What effect could the adaption of policies to building structure and demographic development achieve in German cities?

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Abstract:

Motivation and research question

This paper assesses the retrofit related, theoretical energy savings potential, amended by the impact of demographic development. This amended potential indicates how, and under what conditions, the adoption of retrofit policies to the local demographic development can be favourable.

Why should one look at demographic development? On one hand, growing cities have increased price levels and more intense space usage. These factors make better renovations more economically and ecologically feasible. On the other hand, the increased potential of vacancy in shrinking cities leaves cost recovery and energy savings at risk. Thus, there is reason to wonder, whether policies adapted to local conditions could direct renovation investments towards significantly greater energy savings, at less overall systemic cost. We have therefore developed an approach to evaluate this consideration.

Methodological approach

Initially, German cities with more than 100k inhabitants are clustered with regard to their building stock properties (Statistisches Bundesamt, 2011). For this we use algorithms such as proclus and k-means, combined with a principle component analysis. Secondly, we calculate the energy saving of model cites (1 Mm²) based on this clustering, assuming constant specific savings for buildings with the same age, number of flats and attachment. The comparison of these energy savings amongst clusters shows whether or not the clustering is successful, i.e. whether the similarity of cities within a cluster and the differences amongst clusters, are significant. Finally, we amend the saving potential of the city clusters based on their current and future growth (wegweiser-kommune.de, 2012), so as to assess that demographic influence.

Results and discussion

In the building stock clustering nine clusters covering 40% of the cities were identified. The biggest and most robust cluster (city 1) is formed entirely by eight main eastern German cites. Not surprisingly, the separation of the country has left significant traces, within architecture and building age distribution, which are energy relevant properties.

These traces are reflected in the larger share of multifamily houses (mfh) in model city 1, see figure 1 right, which is based on the eastern cluster properties. The resulting different level of energy demand and energy savings, however, varies only slightly amongst model cities, see

figure 1 left. Generally speaking, a higher energy saving rate means that buildings are either less efficient now or easier renovated.

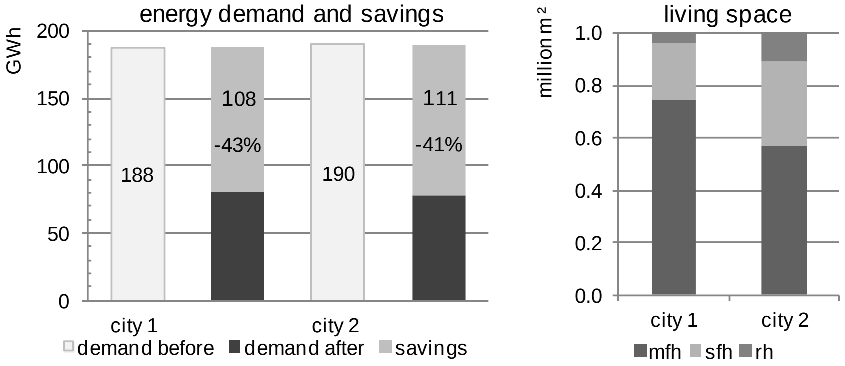

Figure 1: left: energy demand and theoretical savings of model cities; right: living space structure of model cities

And indeed, we found that mfh in the eastern cluster had on average a slightly higher energy demand per m². In accordance with that, slightly more energy per m² can be saved in these buildings in theory. However, the effects appear to be marginal.

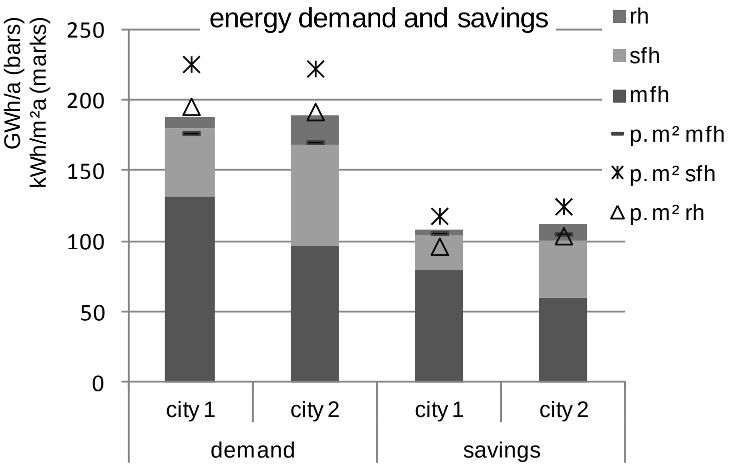

Figure 2: total energy demand and savings (bars); both per m² (marks)

Taking these buildings stock properties into account, how do these cities develop population wise? The eastern cluster contains the biggest variation in growth development. Until 2030 the growth rates vary from -13.2 to 11.8 %. In the second cluster the growth rates vary much less, i.e. between -2.2% and 2.7% and it contains one shrinking city. Using this information, we conclude that some of the savings potential in shrinking cities disappears, whereas it remains constant in growing cities.

The differences in the technical saving potential quantify the opportunities for adaptation of policy for retrofit in buildings to local conditions.

Keywords: building retrofit, demography

1 Introduction

1.1 The role of energetic retrofit

The EU and national governments - and supporting them many scientists - are discussing how energy can be saved in buildings and what political measures or mixes are best to facilitate those efforts.

Currently there are numerous policy instruments implemented in Germany. They encompass minimum requirements for new buildings and renovations, financial support varying with ambition level, and a variety of information tools and consulting offers for building owners and inhabitants.

Therewith, politicians react to the fact, that 40 % of the final energy in Germany is consumed for heating buildings and most of it can be saved using the current available technology. The energy that can technically be saved by retrofitting German buildings at a medium standard, for example, is about 30 % or 600 TWh.

1.2 Barriers of the saving potential

One of the most commonly discussed barriers for ambitioned retrofit is the lack of profitability. The cost optimality requirement in the EBPD (energy performance of buildings directive) lays out the spread for minimum requirements for nearly zero energy buildings. In Germany profitability is a requirement included in the Energy Concept[1]. Despite its emphasis in policies, the profitability, as it is calculated nowadays, leads to less ambitioned renovations and is thus connected to an effect that is called (technology) lock-in. This effect encompasses the missed energy savings that arise over time due to less ambitioned renovations. The lock-in gains significance through the fact that renovation cycles are multiple decades long. Non-ambitioned renovations create an energy savings lock-in for the whole renovation cycle that is 30-50 years. The effect reflects that the planning horizon may be too short and external costs are not sufficiently reflected in profitability calculations.

1.3 Interaction with demographic growth

Given that it will remain difficult to internalize external effects sufficiently in fuel and emission prices, what other options exist to increase profitability for ambitioned retrofit at a macroeconomic level? On the one hand, the cost of a retrofit could be cut by reducing the risk of vacancy. On the other hand, the benefits could be increased, by adjusting the retrofit effort to the needs of the population.

The following two hypotheses show, how the consideration of demographic growth could contribute to lower the profitability barrier and the lock-in effect. Their common thoughts are the compensation of the investment and the risk assessment.

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[1] Bundesministerium für Wirtschaft und Technologie and Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (2010)

Renovations with a higher ambition level can be realized economically in high-price, growing regions. Assuming that **rental and selling prizes for living space are high in growing cities,** recovering the investment or even profiting is more likely there, even for an ambitious retrofit. Another assumption is **that the risk of vacancy is low in growing cities**. The secure future rent leads to lower risk rates for financing. Realizing a higher ambition level avoids the lock-in for missed out savings. Furthermore, if more ambitious renovations are used more often, several effects are triggered. Firstly, the quality of work will rise due to better knowledge of workers. Prices will fall because workers are better trained and possibly scaling effects are realized in better insulation or other material. Secondly, innovations for better solutions possibly are triggered and retrofit costs can decrease. Innovations induce a macroeconomic profit, making the overall energy savings more feasible. When, as a consequence of all three assumptions, more ambitious renovations are conducted the lock-in effect can be avoided. Otherwise, a decision for the cheapest and least ambitious retrofit will prevent energy savings for at least 30 years, since refurbishment cycles are this long.

In most cases, it is more profitable to avoid retrofit when the building use until the end of life is uncertain. Vacant renovated buildings cannot contribute to energy savings and cannot compensate for the renovation investment. **In shrinking cities the risk of vacancy is higher** and should thus be assessed and managed.

The profitability of a renovation depends on the building. Often, the older the building, the more energy is needed to heat it, and thus the more energy can be saved. Therefore, building stock properties like age, thermal insulation and geometric parameters are important.

The economic potential of energy savings in buildings, i.e. the overall profitability of renovations, significantly depends on the ambition level.

The overall renovation activity is more effective if more energy is saved in total. Moreover, the overall renovation activity is more efficient if more energy is saved per investment. A specific renovation activity is less risky and more efficient if more of the investment can be recovered.

2 Methods

German cities with 100.000 inhabitants and more are first clustered based on their building stocks' properties. This allows us to assess which cities can be grouped together for policy design. In a validation step we also determine how similar and different the clusters and the cities are. This validation reveals, if conclusions for one city could be transferred to another. Secondly, we calculate the technical energy savings potential. This potential is amended by demographic factors in a third qualitative assessment step.

2.1 Building stock data

The building stock data in this analysis are a synthesis of data coming from 4 sources. The official population census of 2011 (Statistisches Bundesamt, 2014), updated in May 2014, supplied the number of buildings in each city by attachment, apartment units, building age and owner. These properties form the building stock dataset of 200 dimensions with 10 building periods, four attachment types and five different sizes for each of the 76 German cities under review.

The second data batch, wegweiser-kommune.de, 2012, provided for the demographical data. It includes the growth rates for the past and expectations for the future, the living space per area ratio from 2005 through 2011, as well as the living space of the cities in 2011.

The third source is the German building typology study (Institut Wohnen und Umwelt GmbH, 2003) that identified 44 representative building types for Germany with their properties, as geometry, living space and energetic quality, as the u-values of windows and walls. This study was updated several times (Diefenbach and Loga, 2011) and in 2010 the same institute published data on the retrofit rate and quality in Germany (Diefenbach et al., 2010). These two studies provide for the calculation of energy demand in the buildings stock in 2011 that was performed in EE-LAB/Invert[2]. To assess the energy savings rate, further assumptions, as the future retrofit rate and quality, were needed. These energy parameters were taken from the fourth source the energy projection Klimaszenarien 2050 (Repenning et al., 2014), see Table 4, from the middle scenario KS80, since it is designed to achieve Germany's current political goals. These datasets from the four sources mentioned are condensed using the assumptions described below.

The attachment type (row house, single family house, multifamily house) and the number of apartment units are condensed to match building types according to the German building typology issued by IWU 2010. This condensation was used for the calculation of the energetic values while the clustering was performed on the original spread of data.

Table 1. Mapping of attachment type and apartment units to the building types of IWU 2010

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[2] http://www.invert.at/, Kranzl et al. (2013)

attachment	**units**	**building type**	**building type description**
attached	1	rh	row house
	2		
	3 - 6	smh	small multifamily house
	6 - 12	mmh	medium multifamily house
	13 -	gmh	grand multifamily house
detached	1	sfh	single family house
	2		
	3 - 6	smh	small multifamily house
	6 - 12	mmh	medium multifamily house
	13 -	gmh	grand multifamily house
semi-detached	1	sfh	single family house
	2		
	3 - 6	smh	small multifamily house
	6 - 12	mmh	medium multifamily house
	13 -	gmh	grand multifamily house
other	1	sfh	single family house
	2		
	3 - 6	smh	small multifamily house
	6 - 12	mmh	medium multifamily house
	13 -	gmh	grand multifamily house

Source: own mapping

The building age classes from the population census 2011 and the building typology (Diefenbach and Loga, 2011; Institut Wohnen und Umwelt GmbH, 2003) are matched and condensed for this analysis, as depicted in Table 2.

Table 2. Mapping of building ages among source data and this analysis

building period census 2011	**building period IWU 2010**	**building period in this analysis**
before 1919	before 1919	before 1919
1919 - 1948	1919 - 1948	1919 - 1948
1949 - 1978	1949 - 1957	1949 - 1978
	1958 - 1968	
	1969 - 1978	
1979 - 1986	1979 - 1983	1979 - 1986
1987 - 1990	1984 - 1994	1987 - 1995
1991 - 1995		
1996 - 2000	1996 - 2001	1996 - 2011
2001 - 2004	2002 - 2009	
2005 - 2008		
2009 and later	2010 - …	

Source: own mapping

The following owner structure data were deducted from wegweiser-kommune.de, 2012 and condensed, as depicted in Table 3.

Table 3. Mapping of the owner and occupier structure

owner according to Census 2011	occupier structure used
collectively privately owned	owner-occupier
privately owned	owner-occupier
Municipality, state or country	rented
housing association	rented
private housing or other company	rented
NPO	rented

Source: own mapping

2.2 Clustering German cities

High dimensional data is not easily illustrated or interpreted. Thus we illustrate the clustering approach with simply two dimensions, see Figure 3. In the illustrated excerpt of the data there are cities with a high share in single family homes built between 1919 and 1948 and a low share of those built between 1948 and 1978. Due to their closeness in the graph these cities have similar building stock and belong to one cluster. Other cities have low shares of the older buildings; hence, they are assigned to a different cluster.

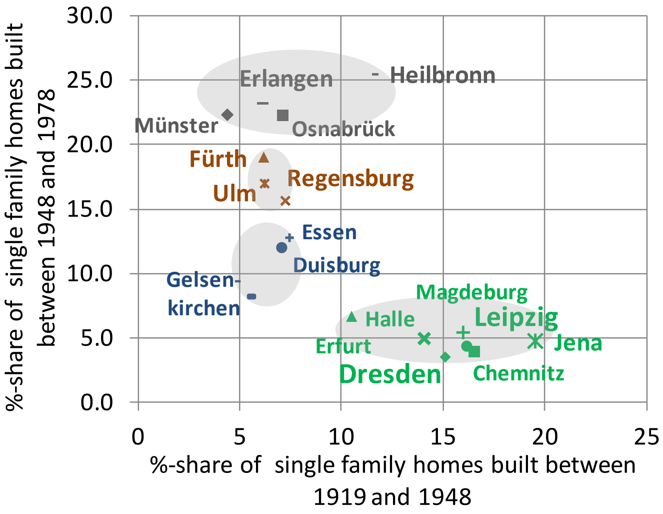

Figure 3. Two-dimensional clustering sample showing the shares of large multifamily buildings and single family buildings built in 1919-1948

The clustering algorithms perform comparisons similar to this visual approach for all 200 building classes, i.e. dimensions. When working with high dimensional data the curse of dimensions appears. In short words, it means that data with a clear clustering in few dimensions may not be as clearly clustered when the number of dimensions increases. Hence, similarity measures like the Euclidean distance lose their expressiveness. The reason for this behaviour is that each new dimension increases the space between all data points, but does not keep similar data points close in the same way. The dimensions that don't contain a lot of differences between the data points will spread them. To counteract the loss of differences, the influence of the significant dimensions can be increased, i.e. through principle component analysis. It decreases the number of dimensions by compressing the variance into few orthogonal components. The resulting principle components are not easy to be read or interpreted by themselves. However, they serve as a basis for the following cluster analysis (Backhaus, 2011).

A variety of cluster algorithms and settings were used to obtain a robust assignment of cities for the clusters. Starting with the k-means algorithm the seed and number of clusters was varied.

One of the easiest and most comprehensible clustering algorithms is the k-means algorithms (Bacher, 1994, p. 309). K-means is an iterative algorithm and it starts by distributing the selected number of cluster centres randomly. In a second step each data point is assigned to the closest centre. After that the centres are updated and moved to the centroid position of the data points assigned to it. The centroid is the mean position of all the points in all of the coordinate directions. Subsequently, the assignment and updating of centroids is repeated until stability is achieved i.e. the cluster assignments of individual records are no longer changing. Apart from the number of clusters, the result is also dependent upon the chosen seed. The seed determines the location of the initial cluster centres. The results may vary with a different seed.

This algorithm was performed on the original data as well as on principle components, since it is not specifically designed for high dimensional data. As opposed to k-means, the Proclus algorithm approaches high dimensions. It spans a subspace through attributes with low variance for each guessed medoid. Points are then assigned to the closest medoid based on that subspace. To perform the clustering we used different tools: KNIME, Elki and RealStat. For comparison the data were also clustered by their attributes, i.e. by age and geometry. Finally the different clustering results were compared and the common, robust clusters identified.

The cities are robustly assigned to clusters and thusthat have similar building properties, i.e. age, attachment and size. In the next step these properties are used to determine the technical energy savings potential

2.3 Determining the technical energy savings potential

The energy savings under consideration encompass the heating of buildings including space heating and warm water supply. The current energy demand of the cities in the clusters is calculated through the specific demand per m², see Table 4.

Table 4. Assumptions of energy demand mapping of attachment type and apartment units to the building types of IWU 2010

building class	energy demand kwh/m²	energy saving kwh/m²
sfh_1919	277	160
sfh_1948	268	157
sfh_1978	243	148
sfh_1986	221	123
sfh_1995	174	83
sfh_2000	130	41
sfh_2011	119	31
lmh_1919	186	107
lmh_1948	174	108
lmh_1978	142	89
lmh_1986	137	80
lmh_1995	115	62
lmh_2011	80	30
smh_1919	239	149
smh_1948	225	136
smh_1978	204	136
smh_1986	169	100
smh_1995	155	84
smh_2000	101	34
smh_2011	101	39
mmh_1919	208	136
mmh_1948	194	117
mmh_1978	173	112
mmh_1986	158	95
mmh_1995	139	76
mmh_2000	91	33
mmh_2011	91	35
rh_1919	242	139
rh_1948	225	120
rh_1978	225	136
rh_1986	175	87
rh_1995	169	81
rh_2000	119	36
rh_2011	105	30

Source: own mapping

These parameters are extracted from the energy projection in Klimaszenarien 2050 based on the building properties. To calculate the savings the energy demand projected in 2050 is compared to the current one. This projection assumes technical energy savings measures to be applied, if they are available and feasible.

Hence, in the scheme of Schlomann et al., 2015, the calculated potential is rather a technical potential, since it considers the economic diffusion of energy saving measures until 2050. Therefore, assumptions for the development of price levels for measures and energy carriers, as well as cost for saving measures are taken from the energy projection in Repenning et al., 2014.

2.4 Amending the technical potential by growth

Growth, here the migration into or out of a city, has an effect on the heated living space and thus on the energy demand. Additionally, it affects the energy savings, and thus the technical energy savings potential through retrofit. The change in energy demand through growth, however, is not related to retrofit activities. Nevertheless, it is important to separate the effects of migration and retrofit, since they overlap and are probably opposing. Growth has a positive correlation to energy consumption and a negative correlation to the energy savings achieved through retrofit. The more energy is used, the more energy can be saved through future retrofit.

In this analysis the technical saving potential of retrofit measures is not amended for growing cities, since there are several, sometimes contradicting mechanisms. For example, living space might be used more intensely. Workers and students may share apartments and rooms, when rents are high. This may increase the heated hours. However, if living standards in growing cities rises, as well as wages and salaries, people can afford more living space and energy cost. In this case, the m²/person and the kWh/m² will increase but . Since there is still some uncertainty in drivers like intense use and heating behaviour in growing cities, the effect is not covered in this analysis.

In a shrinking city, however, vacancy always reduces the technical potential of energy savings through retrofit. The question is how to distribute the population reduction among the different building classes. In this analysis, we assume that buildings older than 25 years and younger than 100 years will become vacant. The other buildings remain used, since they are either historic and protected or young. The latter are assumed to be built in currently growing quarters of the city and remain demanded due to their good thermal quality. In addition to the age consideration, we believe that people will first move out of areas with large multifamily buildings in exurbs around the city centre. The shrinkage of the living space will be evenly distributed among the buildings fulfilling both conditions, age and size.

Three factors remain unconsidered, since they cannot be estimated robustly. Firstly, the vacancy may not affect the complete house. In that case the kWh/m² increases since the number of surrounding non-heated walls rises. However, in this analysis we assume that the vacancy will progress fast within one house, since living becomes more inconvenient and expensive when neighbours move out.

The second factor addresses the fact that older houses are designed for less living space per person. Imagine people moving from younger houses around the centre to older houses in the centre. There the apartments are designed smaller, leading to less heated area. However, modernization activities may redesign the building to offer more space or smaller apartment sizes. The living space per person in a shrinking sample city, Essen rose by 4% between 2005 and 2010, where the population decreased by 2%. Whereas, the living space per person in a growing sample city, Leipzig decreased by 5% while the city grew 7%. Although not part of this analysis, living space per person presumably has an impact on the technical saving potential.

Finally, the third unconsidered factor is the partial heating of apartments. In older buildings with high energy demand people tend to heat partly, i.e. only the living room. That is not the case in newer buildings. Again imagining people moving from newer mfh buildings in the surrounding in the old city centre, people may want to reduce their energy bill, by not heating rooms that are rarely used or have many outer walls. This effect may be caused by an increased energy bill. However, there is yet empirical evidence needed on where people move, when a city shrinks and how their heating behaviour changes.

3 Results

3.1 Robust Clusters

The application and comparison of several different clustering algorithms resulted in the formation of 9 robust clusters, i.e. those clusters that PCA and kmeans as well as proclus had in common. These clusters contain 28 of the 76 German cities with more than 100.000 inhabitants, representing 37 %. 18 of those 28 cities (24 % of 76) are assigned to clusters with more than 2 cities. Those cities contain 6 %of the population and 8 % of the living space.

Table 5. Robust cluster assignment from the cluster analysis

cluster	city	population 2011	living space 2011	model city
1	Erfurt	201,952	7,290,467	city 1
	Jena	106,428	3,778,194	
	Magdeburg	228,910	8,378,106	
	Leipzig	510,043	20,044,690	
	Potsdam	157,603	5,642,187	
	Chemnitz	240,543	9,501,449	
	Dresden	517,765	18,225,328	
	Halle (Saale)	230,494	8,966,217	
2	Erlangen	104,312	4,203,774	city 2
	Osnabrück	154,513	6,396,838	
	Heilbronn	116,716	4,493,566	
	Münster	293,393	11,794,399	
3	Regensburg	136,352	5,781,325	city 3
	Ulm	117,541	4,431,296	
	Fürth	116,640	4,712,256	
4	Essen	565,900	22,522,820	city 4
	Gelsenkirchen	257,994	9,906,970	
	Duisburg	487,470	18,280,125	
5	Augsburg	269,402	10,425,857	
	Nürnberg	490,085	18,819,264	
6	Ingolstadt	126,076	5,043,040	
	Oldenburg (Oldenburg)	157,706	7,002,146	
7	Würzburg	124,449	4,915,736	
	Bielefeld	327,199	12,499,002	
8	Kassel	191,854	7,578,233	
	Pforzheim	115,211	4,401,060	
9	Mönchengladbach	254,834	10,091,426	
	Krefeld	221,864	9,162,983	

Source: own calculations, census 2011

3.2 Technical energy savings potential

Comparing the energy demand and savings of the model cities it the impact of the different building stock structure becomes obvious. All model cities have 1Mm² living space and the buildings structure of the underlying city cluster. For this analysis I chose to compare the building stock structure of the 4 biggest clusters. The light bar on the left shows the energy demand with an average of for the 4 clusters under review. The energy savings vary amongst the model cities, although the specific energy saving is constant for all cities, given the same building properties. It is remarkable that cities of the same size have different remaining energy demands. This means, not every city can save the same portion of energy.

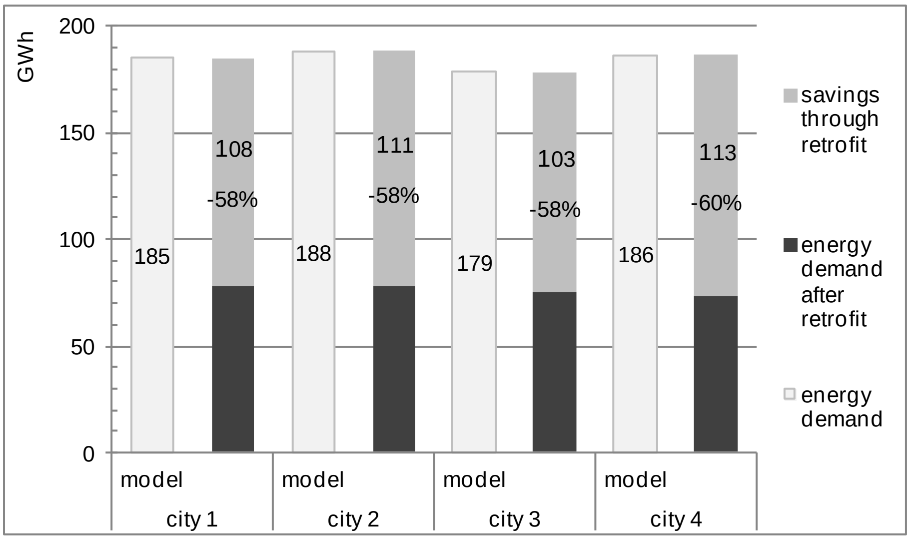

Figure 4. Energy demand and energy savings through retrofit compared across model cities of the 4 selected clusters

Building stock influence on current demand

The energy demand of the model cities 1 trough 4 varies by about 5% around the mean. Reason for this divergence is that different buildings have a different energy demand per m². This can depend on the distribution of the building types: sfh – single family home, mfh – multifamily home, rh – row house, shown in Figure 5. Here you see living space, number of buildings, energy demand and savings for the different clusters according to their building type. For example in cluster 2 the share of single family houses is much higher. Since those buildings have a higher specific energy demand, i.e. per m², the overall demand there is also higher.

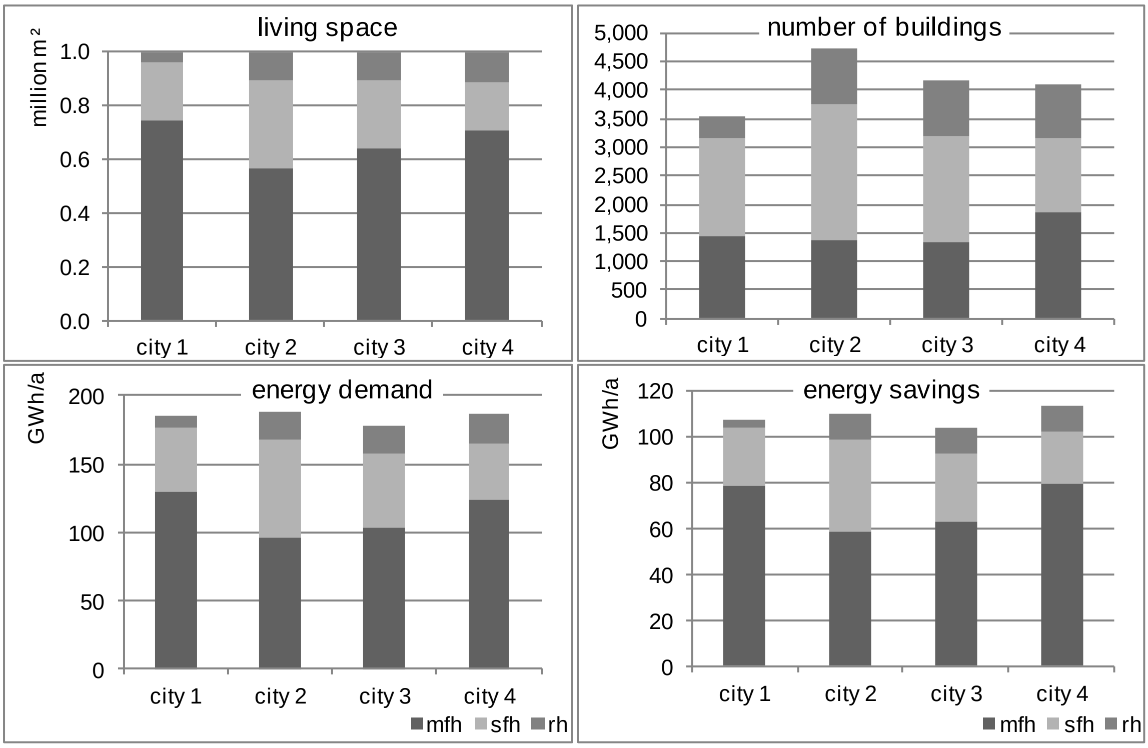

Figure 5. Living space, number of buildings, energy demand and energy savings for the model cities based on clusters 1-4 by building type

Looking closely at the number of buildings comparing cluster 1 and 2, one notices that the mfh – multifamily houses – have the same number. How come they have a different living space and thus a different energy demand?

The answer is provided by an analysis of the building age[3] in Figure 6. In cluster 1 there are substantially less buildings established after World War II in the building period between 1949 and 1978, while buildings of older ages are more common than in any other model city. Since these buildings tend to have a larger size and a larger apartment size, the number of buildings is significantly lower than in other model cities.

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[3] See article: "building age as an indicator for energy consumption" by Aksoezen, Mehmet in Energy & Buildings

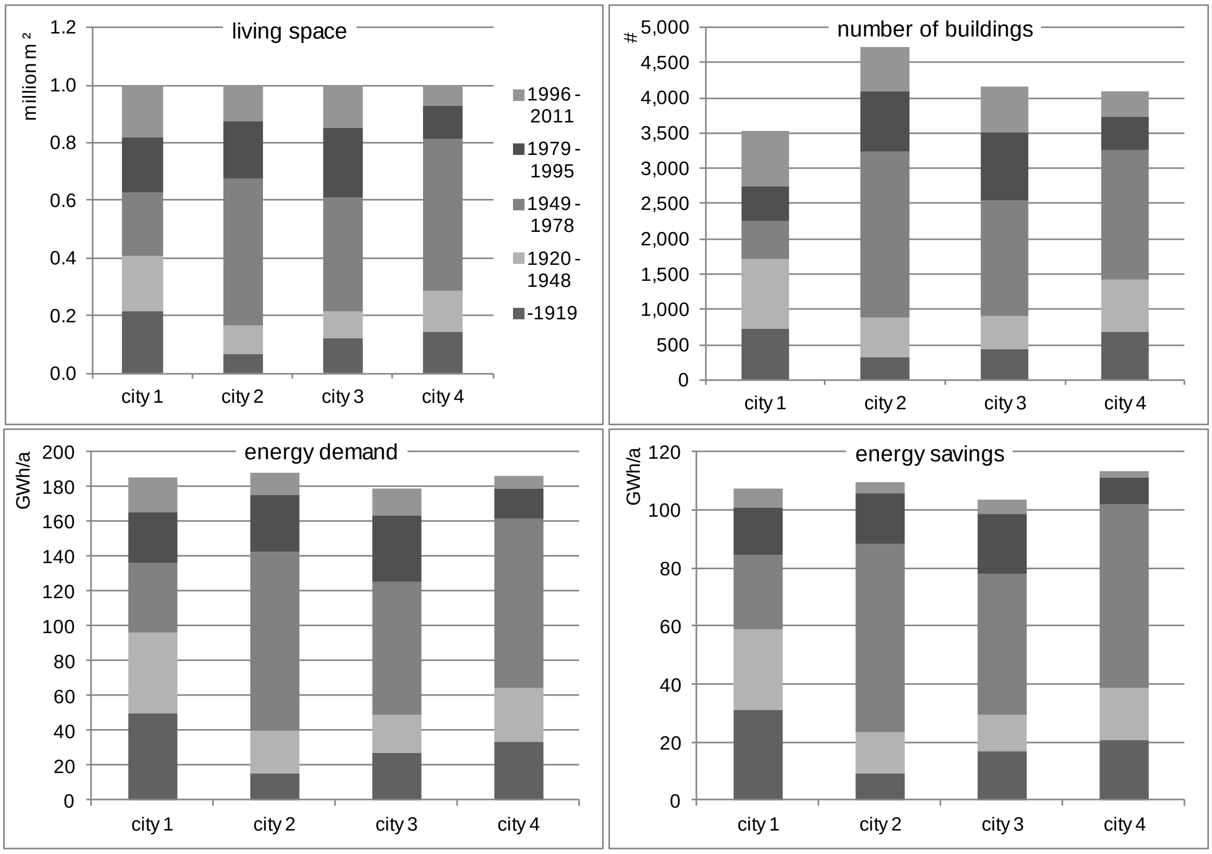

Figure 6. Living space, number of buildings, energy demand and energy savings for the model cities based on clusters 1-4 by building period

In the energy demand and saving sections below, the massive difference can be recognized within the age distribution. A larger share of buildings built between 1949 and 1979 seems to be correlated to an increased demand and savings.

3.3 Growth adapted technical saving potential

The impact of the migration on the technical energy savings potential is influenced by the migration rate. In cluster 1 there are 5 shrinking cities, Chemnitz, Erfurt, Halle, Jena, Magdeburg, with their similar building stock properties forming model city S1 with an energy demand of 187 GWh in 2011. This demand will be reduced through renovation by 58 % down to 79 GWH assuming no change in population. Hence, when the shrinking population is considered the energy demand shrinks by another 4 GWh.

Table 6: clusters of cities with according growth rate until 2030

cluster	**city**	**growth**		**average growth**
1	Chemnitz	-10.6%	Combined in model city S1	-7%
	Erfurt	-3.4%		
	Halle (Saale)	-13.1%		
	Jena	-2.8%		
	Magdeburg	-6.5%		
	Dresden	11.8%	Combined in model city G1	11%
	Leipzig	8.8%		
	Potsdam	11.2%		
2	Osnabrück	-2.2%	model city S2	-2%
	Erlangen	2.7%	Combined in model city G2	2%
	Heilbronn	2.3%		
	Münster	1.4%		
3	Fürth	4.2%	Combined in model city G3	5%
	Regensburg	7.2%		
	Ulm	4.0%		
4	Duisburg	-6.7%	Combined in model city S4	-7%
	Essen	-5.7%		
	Gelsenkirchen	-8.7%		

Source: own calculations, wegweiser-kommune.de, 2015

The equivalent growing model city of cluster 1 consists of Dresden, Leipzig and Potsdam and is expected to grow at a rate of 11% until 2050. As a consequence, new buildings need to be established and we assume a constant energy standard. Hence, the energy demand will increase by 10.5 %. However, if the existing stock is retrofitted at the current rate[4] and market standard, energy demand would drop to 47%.

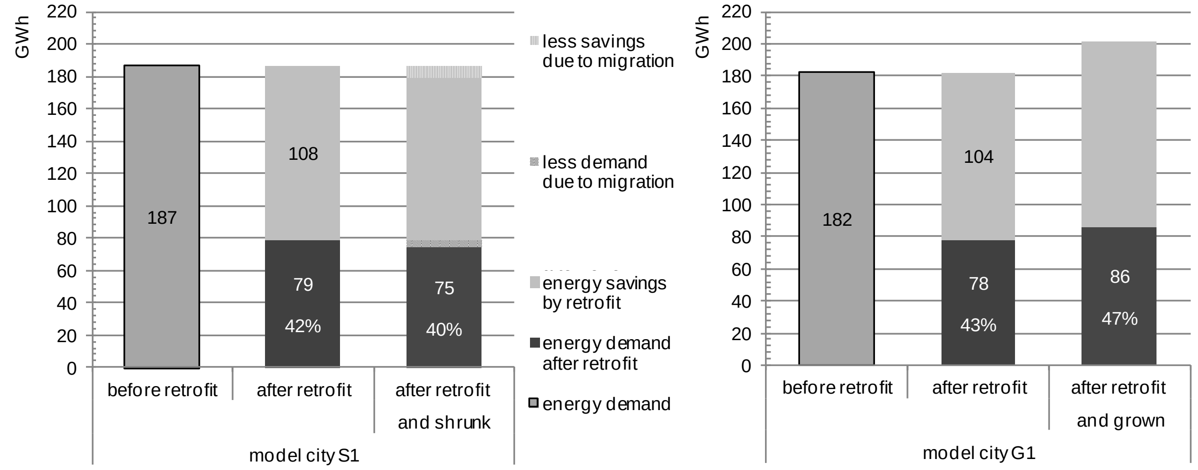

Figure 7. Energy demand and savings, before and after retrofit, excluding and including migration effects for the first clusters growing and shrinking elements

Comparing the different clusters' shrinking elements one can detect the impact of the different building stock properties. The different initial energy demands, as discussed previously, result from the different distribution of buildings across age and size/ attachment

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[4] Currently, about 1% of the buildings are retrofitted annually.

and from the different shrinking rates. Due to the same reason, the energy savings vary with a standard deviation of 3.1 GWh which is 1.63 % of the average energy demand. Migration increases this effect leading to a 2.2 % standard deviation from the average. Notice that not only the energy demand after retrofit is reduced by the shrinking, but also the energy savings. This result does neither include an increase of energy demand in partly inhabited buildings, due to losses in common areas and increased temperature difference to the inside walls. Nor does it include the increase caused by larger space consumption – m² / cap - due to lower price levels in shrinking regions. The reasons for these shrinking energy savings is the reduction of renovated used space, when people move away less buildings get retrofitted and used, hence, less savings are achieved through renovation. However, the energy is still saved, because the space is no longer used and heated.

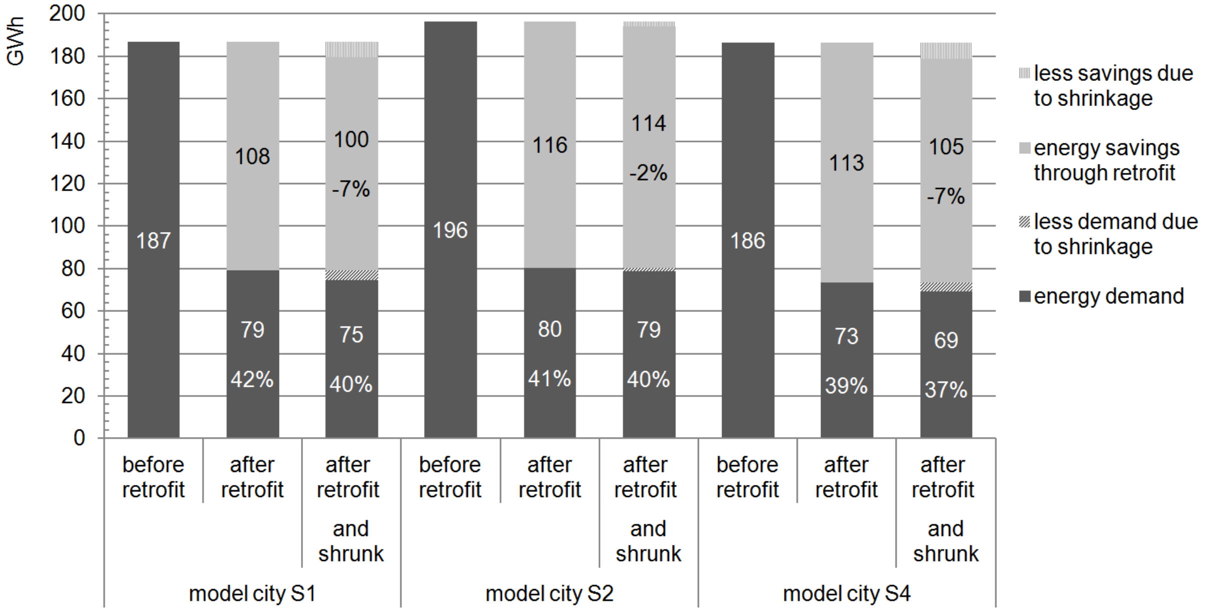

Figure 8. energy demand and savings, before and after retrofit, excluding and including migration effects for the all clusters shrinking elements

For the growing elements of the clusters a similar effect can be observed. The building stock properties cause the increase in energy demand after retrofit and growing to vary by a standard deviation of 5.3% around the average.

Figure 9 shows how different model cities have different additional energy demand due to migration. This effect varies between 1.6 and 8.3 GWh representing 2 to 10%. The big variance in the additional demand is of course related to the different growth rate with some influence of the building stock properties.

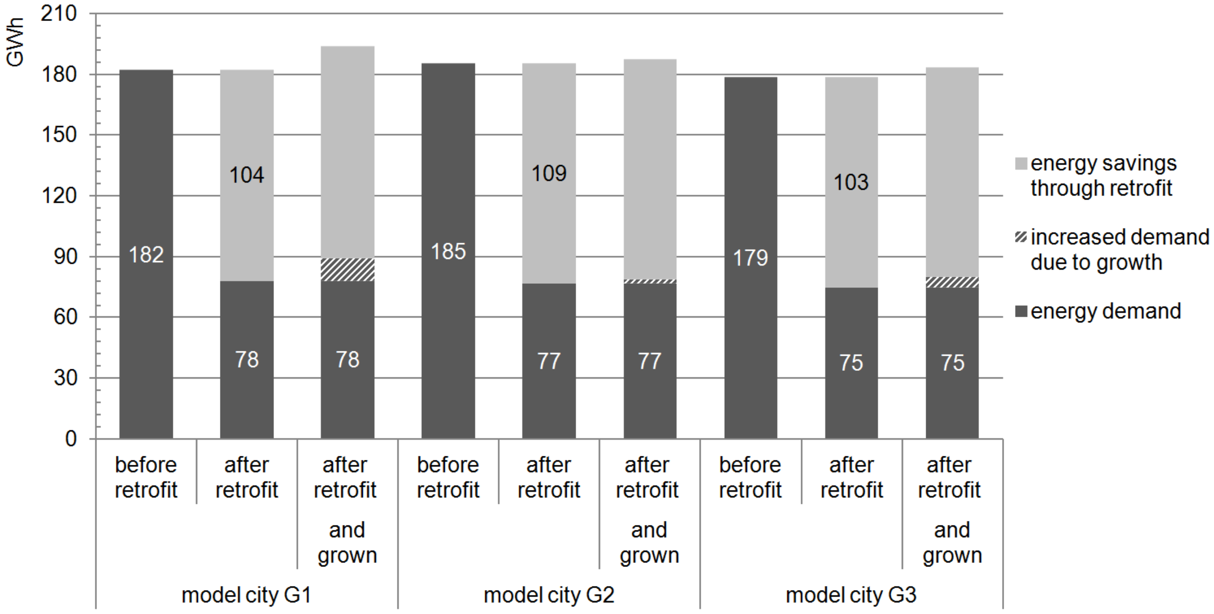

Figure 9. Energy demand and savings, before and after retrofit, excluding and including migration effects for the all clusters growing elements

4 Discussion

This analysis focuses on the impact of energetic retrofit and growth on the energy demand and savings of a city. However, the following aspects were either not in scope or not could not be considered with a decent level of certainty.

The energy savings rate per area (kWh/m²) stays constant for each building class and the building remain in the same building class. Thus, in the calculation of energy savings the replacement of old buildings by new buildings is not considered. We also don't consider the improvement of energy standards of new buildings over time.
In the same manner we assume constant energy demand rates per area (kWh/m²) and constant density rates (m²/cap) over time. Hence, the calculated energy demand does neither account for a higher energy demand in partly inhabited buildings, nor does it reflect a possible intensified use of space in growing cities.

Due to a lack of data, the past retrofit activity in the different cities could not be considered. However, the specific energy demand rates include the average retrofit that was assessed in IWU 2011. What is the impact of this non-city specific consideration of retrofit activity? On one hand, some cities may have undergone more retrofit activities than the average. The buildings in these cities, thus, have a better energetic quality and a lower demand, regardless of their other properties. For these cities, our calculation overestimates the initial energy demand and the energy savings. One the other hand, some cities might have a lower retrofit rate leading to the reverse effect. Starting from there the energy saving potential will be lower than before.

The energy demand of the buildings is assumed based on the buildings age but also on size and attachment type. Size and attachment influence the volume to surface ratio with impact on energy demand. In the analysis of Aksoezen et al., 2015 buildings constructed before 1921 performed better than the average, whereas buildings built between 1947 and 1979, performed worse. If this could be generalized for German cities, i.e. because due to the recovery from World War II living space was needed urgently and building material was scarce. Also in the following years the economies recovered and grew vastly, again increasing the need for living space especially in the cities. The urgent and increased need for living space caused fast solutions lacking quality and energetic performance.

And finally when thinking ahead, especially with some uncertainty in the growth rate, it is worth it considering the energy saved during the time that the retrofitted building is used, even though it might become vacant unforeseen later.

5 Conclusion

Considering the 1-11% impact on the energy demand, we found in Figure 8 and Figure 9, the impact of migration on the technical energy saving potential is tangible. However, when looking at multifamily buildings, the impact rises up to 14%. When narrowing the building periods to 1949 – 1978 the share increases to 25 %. As specified in the methods, especially multifamily houses built after war in times of scarcity until the late '70s with rapid growth and need for living space are impacted. Hence, their energy performance is relatively low – sometimes lower than in earlier years - and they are situated in a suburban multifamily house belt with a high share of living space. In most big cities there is such a belt, rather far from the old town centre, consisting of mostly publicly owned multifamily houses. We assume that people will start to move away from these areas first; since they are distant to the city centre and their energetic quality is relatively low. The last argument will intensify given that the buildings are retrofitted in the order of their construction, then older buildings closer to the centre will need even less energy. However, we did not look at, what people move away first.

If the effect of migration concentrates in this assumed way, certain groups of building owners and certain groups of inhabitants would be affected. The affected buildings are owned by privately and publicly owned housing companies. Since this limits the number of affected investors this focus facilitates the opportunity for national and local policies to take effect. Companies usually have more experience with retrofit, more people to gain information and a choice of buildings to retrofit. In addition they may stick stricter to profitable solutions with banks financing department hopefully checking for the investments' related risks.

However, all this applies only if the shrinking takes place in the 50s-70s multifamily belts. May be it's the single family house owner move away first (or mainly) because their employer takes them to a different city. It is also possible that older people do not want to leave their homes in the mfh belts although it will get harder for them to shop for groceries, go to a doctor and afford a warm home. In a partly inhabited multifamily building, with fewer neighbours around, heating costs will increase. Due to the massive impact on the affected investors it very interesting to see what people move away and which buildings will be deserted. Again, the urban planning department could help identify the growth and shrinking rates in the different areas.

The assumption of a growth rate over a long time like 20 years holds several complications. The first one coming to mind is the uncertainty that growth or shrinking will become real over such a long time. Secondly, the growth rate may vary and in between even reverse in such a long time span. For a long term investment like a retrofit it will reduce recovery risk if growth rates are steady and can be predicted with a decent certainty.

When considering the time frame a retrofit needs to recover the cost (or as much of the cost as possible) the question of the uncertainties of a growth forecast become inevitable. Can rely on the growth rates forecast for 20 years in the future to base our investment risk calculations on them? The migration rates in Germany are commonly analyzed and forecasted by the urban planning department, if such a department exists. Unfortunately especially for smaller cities, those units often don't exist. In addition the urban planning is often not connected to the department(s) that handles climate change and energy matters. The results laid down above show an interaction between growth and energy demand/

savings. Hence, the cooperation of these city units is needed to facilitate the political guidance on a local level for investment in buildings. Then, the value of the integrated assessment of buildings’ energy savings and demographic growth are possible where authorities and institutions are set up and working in a progressive and integrated way.

In addition, further advantages arise from linking the renovation considerations to the demographic growth analysis. The planning horizon of renovations might get adjusted to demographic analysis’ dimensions, allowing i.e. a longer payback period. The time under consideration might thus implicitly increase. Furthermore, the local authorities become aware of solving several problems with one measure i.e. the need for homes of elderly people or social housing may be solved by energetic renovation of city owned buildings. Both of these effects may affect the profitability calculation in a way, where more and more ambitious renovations become economically feasible.

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