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FEEDBACK BETWEEN ANTHROPOGENIC FACTORS AND CLIMATE: ENERGY CONSUMPTION FOR SPACE HEATING

Matthias Berger*
Institute of Mechanical Engineering and Energy Technology, Lucerne University of Applied Sciences and Arts, Lucerne, Switzerland

Jörg Worlitschek
Competence Centre for Thermal Energy Storage, Lucerne University of Applied Sciences and Arts, Lucerne, Switzerland

1. INTRODUCTION

Anthropogenic factors influence global and local climate. Acting as a feedback, emissions from energy consumption are on the other hand driven by changes in climate. We analyze the relationship between climate and energy demand for space heating in Switzerland for the period 1980 to 2017. Results indicate a significant feedback loop, which will influence future heat demand, mix of energy conversion technologies and local emissions.

2. BACKGROUND

2.1 Climate and Energy in Switzerland

Switzerland is characterized by Köppen climate Cfb, Dfb, Dfc and ET, predominatly westerly winds (30% W, 22% NW, 18% SW) and a high mountain range dividing north and south (MeteoSwiss 2018). The resident population (2016: 8’419’550, 85% urbanization) is mostly distributed in cities of 100-400k inhabitants surrounding the Alps, at altitudes of 250-550 AMSL. Across all sectors, energy demand for space heating outweighs the demand for electricity and mobility (2016: 250 TJ, 210 TJ and 235 TJ resp.) (Kemmler and Koziel 2017). Cooling demand is marginal and in most cases there is no equipment installed, therefore the demand is not realized as energy consumption. While electricity production is almost emission free (2/3 hydro and 1/3 nuclear power), space heating is three-fourth fossil-based and next to mobility the second largest emission source (Swiss Federal Office of Energy 2017). Current policies on federal level point towards massive CO2 reduction by means of efficiency gain, technological change towards renewable sources and decentralized production (Prognos AG 2012).

2.2 Space heating demand

Energy demand for the energy end-use of space heating is usually derived by consumption of energy carriers (natural gas, wood pellets, fuel oil etc.) (Hall and Buckley 2016; Suganthi and Samuel 2012). The fuels are then converted or burned to heat a working medium (mostly water), which is then distributed through the heated object by pipes and radiators. Depending on the system configuration, a range in conversion factors are present, from <60% in old centralized oil burners to >400% in ground water heat pumps.

Alternatively, the heat demand could be calculated top-down by aggregating per-capita data on floor space use, per-square-meter consumption, distribution of population and local climate conditions (Berger and Worlitschek 2018), see equations below. The norm climate period of 1981 to 2010 is used there, yet the period is comparably old when looking into the time frame of building renovation and lifetime. New construction should last 50 years, which raises the question how the influence of weather and climate change would influence the heating demand.

$$Q_{sh} = \sum_{p} \sum_{l} \sum_{a} \left(HDD \right) \cdot \overline{Q}_{hdd} \tag{1}$$

$$\forall p, l, a : \overline{Q}_{hdd} = const. \tag{2}$$

$$\overline{Q}_{hdd} \neq f\left(T_{am}, T_{in} \right) \tag{3}$$

Space heating demand Q_{sh} is the sum over population *p* at location *l* and all heating degree days during the year *a* multiplied with the mean space heating demand per heating degree day *HDD* and per head (eq. 1). The latter is an energy quantum, as a statistical statement and only valid for large numbers, not individual buildings (eq. 2). It is furthermore not depending on neither the outdoor nor the indoor temperature (eq. 3). The magnitude of the quantum for residential space heating is about 5.5 MJ, while the mean of heating degree days is 3531 °Cd (“degree Celsius times days”).

**Corresponding author:* Matthias Berger, Institut für Maschinen- und Energietechnik IME, Hochschule Luzern – Technik & Architektur, Technikumstrasse 21, 6048 Horw, Switzerland; matthias.berger@hslu.ch

3. RESULTS

Based on maps of daily mean temperature levels in 1km resolution (Frei 2014) for 1981 to 2017, the annual heating demand has been calculated as shown in Fig. 1.

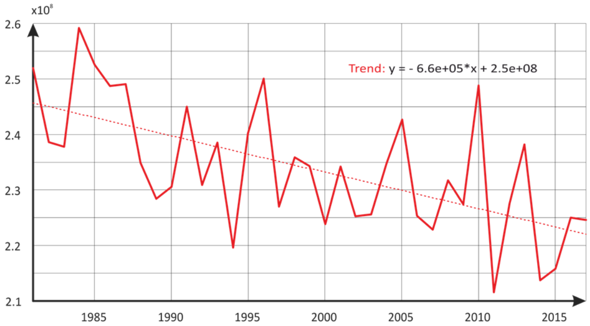

Fig. 1. Calculated heating degree days in Switzerland for 1981 to 2017 with a trend line of -2.5% per decade.

Heating degree days are defined as daily mean temperatures below equal 12°C with respect to an indoor temperature setting of 20°C, and identify the national heating demand. The 37 year observation period indicates a significant reduction of Swiss-wide heating degree days in Fig. 1. Since heating demand is linearly correlated to heating degree days, heating demand would decline as well. Other factors, like the increase in heating efficiency and improved building insulation standards during the past decades would further reduce the energy demand. To some extent these effects have been almost compensated by a net population gain and higher per-capita space use (Federal Statistical Office (FSO) 2017); both aspects could be integrated into a more detailed demand calculation.

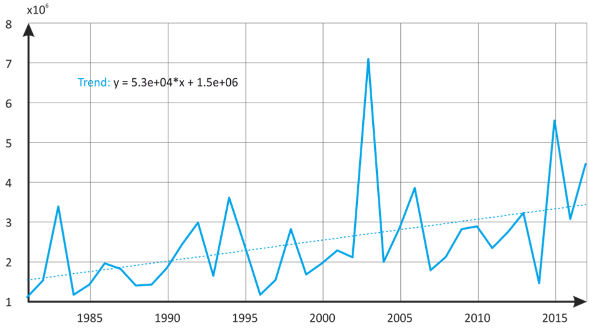

Fig. 2. Calculated cooling degree days in Switzerland for 1981 to 2017 with a trend line of +34% per decade.

Cooling degree days are mean daily temperatures above 18.3°C. In Fig. 2, the influence of local warming is even more obvious.Two individual feedback effects are forcing the trends in Fig. 1 and 2: global climate change and the urban heat island (Grimmond et al. 2010). Global effects are broken down by regional climate models down to urban environments, where recent micro-scale simulations indicate a significant impact of anthropogenic heat (Allegrini and Carmeliet 2017). While the relation to energy consumption as part of the urban heat island is known (Oke et al. 2017), missing data on local heat emission can only be reconstructed through approximation (Boehme et al. 2015).

Data on electricity consumption with high spatial and temporal resolution is rare, but the introduction of smart meters enables progress in understanding demand patterns. Consequently, informed policy making in the electricity domain is feasible. For heat demand with its implications on emissions, the picture is different. Norms are derived from building stock data in conjunction with estimates about achievable retrofit measures (Konferenz Kantonaler Energiedirektoren 2014). Norms are using climate data and the climate norm period 1981 to 2010, because buildings' energy performance depends on the interaction with the seasons.

An open question is, how variations in weather would change the heating demand, in history, present and future. The dimensioning of a heating system is done by considering the location- and building-specific annual demand profile, translated into a histogram. Given the insulation performance, the energy or heating need versus outdoor temperature is determined.

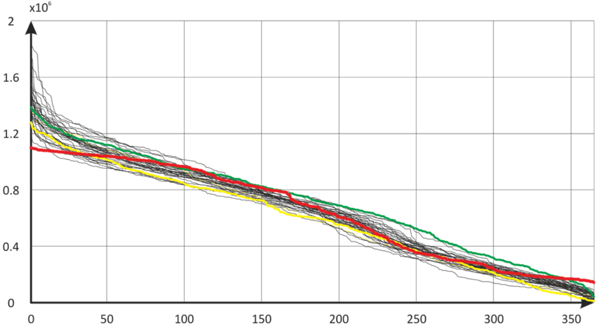

Fig. 3. Histogram of annual distribution of heating degree days in Switzerland for 1981 to 2017, compared to the red line indicating the norm period 1981-2010.

Heating demand by climate norm data in red, individual years in black, the warmest year (see as well Fig. 6) in green and the coldest year (Fig. 7) in yellow are plotted in Fig. 3. The averaging behavior of climate data flattens and broadens the curve, especially filtering the cold spells lasting less than 30 days, as in Fig. 4. The integral under the curves is equal to the annual energy demands. Required peak power, degree of installed capacity utilization and implementation of thermal energy storage however has to take into account the weather data (Vetterli et al. 2017; Jaffal and Inard 2017; Gabrielli et al. 2017).

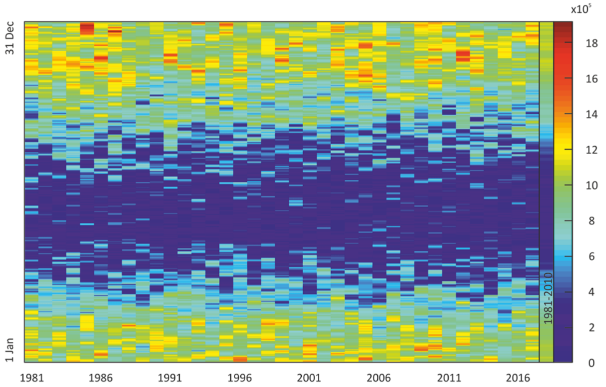

Fig. 4. Pattern of heating degree days in Switzerland for 1981 to 2017 compared to the norm period 1981-2010 on the right side.

The temporal resolution in Fig. 4 as well as in the generalized methodology for top-down estimation of heating demand by Berger and Worlitschek (2018) are limited to daily means. Higher temporal resolution would not yield more insights, due to the thermal constants of buildings' mass. The spatial resolution is only limited by the regional climate model; data on buildings and population is publicly available in a GIS catalogue.

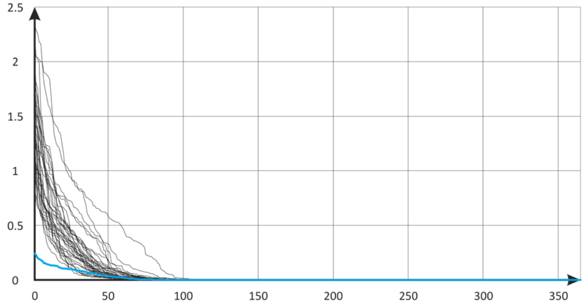

Fig. 5. Histogram of annual distribution of cooling degree days in Switzerland for 1981 to 2017, compared to the blue line indicating the norm period 1981-2010.

Cooling degree days are increasing, according to Fig. 2, yet the duration of cooling periods has less impact than the intensity of heat waves, as shown in Fig. 5. Much higher peak power will be required relatively to the cooling demand. The geographical spread of heat waves is an important factor too, by considering anthropogenic heat emission in response to the cooling demand, which will likely be focused on densely populated urban areas. More pronounced urban heat islands are expected, with a positive correlation of the energy demand for cooling, thus increasing energy consumption and related emissions. Potential solutions would harness the seasonal cold storage capability of local lakes and rivers, as well as injecting summertime solar or ambient heat in underground storages for seasonal heat storage and heating during winter month.

The maps of Fig. 6 and 7 illustrate differences between extreme warm and cold years and the norm climate average. The major Swiss valleys are pronounced bright areas in Fig. 6, suggesting that predominantly dynamic climate effects like the south-to-north 'Föhn' (bringing warmer air from the Mediterranean Basin into the valleys and high altitudes) determine the amount of heating degree days. An opposite behavior is present in Fig. 7, where a cold year mostly affects lower altitudes and regionally the southern part of Switzerland around Lugano and Locarno. The relative differences are calculated as:

$$\partial HDD_{hot}\left[\%\right] = \left(HDD_{2015} - HDD_{8110}\right) / HDD_{8110} \quad (4)$$

$$\partial HDD_{cold}\left[\%\right] = \left(HDD_{1984} - HDD_{8110}\right) / HDD_{8110} \quad (5)$$

for Fig. 6 and 7, resp., pointwise.

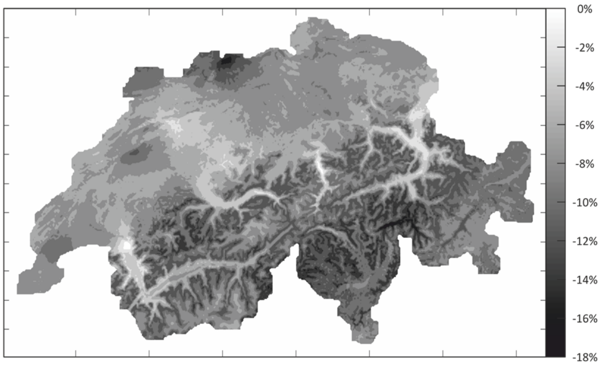

Fig. 6. Map of the relative difference in heating degree days between 2015, the warmest year between 1981-2017, and the norm period 1981-2010.

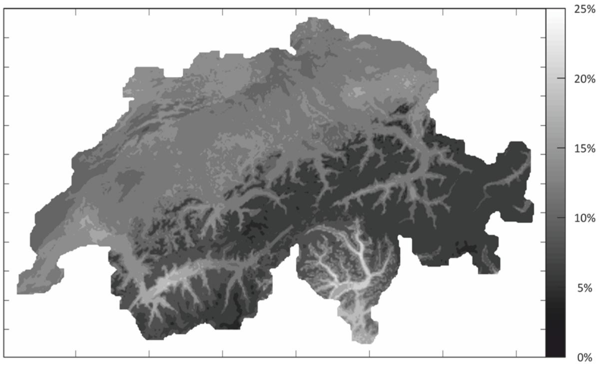

Fig. 7. Map of the relative difference in heating degree days between 1984, the coldest year between 1981-2017, and the norm period 1981-2010.

4. CONCLUSION

Energy-related modelling and simulation is typically considering historical data for consumption and demand in combination with scenarios for future trends (Kannan and Turton 2014). These models often explicitly address the challenges posed by global climate change and propose technological change to counter anthropogenic effects, e.g. by promoting renewable energy. Yet anthropogenic factors are already influenced by climate change, therefore we suggest that the scenarios should include the feedback between climate and energy demand, which has consequences for emissions and other factors for climate models. This bidirectional feedback loop seems to have a net reduction effect on energy consumption for heating, but increases the need for cooling during summer. Policy making based on energy scenarios should take this development into account.

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