacity range.

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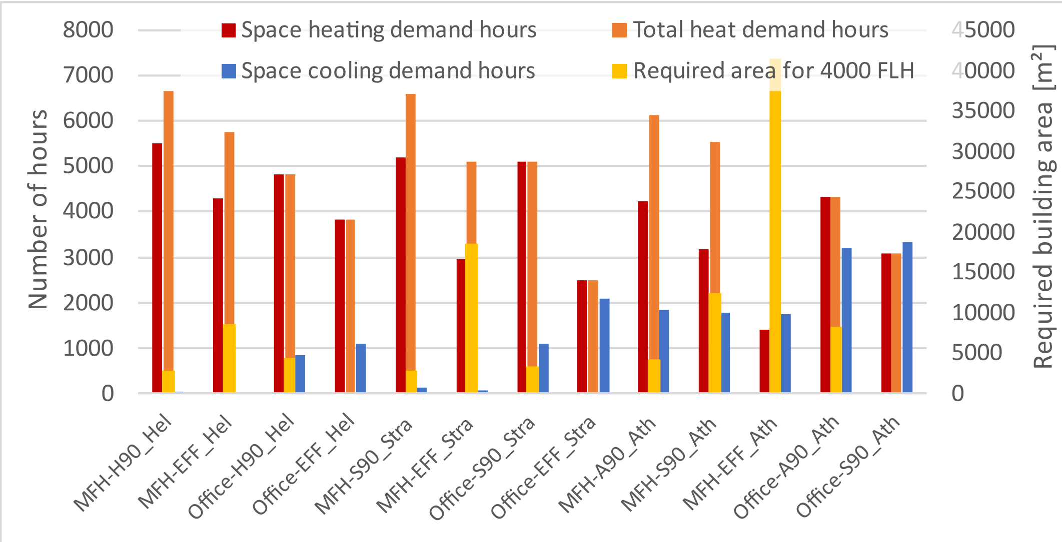

Figure 3: Overview on demand hours (left axis) and heating capacity with which 4000 full load hours will be reached for multi family houses and office buildings with various building standards in three European locations; the columns can be interpreted by this code: application (MFH – multi family house; office building) – building standard (average building of the 1990s in Helsinki/Finland [H], Strasbourg [S] or Athens [A] or highly efficient building [EFF]) – Location:

Not surprisingly, the buildings in Helsinki have the highest number of heating hours. Only the highly efficient office building does not reach the threshold of 4000 FLH here. The older buildings in Strasbourg also exceed the 4000 heating hours. In Athens only the existing office building reaches the minimum amount of heating hours. Yet, as actual comfort requirements in Southern Europe may deviate from normative conditions, these values must be considered cautiously.

The building area required to achieve 4000 FLH with the mGT is also included in the graph. Evidently, the mGT is suitable only for larger buildings. The required areas range from approximately 2800m² for buildings with average building standards of the 1990s in central and northern Europe (Strasburg and Helsinki), to more than 10000m² for highly efficient buildings in these regions and all buildings in southern Europe (Athens). Table 3 in the Annex shows that the mGT should have a capacity of 16% in relation to the maximum heat demand of the building (including DHW) for existing buildings in the northern locations Helsinki and Strasbourg. In most other applications the 4000 FLH are only reached with dimensioning ratios (mGT-capacity to nominal heat load including DHW) below 10%.

With regard to cooling, the office buildings in Athens could be interesting as they have above 3000 cooling demand hours combined with a significant amount of heat demand hours. Again, these results are less reliable due to presumably differing comfort requirements in reality than fixed in the simulations.

In the additional non-residential applications, the heat demand hours exceed the threshold in all cases. If the DHW is considered, there even is constant heat demand throughout the year. Naturally, the specific energy demand per area decreases in all cases.

Concerning the required building area to reach 4000 FLH with the mGT, the values are well below 2500m² for the studied lodging buildings of all ages and the old health buildings. As shown in Table 3 in the Annex, the average electricity consumption is equal or higher than the output of the mGT, which indicates that a high share of onsite self-consumption can be expected.

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As Table 4 indicates, also the dimensioning with regard to the nominal (maximum) heat demand is different compared to the applications studied above: for most cases it is in the range of 20%. Because of the moderate climate in Germany, the space cooling demand hours alone do not justify the use of a TDC. Yet, in combination with additional cooling demands for medical appliances it may be feasible in hospitals (see chapter 4.2).

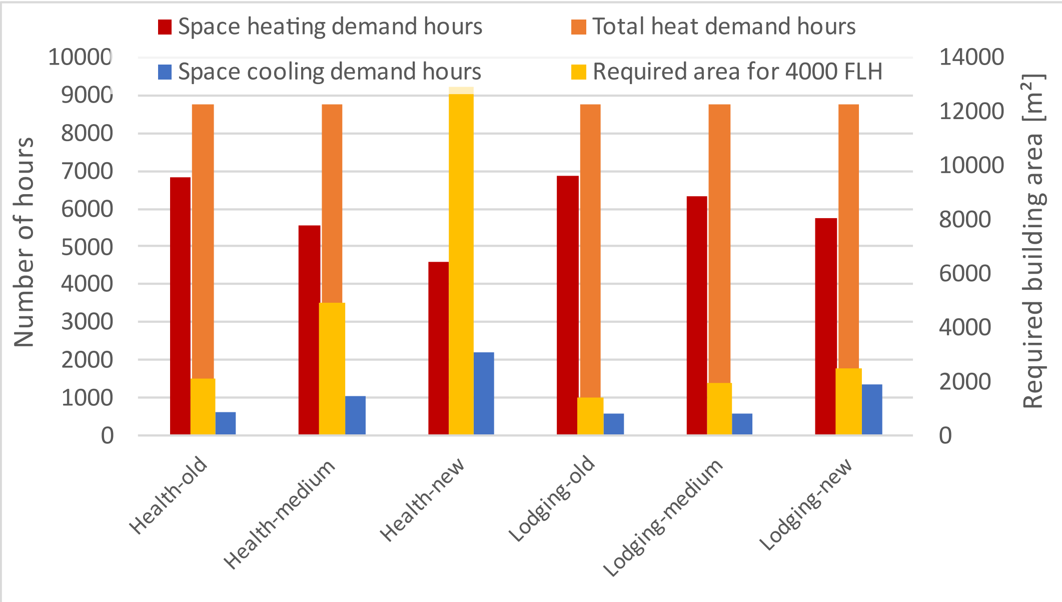

Figure 4: Overview on demand hours (left axis) and heating capacity with which 4000 full load hours will be reached for health and lodging buildings; old: construction before 1979, medium: construction 1979-2009, new: construction after 2009

4.2. Processes

Based on the two studies described in the methodology section, these applications require cooling temperatures above 5°C and can reach a significant amount of operating hours (OH):

- Automotive industry (e.g air conditioning in paint shops, test facilities, cooling of production facilities: >4000 OH (min. 2 production shifts)
- Plastics industry (e.g cooling of products and tools in extrusion or injection molding processes): >4000 OH (min. 2 production shifts)
- Machine construction (e.g. cooling of machine parts): ~2000 OH for (1 production shift), >4000 OH (2 production shifts)
- Paper industry (cooling of rolls, conditioning of production facilities): >4000 OH (min. 2 production shifts)
- Pharmaceutical industry (e.g. air conditioning of production and storage facilities): >4000 OH (min. 2 production shifts)
- Hospitals (cooling of health care technology, air conditioning): 1500…3500 OH
- Data centers (cooling of the information technology): up to 8760 OH

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The time resolved cooling load of these loads varies strongly. While manufacturing processes can require constant cooling for continuously operating machines (e.g. the rolls in paper mills), intermittent processes result in a fluctuating load profile (e.g. batch processes). If the processes require conditioned outside air the acutal climate evidently has a strong impact on the load. The same applies if the air conditions of an application need to be maintained within certain boundaries.

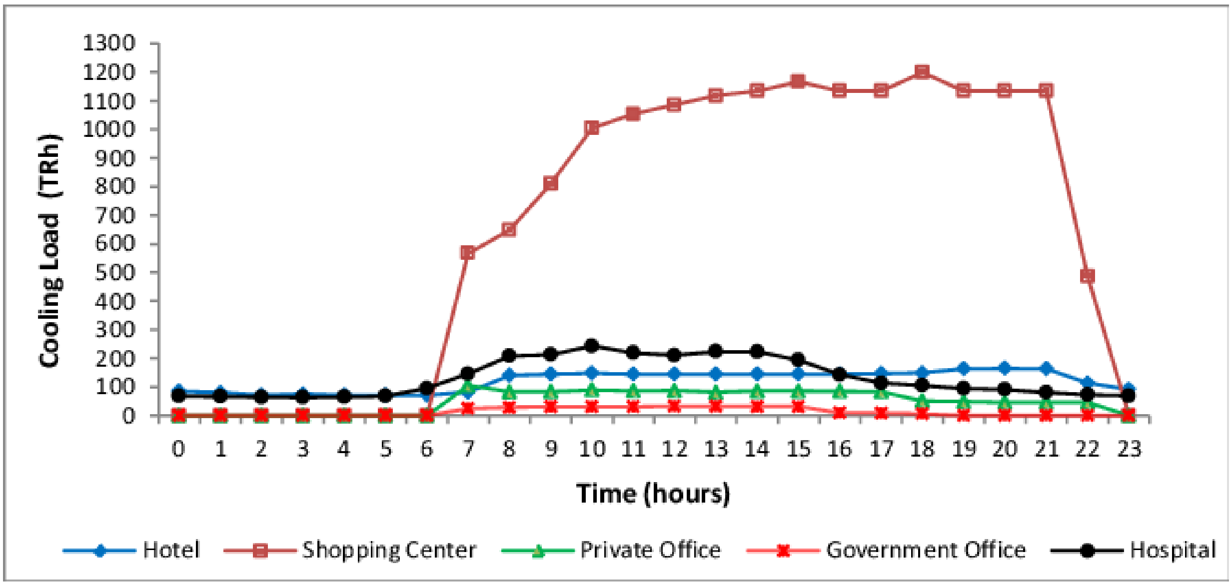

Figure 5: Exemplary load profiles of different non-residential buildings[10]

5. Conclusion and outlook

In this report different applications have been evaluated based on basic evaluation criteria regarding the feasibility of a heat supply system based on a mGT and/or a cooling system combining a mGT and a TDC.

In residential and office buildings the mGT seems promising only for large buildings as a base load supplier of heat (dimensioning typically to <15% of maximum load). In office buildings in southern climates with an extended cooling demand, the combination with a TDC may be feasible.

Non-residential buildings with high occupancy and significant DHW demand such as hospitals and lodging buildings can be regarded as auspicious for mGT systems as well. Due to a more constant load, the mGT can cover a higher share of the required load. A dimensioning to up to 30% of the peak demand can be feasible. The simulated average electricity consumption indicates that a high share of the electricity produced by the mGT can be consumed in the building itself.

The integration of mGT-TDC combinations in processes for cooling depends highly on the demand hours and the required temperature. An overview on possible application is given in chapter 4.2.

The following four use cases have been defined for system development and evaluation in the project:

10 https://www.researchgate.net/publication/292670297_Thermal_Energy_Storage_Optimization_in_Shopping_Center_Buildings

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- Existing (1990s) multi-family house in Helsinki, Finland
- Existing (1990s) office building in Strasburg, France
- Old existing health building in Potsdam, Germany
- Old existing lodging building in Potsdam, Germany

6. Annex

6.1. Result overview for reference buildings in Helsinki, Strasburg and Athens

*Table 3: Characteristic demand values of the buildings studied in reference locations over Europe, scaled to achieve 4000 FLH at 30kW; the columns can be interpreted by this code: application (MFH – mulit family house; office building) – building standard (average building of the 1990s in Helsinki/Finland [H], Strasbourg [S] or Athens [A] or highly efficient building [EFF]) – Location: **Hel**sinki, **Stra**sbourg or **Ath**ens*

		Application - Building Standard - Location												
	Unit	MFH-H90_Hel	MFH-EFF_Hel	Office-H90_Hel	Office-EFF_Hel	MFH-S90_Stra	MFH-EFF_Stra	Office-S90_Stra	Office-EFF_Stra	MFH-A90_Ath	MFH-S90_Ath	MFH-EFF_Ath	Office-A90_Ath	Office-S90_Ath
Space heating (SH) demand	kWh	62771	30415	71431	48517	70370	15242	83302	25234	92203	34222	5252	102345	39285
Peak space heating power	kW	43	30	75	63	46	23	72	47	75	45	23	93	61
Heating hours	h	5517	4299	4810	3812	5198	2957	5107	2489	4233	3180	1390	4338	3089
Total heat demand (SH+DHW)	kWh	72941	40584	71431	48517	80539	25411	83302	25234	102373	44391	15422	102345	39285
DHW-share		14%	25%	0%	0%	13%	40%	0%	0%	10%	23%	66%	0%	0%
Peak heating power	kW	46	36	75	63	52	30	72	47	83	50	30	93	61
Heat demand hours	h	6673	5746	4810	3812	6589	5111	5107	2489	6143	5535	4533	4338	3089
Required area for 4000 FLH	m²	2726	8613	4298	n.a.	2727	18544	3277	n.a.	4120	12460	41412	8149	n.a.
Q_mGT,4000/Q_peak		16%	8%	6%	0%	15%	6%	8%	0%	6%	4%	3%	3%	0%
Space cooling demand	kWh	0	0	2120	2572	125	18	4170	7214	8187	7950	5518	27978	24875
Peak cooling power	kW	0	0	14	12	4	2	17	16	16	13	7	30	25
Cooling hours	h	3	0	844	1093	129	58	1091	2078	1842	1757	1736	3194	3322

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6.2. Result overview for non-residential reference buildings in Potsdam

Table 4: Characteristic demand values of the non-residential buildings studied in the German reference location Potsdam, scaled to achieve 4000 FLH at 30kW

		Application - building age					
	Unit	Health-old	Health-medium	Health-new	Lodging-old	Lodging-medium	Lodging-new
Space heating (SH) demand	kWh	239102	333572	659931	234414	236926	190112
Peak space heating power	kW	140	251	672	115	132	166
Heating hours	h	6841	5555	4599	6887	6344	5754
Total heat demand (SH+DHW)	kWh	246959	352017	708410	284657	306398	280273
DHW-share		3%	5%	7%	18%	23%	32%
Peak heating power	kW	141	254	678	133	152	200
Heat demand hours	h	8760	8760	8760	8755	8755	8756
Required area for 4000 FLH	m²	2095	4919	12927	1415	1939	2480
Q_mGT,4000/Q_peak		36%	7%	1%	15%	11%	17%
Space cooling demand	kWh	5883	27244	180216	4477	7075	21221
Peak cooling power	kW	46	129	359	41	56	77
Cooling hours	h	607	1024	2194	561	561	1343
Peak electric power	kW	29.0	72.4	194.0	28.9	40.5	49.8
Average electric power	kW	9.9	23.5	63.6	10.4	14.4	18.9
Minimum electric power	kW	2.7	6.3	16.7	4.6	6.5	9.4

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6.3. Correlation of heated building area and required peak heating capacity

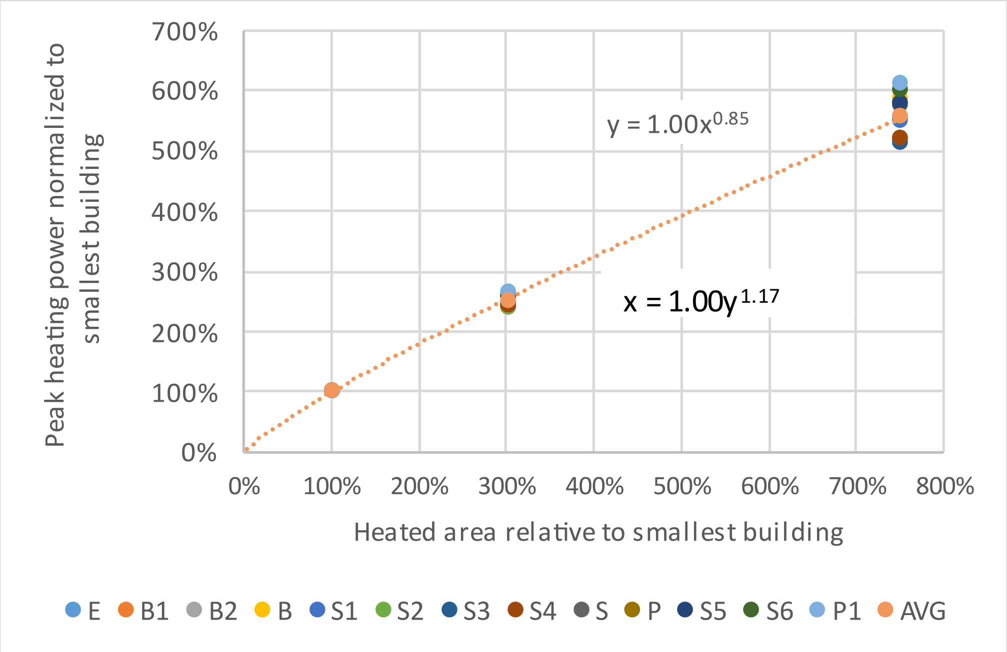

Figure 6: Relation between peak heating power and building area for 13 different variants of building envelops based on typical multi family houses for the German stock[11]

[11] http://www.lowex-bestand.de/wp-content/uploads/2022/03/2022-03-18_AP-1.1_Bestandsanalyse_final.pdf_Table 9-4, page 31

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6.4. Heat demand load profiles for the selected use cases (scaled for 4000 FLH at 30kW)

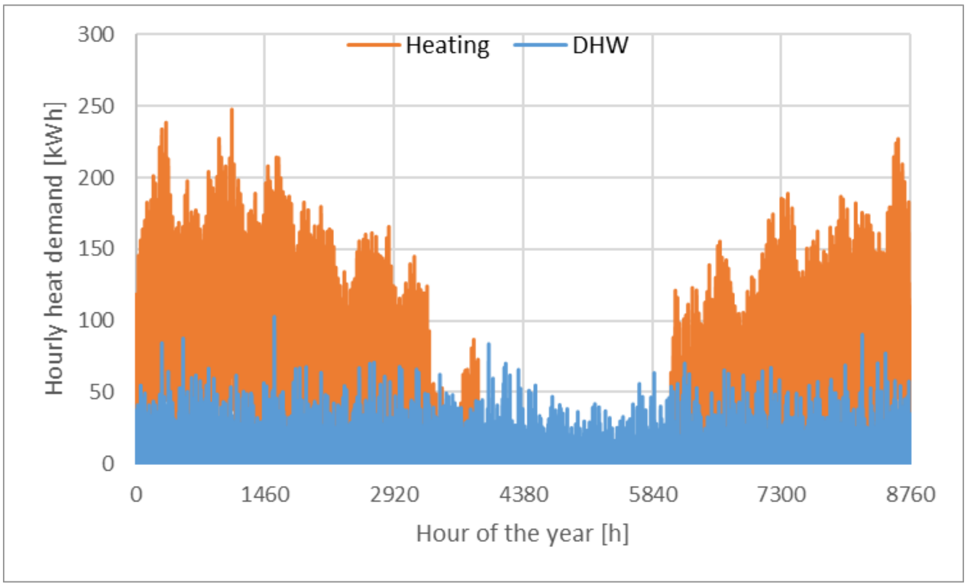

Figure 7: Demand profiles for heating and DHW for the 1990s multi family house in Helsinki

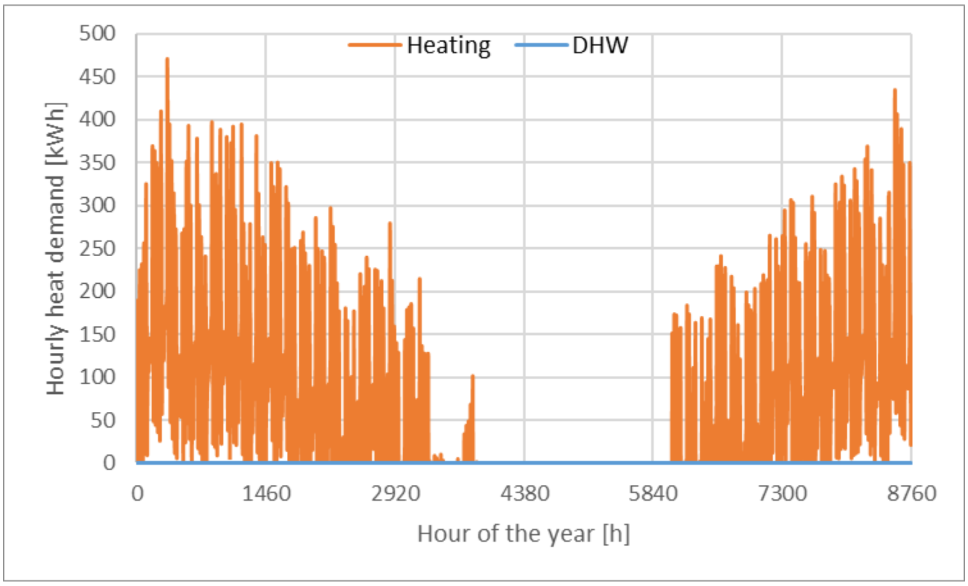

Figure 8: Demand profiles for heating and DHW for 1990s office building in Strasburg

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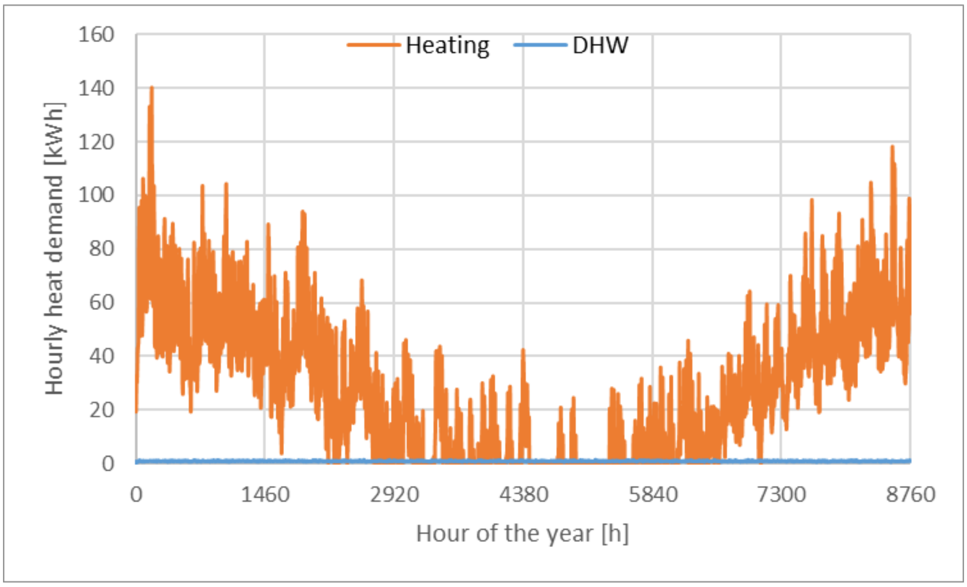

Figure 9: Demand profiles for heating and DHW for the old health building in Potsdam

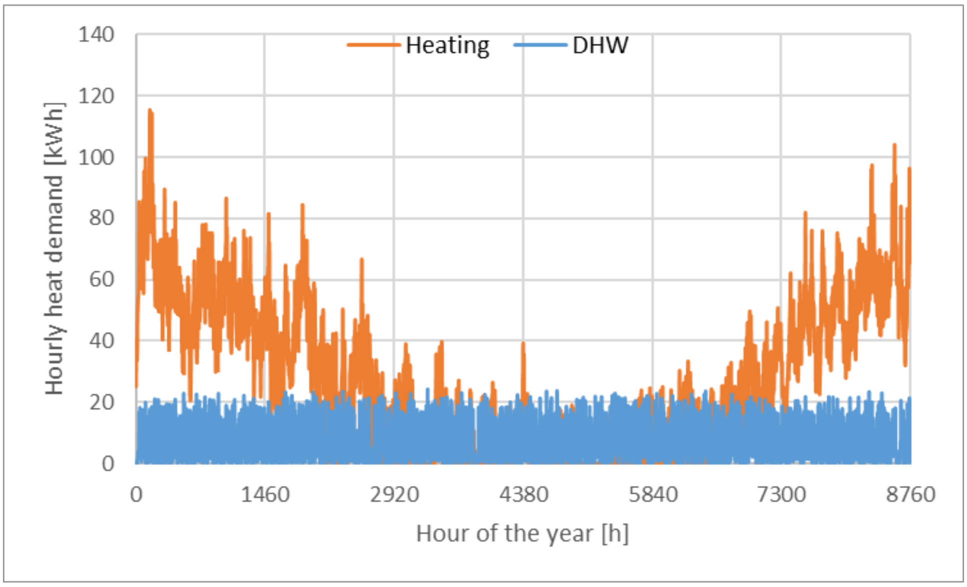

Figure 10: Demand profiles for heating and DHW for the old lodging building in Potsdam

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