Acta Polytechnica CTU Proceedings **38**:429–435, 2022
https://doi.org/10.14311/APP.2022.38.0429

DEVELOPMENT OF A REALISTIC SCENARIO FOR THE THERMAL ENERGY DEMAND OF RESIDENTIAL BUILDINGS IN BAVARIA TILL 2050

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Abstract. To achieve the climate protection goals, enormous efforts must be undertaken in all sectors: households, industry, commerce, and transport. Following a straightforward approach, the political objectives foresee, that in the building sector a massive reduction of energy use for the heat supply is accomplished. However, previous investigations have shown that this reduction of energy consumption is not feasible. Older buildings exhibit especially high energy demand and emissions. Yet, due to the low refurbishment rate, no substantial change of the heat demand can be expected within the next decades. By fully renovating the entire residential building stock, approximately 70 % of the final energy demand and related CO_2 emissions could be saved, still not enough to reach the political goals. Therefore, renovation or renewal of buildings and of the use of renewable energy sources have to be implemented jointly for achieving the desired savings.

The methods used to estimate the characteristics of Bavaria's residential building stock as well as its heating energy demand and related CO_2 emissions for the year 2050 are presented. Alternative goals are given which base upon the achievable final energy saving for a realistic renovation scenario accompanied by further reduction of CO_2 emissions by using renewable energies.

Keywords: Refurbishment, building stock, climate neutrality.

1. Introduction

In order to achieve the European, German and Bavarian climate protection goals, enormous efforts must be undertaken to accomplish substantial emissions reduction in all sectors: households, industry, commerce, and transport. Following a straightforward approach, the political objectives foresee, that in the building sector this goal is reached by massive reduction of the final energy use for the heat supply of buildings. However, previous investigations have shown that the targeted reduction of final energy consumption in the building sector is not feasible. Older buildings exhibit especially high energy demand and high CO_2 emissions. Yet, due to the low refurbishment rate, no substantial change of the heat demand is to be expected in the near future. By fully renovating the entire residential building stock, approximately 70 % of the final energy demand and related CO_2 emissions could be saved, still not enough to reach the political goals. Therefore, goals that achieve reduction of final energy and CO_2 emissions through a combination of renovation or renewal of buildings and the use of renewable energy sources have to be defined in order to meet reasonable objectives regarding CO_2 emissions. The proposed pathway could form the starting point for reformulating the political goals for the future energy use, finally targeting climate neutrality of the building heat supply sector.

2. Methods

To define realistic objectives for an effective transformation of the energy supply to residential houses, a detailed characterization of the heat demand with regard to all relevant criteria is required. There are numerous sources that describe building age classes as well as building types and provide statistical data on flat size, flat layout, specific energy demand and other parameters. However, there is no comprehensive overview available of how the individual criteria influence the heat demand of a specific building. Therefore, data regarding the composition of the Bavarian residential building stock and its final energy demand has been collected and the impact of different criteria has been shown. As final result a very detailed data set comprising 840 building variants, classified by four criteria, has been obtained from which a large number of specific statements can be derived. As shown in the Figures 1 to 4, these data were generated by linking and correlational analysis of individual data sources in order to derive the desired statistical results for the characterization of the building stock and its energy demand for space heating and domestic hot water.

At the beginning, the demand of final energy for the heat supply of the Bavarian residential building stock has been analysed. In a first step, the perspective of the energy supply has been taken to obtain a reference value for the heat supply data, to be derived from the

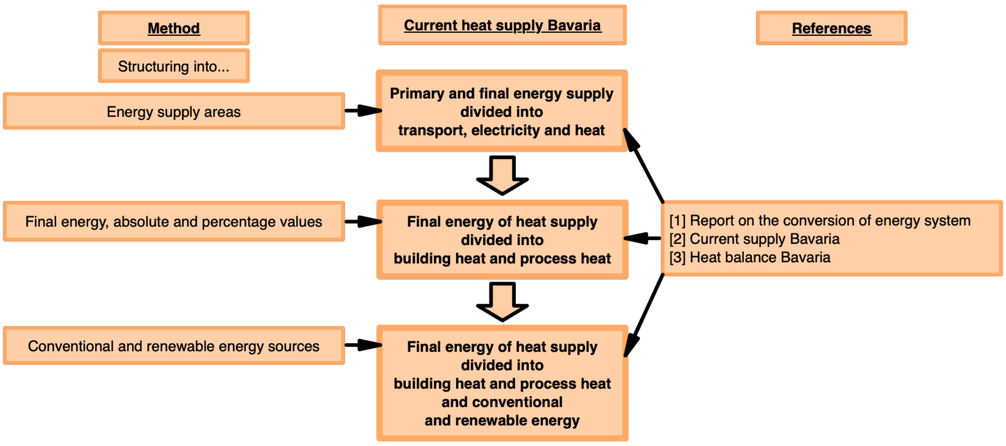

Figure 1. Balance heat supply residential buildings in Bavaria 2016. ([1–3]).

physical data of the building stock in the following step. (Figure 1). For this purpose, it was determined which amounts of the different energy carriers are provided for the heat supply of the residential houses.

In the second step, the situation has been investigated from the perspective of the consumers (Figure 2). The composition of the Bavarian residential building stock has been characterized first, then the final energy demand has been determined, partitioned according to various criteria such as building categories and age. The main part of the physical data comes from the German census [4, 5] and the European wide developed building typology within the TABULA project [10, 11]. The energy values of the two approaches – supply and consumption – are congruent with a deviation of less than 5 %.

Subsequently, a forecast for the development of the Bavarian residential building stock and its final energy demand for the period until 2050 has been generated (Figure 3). For this purpose, assumptions have been made in a realistic scenario about how the construction of new residential houses, the demolition and the renovation rate for existing buildings and the specific energy demand of the different building types will develop in the future.

Results for the energy demand and greenhouse gas emissions have been generated with reference to the climate policy objectives of the EU, the Federal Republic of Germany and the Federal State of Bavaria. These reduction goals were then transferred to the heat supply of the Bavarian residential building stock (Figure 4), comprising the heat quantities for space heating and domestic hot water.

In order to evaluate the reduction potential, it was considered how far the final energy demand of the residential building stock could be reduced until 2050, if all existing buildings were fully refurbished and the new houses had the highest energy standard of the respective year of construction. This shows the theoretical maximum savings potential in final energy and the associated greenhouse gas emissions for the heat supply of the Bavarian residential building stock.

3. Results and Discussion

Detailed results and analysis on the composition of the Bavarian building stock and its energy demand for space heating and domestic hot water preparation have already been published [25, 26]. Examples for the use of these data for further analysis supported by appropriate reference building models have been presented in [27, 28]. A rough summary of the results for the heat demand concerning the shares of different building types are shown in Table 1.

Figure 5 and Table 2 show the results on the final energy values for different scenarios.

Political objectives: Transferring the global political objectives for the energy use in all sectors to the heat demand (space heating and domestic hot water) of residential houses results in a target value for the final energy of approx. 24 800 GWh. Compared to all other scenarios, this represents the politically targeted energy demand of the building sector in 2050.

Rate of refurbishment constant: A constant renovation rate of 1 % per year was assumed for this “business as usual” case. In this scenario, the energy demand is reduced by 19 % from about 101 300 GWh in 2016 to about 82 000 GWh by 2050. Although it is not a pessimistic scenario, the result for the remaining energy demand is more than 57 000 GWh/a above the political goal.

Rate of refurbishment enhanced: This scenario based on optimistic, yet still realistic assumptions, for the development until 2050 still misses the political objectives significantly. The reduction of the final energy demand by approx. 30 400 GWh to approx. 71 000 GWh is not sufficient. An additional reduction of more than 46 200 GWh to about 24 800 GWh would be necessary to reach the political goal. To reach this goal the effort for renewal and renovation of the building stock would have to be increased by a factor of about 2.5.

Full refurbishment: The maximum potential for the reduction of the final energy demand can be exploited through the full refurbishment of the residential build-

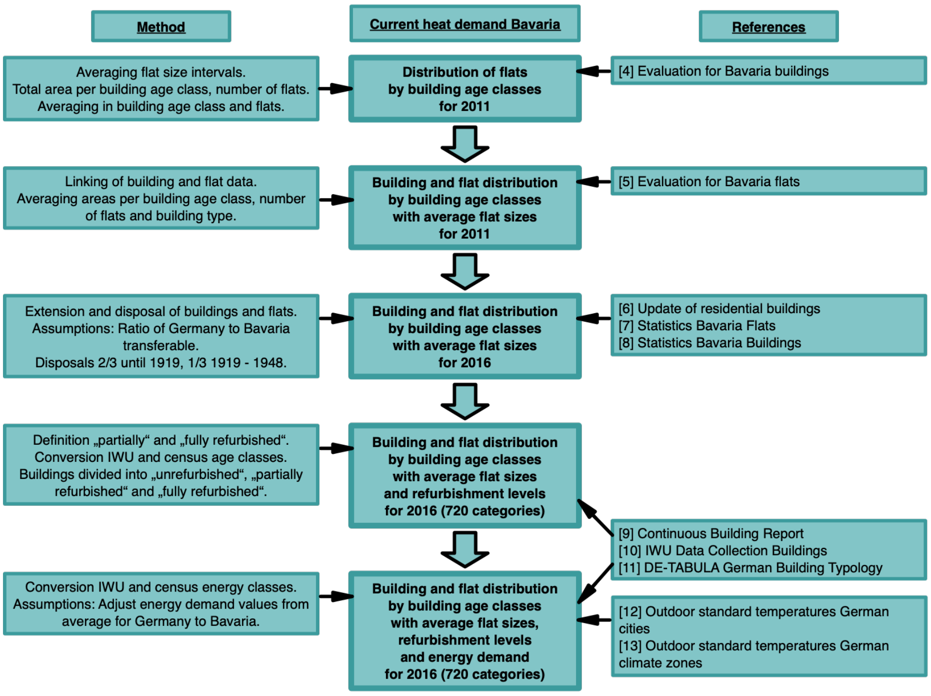

Figure 2. Balance heat demand residential buildings in Bavaria 2016. ([4], [5], [6–8], [9–11], [12, 13]).

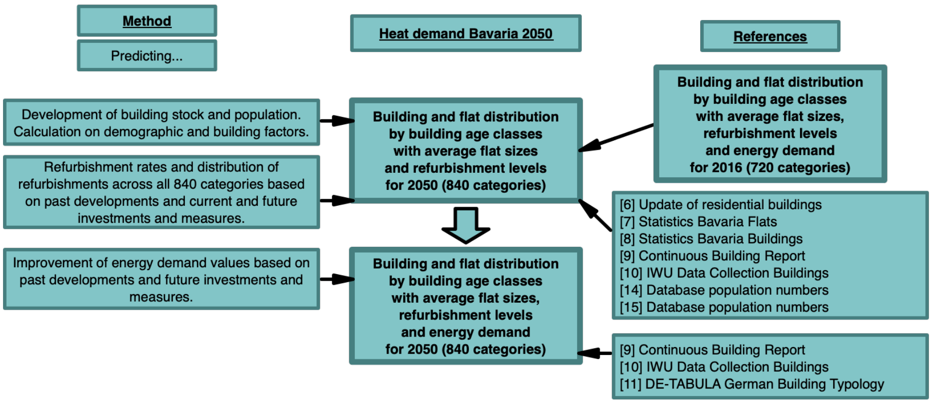

Figure 3. Balance heat demand residential buildings in Bavaria 2050. ([6–10, 14, 15], [9–11]).

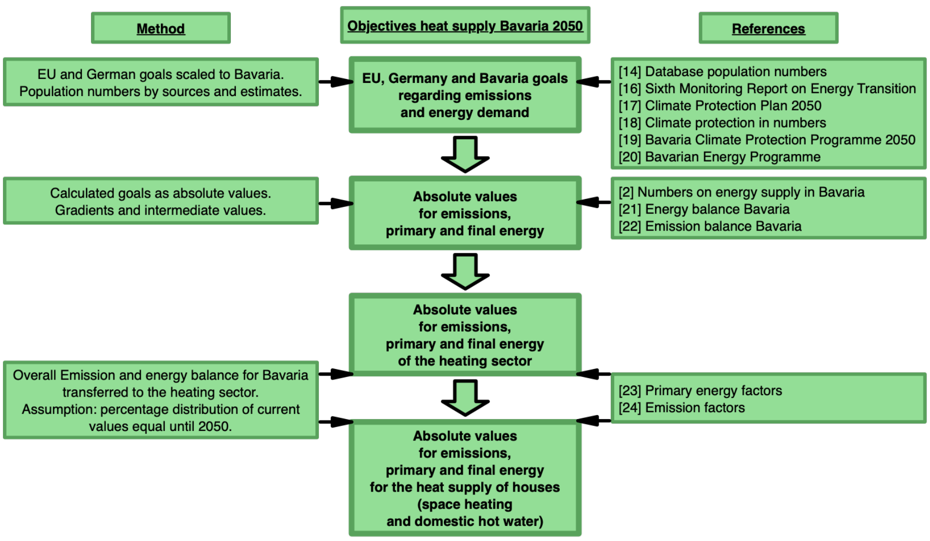

Figure 4. Objectives for the heat supply of residential buildings in Bavaria until 2050. ([14, 16–20], [2, 21, 22], [23, 24]).

	Residential building stock Bavaria 2050			
	Buildings [pcs]		Final Energy [GWh]	
Residential buildings total	3 501 476	100 %	70 895	100 %
Buildings unrefurbished	1 307 604	37.3 %	36 706	51.8 %
Buildings partly refurbished	996 197	28.5 %	23 591	33.3 %
Buildings fully refurbished	1 197 675	34.2 %	10 598	14.9 %
Detached houses	2 347 775	67.1 %	46 308	65.3 %
Semi-detached houses	495 207	14.1 %	7 915	11.2 %
Terraced houses	515 769	14.7 %	13 246	18.7 %
Other building types	142 725	4.1 %	3 427	4.8 %
Buildings with 1 flat	2 358 452	67.4 %	33 100	46.7 %
Buildings with 2 flats	624 305	17.8 %	14 251	20.1 %
Buildings with 3–6 flats	334 530	9.6 %	10 352	14.6 %
Buildings with 7–12 flats	128 601	3.7 %	7 611	10.7 %
Buildings with 13 or more	55 588	1.6 %	5 582	7.9 %

Table 1. Rough summary of the results for the composition of the Bavarian building stock and its energy demand for heating supply. The data for 2050 shows the scenario “rate of refurbishment enhanced”.

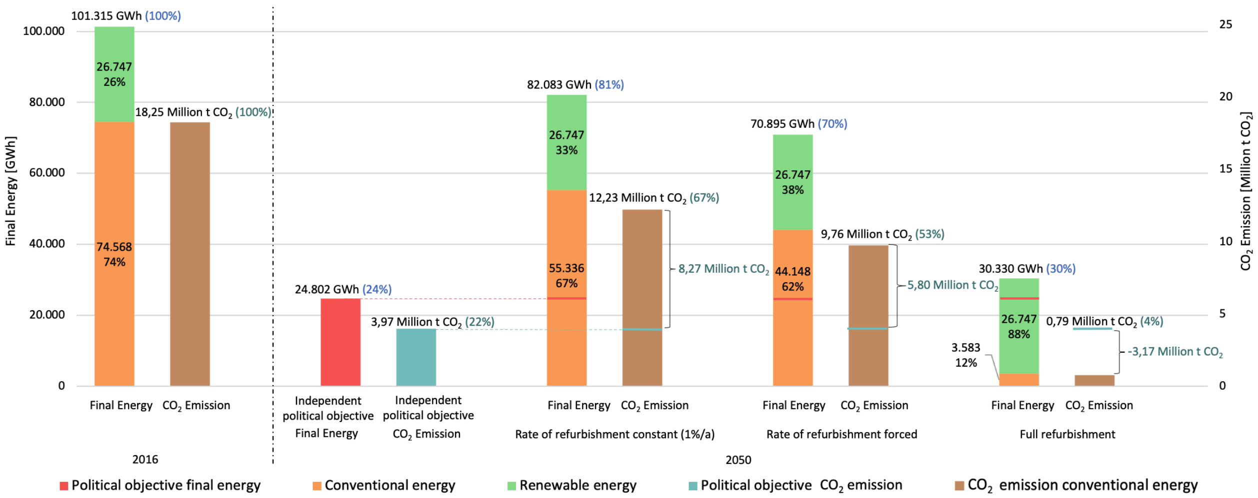

Figure 5. Demand and objective values for final energy and for CO_2 emissions.

Scenarios	2050	Renewable share	Renewable expansion		
	Final energy total	Final energy	Final energy		Resulting CO_2 reduction
Based on a heat demand of 101 315 GWh in 2016	[GWh] (based on 2016)	[GWh] (based on 2050)	[GWh] (based on 2016)		[million t CO_2]
Rate of refurbishment constant	82 083 (81 %)	64 143 (78 %)	+37 396	+140 %	8.27
Rate of refurbishment forced	70 895 (70 %)	52 955 (75 %)	+26 208	+98 %	5.80
Full refurbishment	30 330 (30 %)	7 12 390 (41 %)	-14 357	-54 %	-3.17
Political objective final energy	24 802 (24 %)	6 862 (28 %)	-19 885	-74 %	-4.40

Table 2. Requirements to achieve CO_2 objectives of 3.9 million t CO_2/year.

ing stock. Yet, it is practically impossible to achieve this level of refurbishment. Among other aspects, there is not sufficient capacity available, such as materials and workforce, to realize this scenario. And for a variety of reasons, some buildings cannot reach the highest insulation standard. The protection of historic buildings can be given as an example. Although not realistic, this scenario provides an answer to the question whether the political objectives are theoretically achievable by refurbishment measures. In this case, the final energy demand of the building stock in 2050 is reduced by approx. 70 % to approx. 30 300 GWh, compared to the situation in 2016. Thus, this scenario comes closest to the political objective of 24 800 GWh final energy consumption.

The analysis leads to the conclusion that the political objectives for the final energy demand of the Bavarian residential building stock cannot be achieved by refurbishment alone, taking into account the current state of building renovation and heating technology.

Yet, with regard to the current composition of the energy supply in the Bavarian building sector, as shown in Figure 5 (left section: 2016), it becomes obvious that the political goals have to be re-oriented. Currently, approx. 26 750 GWh of the final energy demand for heating is covered by renewable energy sources. This amount exceeds the remaining energy demand, which is targeted by the political goals, exclusively relying on energy saving measures. Thus, it has to be concluded that the future pathway for the energetic development of the building sector has to focus rather on the emission of the greenhouse gas CO_2 than on the building energy demand only. And in return, development scenarios have to incorporate both improvement of the thermal quality of the building structure and variation of the use of fossil and renewable energy sources.

For this perspective, a target value for 2050 for the reduction of the CO2 emissions related to the heat supply in the Bavarian building sector has been calculated, independently from the limit found for the energy demand, as described in Figure 4. By applying the politically targeted CO_2 reduction rate to the Bavarian residential building sector, the emissions related to the heat supply have to be limited to 3.97 million tons per year.

In order to assess the required contribution of renewable energy for the different refurbishment scenarios described above, it has been assumed that in 2050 fuel oil is fully banned and only natural gas will be used as a fossil energy carrier. The results of this investigation are shown in Table 2 and Figure 5. For the "business as usual" scenario with constant refurbishment rate, it is found that the use of renewable energy sources has to be increased by 37 400 GWh, equivalent to an increase by 140 % relative to the current value of 26 750 GWh. Additional CO_2 savings of 8.3 million tons would be accomplished in order to reach the CO_2 emission goal, calculated with the actual emission factor for natural gas. In total, the renewable share would cover 78 % of the final energy demand of the building heat sector in 2050. In case of the "enhanced refurbishment scenario" the contribution of renewables has to be increased by 98 % in comparison to the current status (2016), covering 75 % of the total demand.

As stated above, in the case of full refurbishment the objective for final energy would be missed. Yet, a rather low absolute amount of renewable energy (12 390 GWh), equivalent to 41 % of the remaining final energy demand, is required to fulfil the objective for CO_2 emissions. Apart from the dramatic reduction of the building energy demand, this scenario could represent a viable transformation path of the energy supply, since the required change of the building stock will in return strongly influence the potential volume for utilization of renewable energy sources. Although the absolute amount of renewable energy would decrease by about 54 % compared to 2016, the renewable share would increase from 26 % in 2016 to 41 %.

If both objectives shall be fulfilled – final energy, and CO_2 emissions – 28 % of the remaining demand of final energy are to be covered by renewable sources.

From these considerations, it can be concluded that a singular focus on the final energy goal does not provide a viable solution, while concentrating on the objective value for CO_2 emissions is expedient. As shown in Figure 5, by combining efforts in refurbishment of the building stock plus enhanced use of renewable energy sources the goal for CO_2 emissions can be achieved. To identify a realistic pathway, future development should achieve the maximum possible saving of final energy and accomplish the remaining reduction in greenhouse gas emissions by expanding the use of renewables. This strategy is best represented by the "enhanced rate of refurbishment" scenario.

4. Conclusions

A method to generate detailed statistical data of the Bavarian building stock, its energy demand for heat supply (space heating and domestic hot water) and their future development until 2050 with regard to the political objectives of the EU, the Federal Republic of Germany and the Federal State of Bavaria have been described. The procedure for creating a realistic scenario to reach the goals until 2050 has been explained. The theoretical maximum potential for saving final energy and reducing the associated greenhouse gas emissions for the heat supply in the Bavarian building sector through full refurbishment and construction of new buildings with the highest energy standard until 2050 has been shown.

Based on the analysis of the possible development of the building structure, it has been concluded that political objective solely related to the building energy demand are unachievable. As an alternative, technically feasible goals have been worked out with focus on reducing CO_2 emissions as extensively as possible by renovating residential houses and achieving further savings through the increased use of renewables. A realistic pathway has been presented, comprising a reduction of the final energy demand of the Bavarian building sector by 30 % accompanied by a 75 % coverage of the remaining demand by renewable sources. As central result, the CO_2 emission of the building stock in 2050 is limited to 3.97 million tons per year, representing a reduction by 78 % compared to the situation in 2016.

The theoretical and practical implementation of the presented alternative objectives is the subject of further research [29]. In these more intensive considerations, embodied emissions are explicitly taken into account. With overall declining emissions, this part is becoming increasingly important.

References

[1] Bayerisches Staatsministerium für Wirtschaft, Energie und Technologie. Fortschrittsbericht 2016/2017 zum Umbau der Energieversorgung Bayerns, Germany, 2018.

[2] Leipziger Institut für Energie GmbH. Aktuelle Zahlen Energieversorgung in Bayern, Germany, 2017.

[3] Bayerisches Landesamt für Statistik. Nettowärmeerzeugung in Bayern nach Energieträgern und Anlagenart, Germany, 2018.

[4] Zensus 2011 Auswertung Bayern. Tabelle: Baualtersklassen, Anzahl Wohnungen, Wohnungsgrößenintervalle, Germany, 2011. [2022-01-17]. `https://www.zensus2011.de/DE/Home/home_node.html`

[5] Zensus 2011 Auswertung Bayern. Tabelle: Baualtersklassen, Anzahl Wohnungen, Gebäudeart, Germany, 2011. [2022-01-17]. `https://www.zensus2011.de/DE/Home/home_node.html`

[6] Statistisches Bundesamt (Destatis). Bestand an Wohnungen und Wohngebäuden – Bauabgang von Wohnungen und Wohngebäuden – Lange Reihen ab 1969–2017, Germany, 2018.

[7] Bayerisches Landesamt für Statistik. Bestand an Wohngebäuden und Wohnungen in Bayern seit 1987. Tabelle 0302: Wohnungen bis 2017, Germany, 2018.

[8] Bayerisches Landesamt für Statistik. Bestand an Wohngebäuden und Wohnungen in Bayern seit 1987. Tabelle 0302: Gebäude bis 2017, Germany, 2018.

[9] Deutsche Energie-Agentur GmbH (dena). Der dena-Gebäudereport 2016 Statistiken und Analysen zur Energieeffizienz im Gebäudebestand, Germany, 2016.

[10] Institut Wohnen und Umwelt (IWU). Deutsche Wohngebäudetypologie: Beispielhafte Maßnahmen zur Verbesserung der Energieeffizienz von typischen Wohngebäuden, Germany, 2015.

[11] Institut Wohnen und Umwelt (IWU). “TABULA” – Entwicklung von Gebäudetypologien zur energetischen Bewertung des Wohngebäudebestands in 13 europäischen Ländern, Germany, 2018. [2022-01-19]. `https://www.iwu.de/forschung/gebaeudebestand/tabula/`

[12] DIN EN 12831-1:2017-09, Energetische Bewertung von Gebäuden – Verfahren zur Berechnung. Tabelle 1: Außen-Normtemperaturen deutsche Städte der Norm-Heizlast, Germany, 2017.

[13] DIN EN 12831-1:2017-09, Energetische Bewertung von Gebäuden – Verfahren zur Berechnung. Tabelle 3: Außen-Normtemperaturen deutsche Klimazonen, Germany, 2017.

[14] Statista. Entwicklung der Einwohnerzahl in Bayern von 1960 bis 2017, Germany, 2019. [2022-01-19]. `https://de.statista.com/statistik/daten/studie/154879/umfrage/entwicklung-der-bevoelkerungvon-bayern-seit-1961/`

[15] Bayerisches Landesamt für Statistik und Datenverarbeitung. GENISIS-Online Datenbank: Reg. Vorausberechnung: Kreise, Bevölkerung, Stichtage. Ergebnisse – 12421-001, Germany, 2017. [2022-01-19]. `https://www.statistikdaten.bayern.de/genesis/online?operation=abruftabelleBearbeiten&levelindex=1&levelid=1677595980361&auswahloperation=abruftabelleAuspraegungAuswaehlen&auswahlverzeichnis=ordnungsstruktur&auswahlziel=werteabruf&code=12421-001&auswahltext=&nummer=4&variable=4&name=KREISE&werteabruf=Werteabruf#abreadcrumb`

[16] Bundesministerium für Wirtschaft und Energie (BMWi). Sechster Monitoring-Bericht zur Energiewende Die Energie der Zukunft Berichtsjahr 2016, Germany, 2018.

[17] Umweltbundesamt, Klimaschutzplan 2050 der Bundesregierung Diskussionsbeitrag des Umweltbundesamtes, Germany, 2016.

[18] Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU). Klimaschutz in Zahlen Fakten, Trends und Impulse deutscher Klimapolitik Ausgabe 2018, Germany, 2018.

[19] Bayerisches Staatsministerium für Umwelt und Verbraucherschutz (StMUV). Klimaschutzprogramm Bayern 2050, Germany, 2015.

[20] Bayerisches Staatsministerium für Wirtschaft und Medien, Energie und Technologie. Bayerisches Energieprogramm für eine sichere, bezahlbare und umweltverträgliche Energieversorgung, Germany, 2016.

[21] Bayerisches Landesamt für Statistik. Energiebilanz 2015. CO2-1. Energiebedingte CO2-Emissionen in Bayern 2015, Germany, 2018. [2022-01-19]. `https://www.stmwi.bayern.de/energie/energiedaten/energiebilanz-2015/`

[22] Bayerisches Landesamt für Statistik. Energiebilanz 2015. CO2-2. Energiebedingte CO2-Emissionen in Bayern und in Deutschland seit 1990, Germany, 2018. [2022-01-19]. `https://www.stmwi.bayern.de/energie/energiedaten/energiebilanz-2015/`

[23] Wissenschaftliche Dienste Deutscher Bundestag. Sachstand Primärenergiefaktoren, Germany, 2017.

[24] Umweltbundesamt. CO2-Emissionsfaktoren für fossile Brennstoffe, Germany, 2016.

[25] L. Schwan, J. Hahn, M. Barton, et al. Analysis and development of reference buildings for the energy transition in the thermal sector. In *Proceedings of the 32nd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems*, p. 1741. 2019. ISBN 9788361506515.

[26] M. Barton, J. Hahn, L. Schwan, C. Schweigler. Bayerischer Wohngebäudebestand und Energiebedarf für die Wärmeversorgung: Aktueller Stand und Prognose für das Jahr 2050. In *Book of Abstracts INUAS Konferenz 2021*, pp. 32–34. 2021.

[27] M. Barton, L. Schwan, J. Hahn, et al. Development of reference building models based on statistical data for the analysis of the building heat demand. *IOP Conference Series: Earth and Environmental Science* **588**(2):022051, 2020. `https://doi.org/10.1088/1755-1315/588/2/022051`

[28] M. Barton, J. Hahn, L. Schwan, C. Schweigler. Comparison and evaluation of statistical databased reference building models for single- and multi-family houses. In *Proceedings of the 33rd International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems (ECOS 2020)*, p. 1947. 2020. ISBN 9781713814061.

[29] CENERGIE – Center for Energy-Efficient Buildings and Districts, Munich University of Applied Sciences, Research group building construction and building climatology. [2022-01-20]. `https://www.ar.hm.edu/organisationen/ansprechpartner_3/professoren_3/essig/essig_2.de.html`