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Energy sufficiency in buildings

Concept paper

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1 What does ‘energy sufficiency in buildings’ mean?

Buildings have a high impact on environmental issues. They need land to be built on and infrastructure to be supplied with energy, water, communication technology, and mobility services. Their construction and maintenance need resources and materials, that have to be exploited, processed and transported. Buildings have to be equipped conveniently with furniture, technology, appliances, etc. depending on their dedicated use. Using buildings demands energy for heating, cooling, electric devices, and others. And at the end of a building’s use, its deconstruction produces waste that has to be treated. Along this life-cycle of a building, there are different options to consider sufficiency and more specifically energy sufficiency aspects.

Both in buildings and in general, **energy sufficiency** as a concept includes both an outcome and a type of actions that will move us towards this outcome.

The concept paper “Energy sufficiency: an introduction” (Darby and Fawcett 2018) that was also prepared for eceee’s energy sufficiency project proposes the following working definition for energy sufficiency **as an outcome**, with the outcome being **a state**:

> Energy sufficiency is a state in which people’s basic needs for energy services are met equitably and ecological limits are respected. (Darby and Fawcett 2018)

This working definition is based on the ‘Doughnut Economics’ (Raworth 2018), which in turn adopts the concept of the ‘Safe Operating Space for Humanity’ that is part of the ‘Planetary Boundaries’ concept by Rockström et al. (2009). While the ‘Planetary Boundaries’ constitute the outer ring of the ‘Doughnut’, i.e., the ecological limits, people’s basic needs for energy services constitute the inner ring. Energy services are understood as the utility we derive from using energy (Thomas et al. 2018), e.g. for keeping buildings comfortable and healthy inside. Meeting basic needs means that ‘enough’ of energy services is one side of and a precondition for energy sufficiency, while on the other side, energy sufficiency also implies avoiding ‘too much’ of energy services, which would lead to exceeding ecological limits.

However, this working definition of energy sufficiency as a state implies that there are multiple ways to achieve this state.

To move towards this state, a number of things can happen:

1. We may need to increase access to energy services to a sufficient level for those whose basic needs are not currently met
2. We can decrease energy demand whilst maintaining the same level of energy services through energy efficiency improvements
3. We can decrease energy demand through **energy sufficiency actions** (for which we propose a definition here below)
4. We can meet energy demand through more sustainable energy supply options, thus increasing the level of demand that can be met within environmental limits.

Therefore, in order to guide policy on how to achieve the energy sufficiency state in reality, we will also need a working definition for **energy sufficiency actions** that distinguishes these from the other three types of potential action mentioned above. Based on Thomas et al. (2015a) and others, we propose the following working definition:

> Energy sufficiency actions are actions which reduce energy demand, to take us towards the energy sufficiency state, whilst at the same time changing the quantity or quality of the energy services demanded in a sustainable way and not below people's basic needs.

Their nature of *changing the quantity or quality of the energy services demanded* is exactly what distinguishes energy sufficiency actions from energy efficiency actions: these will also reduce energy demand but leave the level and quality of energy services unchanged (and this is also the case for actions to make energy supply more sustainable). Energy sufficiency actions thus may be related to changing our daily practices and routines or providing different kinds of infrastructures allowing us to meet our needs with different energy services (Thomas et al 2018). They may also be related to more general changes, e.g. to changing use of time or changes in non-energy policies (Darby and Fawcett 2018), which are, however, beyond the scope of this concept paper on buildings.

How can this concept be applied to **Buildings**? Buildings are meant to provide room, security, usability, and a certain level of comfort. **Four aspects** determine how well a building serves these functions, and the level of energy and resources needed to fulfill them. These four aspects are (1) space, (2) design and construction, (3) equipment, and (4) use of the building, as we will discuss below. The general definition of (energy) sufficiency as a target state in the building sector may thus be set as ***adequate space thoughtfully designed and constructed and sufficiently equipped for reasonable use***.

Not all of this is related to *energy* sufficiency alone. The amount of space or the construction materials used as well as potential water savings in equipment and use are examples for aspects having wider implications on sufficiency in general. We will therefore sometimes speak of energy sufficiency, sometimes of sufficiency in general.

This concept paper will explore energy sufficiency actions, potentials, and policies related to the four aspects mentioned above, which would bring the EU, its member states, and its people and companies closer to an energy sufficiency state in the building sector. We begin with expanding on areas for energy sufficiency actions as well as drivers and opponents for energy sufficiency in buildings in the remainder of this chapter. Chapter 2 provides a qualitative and partially quantitative analysis of energy savings potentials from energy sufficiency actions in buildings in Europe, both at the level of buildings and EU Member States. How policy could set operational targets for energy sufficiency and enable and support energy sufficiency actions in order to achieve such targets, is discussed in chapter 3, followed by conclusions in chapter 4.

Throughout this paper, the reader should bear in mind that this is a concept paper outlining what could be definitions, areas, actions, potentials, targets, and policies for energy sufficiency in buildings. It includes a review of literature available and known to us, but it is not providing a thorough review and analysis of all aspects, and space does not allow to go into every detail. After all, energy sufficiency is much less researched than energy efficiency, so this paper offers many new aspects that may need further research.

1.1 Areas for energy sufficiency actions in buildings

The four aspects – space, design and construction, equipment, use – define the main areas in which sustainability in buildings can be approached, including through energy sufficiency actions.

1. **Space.** Buildings are a relevant parameter for land and energy use. Although the share of land that is covered with buildings appears to be rather small[1] there is a fierce competition between different land use options (residential, commercial, agriculture, energy production, transport, mining, forestry, protected areas, etc.) in some cities and regions. Also, the size of a building is a driver of its actual energy consumption: for any energy efficiency standard, energy consumption particularly for heating and cooling will

[1] In 2015 3.2% of the area of the European Union was covered by residential use. There is a fierce competition between different land use options (residential, commercial, agricultural, energy production, transport, mining forestry, protected areas, etc) in some cities and regions. https://ec.europa.eu/eurostat/web/lucas/data/database (accessed 18/01/2017)

grow with size. For energy sufficiency, the enclosed space of a building offers possibilities in terms of both floor area and height of rooms.

2. **Design and Construction.** A building's design determines many things, including energy efficiency but also the flexibility of floor plans for changes in use. The way a building is constructed (plug-in, screw, adhesive, bonded or other systems and connections) and the material used for the building's elements has a high influence on the energy used for the production of materials and particularly during the useful life of a building. It also confines the potential for reuse and recycling of building components and materials.
3. **Equipment.** Apart from the shape and the shell of a building, it is the equipment that defines and facilitates its usability. It will also influence the building's energy consumption. Number, size and efficiency of appliances and products influence the energy needed for the building's use. In this paper we focus on boilers, heaters, and heating systems while other equipment (e.g. water heaters, air-conditioners, and lighting, appliances, and electronics) are covered in the Concept paper "Energy sufficiency in products" (Toulouse and Attali 2018).[2]
4. **Use.** Next to the efficiency and size of a building's shell and equipment, it is the users' behaviour that determines energy use in buildings. Just as for the equipment, we are looking at space heating, space cooling, and ventilation routines, while energy related behaviour with other equipment is part of the Concept paper "Energy sufficiency in products".

1.2 Drivers and opponents of (energy) sufficiency in buildings

A priori, we may assume that a stock of ***entirely climate-neutral and resource-light buildings and quarters*** that also fulfil the above definition of offering ***adequate space thoughtfully designed and constructed and sufficiently equipped for reasonable use*** will constitute an energy-sufficient target state for buildings. Within this state, buildings have to be

- safe against weather and harm
- warm, light where needed, and dry
- equipped for daily home care, work, or other use
- providing room and space for privacy and community.

With regard to the four areas for sustainability in buildings mentioned above, different trends, drivers, and opponents of sufficiency can be identified.

1.2.1 Space

In many European countries, the sizes of buildings and their technical equipment have been continuously increasing over the last decades (European Commission 2019; European Environment Agency 2018). This development is one of the reasons why energy efficiency gains so far did not lead to the reduction in final energy use in buildings that could be expected with regard to increasing efficiency in buildings and appliances. At the same time, in the residential sector all over Europe the size of households is shrinking, which means that fewer people in a dwelling live on more space (European Union 2018). These are two of several socio-economic, market-driven, and cultural developments in housing that overall tend to increase energy consumption. The following table gives an overview of these developments and trends in Europe.

[2] Machinery in industrial buildings and equipment in commercial buildings are not covered in the papers.

Table 1. Developments in housing increasing the demand of floor area.

Development	Impact on floor area increase
Bigger dwellings in new built houses	New built houses usually offer more floor area than by number of rooms comparable buildings of earlier ages.
Volume in new built houses	In addition to the increasing floor area also the volume of new built houses increased, while there is a decreasing trend of the room heights over time.
Detached houses bigger than flats in multi family houses	Overall floor space in detached, semi-detached and terraced houses is higher than in by number of rooms comparable dwellings in multi family houses. This aspect is relevant for countries with a high share of single family houses (see Figure 3).
Smaller households	In most European countries the number of household members is shrinking. With the existing building stock and by trend bigger dwellings in new built houses smaller households live on more floor area.
Owners live in bigger dwellings	Generally, it can be stated that owners of a dwelling live on more space than tenants. However, the demand for floor space (owners and tenants) in different European countries is spread widely (see Table 5).
Aging effect	Households with older members usually use more living space. This is due to generally better income over the years and the growth of households in case of family formation.
Cohort effect	The cohort effect is a combination of the development of overall bigger dwellings and the aging effect. Thus, housing standards of different age groups are increasing and with it the demand for living space of the specific age groups over the years.
'Empty nest' effect	Elderly households often stay in the dwellings they used to live for years, also when the household is shrinking (e.g. children moving out). The floor space per person then increases for the remaining members.

Source: Based on Bierwirth, Thomas 2015.

The development of increasing demand for floor space can be seen in non-residential buildings, too, e.g. in offices (for Germany: Jones Lang Lasalle 2009) or shopping centres in Europe in which sales areas increase while the number of shops decrease (ECE 2015). Due to a lack of data it is not possible to generalise a trend for all non-residential buildings.

On the other hand, there are not only obstacles but also drivers for sufficiency. The decision to use less space than before or than others can derive from different intrinsic and extrinsic motivations. Financial or social restrictions for example can force people to change their way of housing. Isolation and the desire for social connection, security and care in a community can be reasons to move into a co-housing project. And affluence can lead people to choose a simplified life with less things and space. In some European cities, the wish for and benefits of co-housing projects are supported actively (e.g. City of Bonn), and especially in cities with tight housing markets, several projects of micro apartment buildings are realised to provide small but affordable housing (O2 Village Munich, Bauhaus Campus Berlin, Bokompakt Lund). In these markets in general, the high cost of housing, whether owner-occupied or rented, will also force people to live on fewer m² on average than in less costly areas. This proves that sufficiency is not necessarily voluntary, which brings us back to the question of limits, minimum standards, and maximum demands. What is the "sustainable energy safe space" for buildings?

1.2.2 Design and Construction

Construction is most relevant for energy and resource efficiency (see next chapter). However, design also determines how flexible a building/dwelling is for changing uses, or for changing household sizes, or for shared dwelling concepts. For example, biographical developments like family foundation, children moving out, or the loss of a partner cause changes in the demand for floor space and/or shape of a floor plan. The adaptation to changing demands usually enforces moving to another flat or building – in conjunction with the related physical, financial and mental efforts. Especially elderly people often dread these efforts and the loss of their familiar surroundings. Some building concepts offer a flexibility that allows to adapt the shape and the size of a house or a dwelling to changing needs without moving. Thus, more flexibility could support smaller floor areas per capita. In that respect, the fact that many real estate markets are dominated by commercial developers that usually build standard floor plans is not supporting energy sufficiency.

1.2.3 Equipment

With increasing wealth, more or all rooms in a building get heated and/or cooled. The installation rates and size of central heating systems and of air-conditioning units or systems will also increase due to the increasing size of dwellings. On the other hand, building shell energy efficiency will reduce the need to heat or cool rooms, and in some climates may eliminate the need for heating or cooling systems altogether. Better controls for systems enable heating and cooling only when and where is needed.

1.2.4 Use

Increasing wealth allows people to set indoor temperatures they perceive as comfortable higher in winter and lower in summer, or at the same level around the whole year, instead of adapting the clothing they wear. This is easier the more energy-efficient the building. On the other hand, high energy prices motivate people to heat (and cool) in a more energy-conscious way, as could be seen during the period of high oil and gas prices from 2009 to 2014 in Germany. During this period, heating demand reduced by much more than what could be calculated as a result of energy efficiency investments alone (Galvin and Sunikka-Blank 2014).

Smoking indoors requires higher ventilation rates and thus higher energy losses associated with the ventilation, whether by opening windows or through higher flow rates in ventilation systems. Putting plants and other ornaments on window sills disables wide window opening for the more energy-efficient short-term ventilation, as compared to longer-term narrow window opening, e.g. through tilting.

2 Analysis of energy savings potential from energy sufficiency actions

2.1 Potential energy sufficiency actions

To estimate the potential for energy sufficiency actions in buildings, it is necessary to identify actions that address specific (and assessable) aspects of buildings and can lead to the reduction of energy use, while differentiating them from actions that would improve energy or material efficiency and consistency.

To clarify the suggested approach for estimating an energy sufficiency potential, Table 2 provides some examples of actions differentiated between efficiency, consistency, and sufficiency regarding the areas of space, design and construction, equipment, and use.

Table 2. Examples for efficiency, consistency, and sufficiency in space, design and construction, equipment, and use of buildings.

	Efficiency	Consistency	Sufficiency
Space	Choosing an efficient surface area to volume ratio		Smaller buildings / flats; Optimised use of room and space
Design and construction	Energy and materials efficiency of the building envelope	Reuse and recycling of material	Design for flexible use of space; Construction to ease decomposition of building; Components for reuse (instead of demolition)
Equipment	Choosing energy-efficient appliances, equipment, and systems	Energy supply from renewable energies; Recycling of appliances, etc.	Reducing numbers, sizes, or energy-using features of equipment, appliances
Use	Using laptop instead of desktop (if same screen size); Choosing the more energy-efficient heating fuel (if more than one is available and the energy service is the same)	Correct disposal for recycling	Choosing a lower room temperature Using appliances and equipment only when needed, e.g. avoiding stand-by

Source: Own compilation.

With regard to ***space*** – and respectively land use – savings potentials can be seen in actions that reduce (1) the size of a single building, (2) the total number of buildings needed for a specific use or a specific number of people, and (3) the area used to build them. In the residential sector for example detached houses generally provide more floor area than flats in multi family houses. At the same time, they need more land, as a specific number of living units are spread more widely than the same number in a multi family house. In addition, table 3 below presents an overview on types of actions that may help to reduce space demand through the design/construction and use of buildings.

The ***design and construction*** aspect covers first of all the energy efficiency of the building, but also the choice of material (renewable, energy intensive production etc.) and the way single elements are connected. Usually constructions that can be separated into single materials can be reused or recycled more easily than constructions with composite materials (e.g. different types of insulation). These aspects are closely linked to the strategy of consistency. Another aspect is the question of how much material is used for a building. This in turn can be contradictory to energy efficiency (e.g. less insulation would need less material but cause higher energy use, and vice versa). But design and construction also cover the possibility to easily adapt a building to changing needs. With regard to sufficiency this aspect is very relevant (e.g. the ability to reduce to a smaller flat when family members move out). Table 3 below discusses a number of options to reduce space requirements through design and construction.

Also, the use of a room that is access to other rooms offers less privacy than a separate room as it limits the variety of use: In Figure 1 the flat with the walk-through room on the left could be used by a single person or a couple furnishing a living room and a bedroom. But it is less suitable as a two-bedroom apartment e.g. for student co-housing than the flat with the two separate rooms on the right.

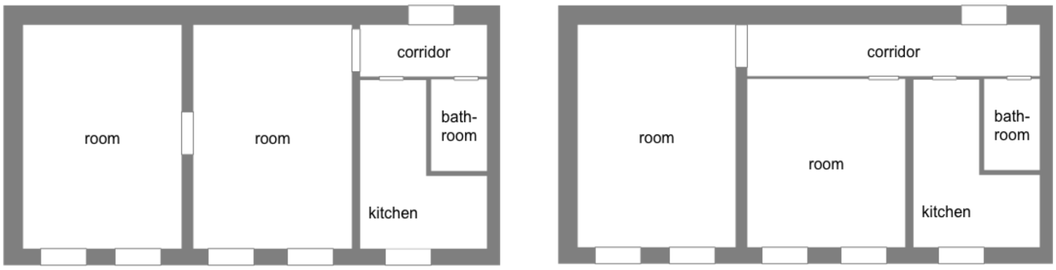


Figure 1. Floor plans with and without walk-through room. Source: Own illustration.

Similarly, the floor plans, design, and construction of other types of buildings and dwellings provide more or less options for sufficiency: Does a detached house offer the opportunity to be used by two households? Can a non-residential building that is not needed anymore easily turned into a residential building? And are users able and willing to realise the sufficiency opportunities they offer?

As mentioned above, the ***equipment*** focus of this paper is on heating. From a sufficiency perspective, the main potential is the size and respectively power of a heating system in relation to what the building needs. In efficiently renovated buildings, older heating systems often are oversized and thus need more energy than necessary to heat the building. Highly efficient buildings, such as passive houses, may not need a heating or cooling system at all, thus sufficiency and efficiency are closely linked in this aspect.

Progressing digitalisation, smart homes and intelligent control systems in buildings are supposed to support energy savings. Regular monitoring and controlling systems help to identify energy waste especially in bigger non-residential buildings, smart appliances, smart meter, and heating systems can be controlled via smart phones or tablets, etc. Pilot studies on smart metering in residential buildings show energy savings of 3% to 10% (ASUE 2011; Schleich et al. 2011); the higher ranges can only be achieved with strong, possibly individualised feedback action. However, it is clear that the energy and resources needed for the devices and systems, their use, and data processing lead to rebound effects. To date, it is not clear if this development in sum decreases or increases the energy demand in buildings.

From a sufficiency perspective finally the size, the design and construction, and the equipment of a building are closely linked with their ***use***. An oversized building can be used by more persons to make it more sufficient. But it has to be stated that the potential of this aspect is limited by the design and construction of a building such as the shape of the floor plan as mentioned above. Another point of use is the decision on indoor temperature and ventilation habits: energy-saving behaviour is choosing a lower indoor temperature when heating or a higher temperature when cooling a room and turning down the heater or air conditioner when windows are open. Also, short-term wide opening of windows is a natural ventilation practice that will lead to less energy loss than long-term tilting of windows or similar forms of narrow opening[3].

[3] The air exchange rate of narrowly open windows is low. Thus, for a comfortable air quality windows usually are open for a long time which leads to higher heat losses in the heating season and walls around the window cool down. Due to the high air exchange rate of wide open window it is sufficient to open the windows for up to five minutes. In this way, only the indoor air gets exchanged by fresh and cool outside air which heats up again fast, while the walls will not cool down.

The table below aims to provide some clarification on which types of building design and user concepts or actions can reduce floor space demand.

Table 3. Classification for building design and user concepts or actions that can reduce floor space demand.

	Building design	Building use
Less	Tiny houses/caravan/container housing Micro flats	Organisation/home office Virtual rooms
Flexible	Growing/shrinking dwelling size Inner development Multi-functional planning	Multiple use Reuse/Change of use Temporary use
Shared	Residential homes for special groups Building/housing co-operatives Community areas/rooms	Shared areas/rooms Shared furniture/equipment/products

Source: Based on Bierwirth, Thomas 2015.

2.2 Indicators for estimating the energy sufficiency potential

Based on the above analysis, we propose the following indicators to approach a sufficiency potential in buildings:

Table 4. Indicators for assessing and estimating energy sufficiency and insufficiency of buildings, and their measurement units

Indicator	Unit of measurement
floor area per person rooms per person time a building/dwelling is used	m^2/cap room/cap h/day or days/month
flexible size and organisation of rooms multiple usable rooms / areas flexibility of construction can be adapted easily to changing needs	yes/no yes/no yes/no
Heating/cooling system adequate for size and performance of building (kWh final energy use / h of full-load hours)	kW or W/m^2
building can be comfortable without heating or cooling equipment	yes/no
indoor temperature levels windows closed while heating or cooling shock ventilation with short-term wide window-opening instead of long-term tilting room by room, daytime / night-time temperature control energy use for heating per person	°C yes/no yes/no yes/no kWh/cap
share of dwellings equipped with sanitary facilities (indoor bath, shower, flushing toilet)	%

Source: Own compilation.

Some of these indicators, such as floor area or number of rooms per person, and the indoor temperature levels, are related to basic needs. So, analysing the sufficiency potential will imply an assumption about a sufficient level for these indicators that distinguishes between what are the 'basic needs' and the 'wants' exceeding these needs (see Darby and Fawcett 2018 for a discussion in these concepts).

A main problem to assess a sufficiency potential is missing data at EU level. Thus, as an approach, existing data is reviewed at EU level and at national level where available.

Furthermore, it has to be considered that some indicators are not applicable for residential and non-residential use or have to be adjusted to different kinds of non-residential uses. The variety of non-residential buildings can only be approached by descriptive examples of sufficiency potential in single projects. An overall quantitative estimate is not possible within this paper.

2.3 European status quo and trends in buildings

The following sections give an overview of most relevant data describing the status quo and existing trends in the European building sector that refer to the four areas for sustainability in buildings mentioned above and the related indicators in Table 4 above.

2.3.1 Space: Floor area and types of buildings

At European level, the share of residentially used floor area is higher than the non-residential share. Thus, the residential sector is most relevant for the indicator of floor area used (see Figure 2).

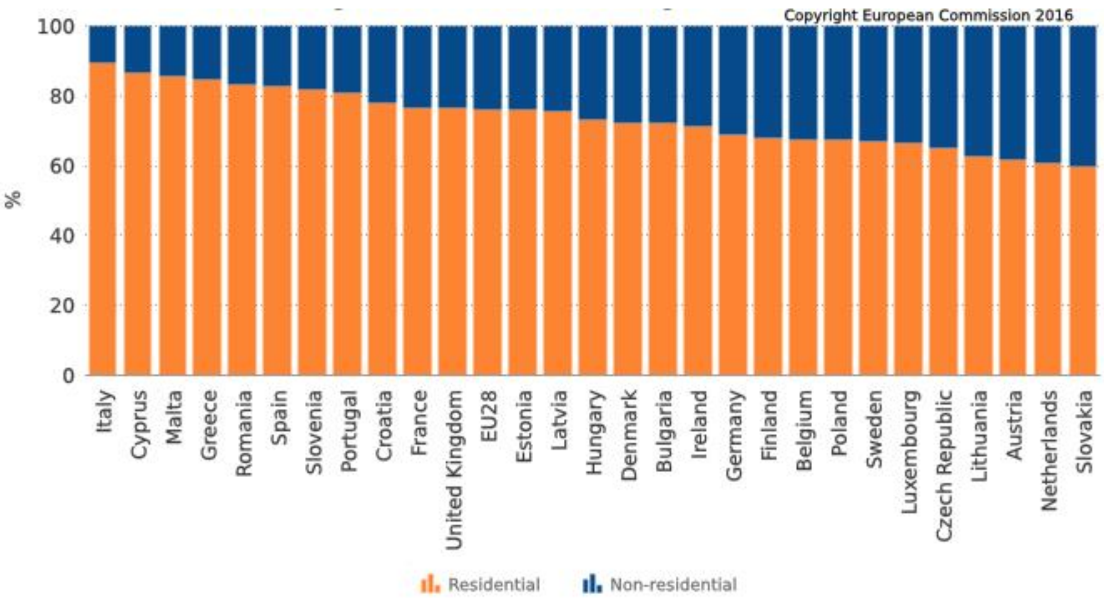


Figure 2. Breakdown of building floor area (2013). Source: European Commission 2016.

Regarding residential buildings and the distribution of floor space in single and multi family buildings (detached and semi-detached houses / flats), the picture differs widely between the countries (see Figure 3). Similarly, diverse is the average floor area per person in the residential sector in European countries, ranging from 18 m^2/cap in Romania to 63 m^2/cap in Portugal and Denmark (see Table 5)[4]. Countries with a higher average floor area per person could aim to reduce that average to a size of similarly wealthy countries, or at

[4] It has to be stated that it is not clear to which extent secondary homes, holiday homes and other rarely used buildings and dwellings are included in the data. These types of residential buildings increase an average floor space. On the other hand, it is not clear to which extent old peoples' homes, student homes and other housing communities are counted in, which would reduce average floor space. To be able to work with comparable data, the total residential floor area is divided by the total population.

least not let it increase even further. This would offer a way to calculate an energy sufficiency potential resulting from dwelling size.

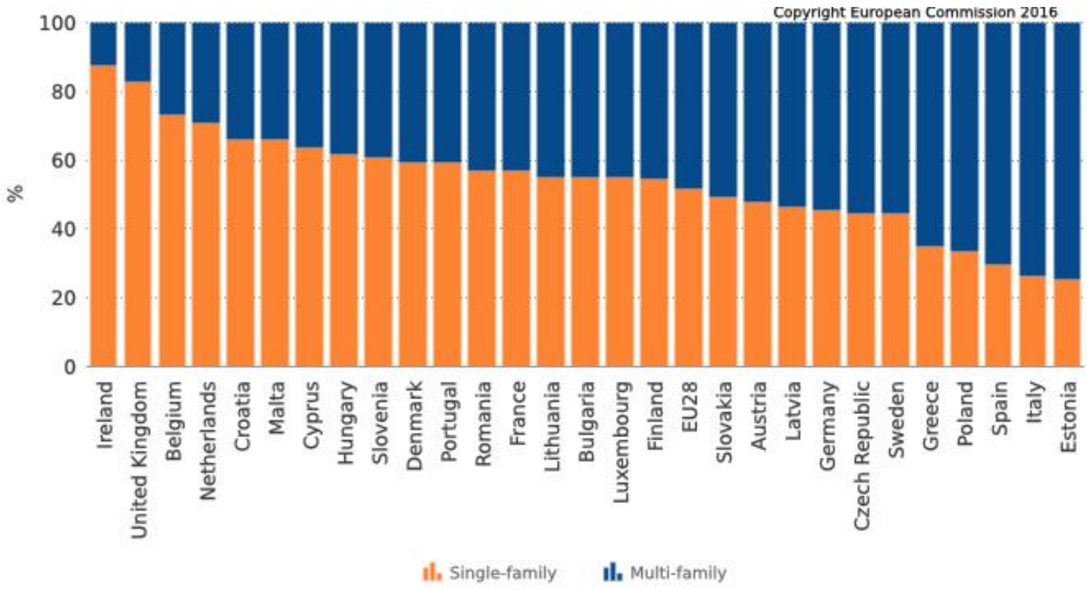


Figure 3. Distribution of dwellings in multi- and single-family houses in the residential sector. Source: European Commission 2016.

Table 5. Average floor space per capita by country. Source: Eurostat (population 2015) EU Buildings Database (Total floor area of dwellings 2014).[5]

Country	m^2/cap	Country	m^2/cap
Romania	18,1	Germany	46,6
Poland	27,1	France	46,9
Lithuania	29,8	Sweden	48,5
Estonia	31,5	Italy	49,1
Slovakia	31,6	Luxembourg	51,1
Croatia	33,0	Spain	52,4
Latvia	34,6	Netherlands	52,4
Slovenia	34,6	Finland	52,6
Czech Rep.	35,6	Greece	53,8
Belgium	38,3	Austria	55,0
UK	42,0	Cyprus	59,0
Ireland	45,5	Malta	62,2

[5] See previous footnote: It has to be stated that it is not clear to which extent secondary homes, holiday homes and other rarely used buildings and dwellings are included in the data. These types of residential buildings increase an average floor space. On the other hand it is not clear to which extent old peoples' homes, student homes and other housing communities are counted in, which would reduce average floor space. To be able to work with comparable data, the total residential floor area is divided by the total population.

Hungary	45,7	Denmark	62,7
Bulgaria	46,1	Portugal	63,7

It is also important to note that the trend in average floor space per capita is still rising even in the wealthier EU Member States, as the following table shows.

	2008	2009	2010	2011	2012	2013	2014
Romania	15,58	16,05	16,38	17,17	17,45	17,71	17,99
Poland	24,22	24,59	25,61	25,92	26,25	26,60	27,05
Lithuania	25,60	26,06	26,64	27,90	28,58	29,00	29,53
Estonia	29,36	29,80	30,05	30,34	30,67	31,06	31,44
Slovakia	30,48	30,70	30,92	31,14	31,32	31,53	31,67
Croatia	31,39	34,04	34,76	35,39	36,24	37,19	38,23
Latvia	28,57	29,00	29,81	30,98	31,76	33,14	34,30
Slovenia	33,19	33,31	33,49	33,79	33,99	34,17	34,61
Czech Rep.	34,05	34,40	34,78	34,64	35,09	35,13	35,70
Belgium	38,06	38,11	38,14	37,91	37,94	38,07	38,35
UK	40,08	40,03	40,24	39,97	40,37	41,62	42,37
Ireland	40,62	41,29	42,15	43,06	43,27	44,42	45,76
Hungary	38,26	38,18	39,79	43,97	44,24	44,87	45,61
Bulgaria	32,02	32,45	32,80	38,50	38,99	44,17	45,83
Germany	42,10	42,44	43,69	44,82	45,00	46,48	46,87
France	45,61	45,84	46,09	46,35	46,63	46,90	47,24
Sweden	49,22	49,45	49,51	49,79	49,69	49,57	49,05
Italy	48,95	49,17	49,56	49,57	49,69	49,57	49,14
Luxenbourg	52,69	52,75	52,78	52,93	52,76	52,64	52,34
Spain	49,72	50,03	50,35	50,59	50,79	51,10	52,33
Netherlands	48,42	49,17	49,79	50,37	50,99	51,92	52,66
Finland	50,73	51,16	51,21	51,74	52,22	52,60	52,82
Greece	50,80	51,12	51,40	51,61	51,55	52,41	53,44
Austria	48,50	48,87	49,42	52,50	49,97	51,80	52,57
Cyprus	72,08	73,39	73,69	74,03	73,41	73,95	77,59
Malta	43,79	44,44	45,05	57,40	59,08	60,83	62,81
Denmark			59,13	62,08	62,42	62,62	63,10
Portugal	51,52	51,85	59,22	60,66	61,12	61,65	63,39

$\leq 30\ m^2/cap$ $30\ m^2/cap < \ < 50\ m^2/cap$ $\geq 50\ m^2/cap$

Figure 4. Development of average floor space per capita by country. Source Eurostat, EU Building Database (Total Floor Area Of Dwellings)

The question then arises how such trends could be stopped or even reversed. Chapter 2.3.2 provides some examples of new concepts for building design and use, expanding on Table 3 above.

2.3.2 Design and construction: Flexibility, multiple use, and common use of rooms and areas

Flexibility, multiple use, and common use of rooms and areas in residential and non-residential buildings can reduce the demand for floor area, equipment and energy use.

In the residential sector some co-housing projects in Switzerland, Germany and Austria explicitly mention the limitation of floor area per person as a target of the community (e.g. Hunziker Areal, Zurich, Switzerland[6]). They offer different kinds of housing concepts from single apartments to large flat-sharing groups, flexible rooms that can be rented when the family is growing, common rooms like guest rooms, kitchens, working spaces and party rooms and often common or public outdoor areas like gardens, playgrounds, or barbecue.

[6] https://www.mehralswohnen.ch (accessed 07/13/2017).

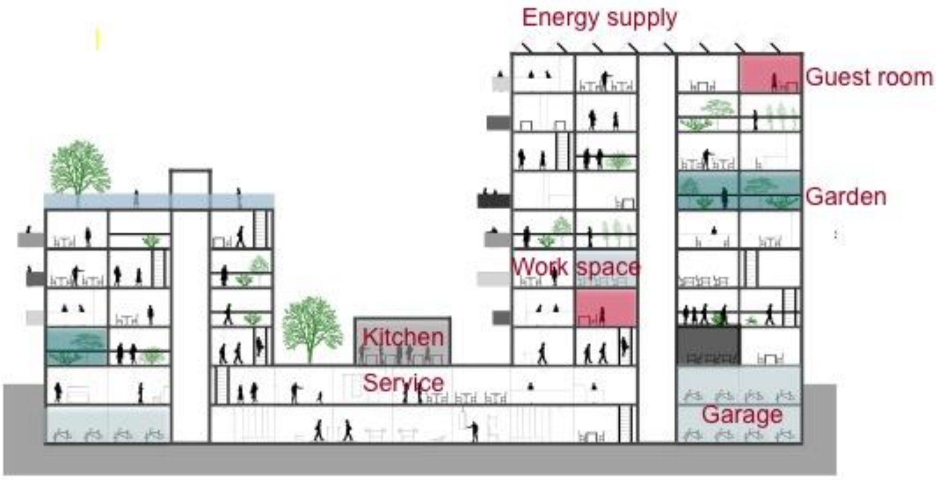


Figure 5. Concept of a co-housing project. Source: 'Living Hub' by werk.um architects

Flexibility can be given in single family houses, too, that offer the opportunity to be separated into two dwellings when less space is needed (e.g. '[7]Just K', Tübingen, Germany) or are based on a modular concept that allows to add and remove single rooms (e.g. 'Joker room', Kalkbreite Zurich, Switzerland). Also, the interior design can offer flexibility. Especially in tiny houses and micro apartments movable parts, furniture, and walls enable multiple use of a single room (e.g. "micro compact home", London).

In non-residential buildings there are similar examples of flexible, multiple and common use of rooms, equipment and areas. Co-working spaces offer a limited number of working places to different people sharing place and equipment. Prefabricated modular concepts allow a variety of room, size and formation, and the reuse of single modules (see Figure 6).

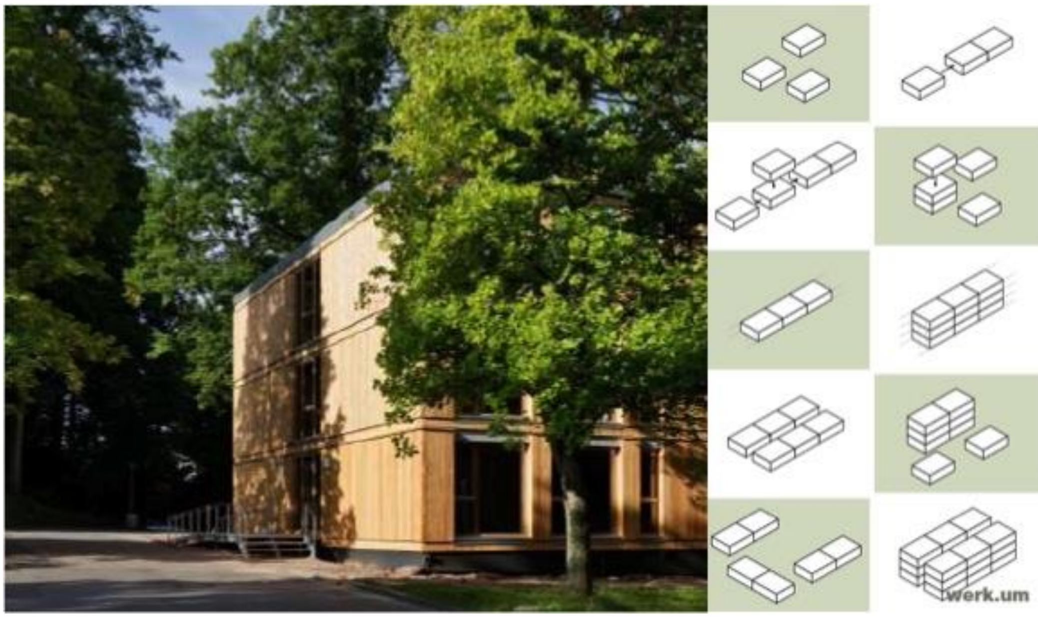


Figure 6. Concept of modular and flexible building. Source: 'mobispace' by werk.um architects[8]

Start-up centres offer the possibility to start a business and to use room and equipment of the centres. When companies are growing, they can rent more space and expand to a limited extent. In some cities schools and other non-residential buildings that are used only parts of the day allow clubs or other associations to use rooms in the evenings.

[7] ‚Just K' was built for a six person family by AMUNT Nagel, Theissen architects. The 138 m² of the wooden detached house can be separated into two dwellings of 81 m² and 57 m².

[8] http://www.mobispace.de/

Up to date there is no existing data about the flexibility, multiple or common use of buildings in Europe. But it can be stated that in some countries co-housing, co-working and other concepts in the residential as well as in the non-residential sector increase (for Germany: RWTH Aachen 2012; BBSR 2014).

2.3.3 Equipment: Heating and cooling systems

As stated above, in efficiently renovated buildings, older heating systems often are oversized and thus need more energy than necessary to heat the building. Adapting the capacity to the needs offers an energy savings potential, however the data to calculate it separately from the overall energy efficiency and savings potential from exchange of old boilers are unlikely to exist.

Highly efficient buildings, such as passive houses, may not need a heating or cooling system at all, thus sufficiency and efficiency are closely linked in this aspect. This is a complex function of (regional) climates and building shell performance and also sometimes depends on intelligent use of the building, so it is even more complex to quantify the energy savings possible from completely avoiding heating systems.

2.3.4 Use: Heating and ventilation practices

The question what indoor temperature is perceived as 'comfortable' depends on various factors, individual as well as physical. Individually are aspects like age (elderly people usually prefer higher indoor temperatures), indoor activities (physical or seated activities), the aspect how much time is spent in a room or a building, and of course how a person dresses (wearing t-shirts or warm pullovers in winter), or general different perception of warm and cold. Building physics are relevant as components with low efficiency (e.g. single glass windows, walls, floors or ceilings without insulation) cool down fast in winter and can lead to draught effects that are perceived as uncomfortable. Furthermore, indoor dimensions play an important role. High ceilings and large rooms in dwellings need more energy to be heated to a comfortable level. Generally different temperatures for different rooms are perceived as comfortable (e.g. higher temperature in living rooms than in bedrooms). However, reduced indoor temperature (e.g. 20°C instead of 22°C) can lower energy use significantly, about 6% per degree.

As stated above, we understand sufficiency not as 'suffer' but as 'sufficient'. Thus, it is clear that reduced indoor temperature and changed ventilation habits must not harm people or buildings. Low indoor temperatures and improper ventilation practices can lead to health problems such as respiratory diseases. And low indoor temperatures in inefficient buildings can lead to dampness and mould. Nevertheless, there are some aspects of heating and airing that in many households can lead to energy savings, e.g.:

- daytime / night-time-reduction (depends on the building) and room by room control heating systems (and making use of them),
- closing windows while heating or electrically cooling a room or a building,
- shock ventilation with short-term wide window-opening instead of long-term tilting,
- wearing warm clothes in winter also at home.

There is no data available about heating and ventilation practices on European level. Furthermore, heating and ventilation needs and energy saving potentials have to be considered against different climates in Europe. Thus, an estimation of EU-wide sufficiency energy saving potentials is not possible within this paper.

2.4 Energy saving potential of energy sufficiency in buildings

Up to date there is little literature on quantified energy sufficiency potentials in buildings and the related energy savings in Europe. We only found some examples in Switzerland[9], France, and Germany, discussed in the first section of this chapter.

2.4.1 Examples for estimates of potential energy savings from energy sufficiency

2.4.1.1 Switzerland: The City of Zurich

> Ten years ago, the vision of a "2000-Watt Society" was developed at the Swiss Federal Institute of Technology (ETH) in Zürich. It is a model for energy policy which demonstrates how it is possible to consume only as much energy as worldwide energy reserves permit and which is justifiable in terms of the impact on the environment. It is possible when every person in every society limits their energy consumption to a maximum of 2000 watts. (City of Zurich 2017)[10]

With the target of an absolute reduction of energy use the city of Zurich went on a different path in climate policy than those with a percentage reduction target of greenhouse gas emissions. While emission reduction often is addressed by efficiency and renewable energy development predominantly, the city of Zurich developed an accompanying sufficiency strategy rather early.

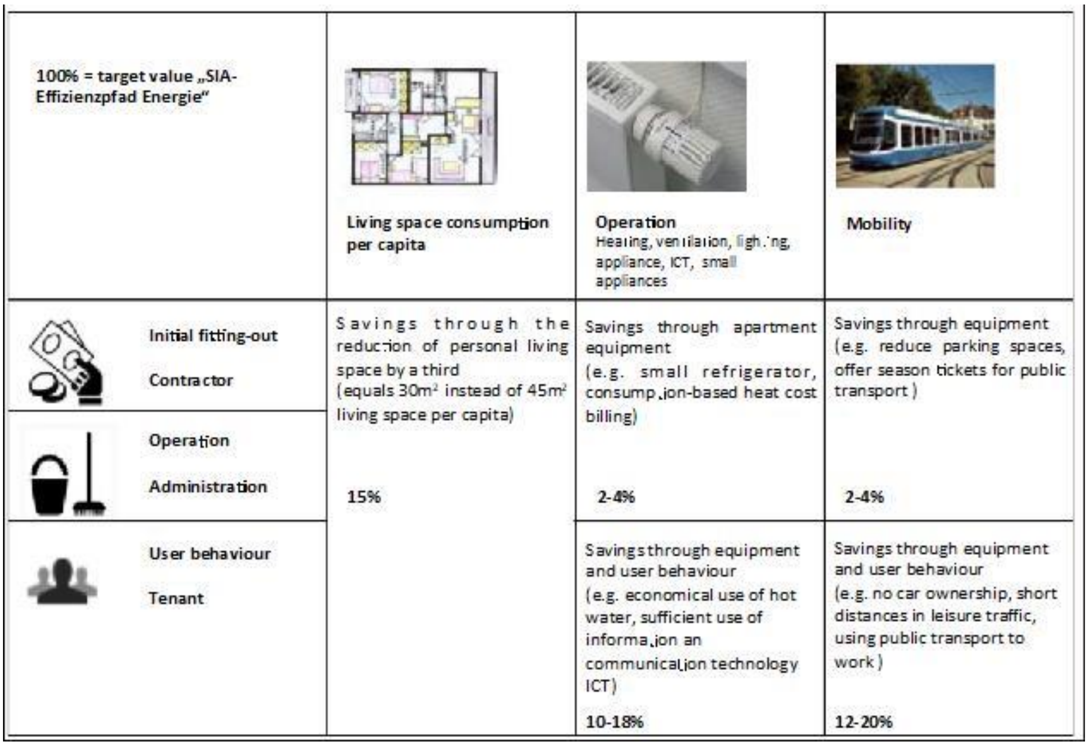
For the residential sector the potential of sufficiency in housing was estimated by Pfäffli et al. (2012). They differentiate between three periods

- Construction / first equipment
- Period of use: administration
- Period of use: users

and three relevant energy consuming aspects in housing

- floor area per person
- user behaviour
- (daily) mobility[11]

[9] Switzerland is considered here not being part of the European Union but as a country on the European continent.
[10] https://www.stadt-zuerich.ch/portal/en/index/portraet_der_stadt_zuerich/2000-watt_society.html
[11] This is not to be assessed here, as there are plans for an energy sufficiency in mobility concept paper as another input to the energy sufficiency policy guide.



100% = target value „SIA-Effizienzpfad Energie"		Living space consumption per capita	Operation Heating, ventilation, lighting, appliance, ICT, small appliances	Mobility
	Initial fitting-out Contractor	Savings through the reduction of personal living space by a third (equals 30m² instead of 45m² living space per capita) 15%	Savings through apartment equipment (e.g. small refrigerator, consumption-based heat cost billing) 2-4%	Savings through equipment (e.g. reduce parking spaces, offer season tickets for public transport) 2-4%
	Operation Administration			
	User behaviour Tenant		Savings through equipment and user behaviour (e.g. economical use of hot water, sufficient use of information an communication technology ICT) 10-18%	Savings through equipment and user behaviour (e.g. no car ownership, short distances in leisure traffic, using public transport to work) 12-20%

Figure 7. Saving potentials by moderate sufficiency by actors.
The percentage values refer to savings compared to a typical behaviour in primary energy and the green house gas emissions of construction, operation and mobility for an efficient and consistent building, efficient equipment, factory equipment and car pool. (New building and renovations) Source: Pfäffli 2012.

When interpreting the findings presented in the above figure, the reader should be aware that the percentages refer to the total primary energy consumption of the household for construction, heating, appliances, and mobility. Hence, the savings on heating energy alone from reducing floor area by a third are likely to be closer to 33 % than to 15 %.

Another study of the sufficiency potential in different consumption areas of private households in the city of Zurich shows that the highest potential can be found in the highest income groups (Econcept 2013).

2.4.1.2 Germany: Living in oversized dwellings and stopping the growth in average per capita floor area

In Germany, a quantitative estimate of a total energy sufficiency potential in residential buildings, or even in all buildings, is missing yet. But there are calculations related to policy instruments analysed in two studies (Fischer et al. 2016 and Thema et al. 2016). Linked to the latter study, a survey in private households showed that "… 10 % of the interviewed think their flat is 'too big' … [see Figure 8]. Their living space per capita is about 78 m². They are typically owning the flat and are older citizens (54.4 % are older than 60) and are single or in couple. 5 % of those who rated their apartment as being right or too large were pleased to say that they would like to move into a smaller apartment, and 34% can imagine this under certain conditions (including not leaving their present neighbourhood, no increase in rent, and support through policy instruments)" (Thomas 2017).

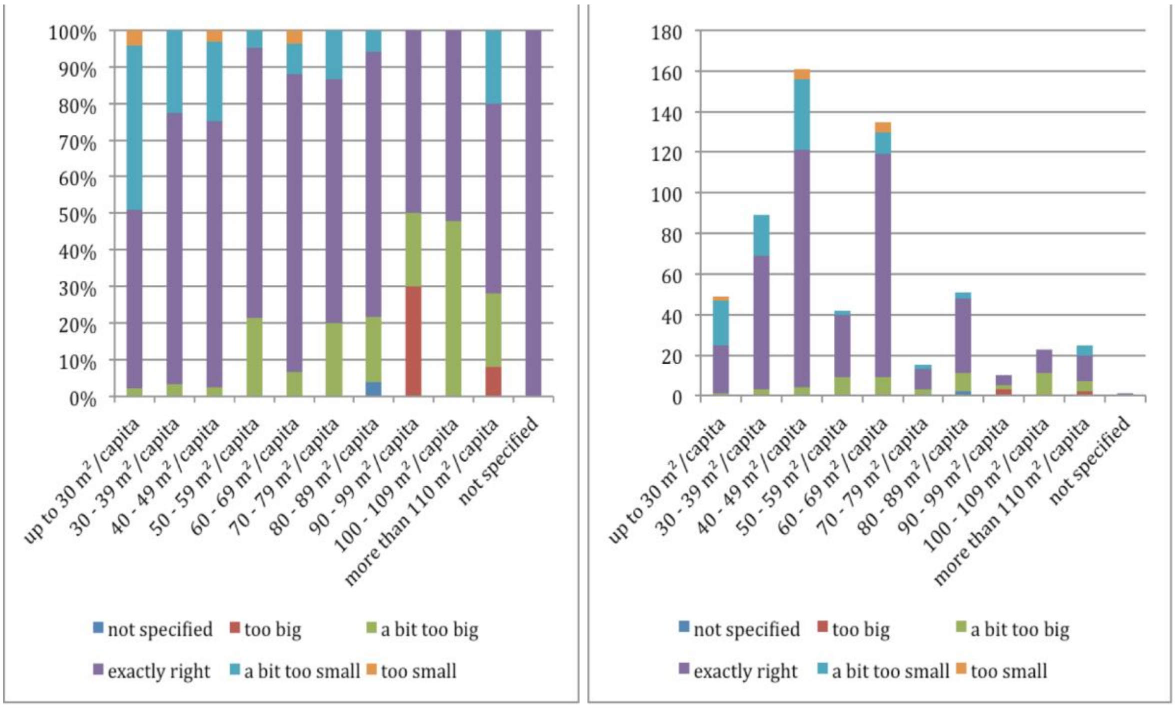


Figure 8. Answers of interviewees to the question of how they would assess their flat with regard to the size in relation to the per capita living space they live on.
(Left graphic: percentages, right diagram: number of respondents (N = 601).) Source: Thomas 2017.

Thema et al. 2016 have also calculated the potential from stopping the growth in average per capita floor area, based on existing energy scenarios. For example, Matthes et al. (2013, p. 25) expect the occupied dwelling floor area (without vacancies) in Germany to grow by 6.4 % between 2015 and 2030. Per capita, this means an increase of 10,8%, from 40.7 to 45.1 m². The latter is just a little higher than the existing dwelling stock in 2015, which was 44.2 m² per capita, including 8 % of empty dwellings. If Germany succeeds in avoiding the net addition to the stock of 0.21 bn. m², and assuming an average energy consumption for heating and hot water of 70 kWh/(m²*a) and a greenhouse gas intensity of 0.23 kg/kWh (natural gas), this will save almost 15 TWh/yr of energy and around 3.4 mn. tons of CO_{2eq}/yr of greenhouse gas emissions. If residential electricity consumption is proportional to dwelling size too, electricity savings of 8.4 TWh/yr and greenhouse gas emissions reductions of 4.2 mn. tons CO_{2eq}/yr may be added.

For 2050, current projections already foresee a stabilisation of total residential floor area, so a cap on this total would not bring any further savings beyond 2030.

However, this scenario was developed before the large number of refugees from Syria and other countries came to Germany in recent years, so housing a higher than expected population in the existing total floor area, instead of building 350,000 new dwellings per year as German policy now is aiming for, would yield a higher energy savings potential from energy sufficiency than calculated above.

2.4.1.3 France: NegaWatt Scenario

In France, the Association NegaWatt published a 2050 scenario including explicitly sufficiency assumptions. According to their modelling energy reduction from sufficiency ('sobrieté') measures account for a reduced energy demand for heating and electricity (including products) of 512 TWh in 2050 against a business as usual scenario (Association NegaWatt 2017). "The model output shows that such sufficiency evolutions could help reducing the country's final energy consumption by about 30% by 2050, comparable to what energy efficiency could achieve over the same period" (Toulouse et al. 2017). In the residential sector they find a decrease in energy use by 21% against business as usual and having a closer look at the Nord-Pas-de-Calais Region they find a sufficiency reduction potential of 13% to 30% in residential and tertiary buildings (Toulouse et al. 2017).

2.4.2 Energy sufficiency potential and its restrictions

As mentioned above, in Zurich the highest potential for energy reduction by sufficiency has been found in the highest income groups (Econcept 2013). It can be assumed that this is true for other cities and European countries in general, too. Scaled up to the European level the question is, in which countries the highest sufficiency potentials can be identified.

2.4.2.1 Sufficiency potential of adequate floor space and room per person

Looking at the indicator 'floor area per person', the Zurich study finds a reduction of total household primary energy of 15% when reducing floor area from 45 m^2 to 30 m^2 per person (see Figure 7). Reduction in heating energy alone is likely to be much higher, closer to 33 % than to 15 %. **Assuming 30 m^2 as an average target value**[12] as in the Swiss study, most European countries show a high energy sufficiency potential except for Romania, with only 18m^2 per person in 2014 (EU Buildings Database, Eurostat 2017)[13]. Generally speaking, western European countries show the highest sufficiency potential with regard to floor area per person (see Table 5).

An average floor area per person has to be considered against the background of number of persons per household. Single persons usually occupy more space than single members of a bigger household due to the rooms and areas that they use commonly such as kitchen, bathroom, corridor. This is also reflected in the definition of the 'adequate floor area' for households and single persons that receive housing allowances in Germany:

> 'Adequate' ... are the following sizes of flats: (a) for a single person: 50 m^2 living space, (b) for a household with two persons: 2 rooms or 65 m^2 living space. For each other person that belongs to the household the living space increases by 15 m^2. The number of rooms is in addition to a kitchen (up to 15 m^2) and secondary rooms. (§8 (2) Wohnraumnutzungsbestimmungen (living space usage regulation) of the Federal State of North Rhine-Westphalia)[14]

Based on this regulation and assuming each household in Germany 2016 would have lived in a dwelling offering the adequate size as defined above the average floor space per person would have been 32,3 m^2 per person (see Table 6). This is 13.9 m^2 per person (30%) less than the average floor area was in 2015 (and corresponds to the average floor area of the mid 1980s in Germany). To further reduce the floor space per person (e.g. to the estimated 30 m^2 per person in the Swiss study), single person households have the highest influence: in terms of moving to shared dwellings and / or lower the size of dwellings e.g. by having smaller single apartments in combination with shared areas and rooms.

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[12] This would then be the ‚adequate' or ‚sufficient' level of dwelling floor area per person, distinguishing 'needs' from 'wants'. Of course, this is a value that needs to be decided through societal debate that will materialise in political value-setting, as the example from Germany shows. The level of 30 m^2/cap was taken from the Swiss study to demonstrate potential ways of calculating an energy sufficiency potential from floor space policy.

[13] http://ec.europa.eu/energy/en/eu-buildings-database (accessed 08/30/2017); http://ec.europa.eu/eurostat (accessed 08/30/2017).

[14] https://recht.nrw.de/lmi/owa/br_text_anzeigen?v_id=10000000000000000462 (accessed 07/13/2017).

Table 6. Theoretical average adequate floor space per capita in Germany 2015 based on the definition of 'adequate space'. Source: Based on destatis 2017.

Size of household	Adequate size	m^2/cap	Share of households	Number of persons	Total m^2	Average m^2 / person
1 person	50	50.0	41,4%	16,834,560	847,872,000	
2 persons	65	32.5	34.2%	28,016,640	910,540,800	
3 persons	80	26.7	12.1%	14,868,480	396,492,800	
4 persons	95	23.8	9.0%	14,745,600	350,208,000	
5 persons +[15]	110	22.0	3.2%	7,588,282	151,765,647	
Sum				**82,176,442**	**2,656,879,247**	32.3
Floor area 2015					3,794,976,000	46.2
Difference					1.138.096.753	13.9

In European statistics and some countries like the UK, the indicator 'rooms per person' plays a major role to define overcrowding and under-occupation of dwellings. The UK office for National Statistics, in the Housing (Overcrowding) Bill of 2003, defines the bedroom standard as follows:

> For the purposes of the bedroom standard a separate bedroom shall be allocated to the following persons—
>
> (a) A person living together with another as husband and wife (whether that other person is of the same sex or the opposite sex)
>
> (b) A person aged 21 years or more
>
> (c) Two persons of the same sex aged 10 years to 20 years
>
> (d) Two persons (whether of the same sex or not) aged less than 10 years
>
> (e) Two persons of the same sex where one person is aged between 10 years and 20 years and the other is aged less than 10 years
>
> (f) Any person aged under 21 years in any case where he or she cannot be paired with another occupier of the dwelling so as to fall within (c), (d) or (e) above[16].

In Europe the overcrowding and under-occupation rates differ widely between the countries as well as between owner occupied and tenant occupied dwellings. Slightly different from the UK bedroom standard, European statistics define overcrowding and under-occupation by a minimum number of rooms per person and household as follows:

> A person is considered as living in an overcrowded household if the household does not have at its disposal a minimum number of rooms equal to:
>
> - one room for the household;
> - one room per couple in the household;
> - one room for each single person aged 18 or more;

[15] Households with more than five members are considered by calculating with 5,8 persons per household which in sum corresponds to a total population of 82,18 million in Germany 2015 (destatis 2017).
[16] https://www.publications.parliament.uk/pa/cm200203/cmbills/046/03046.i-5.html#NewClause (accessed 07/13/2017).

- one room per pair of single people of the same gender between 12 and 17 years of age;
- one room for each single person between 12 and 17 years of age and not included in the previous category;
- one room per pair of children under 12 years of age.[17]

> … For statistical purposes, a dwelling is defined as under-occupied if the household living in it has at its disposal more than the minimum number of rooms considered adequate, …[18].

Determining that a high overcrowding rate restricts and a high under-occupation rate offers a higher sufficiency potential it can be also stated that the potential in western European countries overall is significantly higher than in eastern countries and in owner occupied dwellings higher than in households renting their dwellings (see Table 7).

Table 7. Overcrowding and under-occupation rate in European countries in 2015. Source: Eurostat 2017.[19]

Country/Geographic area	Overcrowding rate (%)		Under-occupation rate (%)	
	Owner	Tenant	Owner	Tenant
Belgium	0.3	4.5	81.6	43.4
Cyprus	0.5	3.3	74.6	49.1
Ireland	0.7	6.1	82.5	41.0
Switzerland	1.0	10.1	71.0	26.7
Netherlands	1.2	6.4	60.4	33.4
Norway	1.2	24.7	59.2	9.3
Germany	1.4	11.8	56.2	11.5
Finland	1.5	16.7	61.8	12.2
United Kingdom	1.9	16.1	69.4	19.6
Malta	2.1	7.3	71.6	47.8
Luxembourg	2.5	20.6	67.9	21.1
Spain	2.8	11.7	61.6	37.2
France	3.0	16.1	57.5	16.7
Denmark	3.7	14.9	61.6	15.9
Sweden	3.9	28.7	57.5	9.7
Austria	4.3	32.1	45.8	7.7
Iceland	5.6	13.9	37.8	12.3
European Union (27 countries)	10.5	19.8	42.2	16.0
Portugal	13.3	16.6	41.2	19.5
Estonia	18.5	18.4	31.0	6.2
Slovenia	18.9	38.5	32.1	4.5
Czech Republic	18.9	40.9	26.1	3.9
Lithuania	20.9	62.6	20.7	5.6

[17] http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Overcrowding_rate (accessed: 08/16/2017).
[18] http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Under-occupied_dwelling (accessed: 08/16/2017).
[19] http://ec.europa.eu/eurostat/data/database (accessed: 07/14/2017).

Country/Geographic area	Overcrowding rate (%)		Under-occupation rate (%)	
	Owner	Tenant	Owner	Tenant
Italy	24.6	45.7	18.2	4.3
Slovakia	25.3	61.6	32.1	1.2
Latvia	35.7	63.3	12.5	2.0
Poland	37.8	71.2	13.6	1.0
Greece	38.2	32.2	11.8	2.6
Romania	38.2	81.0	5.5	2.9
Croatia	39.8	65.2	10.3	4.9
Hungary	40.1	61.9	8.8	2.0
Macedonia	49.1	75.4	14.0	5.3
Bulgaria	49.6	82.0	11.2	0.4
Serbia	51.3	74.7	5.2	0.5

Another aspect that has to be considered when it comes to the size of dwellings is the provision of basic equipment, e.g. with sanitary facilities. For sufficiency understood as a minimum standard as well as a maximum Table 7 shows that in some countries an upgrade is needed in some buildings to reach a decent standard including access to indoor sanitary facilities. It is possible that – depending on the shape and construction of a building – this demands more floor space in dwellings.

Table 8. Percentage of the population with housing problems or deprived of some housing items by poverty status, 2015. Source: Eurostat 2017.

	Leaking roof / damp walls / floors / foundation or rot in window frames		Lack of bath/shower		Lack of indoor flushing toilet		Dwelling too dark	
	Total population	Population at risk of poverty	Total population	Population at risk of poverty	Total population	Population at risk of poverty	Total population	Population at risk of poverty
EU-28	15.2	24.0	2.2	6.6	2.4	6.9	5.5	8.7
EA-19	16.0	24.4	0.5	1.3	0.6	1.5	5.6	8.8
Belgium	18.2	30.9	0.7	1.6	2.3	4.3	7.4	14.3
Bulgaria	12.9	26.3	11.6	33.2	18.6	45.0	6.4	13.5
Czech Republic	8.9	17.8	0.3	1.0	0.6	1.6	3.9	8.1
Denmark	16.1	22.2	2.2	6.7	0.6	2.9	3.4	6.6
Germany (¹)	12.8	19.7	0.0	0.0	0.1	0.1	4.0	7.5
Estonia	13.4	21.8	7.3	15.4	6.9	13.3	4.9	6.2
Ireland	13.6	19.6	0.2	0.4	0.1	0.2	5.1	6.0
Greece	15.1	20.4	0.5	0.9	0.5	1.0	5.7	9.6
Spain	15.2	21.3	0.1	0.2	0.1	0.3	3.9	5.1
France	12.6	23.9	0.5	1.0	0.5	1.0	7.4	10.9
Croatia	10.9	21.0	1.7	5.9	2.0	6.5	5.1	7.3
Italy	24.1	32.2	0.4	0.6	0.6	0.7	7.0	11.0
Cyprus	26.5	33.9	0.9	2.9	0.9	3.0	5.6	8.6
Latvia	24.4	38.7	15.3	36.0	13.6	31.8	8.5	15.4
Lithuania	17.0	30.3	11.5	30.3	12.4	31.7	5.1	6.7
Luxembourg (²)	14.4	25.8	0.1	0.0	0.0	0.0	7.1	12.3
Hungary	25.4	44.9	3.7	15.8	3.9	16.7	8.6	16.1
Malta (³)	10.2	12.8	0.2	0.1	0.0	0.0	7.2	9.9
Netherlands (³)	15.7	21.5	0.1	0.2	0.0	0.2	4.8	7.1
Austria	11.7	16.5	0.5	1.1	1.0	3.1	5.6	9.9
Poland	11.9	21.2	3.3	10.0	2.7	8.3	4.5	7.6
Portugal	28.1	36.6	1.5	3.0	1.0	2.6	8.0	11.0
Romania	12.8	26.6	30.8	65.5	32.8	68.0	5.8	10.4
Slovenia	26.9	37.2	0.5	2.4	0.3	1.4	5.7	9.6
Slovakia	6.3	17.6	0.8	5.5	1.4	8.0	3.1	9.2
Finland	4.4	6.2	0.8	2.4	0.5	1.5	4.0	6.0
Sweden	7.5	9.7	0.6	2.2	0.0	0.0	5.3	5.9
United Kingdom	14.8	21.8	0.6	1.3	0.4	0.8	5.2	6.6
Iceland	19.3	23.7	0.1	0.7	0.0	0.0	2.6	5.2
Norway	6.8	11.5	0.3	1.4	0.0	0.0	3.0	6.2
Switzerland (2014)	11.3	17.4	0.2	0.2	0.2	0.2	7.2	12.7
FYR of Macedonia	12.2	21.2	4.2	10.2	5.7	12.5	3.9	6.7
Serbia	23.4	30.7	3.8	9.6	4.2	10.6	8.3	11.9

(¹) Values not significant for 'Lack of bath/shower' for the total population.
(²) Values not significant for 'Lack of bath/shower' for population at risk of poverty nor for 'Lack of indoor flushing toilet'.
(³) Values not significant for 'Lack of indoor flushing toilet' for the total population

2.4.2.2 Sufficiency potential of the use of buildings and its limitations

In terms of energy consumption in buildings user behaviour plays an important role. The right heating and airing practices can not only save energy but also can prevent unhealthy room conditions such as mould or benefit the thermal comfort. In general, each degree of indoor room temperature accounts for 6-8% (Jørgen 2014). Also, different feedback measures contain energy saving potentials, e.g. smart home systems (5 – 20 %), ventilation/air quality 'traffic lights' (up to 31 %), energy audits (5 – 20 %) or community-based initiatives (5 – 20 %) (numbers would not simply add up to a total due to overlaps) (EEA 2013; Lovric & Grinewitschus 2017).

With regard to the use of buildings there are restrictions of the sufficiency potential when it comes to energy poverty and households that cannot afford to heat their homes in winter (see Figure 9) and cool them in summer (see Figure 10) to a comfortable and healthy temperature. This can be due to an insufficient quality of the building, or to the low income of a household, or a combination of both.

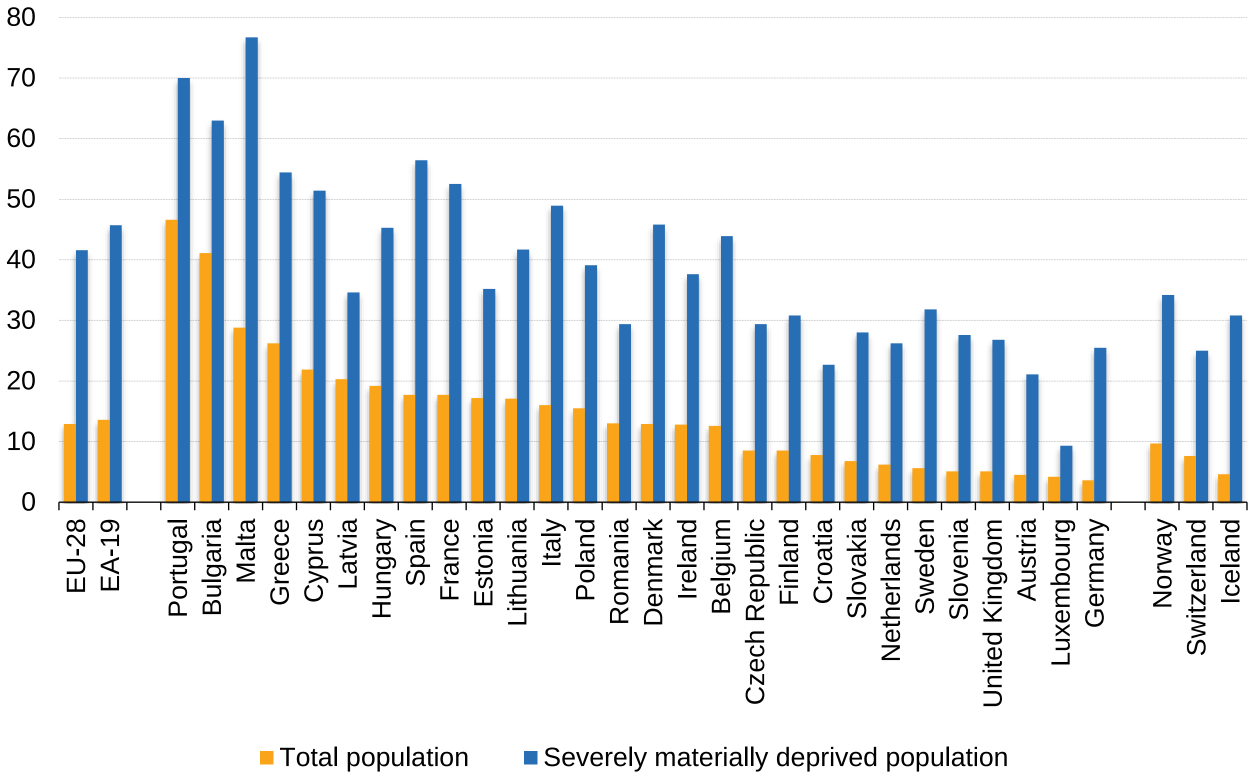

Figure 9. Share of population living in a dwelling not comfortably warm during winter time by material deprivation status[20], 2012 (% of specified population).
Source: Eurostat 2012 ad-hoc module 'Housing conditions' (HC060).

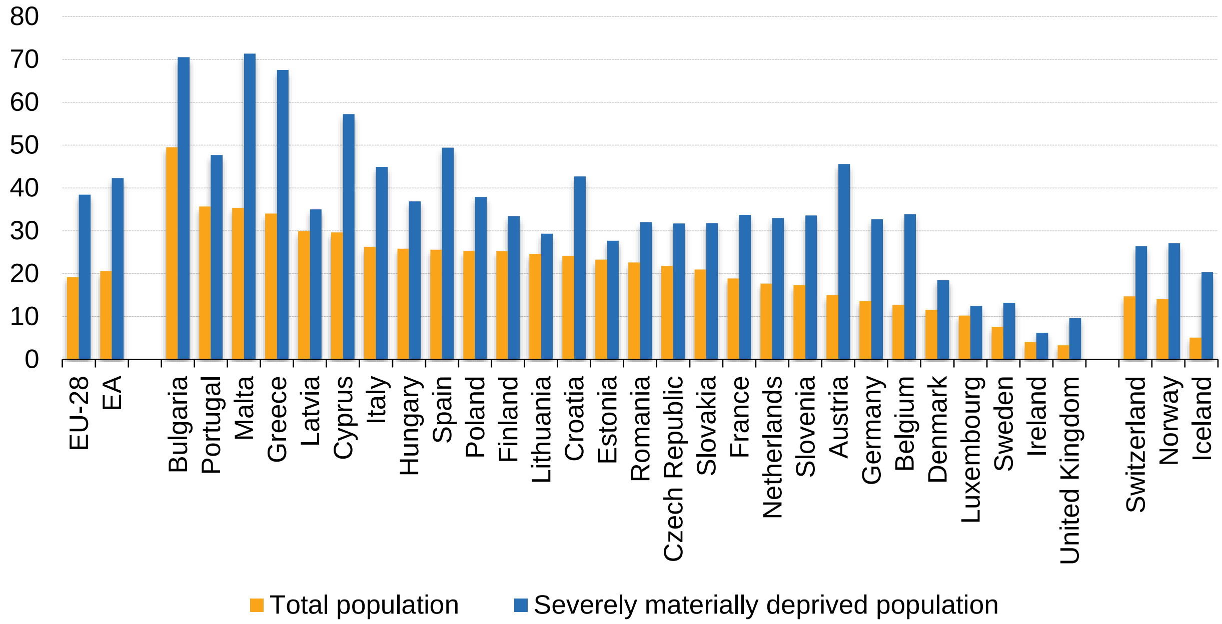

Figure 10. Share of population living in a dwelling not comfortably cool during summer time by material deprivation status, 2012 (% of specified population).
Source: Eurostat 2012 ad-hoc module 'Housing conditions' (HC070).

[20] Severe material deprivation rate is defined as the enforced inability to pay for at least four of the items: rent, mortgage or utility bills; to keep their home adequately warm; to face unexpected expenses; to eat meat or proteins regularly; to go on holiday; a television set; a washing machine; a car; a telephone.(http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Material_deprivation).

Another limitation of lowering indoor temperatures for energy savings are the building's physics. Depending on the gradient between indoor and outdoor temperature condensation water can lead to damp walls in cold winter periods and consequently – especially in combination with too little airing – to mould in buildings. Low efficient components that cool down fast are especially susceptible.

Estimating an overall sufficiency potential these aspects have to be considered as limits for sufficiency or – in some cases – as buildings in need of efficiency measures and an upgrade to the "sustainable energy safe space". Depending on the building and its performance this might come along with a higher demand for space, energy, resources and energy services. On the other hand, depending on the household and specific housing conditions sufficiency can be part of the solution, e.g. if low income household live in oversized dwellings that they are not able to maintain.

2.4.3 Approaches to estimate an energy sufficiency potential in heating of dwellings at EU level based on dwelling size and equipment

To quantify a sufficiency potential for EU countries, the question appears how the aspects analysed above can all be reasonably considered.

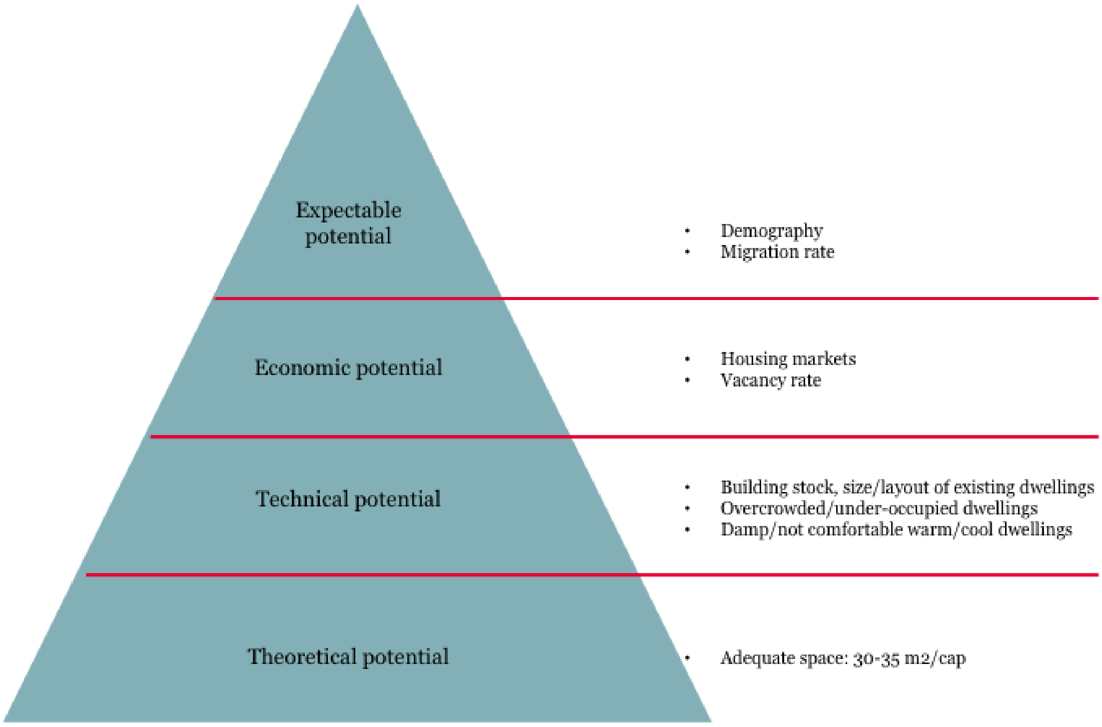

Figure 11. Potentials pyramid and factors influencing the size of each level of potential. Source: own analysis

Based on the differentiation of a theoretical, technical, economical and expectable potential (see Figure 11 with our analysis of a possible set of parameters determining each stage), a first approach is the assumption that all countries reduce their average floor space per person to **two experimental levels** of "adequate space" of 35 to 30 m^2/cap. The theoretical potential following from this calculation experiment would be a reduction of floor space demand of 21.4% to 32.6%. Most countries could reduce their floor space except from Estonia, Croatia, Latvia, Slovenia, Slovakia (only in the 35 m^2/cap assumption), and Lithuania, Poland and Romania (in the 35 m^2/cap and also in the 30 m^2/cap assumption). These countries would raise their average floor space per person (see Table 9).

Table 9. Theoretical energy savings potential (TJ) in EU countries by lowering average floor space per person to 30 and 35 m²/cap.

Country	current m²/cap	Reduction to 35 m²/cap	Reduction to 30 m²/cap	Energy use space heating	Energy savings space heating	
					35 m²/cap	30 m²/cap
Belgium	38,2	8,3%	21,4%	–	–	–
Bulgaria	46,1	24,1%	34,9%	48.892	11.777	17.079
Czech Rep.	35,6	1,7%	15,8%	188.586	3.261	29.736
Denmark	62,7	44,2%	52,2%	108.654	48.037	56.696
Germany	46,6	24,9%	35,7%	1.518.242	378.547	541.361
Estonia	31,5	-11,2%	4,7%	–	–	–
Ireland	45,5	23,1%	34,1%	69.256	16.016	23.622
Greece	53,8	34,9%	44,2%	114.045	39.819	50.422
Spain	52,4	33,2%	42,7%	275.292	91.403	117.673
France	46,9	25,3%	36,0%	1.020.262	258.128	367.004
Croatia	33,0	-6,1%	9,1%	69.147	-4.191	6.286
Italy	49,1	28,8%	38,9%	931.928	267.987	362.836
Cyprus	59,0	40,7%	49,2%	–	–	–
Latvia	34,6	-1,3%	13,2%	29.671	-373	3.919
Lithuania	29,8	-17,6%	-0,8%	40.564	-7.157	-340
Luxembourg	51,1	31,5%	41,3%	16.151	5.090	6.670
Hungary	45,7	23,4%	34,4%	182.798	42.825	62.821
Malta	62,2	43,8%	51,8%	537	235	278
Netherlands	52,4	33,3%	42,8%	252.488	83.964	108.039
Austria	55,0	36,4%	45,5%	172.950	62.891	78.613
Poland	27,1	-29,3%	-10,9%	510.423	-149.784	-55.468
Portugal	63,7	45,1%	52,9%	22.745	10.249	12.034
Romania	18,1	-93,8%	-66,1%	204.106	-191.508	-134.992
Slovenia	34,6	-1,2%	13,2%	30.371	-371	4.021
Slovakia	31,6	-10,6%	5,2%	–	–	–
Finland	52,6	33,5%	43,0%	133.100	44.574	57.220
Sweden	48,5	27,9%	38,2%	166.637	46.458	63.626
UK	42,0	16,7%	28,6%	1.046.251	175.038	299.497
Norway	–	–	–	54.428	0	0
Total		21,4%	32,6%	7.207.524	1.232.915	2.078.655

Negative numbers mean an increase of floor space/energy use. Source: Own calculation based on EU Buildings Database (Total floor area of dwellings 2014), Eurostat 2017 (population, energy consumption in the residential sector 2015).

As a simplified assumption, the reduction of floor space is translated to the savings in energy consumption for space heating in the residential sector. Simplified therefore, as energy consumption and savings are not necessarily related one to one to the floor space used. The goal here is a first approximation. **Based on the data, available savings sum up to a theoretical potential of 1.7 to 2.5 million TJ (see Table 9), which means percentage savings of energy used for space heating of 17,1% (at a 35 m²/cap) to 28,8% (at a 30 m²/cap).**

However as discussed before, the average floor space has to be reflected against the existing building stock and its possibilities to be used in a more sufficient way. This determines the technical potential (see Figure 11). With regard to floor space per persons this can be assumed by taking the overcrowding and under-occupation rates (see Table 7) and missing indoor sanitation (see Table 8) into consideration, with regard to changed heating and ventilation behaviour the data about damp dwellings (see Table 8) and those not being comfortably warm or cool (see Figure 9 and Figure 10). However, estimating to what extent these factors restrict a sufficiency potential or even demand more space, rooms and energy in some countries is prone to methodological problems. It is not clear how many of the aspects mentioned above accumulate in the same dwellings and how many people are affected by more than one insufficient housing aspect: How many people live in damp, overcrowded dwellings without indoor sanitation and not comfortably warm in winter? And are dwellings damp due to insufficient heating systems, to the building's physics, or to improper heating and ventilation practices? A quantitative estimate at this point would be no more than a guess.

Thus, in an experimental approach, the technical potential is estimated qualitatively based on the indicators

- floor space per person (reducing this will allow energy savings),
- population in under-occupied (reducing this will allow energy savings) and overcrowded dwellings (reducing this will need more energy), and
- indoor flushing toilets in dwellings (adding them may add floor space and hence energy)
- bathroom / shower in dwellings (adding them may add floor space and will in any case increase energy consumption)

taking into account a general availability of floor space to be shared or reduced, and

- dwellings not comfortably warm in winter ((these would in the first place need more energy, which could be (more than) counterbalanced by improving energy efficiency; but energy-efficient dwellings then offer possibilities to save energy by changed behaviour.)

The indicators "damp dwellings" and "not comfortably cool in summer" are not taken into account. Dampness, as stated before, can be due to physical problems of a building, inappropriate heating and airing or missing heating and ventilation options. And the share of the energy consumption for cooling in households is even in southern countries smaller than for heating. Overall it was 0.5% for cooling and 64,7% for space heating in 2015 (Eurostat 2017).

Each of the five indicators is rated from 0 (hardly any potential for sufficiency) to 4 (very high potential). The single ratings are added and then divided by the number of indicators (five). The experimental classification of indicators chosen for this approach is listed in the annex (see chapter 6). Further research would be needed to analyse the results of different classifications of indicators or even completely different indicators and approaches (e.g., a non-equal weighting of the indicators). In the end, this may also be subject to political debate and decision. The intention of this experiment was simply to explore a potential way of defining and calculating a technical potential for energy sufficiency in buildings.

Let's take Belgium as an example:

For the 35 m²/cap target Belgium shows a theoretical potential of 8.3% (see Table 9). According to the proposed classification this is rated 1 (low potential). Subtracting the population living in overcrowded dwellings from those living in under-occupied flats 70% are remaining in under-occupied dwellings which is rated a 4 (very high potential). 0.2% of the Belgian population lives in dwellings without shower, bath, and indoor flushing toilet which is rated a 3 (average potential). Finally, 12.6% report that their dwelling is not comfortably warm in winter which corresponds to a 3 for this indicator.

So the total rating is 2.8 (1+4+3+3) = 11 divided by 4 (indicators) = 2.8) which corresponds to the classification "high potential" (see Table 10).

Table 10. Qualitative estimate of technical sufficiency potential in EU countries based on indicators for floor space, under-occupation and overcrowding rates, indoor sanitary facilities, and comfort of warmth.

Country	Score	Country	Score
Luxembourg	3,8	Portugal	2,5
Germany	3,5	Italy	2,3
Ireland	3,5	Czech Republic	2,0
Netherlands	3,5	Slovenia	2,0
Denmark	3,3	Greece	1,8
Cyprus	3,3	Hungary	1,8
Malta	3,3	Estonia	1,5
Finland	3,3	Slovakia	1,5
Spain	3,0	Croatia	1,3
Austria	3,0	Bulgaria	1,0
Sweden	3,0	Poland	1,0
United Kingdom	3,0	Latvia	0,8
Belgium	2,8	Lithuania	0,8
France	2,8	Romania	0,8

very low potential	0–0,8
low potential	0,9–1,6
average potential	1,7–2,4
high potential	2,5–3,0
very high potential	3,1–4

Source: Own calculation based on EU Buildings Database (Total floor area of dwellings 2014), Eurostat 2017 (population, comfort, occupation, and sanitation rates 2015).

The results show the highest potential for sufficiency in western Europe while in eastern countries the potential is rather low.

For an economic potential, further aspects would have to be taken into account, e.g. the housing market in a specific region or vacancy rates that allow people to move to a smaller dwelling. To estimate an expectable potential, demographic developments, migration trends within cities, regions, countries and internationally would have to be considered. Due to missing data, the potential for sufficiency in buildings in EU Member States cannot be elaborated further at this point.

As an estimate for a minimum potential for energy savings from energy sufficiency in buildings, a calculation could be done for all Member States with more than 35 m² of average dwelling floor space per capita: what could be saved if the total dwelling (and non-residential building) floor area was not allowed to increase any more? This was also not (yet) possible in this project.

3 Energy sufficiency policy for buildings

3.1 Options for political interventions

Just as the definition for energy sufficiency discussed in Chapter 1 has the two facets (1) of an energy sufficiency **state** and (2) of energy sufficiency **actions**, the subject of an energy sufficiency policy for buildings is two-fold too.

One the one hand, there is the need to ***set targets and develop strategic policy roadmaps*** that pave the way towards the "energy-sufficient state". For buildings, the target would be to achieve what we proposed above: *a stock of entirely climate-neutral and resource-light buildings and quarters* that also fulfil the above definition of offering *adequate space thoughtfully designed and constructed and sufficiently equipped for reasonable use*.

For example, Germany aims to achieve a "climate-neutral building stock" by 2050, with 80 % less primary energy use. However, for the rest of the proposed "energy-sufficient state" for buildings, the country does not yet have specific targets, although research is increasing on resource consumption, adequate space, thoughtful design and construction, equipment, and use. The policy roadmap will need to integrate all four areas contributing to the "energy-sufficient state" (Energy and resource efficiency actions, energy and resource sufficiency actions, renewable and overall more sustainable energy and material supply, and combatting energy poverty, see Chapter 1).

Here, we are mainly interested how it can address energy sufficiency actions. Therefore, ***policy instruments that support or mandate energy sufficiency actions*** are the second area of an energy sufficiency policy we will be discussing here. As this area is much more diverse and complex, it is the main part of this chapter. These actions relate to one or more of the four areas discussed in Chapters 1 and 2:

- Space /size – the absolute size of dwellings but more importantly, the average per capita floor space
- Design and construction – in terms of energy sufficiency, mainly related to providing flexibility of use and enabling shared living concepts, which may make it easier to reduce size per capita
- Equipment – adapt the size of boilers/heating/cooling systems to energy demand
- Use – this involves, particularly (see Chapter 2):
    - adjusting the indoor temperature,
    - differentiating heating/cooling temperature for different rooms, not heating/cooling some rooms at all,
    - daytime / night-time temperature control, switching off heating at night
    - keeping windows closed while heating/cooling,
    - where there is an energy-efficient ventilation system installed: using it in an intelligent way, e.g. at the lowest settings allowing good indoor air quality, and keeping windows closed while heating/cooling,
    - where there is no ventilation system installed: using shock ventilation with short-term wide window-opening instead of long-term tilting.

3.2 A general method for analysing energy sufficiency policies

For the development of an integrated energy efficiency and sufficiency policy package, we developed a process of analysis and used it for analysing electricity use in the household in a previous study, as described in detail in Thomas et al. (2015a). An updated graphical presentation is provided in Figure 12. Any sufficiency action or intervention follows one of the three basic energy sufficiency approaches explained at the bottom of the graph – reduction, substitution and adjustment – and changes the translation chain from basic needs (left end of the graph) to the finally supplied technical service (in the centre of the graph). The first three steps of the analysis concern (1) each demand, need, or want (in our case here: having comfortable indoor conditions in our buildings), (2) the current situation, and (3) the potential energy sufficiency actions for changing practices regarding this demand, need, or desire (which, for buildings, would be those actions listed above). Steps 4 to 7 of the policy analysis are presented in the four bars to the right: (4) the analysis of prerequisites and framework conditions needed for households and their members to make the change in practices happen; (5) the sustainability check: is the action reducing energy and resource demand, and socially acceptable? (6) the analysis of the need for energy sufficiency policy and (7) integrating the single policies to a consistent package.

This approach can be used for a thorough analysis of the potential energy sufficiency actions for buildings listed above. Here, we can mainly report results from a previous analysis regarding the areas of size and flexibility.

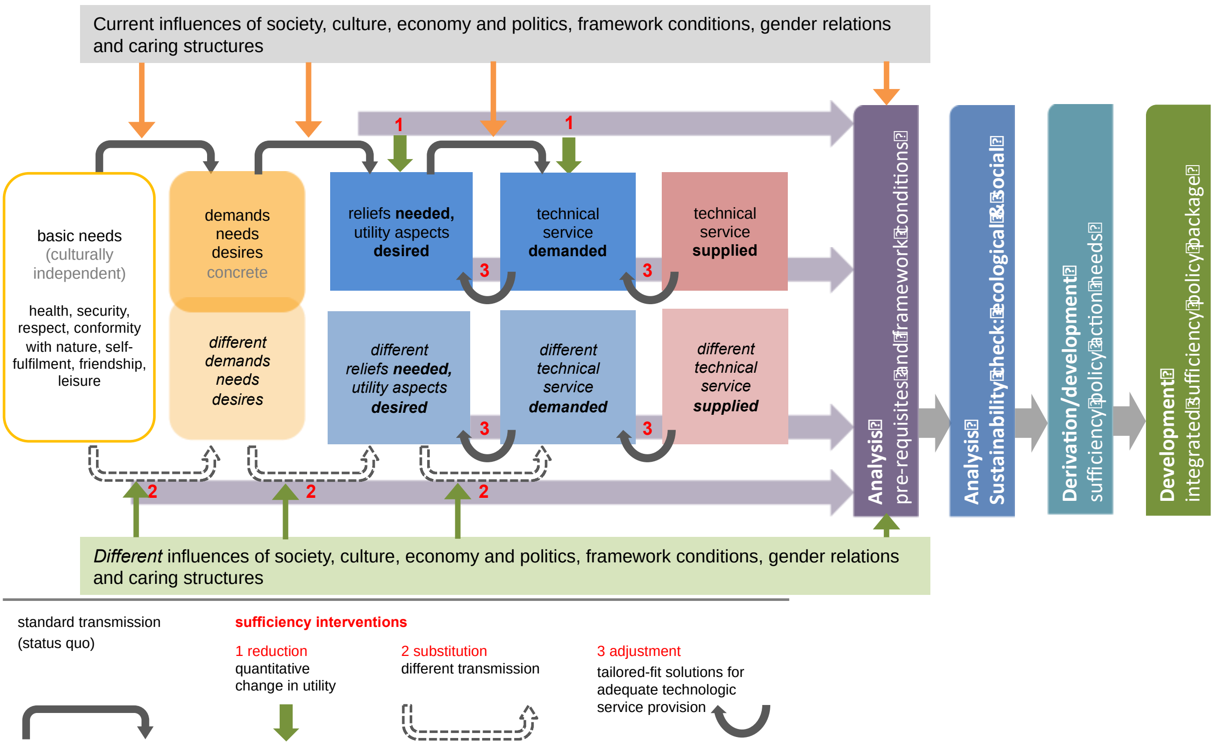

Figure 12. Standard transformation chain of the determinants of household energy consumption and methodological approach for developing integrated energy sufficiency policy packages (Source: Thomas et al. 2017)

3.3 Energy sufficiency policies

Before we embark on details in what kinds of policy instruments could advance energy sufficiency in buildings, the following paragraphs outline why we see two main areas of policy intervention. These are addressing (1) per capita dwelling size (space) and influences of design/construction on it, and (2) equipment as well as use of buildings and equipment. Particularly the second should also be linked to energy efficiency policies for building design/construction and equipment, as it is often the same types and packages of policies addressing both energy efficiency and sufficiency actions, and they should thus be integrated. This is also outlined here below.

As said above, in terms of energy sufficiency, design and construction options are mainly related to providing flexibility of use and enabling shared living concepts. These may make it easier to reduce dwelling size per capita, if and when dwelling size can be reduced while family size reduces, or in a larger dwelling or housing project, as people not related to each other share facilities that each of them would otherwise need to have in their own apartment. Similarly, for non-residential buildings, shared offices and other innovative concepts may enable less space per workforce. We therefore propose **a set of integrated energy sufficiency policy instruments** to address **size (space) and design / construction** for flexibility, in the following chapter 3.3.1.

Of course, **energy *efficiency*** in **design and construction** and building-integrated **equipment** should continue to be advanced with the usual, proven **policy package** (with the main instruments of building energy codes and equipment MEPS, building energy certificates and equipment energy labels, targeted energy advice, financial incentives and financing, training and the related certification, networking, and all kinds of innovation strategies, see e.g., Thomas et al. 2013; 2015b).

The **target** of achieving, as quickly as possible, e.g. by 2050, a stock of entirely climate-neutral and resource-light buildings and quarters that offer adequate space thoughtfully designed and constructed and sufficiently equipped for reasonable use will be **overarching both** this energy efficiency policy package **and** the **energy sufficiency policies** targeting the **use of buildings and equipment** that have been designed/constructed or purchased in both an energy-efficient and energy-sufficient way. Some policy instruments, such as energy pricing policies will also target both energy efficiency and sufficiency; other types of instruments will be similar and could in fact also be addressing energy efficiency and sufficiency actions for the use of buildings and equipment in an integrated way. Section 3.3.2 discusses instruments supporting energy-efficient and sufficient purchase of equipment and use of buildings and equipment.

Section 3.3.3 then expands on policies for energy sufficiency in non-residential buildings, while 3.3.4 holds some general requirements for energy sufficiency policies. All of the previous is put together to the integrated energy sufficiency policy package for buildings, equivalent to step 7 in the energy sufficiency policy analysis (Figure 12) in section 3.3.5. Finally, section 3.3.6 collects a number of examples for existing policies representing the types of policies discussed in the previous sections of this chapter.

3.3.1 Instruments for limiting average dwelling floor area per person

For space heating and cooling, but also for many end uses of electricity in the home, energy demand depends on the dwelling floor area per person. Therefore, instruments for limiting average dwelling floor area per person – not only in homes, but also in offices and factories – will be an important part of the energy sufficiency policy package. They will address one important driver of energy consumption and non-sufficiency.

Events in life such as children moving out to their own household, divorce or separation of partners, or the death of a partner create phases, during which routines and practices may change dramatically. Usually, this will also have a financial impact. Such phases are, therefore, also a window of opportunity for policy instruments supporting the move to a smaller apartment or the (sub-)letting of a part of the house or flat. In principle, the macro drivers for the growth of per capita dwelling space, such as increasing income and wealth, should also be addressed by policy. However, it is at present unclear how this could be done.

In a recent project[21] we therefore analysed concrete instruments to support the move to a smaller dwelling, forms of communal housing, or (sub)letting a part of the home or flat. We see a major role in implementation for the municipal administrations, which however will need law-making and financial support from national/federal and state/regional governments. Three particular instruments were analysed in our project:

- Municipal living space agencies, offering a combination of living space advice, practical support for moving, and the provision of financial support
- Financial incentives for alternative forms of housing and the dwelling space needed for them

[21] "Energy Sufficiency - strategies and instruments for a technical, systemic and cultural transformation towards sustainable restriction of energy demand in the field of construction and everyday life"; this chapter is based on Thomas et al. (2017)

- A cap on dwelling floor area per person as an overarching instrument.

These were analysed for residential buildings but may be adapted to also support the reduction (at project level) of working space, in order to limit the average growth or even achieve absolute reductions.

3.3.1.1 Municipal living space agencies: living space advice, practical support for moving, and the provision of financial support

As the survey mentioned in 2.4.1.2 showed, households interested in moving to a smaller dwelling face a number of barriers. Two main difficulties are: first, the rent for newly rented smaller flats is often higher than the current one for a big flat, in which the tenant may have lived for many years. Secondly, people want to stay in their neighbourhood, where they know the infrastructure and have their social networks. In addition to these barriers, moving to another home requires a lot of effort and money for the search, the renovation, and the actual moving. When moving to a smaller dwelling, there may be excess furniture.

Therefore, combining instruments to a package may overcome these barriers potentially better than any single instrument alone: municipal living space agencies should not only be providing living space advice, but also practical support for moving (e.g. for the search of a smaller dwelling and for the organisation of the moving; swapping dwellings between young growing families and elderly declining in numbers could be of interest too), and the necessary financial support. For example, the effectiveness of information platforms for dwelling exchange is very limited, as the survey mentioned in 2.4.1.2 confirmed, with less than 5% saying this would be enough. Especially for households moving into a dwelling they own, the advice should be coupled with an individual energy efficiency and sufficiency advice.

The financial incentives should be funded by the central government but handed out or allowed through the municipal agencies. Incentives could take several forms, such as waiving a tax for the acquisition of smaller real estate, or waiving property taxes (for the new, smaller dwelling) for some time. Bonus payments or tax incentives to older couples who sell their houses in favour of bigger families might be possible as well. Tenants could receive direct payments or an aid to the new rent for some time, all could receive a grant on the costs of moving. Incentives could also be given to those sharing their dwellings.

Potential: What is the potential impact of supporting a move through policy instruments? We only have data for Germany where, for example, 7 TWh of heating energy could be saved a year if by 2030, 20% of 4 million pensioner households constituting a target group decided to move into smaller flats or share the flat with others. This corresponds to 1.81 million t CO_2 / yr (Fischer et al 2016). However, not only pensioners could be willing to move to smaller homes. According to the results of the above-mentioned survey, the potential of those who already today consider a move is 10% to 15%. With fewer persons per household in the future, this potential will increase to 17% to 23%. This is about ten times the number of households on which the energy saving potential cited above as calculated by Fischer et al (2016) is based (20% of 4 million pensioner households is 2% of the total of around 40 million households in Germany, so 17% to 23% of all households is ten times as many).

3.3.1.2 Financial incentives for alternative forms of housing with smaller per capita area and the dwelling space needed for them

For Germany, Fischer et al. (2016) found that the number of small apartments is too small to allow many households moving to smaller apartments. One solution could be to provide incentives for the splitting of large homes or flats into smaller ones. The survey mentioned above, however, suggests that what people seek is rather to move back into bigger communities, such as shared flats or multi-generation housing. Large potential therefore seems to rest in the support for such projects. If, for example, older people leave their houses they will look for barrier-free apartments. If the apartment is small and the children come for a visit, it will be necessary to have some guest rooms available. In cities with a shortage of dwelling floor space, such approaches are occasionally already applied today. In addition to shared flats or multi-generation houses, they include other communal housing projects with shared rooms for fitness, hobbies, festivities, guests, but also the re-use of already existing buildings, including non-residential buildings. Some examples were presented in Thomas et al. (2015a).

In addition to financial incentives, policy may also support such approaches e.g. through public architectural competitions or requiring that any such competitions should include guidelines and requirements for less living space per person.

Potential for Germany: If households with at least two people are asked what they would do if their household size shrank in the future, 22% of these households (13% of all respondents) can imagine to move to a shared apartment, and even 29% of the households with at least two people (17% of all respondents) can imagine to live in a multi-generation house. This is likely to be the case for many of those living as a single-person household too. It will probably take many years to enhance the supply of buildings for multi-generation housing to the level needed to satisfy such a high demand even with a financial incentive programme, whereas the reconstruction of dwellings supporting shared households may be possible much more quickly. Still, we expand a little on communal housing and how it could be supported by municipalities in the next section 3.3.1.3.

3.3.1.3 Communal living – a high-quality and climate-friendly role model?

Can communal living enable individuals to lead a more energy sufficient lifestyle? Is it possible to reduce energy consumption by sharing infrastructures and living spaces? Which barriers and chances do communal living projects face? These and more questions lead to an investigation of other, new forms of housing within a research project (Thomas et al 2017).

Two important insights that are closely tied to energy sufficiency stood at the beginning of this investigation. First, several studies show decreasing electricity consumption per capita the more people live within the household. In a single household in Germany, the average electricity consumption is about 1900 kWh/yr/capita. This figure decreases to ca. 1200 kWh/yr/capita in a four-person household (Frondel et al. 2013; Lehmann 2013). Whether this reduction is because today four-person households are often families with children who may use less energy, or because the floor area per capita is lower in four-person households than for singles, or because there are base loads irrespective of size, or because energy consumption of some appliances for the same level of service (e.g. a litre of volume or a kg of wash) decreases with size, or if it holds for communal living projects was not possible to clarify due to a lack of studies. However, an argument for a potential is that in communal living projects, habitants can more easily share some appliances like freezers or even fridges with their co-habitants. Secondly, decreasing household size is strongly linked with an increase of living space per capita. In Germany, a continuous increase in living space per capita can be observed from 35 m^2 in 1991 to 46 m^2 in 2015 (destatis 2016) with a projection of 47 m^2/cap (BBSR 2015) to 52 m^2/cap (Deschermeier & Hengel 2015) in 2030. This development does not only counteract efforts of increasing energy efficiency but also reduces the absolute energy saving potential in the heating sector. With an average of 68.3 m^2 the per capita living space of single households is the highest, while four-person households only have a per capita living space of 30,7 m^2 (Umweltbundesamt, 2016). Communal living projects can help to reduce per capita living space with comparable amenities and comfort by a combination of reduced private living space plus communal or shared living spaces.

But what is meant with the term ‘communal living’ projects? These forms of living are characterized by three main criteria:

1. The people living together share a part of the living space between each other. Shared living space means more than for example common hallways in apartment buildings, but also common kitchen, living room or bathrooms.
2. Living together is self-organized. Thereby monasteries, boarding schools, orphanages, nursing homes and others similar to these are excluded from this definition.

3. The people living together are not linked through family ties. Families can be part of a communal living project, but a family living in a single-family apartment is clearly not such a project.

With this definition, we find two main forms of communal living. One is the well-known flat share that is widely practiced particularly among students in Germany. Another one is a special communal living project. This form is not yet well known but its popularity is growing in Germany. Future residents are engaging in such projects with different aspects of motivation:

- Some potential residents are searching for living in a community instead of today's anonymity of big cities.
- For others communal living is a political project to create low-cost housing by excluding the buildings from the real estate market and thereby minimizing the influence of speculation on the rents.
- In intergenerational projects, people search for housing in comfort and with the help and community of co-habitants.

A special form of communal living projects is multi-generation housing. These projects have a special focus on a balanced age structure of inhabitants aiming for mutual help and support (e.g. elder people supporting young families in terms of child care, younger people supporting elder people with heavy shopping and other physical demanding work).

But all of these projects are characterized by the criteria mentioned above which also bring about ecological, social and economic benefits and co-benefits (depending on the motivation) (Duscha, 2015). A popular and—with regard to energy sufficiency—particularly interesting project is the Hunziker Areal in Zurich, Switzerland[22]. Some of many aspects of this project are: the number of rooms per person are limited which leads to a floor space demand of less than 35 m^2 on average; different (co-) housing concepts have been built in 13 buildings on a former industrial site; only few residents can own a personal car (e.g. disabled persons), others have the possibility to rent different kinds of bicycles and other (also electric) vehicles; each building provides washing rooms and other common infrastructure for residents such as a library, party room, repair shop, etc.

Because of the identified benefits that communal living possibly brings about, the project from which these findings are taken (Thema et al. 2016) investigated governance options to support and foster these projects. A case study on existing and possible improvements of governance measures in Heidelberg, including a literature review of measures in other municipalities, was carried out. Among the identified governance measures supporting communal living are the following:

- Including a reduced or at least not an increasing average per capita living space as conditions for financial support schemes
- Including additional benefits or separate financial support schemes for shared spaces in communal living and multi-apartment buildings, under the condition that they replace a larger area of individual space
- Creating informational offers like leaflets or advising services (help desks) for interested people
- Integrating communal living in the urban development plans of municipalities
- Creating lighthouse projects to inform the broader public of these modern, multi-benefit forms of living.

Nevertheless, communal living is not the only means by which per capita living space can be stabilized or decreased. The co-benefits include other services that can be organised together, social live, shared maintenance and social benefits through a less anonymous environment.

[22] https://www.mehralswohnen.ch/ (last access: 09/01/2017).

3.3.1.4 A cap on average dwelling floor area per person as an overarching instrument

A centralized cap for the total existing and new living space within a municipality – i.e. on the average per inhabitant (but not for individual households) – would make the incentive and conversion programmes discussed above even more attractive to municipalities: Cities e.g. in Germany are in competition to each other. They are also competing for inhabitants. Interesting new building projects in the housing market are created to attract young families. Each additional taxpayer will increase the income of the city. Thus, it is difficult for the cities to restrict any new build activities: they fear the advantage for neighbour cities. This problem may only be solved by establishing a common target for floor space consumption applicable to all cities and towns in a country.

A more radical approach for such a regulation might be to allow the building of new, additional houses only in cities with a growing number of inhabitants. Such a regulation would potentially be the most powerful, but certainly a very contentious instrument. As required, they may be allowed to buy or sell rights of dwelling space from shrinking cities (who would then have to demolish empty buildings). This would satisfy the needs of growing cities but also give an incentive to all municipal authorities to limit new build of dwellings.

In practice, the cap can only be kept through the kind of financial incentive programmes and services for reconstruction and moving by municipalities to their citizens as discussed above. Only with such programmes will it be possible to avoid shortages and excessive rents or purchase prices and make the cap scheme acceptable. Therefore, the central government will also need to accompany the cap by adequate funding to local authorities. An alternative may be to give the task of implementation and/or funding to energy companies.

Still, the political resistance against such a legal cap could be too high. In this case, the cap could be set as a strategic but non-binding policy target. The central/federal and regional governments would need to monitor compliance with the target and support meeting it through the other instruments discussed above, in connection to regional planning that aims at a balanced development between municipalities in a region.

There are several options for funding the whole housing policy package. They include using revenues from property (acquisition) taxes or energy taxes. Municipalities will save on costs for preparing land for construction. In addition, a luxury tax could be levied for dwellings above a certain total size (e.g. in terms of m^2 or number habitable rooms). This would avoid the social problems that came along with a general dwelling space tax (Fischer et al. 2016), which are the reason why we do not propose such a general tax.

Potential: In principle, the cap on dwelling floor area could fully implement the potential for limiting the growth of floor area, in conjunction with the other instruments aiding compliance with the cap. For the example of Germany, the potential has been calculated in section 2.4.1.2.

3.3.1.5 Securing and creating the energy-sufficient building infrastructure

There is one more aspect related to **design and construction** that is linked to the following fact: Households will only be able to perform some types of energy-sufficient practices, if the necessary infrastructure is available to them at all. Examples are places for hanging clothes to dry outside or in the loft, or cool storage rooms that may partially substitute refrigerators. The legal requirements should be created in tenant or building (refurbishment) legislation to allow external drying and to at least safeguard existing drying or food storage rooms in residential buildings. New build of such rooms, however, may not reduce the overall energy consumption, given the ‘grey energy’ of the materials needed. It will need further analysis to determine if such rooms should also be required in new build.

3.3.2 Instruments supporting energy-efficient and sufficient purchase of equipment as well as use of buildings and equipment

As said above, the target of achieving, as quickly as possible, e.g. by 2050, a stock of entirely climate-neutral and resource-light buildings and quarters that offer adequate space thoughtfully designed and constructed and sufficiently equipped for reasonable use will be overarching both the policy package addressing energy efficiency in design/construction and equipment, and the following energy sufficiency policies targeting energy sufficiency for equipment and the energy-intelligent use of energy-efficient buildings and equipment.

Some instruments of the energy sufficiency policy package may be the same as for energy efficiency—such as energy taxation, and linear or progressive energy prices. Some may simply adapt technology-specific energy efficiency policy instruments. Examples are equipment efficiency standards based on absolute consumption, financial incentives, or providing energy advice. However, sufficiency may also require radical new approaches, e.g. linked to addressing the drivers of non-sufficiency. In the following subchapters, we expand on a number of these policy instruments. This will focus on the energy-intelligent **use** of energy-efficient buildings and equipment, since the only energy sufficiency action for heating and cooling **equipment** we identified is adapting the size of boilers, heating systems, or cooling systems to energy demand. We therefore discuss this before the other instruments here:

The main barrier to this action is that it both requires more effort for the installation contractor to determine the appropriate size, and possibly offers less revenue for a smaller boiler or heating/cooling system. Training energy advisors and installation contractors will therefore be necessary to ensure the quality of size calculation but not sufficient. Energy advice to investors will support demand for correct sizing but neither guarantee supply, due to the above barrier. Therefore, a financial incentive for the correct design, using standard software and requiring a certificate of training, may be needed in addition to the above instruments to make this action financially attractive also for the energy advisor and/or the installation contractor. Encouraging energy service contracts could be a complementary policy to support correct sizing, since there should be an inherent incentive for the ESCo to benefit from the energy savings that will be enabled by avoiding oversizing.

3.3.2.1 Energy pricing instruments

Energy taxation is an instrument to internalise external costs of energy supply into energy prices. It thereby increases the energy prices and hence the economic motivation to save energy. This motivation supports both energy efficiency and energy sufficiency alike. Some have observed that energy taxation and the signal for energy sufficiency it sends can also be a measure to counterbalance the rebound effect from energy efficiency action and policy. However, energy taxation alone will not be sufficient to overcome barriers that are not related to the energy price and will therefore not realise anywhere near the full potential, for both energy efficiency and sufficiency.

The same holds true for linear or progressive energy prices. They both improve the price signal for saving energy, including through energy sufficiency.

The potential impact of energy pricing policies could be seen, e.g. during the period of high oil and gas market prices from 2009 to 2014 in Germany. During this period, heating demand reduced by almost twice as much as what could be calculated as a result of energy efficiency investments alone (Galvin and Sunikka-Blank 2014). So, the difference is likely to be due to intelligent or otherwise reduced use of heating.

3.3.2.2 Sufficiency-oriented product and buildings standards and labelling policy targeting building and equipment use

Many legal requirements are conceivable that could require, nudge, or encourage an energy-intelligent and energy-sufficient use of buildings and equipment. We simply list some ideas below, but there may be many others.

One example are EU Ecodesign and labelling requirements for boilers and air-conditioners, which should be updated to require the provision and mandatory operation of daytime / night-time temperature control, and switching off heating at night.

Further ideas on product or building energy requirements to support energy sufficiency include:

- Requiring occupancy control for the heating or cooling of rooms, turning down heating temperatures / turning up cooling temperature, or turning heating/cooling completely off if external temperatures allow, after e.g. one hour of inoccupancy: This would help the occupants in differentiating heating/cooling temperature for different rooms, or not heating/cooling some rooms at all;
- Alternatively, requiring occupants to confirm every day the on-times and settings of heating or cooling for each room (although this kind of 'nudging' may soon annoy people);
- Requiring heat recovery ventilation in building codes[23]: This would take the responsibility for energy-intelligent ventilation off the occupant, particularly if coupled with sensor-control of indoor air quality and consequently air exchange rates – it would combine energy sufficiency with improved health and comfort;
- Requiring the linking of heating/cooling thermostats to sensors for window opening: This would close down heating or cooling whenever a window is open or, vice versa, guarantee keeping windows closed while heating/cooling.

Labelling and Ecodesign requirements should also oblige manufacturers to install an automatic switch-off after a time to be determined for appropriate types of equipment, such as air-conditioners. All programmes and settings should directly display the data on their energy consumption and settings (boilers, air conditioners, radiator thermostats).

3.3.2.3 Energy sufficiency advice

As for energy efficiency, lack of information and motivation can be an important barrier to implement energy sufficiency actions in the use of buildings, particularly in heating and ventilation practices. Personalised energy sufficiency advice can be much more effective than general publicity and information campaigns in making people aware of their own options and in convincing them of advantages and benefits or that e.g. perceived risks are not a problem. For cost and effectiveness reasons, such advice should be integrated with advice on energy efficiency options.

In our example of buildings, advice would particularly concern actions such as adjusting the indoor temperature, differentiating heating/cooling temperature for different rooms, not heating/cooling some rooms at all, keeping windows closed while heating/cooling, or using shock ventilation with short-term wide window-opening instead of long-term tilting, but in principle all the possible actions for energy-intelligent and energy-sufficient use of buildings and their equipment.

Many of these types of action have for a long time been included in energy advice as means to save energy in the home. They did not use to be classified as 'energy sufficiency' but as 'energy-intelligent user behaviour' or similar, but they are energy sufficiency actions in our understanding. This is an example showing that what we are considering here is often not something completely new and strange, but in fact something that we already have been doing for a long time but could develop to achieve further energy savings.

3.3.2.4 Financial incentives

Financial incentives, such as grants or tax deductions, may be justified for the purchase of products supporting or enabling the energy-sufficient use of buildings, such as heat recovery ventilation, controls like occupancy controls for the heating or cooling of rooms, or

[23] This is predominantly a more energy-efficient way of ventilation, as it recovers the heat (and cold), which would be lost through window ventilation. However, it also includes an energy sufficiency component: it both avoids too little exchange of air, so safeguards sufficient ventilation for good indoor air quality; and it avoids excess ventilation, hence adapting the level of ventilation to what is needed for the service required.

linking of heating/cooling thermostats to sensors for window opening. Some low-cost products aiding the dweller to use his or her building in a more energy-intelligent way may also be given to him/her for free.

3.3.2.5 Promotion of energy sufficiency services

Building energy management has also been offered as a commercial service, particularly for larger buildings. It can integrate energy sufficiency more than in the past by using all the types of controls mentioned above, and also by offering energy sufficiency advice to users.

3.3.3 Instruments for energy sufficiency in non-residential buildings

All the instruments discussed here can in principle also be adapted and implemented to support energy sufficiency in non-residential buildings. For example, a concept that gains practical application to save office space – and the related energy use – are flexible and shared offices, in which users own a container and can occupy any free office room but do not own an office of their own any more. It could be supported through a combination of information, targeted advice, and possibly financial incentives. Energy sufficiency advice focussing on practices of e.g. using heating, ventilation, lighting, and office equipment has been quite successful too, e.g. the ‘mission E’ programme of the energy agency of North Rhine-Westphalia (see table 10 below).

In addition, in order to support building sustainable non-residential-buildings, there are some Green Building Certification systems like LEED, BREEAM or DGNB in place, which determine the level of sustainability using a scoring system for various categories like energy, material, transport, etc. Some of them also include aspects that support sufficiency, such as the land use category. But each category is assessed and scored for certification which means higher ambition in one category can compensate less effort in another one. Thus, the schemes do not support sufficiency aspects comprehensively, and as certifications are voluntary there still is a high potential to increase the number of certified buildings.

3.3.4 General requirements

A number of energy-sufficient practices may not need financial investment, but additional coordination efforts or time. This requires safeguarding sufficient time budgets and windows for housework. And it creates the need for changes in the professional economy in order to take the caring economy into account too.

It is also important that energy sufficiency policy is designed and implemented in a way sensitive to the individual vulnerabilities, restrictions (e.g. financial shortages or lack of the necessary infrastructure), and particularly to the demands from caring and being cared for, as well as for the needs of those doing the caring or being cared for. This is equally relevant for the instruments on the micro and meso level discussed above as for the overarching instruments for limiting average dwelling floor area per person or electricity sales. Detail can be found in the criteria-based analysis of energy sufficient practices (Thema et al. 2015) and in Spitzner und Buchmüller (2016). A professional training corresponding to these sensitivity requirements for businesses, administrations, policy, and particularly for consultants is a necessity too.

In addition, both the caring economy and energy sufficiency should be defined as tasks of consumer protection, along with the necessary rights and funding. This includes representation of the rights of households vis-a-vis the relevant infrastructure and service providers.

3.3.5 An integrated energy sufficiency and efficiency policy package

An integrated policy to advance energy sufficiency and efficiency needs to address the manifold preconditions, barriers, and situations faced by households and market actors, if it is to succeed. Figure 13 provides an overall picture of the micro- and meso-level approaches and instruments for supporting energy sufficiency in buildings. On the one hand, they promote more energy-sufficient and energy-efficient practices and decisions for *design/construction, equipment, and use* of buildings in an integrated way. On the other hand, they aim at limiting the increase in per capita dwelling space, i.e. building *space*, which has been an important driving factor increasing household energy consumption so far.

Both for design/construction, equipment, and use of buildings and for dwelling space (size) policy, a *combination of an instrument creating a binding overarching target with concrete instruments of financial incentives, advice, and regulation* appears most promising and successful.

For target setting, a target of achieving, as quickly as possible, e.g. by 2050, a stock of entirely climate-neutral and resource-light buildings and quarters that offer adequate space thoughtfully designed and constructed and sufficiently equipped for reasonable use *plus* an energy efficiency and sufficiency fund can provide this function for buildings.

A cap could be put on municipalities to limit average dwelling floor area per capita too. The latter needs clarification of whether it could be legally binding or just serve as a policy target. The municipalities, with financial support from the central governments, would be in charge to stay within the limits of the cap, using e.g. the instruments outlined above for supporting and informing new forms of housing, moving to smaller flats, or shared living.

In addition, there is the need to develop instruments that *limit the macro drivers of energy consumption* (Thomas et al. 2015a), we are not aware of an analysis of what these could be so far.

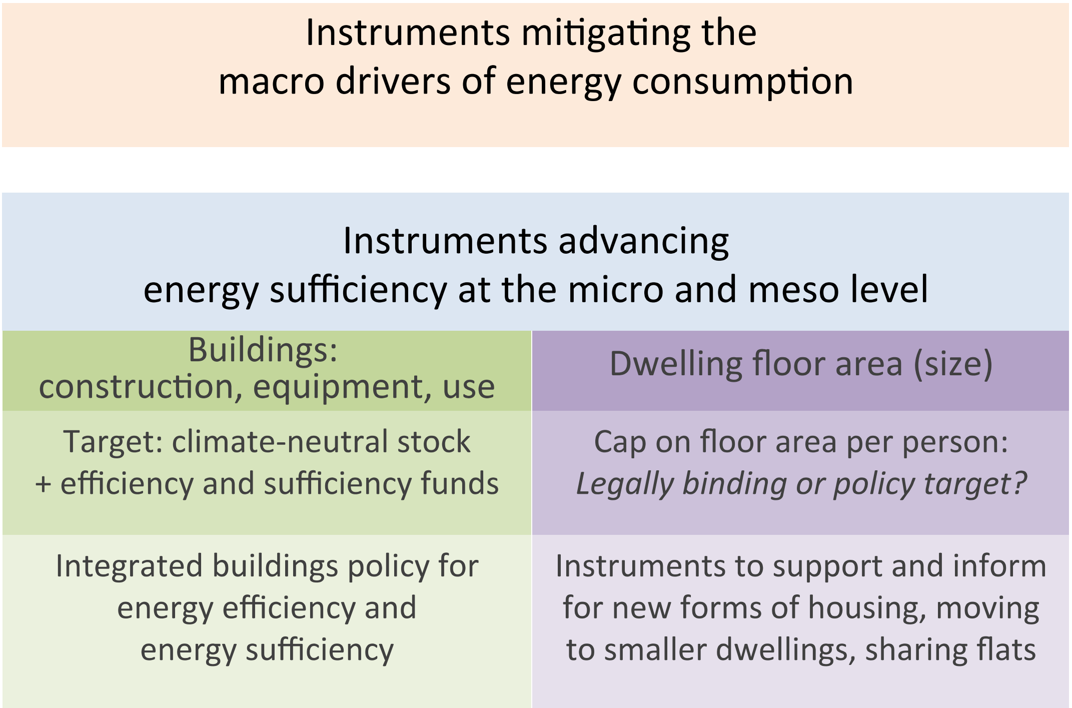

Figure 13. Overview of approaches in the integrated energy sufficiency policy package; instrument with a question mark needs further research.
Source: own analysis for this paper.

3.3.6 Examples of existing policies

Looking at the list of potential energy sufficiency policies above, some are more common, others less so. For example, due to the EU's energy taxation directive, each Member State has to have at least a minimum level of energy taxation. The EU Emissions Trading Scheme is also valid throughout the EU. As said above, there is also a plethora of energy advice schemes. However, few of these already explicitly address energy sufficiency, but most do so implicitly via 'energy-saving user behaviour'. A scan of the MURE database (odyssee-mure.eu) found many examples for energy advice schemes but no policy mentioning energy sufficiency as a subject. As for instruments to tackle the growth in building floor space, some local programmes and projects exist, but we are not aware yet of larger schemes at national level.

Therefore, we grouped what we know in the following table along the types of instruments discussed above.

Table 11. Examples of existing policies for energy sufficiency in buildings (Source: own collection).

Type of policy	Examples
Instruments on building floor area	
A cap on average dwelling floor area per person as an overarching instrument	No example known on national level; however, Switzerland's Spatial Planning law of 2014 only allows new build within existing settlements or after proof of demand (Thema et a. 2016). Examples can be found on project level (see Hunziker Areal in Zurich above).
Municipal living space agencies: living space advice, practical support for moving, and the provision of financial support	There are, e.g., agencies in Germany in most cities giving advice mainly to elderly people to adapt their dwellings to their needs: Size, equipment, barriers etc. They could be used as starting point to add financial and practical support or integrate them with energy advisors to develop an integrated advice for all households. In 2014 six municipal housing companies in Berlin agreed to support elderly people in big flats to move to smaller dwellings. They help finding an appropriate dwelling, support packing and transport, guarantee low rents, and in some cases give financial support up to 2,500 Euros depending on the size of the household. Other examples that could be upgraded and replicated are interim use agencies for vacant space in the non-residential sector, vacancy notification tools that allow people to post information about vacant dwellings or buildings[24], housing agencies.
Financial incentives for alternative forms of housing with smaller per capita area and the dwelling space needed for them, e.g. communal housing	There are no direct financial incentives known so far, but there are examples of cities giving preference to / reserving land for communal housing groups instead of letting it (all) to the highest bidder (e.g. Clouth-Quartier in Cologne, Germany[25]).
Securing and creating the energy-sufficient building infrastructure, e.g. clothes drying or cool storage rooms	No legislation known to us that would protect existing clothes drying or cool storage rooms
Buildings: design and construction, equipment, use	
Targets for a climate-neutral building stock	For example, Germany has such a target ("an almost climate-neutral building stock", coupled with a target of minus 80 % of primary consumption in buildings) for 2050. The government at least has commissioned studies looking at how to achieve such absolute reductions of energy consumption, including through energy sufficiency, e.g. limiting total floor space.
An energy efficiency and sufficiency funds	There are energy efficiency funds in a number of countries, which often also fund energy advice programmes, but we are not aware of one explicitly having energy sufficiency as part of its mission.
Energy pricing instruments	Due to the EU's energy taxation directive, each Member States has to have at least a minimum level of energy taxation. The EU Emissions Trading Scheme is also valid throughout the EU. Tax and ETS price levels could be higher though, in order to provide higher incentives for energy sufficiency.

[24] see (German only): https://www.leerstandsmelder.de/ (last access: 09/01/2017).
[25] https://www.modernestadt.de/projekte/clouth-quartier/.

Sufficiency-oriented product and buildings policy targeting building and equipment use (MEPS, labelling)	Some nZEB definitions are stringent enough to need heat recovery ventilation, so implicitly require it, but no explicit requirement known, also not for retrofit in all existing buildings. We are not aware if any of the other ideas discussed above are required somewhere. This also applies to the ideas for energy labelling (display of energy consumption and settings on boilers, air conditioners, thermostats)
Energy sufficiency advice	There is also a plethora of energy advice schemes in operation. However, few of these already explicitly address energy sufficiency, but most do so implicitly via 'energy-saving user behaviour'. This is also the case for non-residential buildings, like with the 'mission E' programme of the Energy Agency of North Rhine-Westphalia. It shows savings of up to 15 % for electricity and up to 20 % for heat, at a cost of 0.39 Cent/kWh (www.missionE.nrw, EnergieImpulse 3/2017, pp. 10f).
Financial incentives	There are probably a few financial incentive programmes for the purchase of products supporting or enabling the energy-sufficient use of buildings, such as heat recovery ventilation, or linking of heating/cooling thermostats to sensors for window opening. We assume this is less likely for occupancy controls for the heating or cooling of rooms. We are not aware of concrete examples yet.
Promotion of energy sufficiency services	Building energy management has been offered, required, or promoted as a commercial service, particularly for larger buildings. It can integrate energy sufficiency more than in the past by using all the types of controls mentioned above and other ways of energy sufficiency action.

4 Conclusions

What did we learn from our analysis of areas for energy sufficiency in buildings, actions, indicators, potentials, and the policy analysis: methodologies, concrete policies and measures, and an approach towards a comprehensive policy package for energy sufficiency?

With regard to data, indicators, and methodologies, it becomes clear that to date there is a lack of knowledge to analyse sufficiency or estimate a saving potential in buildings. Data about the European building stock still is not detailed and profound enough to develop a clear picture of the distribution of floor area, times and kinds of the use of buildings, efficiency standards, and living conditions. We found this true for the residential sector and much more for non-residential buildings. Further research needs to develop mixed method and multi-level approaches that allow interdisciplinary work on the options of design and engineering, economic aspects, social, and psychological methods to find out connections between buildings, their use, and their users. Also, the definition of the energy-sufficient level of basic needs may need further research. An indication may be provided by many social policies supporting low-income households across Europe, but we are not aware of a study that systematically compared and analysed it.

Nevertheless, first approaches in this paper to analyse and estimate a sufficiency potential show that sufficiency has a high potential to reduce the demand for floor space, energy, and resources, especially in Europe. But we also found that sufficiency as a strategy for sustainable buildings and development in general is hardly implemented in policies yet. We found some good examples of single projects on city, neighbourhood or building level and some instruments that incorporate sufficiency action (without explicitly naming it). But so far, there is no overarching strategy found in European countries that integrates sufficiency options, although there are various options.

On the one hand, energy sufficiency actions and the policy support they need are sometimes very different from energy efficiency: With sufficiency actions, utility aspects are reduced or change qualitatively; and they include actions regarding building size and design/construction not directly addressing energy consumption. On the other hand, the types of policy instruments that seem adequate for supporting the energy-intelligent use of buildings and equipment look quite similar overall to those in the well-known energy efficiency policy package. However, energy sufficiency policy has to deal with different constraints that people have on taking sufficiency actions and be careful not to unfairly impact on any particular group, for example those with caring responsibilities, who are less able than others to respond to policy levers. It has to consider norms and social practices determining the demand for technical services, which are not as relevant for energy efficiency, because the latter does not imply a change in the demand for technical services. Taking these preconditions on board, it has been possible to add to the energy efficiency policy package for buildings some instruments to address sufficiency, and to develop a first set of policies for limiting the growth of average dwelling floor space. Implementation of the latter, however, will also need to avoid increasing needs for transport.

As some services and practices that need to be developed as well as some instruments in the policy package are quite new, policy experimenting may be needed to create good practice case studies before broad implementation. Future work will need to test, evaluate, and refine the micro and meso level policies in this sense, but also to take a closer look at the macro drivers of energy demand, and how policy could contain them.

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6 Annex

6.1 Classification of indicators for a technical potential estimate in dwellings

	Theoretical potential of 35 m²/cap floor space			Total population in under-occupied dwellings minus population in overcrowded dwellings		
	Belgium	8,3%	1	Belgium	70%	4
	Bulgaria	24,1%	3	Bulgaria	-31%	0
	Czech Rep.	1,7%	1	Czech Republic	3%	1
	Denmark	44,2%	4	Denmark	37%	3
	Germany	24,9%	3	Germany	29%	3
	Estonia	-11,2%	0	Estonia	16%	2
	Ireland	23,1%	3	Ireland	68%	4
	Greece	34,9%	3	Greece	-18%	0
	Spain	33,2%	3	Spain	52%	4
	France	25,3%	3	France	36%	3
	Croatia	-6,1%	0	Croatia	-32%	0
	Italy	28,8%	3	Italy	-12%	0
	Cyprus	40,7%	4	Cyprus	70%	4
	Latvia	-1,3%	0	Latvia	-30%	0
	Lithuania	-17,6%	0	Lithuania	-6%	0
	Luxembourg	31,5%	3	Luxembourg	49%	4
	Hungary	23,4%	3	Hungary	-33%	0
	Malta	43,8%	4	Malta	65%	4
	Netherlands	33,3%	3	Netherlands	49%	4
	Austria	36,4%	3	Austria	16%	2
	Poland	-29,3%	0	Poland	-31%	0
	Portugal	45,1%	4	Portugal	27%	3
	Romania	-93,8%	0	Romania	-44%	0
	Slovenia	-1,2%	0	Slovenia	16%	2
	Slovakia	-10,6%	0	Slovakia	-27%	0
	Finland	33,5%	3	Finland	42%	4
	Sweden	27,9%	3	Sweden	32%	3
	United Kingdom	16,7%	2	United Kingdom	44%	4

0	very low potential	negative number	very low potential	negative number
1	low potential	0,1%–10%	low potential	0,1%–10%
2	average potential	10,1%–20%	average potential	10,1%–20%
3	high potential	20,1%–40%	high potential	20,1%–40%
4	very high potential	more than 40%	very high potential	more than 40%

	Total population having neither a bath, nor a shower, nor indoor flushing toilet in their household			**Dwelling not comfortably warm during winter time**		
	Belgium	0,20%	3	Belgium	12,6%	3
	Bulgaria	11,10%	1	Bulgaria	41,1%	0
	Czech Republic	0,20%	3	Czech Republic	8,5%	3
	Denmark	0,50%	3	Denmark	12,9%	3
	Germany (e)	0,00%	4	Germany	3,6%	4
	Estonia	4,90%	2	Estonia	17,2%	2
	Ireland	0,00%	4	Ireland	12,8%	3
	Greece	0,40%	3	Greece	26,2%	1
	Spain	0,10%	3	Spain	17,7%	2
	France	0,30%	3	France	17,7%	2
	Croatia	1,50%	2	Croatia	7,8%	3
	Italy	0,00%	4	Italy	16,0%	2
	Cyprus	0,80%	3	Cyprus	21,9%	2
	Latvia	12,30%	1	Latvia	20,3%	2
	Lithuania	10,60%	1	Lithuania	17,1%	2
	Luxembourg	0,00%	4	Luxembourg	4,2%	4
	Hungary	3,40%	2	Hungary	19,2%	2
	Malta	0,00%	4	Malta	28,8%	1
	Netherlands	0,00%	4	Netherlands	6,2%	3
	Austria	0,30%	3	Austria	4,5%	4
	Poland	2,60%	2	Poland	15,5%	2
	Portugal	0,90%	3	Portugal	46,6%	0
	Romania	30,50%	0	Romania	13,0%	3
	Slovenia	0,30%	3	Slovenia	5,1%	3
	Slovakia	0,70%	3	Slovakia	6,8%	3
	Finland	0,30%	3	Finland	8,5%	3
	Sweden (e)	0,50%	3	Sweden	5,6%	3
	United Kingdom	0,40%	3	United Kingdom	5,1%	3

0	very low potential	more than 20%	very low potential	more than 20%
1	low potential	10,1%–20%	low potential	10,1%–20%
2	average potential	3,1%–10%	average potential	3,1%–10%
3	high potential	0,6%–3%	high potential	0,6%–3%
4	very high potential	< 0,5%	very high potential	< 0,5%

(e) means estimated due to missing data for 2015.