Residential energy consumption patterns in Finnish households

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Summary

Promoting higher energy efficiency is one of the focus areas of current policies intending to advance more sustainable future. Buildings and residential energy consumption, heating, cooling and operation of the residential buildings as well as household electricity use, are in the focus as the share of these is estimated to be 30-40% of the global energy use. Despite extensive research around the issue, there still seems to be a gap in the literature on the overall energy consumption patterns of different types of households living in different types of areas. This is due to three factors. First, when actual consumption data is utilized, it may well appear that the energy consumption deviates significantly from the theoretic efficiencies due to just user behavior. Second, it is not enough to look at the energy consumption on an apartment level as a large share of energy use, especially heating energy in apartment buildings, relate to communal spaces and the majority of the operational and maintenance activities require energy that is communal in nature in apartment buildings. Finally, residential spaces other than the primary residence, such as summer cottages and other second homes, increase the overall energy use. In this study we take a step towards filling this gap. We conduct a comprehensive analysis on the energy consumption patterns in Finnish household taking into account heat and electricity on both communal and household direct consumption levels. We take into account possessed summer cottages and other second homes. We calculate the energy requirements of average households living in different types of areas in Finland using a four category division of Helsinki Metropolitan Area (HMA), (other) cities, semi-urban areas and rural areas. We utilize statistical data of Statistics Finland and Metla including statistics on housing companies and household expenditure data to put together a comprehensive analysis. The results show that when the overall energy requirements of operating apartment buildings is taken into account, the differences in housing energy consumption of households living in different types of areas are small. In fact, whereas the overall energy requirements are slightly lower in apartment building dominated cities on household level, in less urbanized areas less energy (in kilowatt hours) is used on both per capita and per square meter, and the share of renewable fuels in the energy-mix is higher.

Keywords: energy, energy use, energy requirements, household, building, residential, renewable, non-renewable, lifestyle

1. Introduction

Promoting higher energy efficiency is one of the focus areas of current policies intending to advance more sustainable future. Lower energy demand would both decrease the greenhouse gas emissions directly and accommodate the transition towards renewable energy sources. Urban areas and urbanization seem to play a central role, as according to the International Energy Agency, the urban areas are accountable for approximately two thirds of the global energy use [1].

Improvements in energy efficiency can occur on any products or production process. Buildings and residential energy consumption, heating, cooling and operation of the residential buildings as well as household electricity use, are in the focus in urban planning as the share of these is estimated to be 30-40% of the global energy use [2]. Residential energy is also the single largest source of energy demand from the consumer perspective [3-6]. As a consequence, housing energy use has been studied extensively. However, these studies have largely concentrated on the overall energy requirements of different types of households or consumers with comparisons between the energy requirements related to different consumption categories, e.g. [5, 7-9]. On the other hand, an extensive body of literature exists that focuses on just the building related energy requirements. These predominantly compare the energy requirements related to different building characteristics or between building life cycle phases [10-12]. Especially related to urban sprawl research, studies that compare urban core and suburban areas exist, which often look at both the residential energy use and energy related to transportation. The traditional conclusion of these studies has been that a more dense or compact urban form can reduce the energy consumption due to reduced living spaces and multi-story apartment buildings replacing detached houses [13-15].

Nevertheless, there still seems to be a gap in the literature on the overall energy consumption patterns of different types of households living in different types of areas. Firstly, when actual consumption data is utilized, it may well appear that the energy consumption deviates significantly from the theoretic efficiencies due to just user behavior [16, 17]. It may also be that the fiscal incentives lead to significantly different behavior. For example, in an apartment building with central heating and/or cooling the residents often have little incentives to save energy and may even be unable to affect the majority of the energy use [18]. Heating and cooling energy tend to be embedded in housing management and rental payments and thus don't create fiscal incentives for energy efficient behavior. On the other hand, in detached houses the residents pay for their energy use directly and thus also gain directly from energy saving behavior. Secondly, it is not enough to look at the energy consumption on an apartment level as a large share of energy use, especially heating energy in apartment buildings, relate to communal spaces [18]. Also, the majority of the operational and maintenance activities require energy, which also adds to the communal energy share in apartment buildings. Finally, when the energy requirements of households are concerned, spaces other than the primary residence increase the overall energy use. Living in a less spacious city apartment may be compensated by summer cottages and other second homes and by increased use of public spaces such as restaurants, cafés and hotels [19].

In this study we take a step towards filling the described gap by conducting a comprehensive analysis on the energy consumption patterns in Finnish household taking into account heat and electricity on both communal and household direct consumption levels. We take into account possessed summer cottages and other second homes, but leave out services related space use due to data restrictions. We calculate the energy requirements of average households living in different types of areas in Finland using a four category division of Helsinki Metropolitan Area (HMA), (other) cities, semi-urban areas and rural areas. We utilize statistical data of Statistics Finland and The Finnish Forest Research Institute (Metla) including statistics on housing companies and household expenditure data to put together a comprehensive analysis. The results show that when the overall energy requirements of operating apartment buildings are assessed, the differences in housing energy consumption of households living in different types of areas are small. In fact, whereas the energy requirements are slightly lower in apartment building dominated cities on household level, in less urbanized areas less energy (in kilowatt hours) is used on both per capita and per square meter.

The remainder of the paper is structured as follows. In Section 2 the methods, data and the research process are explained. Section 3 shows the results and Section 4 discusses the findings and their significance as well as evaluates the robustness of the results. Finally, Section 5 presents the key conclusions of the study and sets the path for extensions of the study in the future.

2. Methods, data and research process

The study concentrates on calculating the overall residential space related energy requirements of average households living in different types of areas in Finland. For the area types we utilized the categorization of statistics Finland that separates three different area types in Finland based on the degree of urbanization on municipality level: cities, semi-urban areas and rural areas. To achieve a more informative selection, we further disaggregated Helsinki Metropolitan Area from other cities, thus ending up with four different types of areas. Table 1 shows some main characteristics of the four areas to depict the differences important for the housing energy requirements.

Table 1 The main characteristics of the four area types of the study.

Area / Characteristics	*HMA*	*Cities*	*Semi-urban areas*	*Rural areas*
Definition (stat.fi)	*Four cities: the capital Helsinki and its neighbors Vantaa, Espoo and Kauniainen. Area's total population is about one million and it forms an inseparable entity of workplaces, public transport etc.*	*"municipalities in which at least 90 per cent of the population lives in urban settlements or in which the population of the largest urban settlement is at least 15,000"*	*"municipalities in which at least 60 per cent but less than 90 per cent of the population lives in urban settlements and in which the population of the largest urban settlement is at least 4,000 but less than 15,000"*	*"municipalities in which less than 60 per cent of the population lives in urban settlements and in which the population of the largest urban settlement is less than 15,000; and those in which at least 60 per cent but less than 90 per cent of the population lives in urban settlements and in which the population of the largest settlement is less than 4,000"*
Average family size	*1.93*	*2.05*	*2.27*	*2.33*
Housing types				
- Apartment	*72%*	*60%*	*32%*	*14%*
- Terraced/detached	*27%*	*40%*	*67%*	*86%*
Heating modes				
- Electricity	12%	21%	28%	36%
- District heat	81%	60%	29%	14%
- Oil	5%	14%	22%	20%
- Wood	0%	3%	11%	18%
- Other	2%	9%	10%	12%
Living space per household (m2)	*76*	*82*	*103*	*103*
Area density (households/km2)	688	*40*	*7*	*2*

We comprised three data sets in the study to create a comprehensive picture of the actual energy requirements of the average households living in each of the four types of areas. The primary data is formed by the Household Budget Survey 2006 of Statistics Finland [20], which is the most recent budget survey conducted in Finland. The survey comprises the private consumption of Finnish households according to the international CIOCOP categorization. In the study, the category 4.5 "Electricity, gas and other fuels" was separated from the rest of the data. The data was complemented with an assessment of the energy expenses embedded within rental payments and housing management charges in the Household Budget Survey. The disaggregation of the housing management charges was done according to the data of Statistics Finland on the finances of housing companies in Finland [21]. Table 2 shows the distributions of energy expenses within housing management fees in Finland. Different distributions were used for HMA and the rest of the country to avoid biases from the higher housing costs in HMA.

Table 2 Energy expenses embedded in the housing management fees in Finland.

Shares of energy in the housing management charge	*HMA*	*Rest of the country*
- Electricity	*3%*	*5%*
- Heat	*20%*	*25%*

To add the energy embedded in rental payments into the analysis, we first disaggregated the rents to housing management charges and other, and then further to energy and other costs according to the shares depicted in Table 2. To extract the housing management charges from rental payments we assumed that the average rent in each area comprises a housing management charge similar to the average housing management charge in the area. We also separated the primary apartment related energy expenses from those related to summer cottages and other second homes. Table 3 depicts both the direct energy purchases extracted from the Household Budget Survey and the assessed values for the energy paid within housing management fees and rental payments.

Table 3 Average households' annual energy purchases for primary homes in the different area types in Finland.

Area / Purchase value (€/a)	*HMA*	*Cities*	*Semi-urban areas*	*Rural areas*
Direct energy purchases				
- Home electricity	374	516	740	860
- Heating oil, etc.	74	132	231	212
- Firewood	13	53	172	230
- District heat	129	134	74	69
Total	*591*	*835*	*1,218*	*1,371*
Indirect energy purchases				
Housing management charges	*1 111*	*615*	*326*	*172*
Housing charges paid within rents	*850*	*596*	*369*	*314*
Of which				
- electricity	54	60	34	24
- district heat	375	244	87	39
- oil and other	19	47	89	85
Total	*358*	*274*	*148*	*147*
Overall energy purchases	*1,043*	*1,202*	*1,428*	*1,518*

Next we repeated the same process with summer cottages and second homes. The only difference in the analysis is that we used the Finnish average percentages for energy costs embedded in the housing management charges: electricity 4%, heat 24%. This choice was done since the locations cannot be traced from the utilized data. Table 4 shows summer cottages and second homes related annual energy expenses in possession of the average households of each area.

Table 4 Average households' annual energy purchases for summer cottages and secondary homes in the different area types in Finland.

Area / Purchase value (€/a)	*HMA*	*Cities*	*Semi-urban areas*	*Rural areas*
Direct energy purchases				
- Home electricity	77	45	40	31
- Heating oil	5	1	0	1
- Firewood	5	4	4	5
- District heat	10	9	24	19
Total	*96*	*59*	*68*	*56*
Indirect energy purchases				
Housing management charges	*20*	*15*	*39*	*23*
Housing charges paid within rents	*41*	*32*	*18*	*18*
Of which				

- electricity	3	2	2	2
- district heat	11	8	10	7
- heating oil	4	3	4	3
Total	*18*	*13*	*16*	*12*
Overall energy purchases	*114*	*72*	*84*	*68*

To convert the monetary expenditures into energy consumption, energy prices for the reference year 2006 were retrieved from energy statistics of Statistics Finland for electricity, oil, and district heat [22]. The energy prices for each of the areas were calculated by taking into account the distribution of the building types in each area as depicted in Table 1. Oil prices are the spot market prices for Finland as a whole, but the prices of both district heat and electricity decrease along the size of the annually purchased amount. Electricity price is thus lower for detached houses using electricity for heating and district heat for the largest housing companies. Table 5 comprises the utilized energy prices the different area types, calculated according to the building type distribution in each area.

Table 5 Energy prices for oil, electricity and district heat in the different areas.

Average price (cent/kWh) / Energy type	*HMA*	*Cities*	*Semi-urban areas*	*Rural areas*
- Electricity	11.0	10.4	9.4	8.7
- Heating oil	5.85	5.85	5.85	5.85
- District heat	4.52	4.57	4.67	4.74

At this point we also employed the above mentioned third data set to assess the energy from domestic burning of firewood. There is a lack of data for firewood prices for the reference year 2006, and the method to report wood values in the Household Budget Survey are likely to lead to significant underestimation of wood usage in households with fire places and wood heated saunas. The third data set is provided by Metla, and it comprises the firewood use in detached houses and terraced houses in Finland based on the burned quantity. According to the data, a household living in a detached house in Finland burns an average of 3.2 m3 of firewood per annum [23]. However, in the Southern Finland the annual amount is only less than half of the national average, 2.1 m3 per annum, and thus we utilized this figure for detached type primary homes in HMA. The respective amount in terraced houses is approximately 0.4 m3 per annum. No data were available to distinguish HMA from the rest regarding terraced houses, but the amount is such small that the impact for the energy assessment is insignificant.

According to the same data, approximately 1.8 m3 of firewood is used at a summer cottage per annum, which was used to assess the overall energy use related to summer cottages in possession of the average household in each area type. The figures for the summer cottages in possession were retrieved from the primary data, Household Budget Survey, according to which 25% of the households in HMA possess a summer cottage or such, 22% in other cities, 23% in semi-urban areas and 20% in rural areas.

To calculate the energy content of the burned firewood we used two conversion factors. First, according to Alakangas the heating value of firewood is 1.25 MWh/m3 [. Second, a one m3 stack volume of firewood is equivalent to 0.67 m3 of full firewood.

Finally, according to the purchases, unit prices and the quantity information for firewood, we calculated the overall annual energy use of the average households in the different types of areas (in kWh/a). In addition, we also calculated the figures on per capita basis and on per square meter (m2) basis. The results are presented in the next section.

3. Results

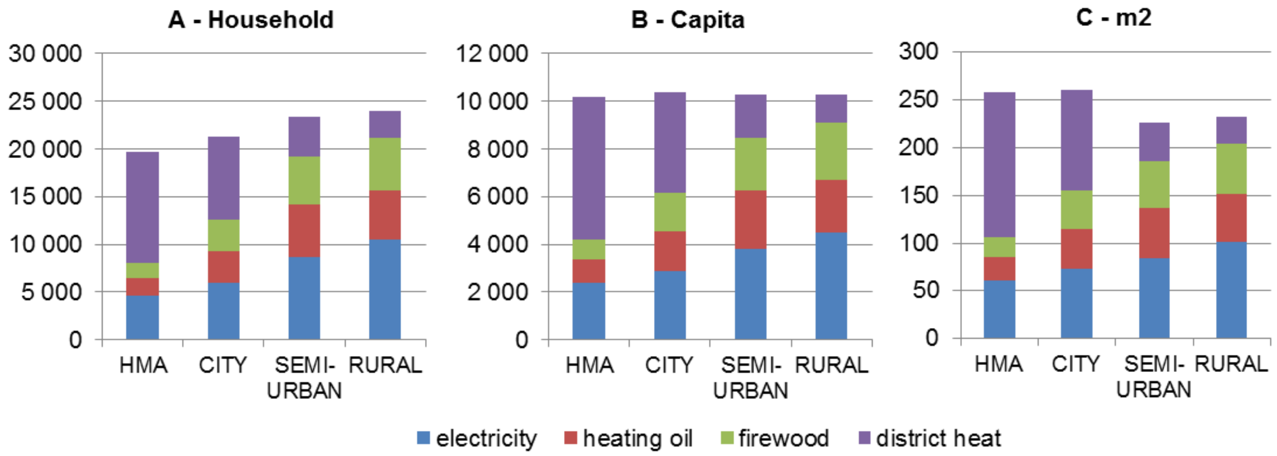
Complying with many previous studies, the households living in the least urbanized areas seem to have on average the highest annual energy consumption according to the study. In rural areas the annual amount of energy use is 24,000 kWh, in semi-urban areas 23,400 kWh, in cities 21,300 kWh and in HMA 19,700 kWh. Approximately 90% of the annual energy use is related to the primary residence in each of the areas, from the lowest 88% in HMA to 93% in rural areas. Summer cottages and other second homes contribute between 1,600 kWh (rural areas and cities) and 2,200 kWh (HMA) annually to the overall energy use of the average households.

As the monetary purchases depicted in Section 2 already indicated, the distribution of used fuels is but equal between the areas. When looking only at the primary residence, electricity use more than doubles from the average of 3,900 kWh/a in HMA to 10,200 kWh/a in rural areas. Cities are closer to HMA with 5,500 kWh/a, and semi-urban areas to rural areas with 8,300 kWh/a. Reversely, 11,100 kWh/a of district heat is used in HMA, but only less than 2,300 kWh/a in rural areas. Again, cities are closer to HMA, and semi-urban areas follow the pattern of rural areas. Oil and firewood are both sources of slightly lower importance, but both are used significantly more in the less urbanized areas. Table 6 depicts the overall energy use of the average households in the different areas divided into the primary residence and summer cottages and other second homes.

Table 6 Annual average energy use per household in the four area types in Finland.

	HMA	*Cities*	*Semi-urban areas*	*Rural areas*
PRIMARY HOME				
home electricity	3,420	4,940	7,900	9,930
communal electricity	490	570	360	280
heating oil	1,680	3,330	5,480	5,060
firewood	770	2,580	4,220	4,880
district heat	11,140	8,280	3,450	2,270
TOTAL	*17,500*	*19,690*	*21,410*	*22,410*
SUMMER COTTAGES AND OTHER SECOND HOMES				
home electricity	700	410	360	280
communal electricity	20	20	30	20
heating oil	150	60	60	60
firewood	840	740	770	670
district heat	470	380	720	560
TOTAL	*2,180*	*1,620*	*1,950*	*1,590*
OVERALL	**19,680**	**21,310**	**23,360**	**24,010**

When the energy use is looked on per capita and per m2 levels the differences even out significantly. However, due to the differences in the household sizes, on per capita level the energy use is almost equal in all the areas at 10,200-10,400 kWh. On the per m2 level the results are actually reverse if only the reported living spaces are taken into account; 230 kWh/m2/a in HMA, 240 in cities, 220 in the two least urbanized areas. Figures 1 A-C depict how the functional unit affects the results.



Figures 1 A-C The annual energy use (kWh/a) in the different area types in Finland measured in different functional units.

One additional interesting perspective is to look at how the utilized fuels are distributed between renewable and non-renewable sources. If first firewood use is erased from the energy use figures, a very similar quantity is used annually in all the areas even on a per household level: 18,100 kWh

in HMA, 18,000 in cities, 18,400 in semi-urban areas and 18,500 in rural areas. Looking these figures in per capita terms shows that in the more urbanized areas, HMA and cities, more kilowatt hours are used when wood is omitted from the figures: 9,400 kWh/a in HMA, 8,800 in cities, 8,100 in semi-urban areas and 7,900 in rural areas. On per m2 level the differences now appear as relatively large, from 240 kWh/a in HMA to 220 in cities and 180 in semi-urban and rural areas.

The analysis on renewables–non-renewables can be taken further by looking at the production fuels at the power plants in Finland. To facilitate the analysis we adopted an assumption that in all four areas the Finnish average energy, both electricity and heat, is used. In electricity production the Finnish average fuel distribution consists of 34% of renewables, 34% fossil fuels (coal, natural gas, oil) and peat, and 32% of nuclear power [25]. District heat is produced largely as combined heat and power production (CHP) where fossil fuels dominate. In heat production the share of coal, natural gas, oil and peat is approximately 75% [25].

Now, if the overall annual energy use of the average households in each area is divided into renewable fuels, nuclear power and other non-renewables, in all the areas a rather equal amount of non-renewable fuels seem to be used. On per capita basis less non-renewable fuels are required for the energy use in the less urbanized areas. Figure 2 shows the distributions.

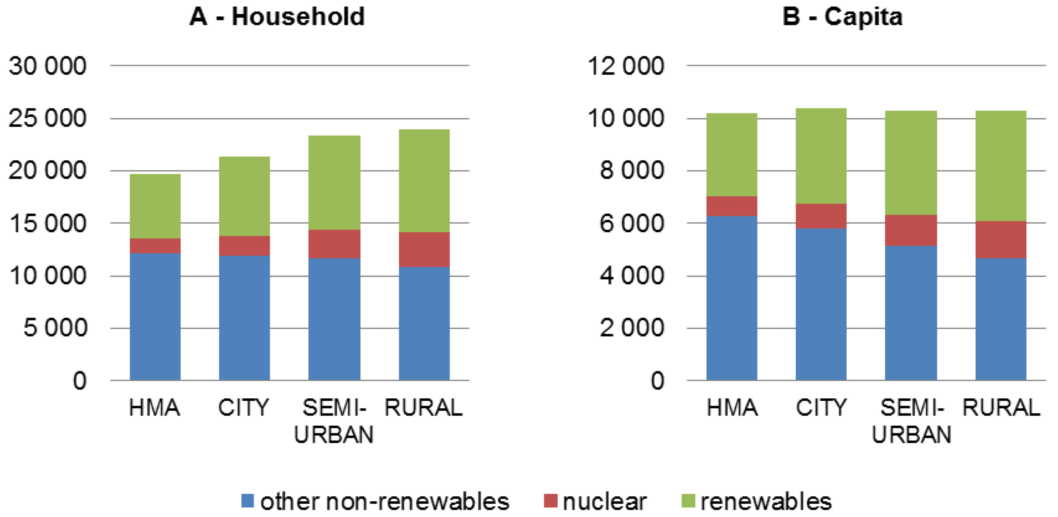


Figure 2 A-B The shares of renewable and non-renewable fuels in the annual average energy use in Finnish households (kWh/a) on per household and per capita basis.

4. Discussion

The study was set to conduct a comprehensive analysis on the energy use patterns of the average households in Finland living in different types of areas. The motivation for the study is that even though the energy requirements of both buildings and households have been studied extensively, not many studies have approached the issue with actual consumption data. There are considerably different incentives for energy efficient behavior related to different types of residences, especially between homeowners living in detached houses and households living in housing company operated apartment buildings (see e.g. [18]). Thus, while it is obvious that in theory more energy is used in the more spacious detached houses, the actual differences may appear much smaller just due to distinct user behavior.

In addition, to get a comprehensive picture of the energy requirements of households living in different types of residences, it is not enough to consider their direct own apartment related energy. This would strongly favor apartment buildings where a significant amount of energy is needed for heating and lighting the communal spaces of a building, operate elevators, heat communal saunas etc. [18]. Even the building maintenance doesn't show in the direct energy use of a certain household in an apartment building, but is embedded in housing management charges or rental payments. Finally, households living in different types of surroundings may have different incentives to possess and use summer cottages and other second homes, which should be taken into account when comparing the energy use of households.

We chose to calculate the energy requirements of average households living in different types of areas in Finland using a four category division of Statistics Finland of Helsinki Metropolitan Area (HMA), (other) cities, semi-urban areas and rural areas that together include the whole Finland. As indicated in Table 1, the characteristics of the average households in these four types of areas deviate significantly from each other providing thus a good basis for an analysis of the study.

The study depicted that in overall terms the household energy requirements are the lowest in the most urbanized areas of HMA and cities with an approximately 20% increase from HMA to rural areas. As Table 1 shows, the household sizes also increase towards the less urbanized areas and thus the difference is reduced to almost zero on per capita level despite the more spacious residences in the less urbanized areas. This would indicate that the above stated assumption of distinct incentives to energy efficient behavior indeed has an impact on the actual energy use.

The share of energy use related to summer cottages and other second homes is only 7-12% of the overall annual use. The differences are not huge, but in absolute terms a household in HMA uses 2,200 kWh/a to operate a summer cottage or second home, approximately 600 kWh more than a household in rural areas and in cities, and slightly more than a household in semi-urban areas. The households in the less urbanized areas also seem to own city apartments since they seem to purchase more district heat for their second homes than the households in the more urbanized areas.

To get a comprehensive comparison of energy use in different types of contexts, we also assessed firewood use that is often neglected in similar assessments. Firewood actually appeared to be in a relatively significant role, especially in the less urbanized areas where detached houses dominate housing modes. The share of over 20% of overall energy use in the less urbanized areas can be interpreted as further evidence of behavior intending to save on energy consumption. The firewood used in detached houses is often own or benefit-in-kind and thus decreases the energy bills. If firewood is omitted from the comparison of energy use, the result is interestingly that the differences on per household level are greatly reduced and on per capita level the less urbanized areas appear as more energy efficient.

When the analysis of the use of renewable and non-renewable fuels was taken further, the result was interesting, as on per household basis the amount of non-renewable fuels required annually is almost equal between the different areas. On per capita basis the absolute amount of non-renewables steadily increases towards the more urbanized areas and the amount of renewables decreases.

The results of the study actually comply with many earlier studies even though the overall findings indicate that living in less dense less urbanized areas in detached houses is not necessarily very energy intensive compared to apartment buildings in the more urbanized areas. On per household basis the average energy use seems to be higher in the less urbanized areas. The difference is even relatively significant if only the energy related to just the living space is taken into account, and the communal energy use in apartment buildings omitted. This is in accordance with e.g. Fuller and Crawford (2011) who hypothesize, concerning Australia, that energy use would increase significantly towards the less urbanized areas, but explain the increase predominantly with rapidly increasing living space [26]. Norman et al. (2006) present very similar results, reporting energy use to increase significantly towards the less dense suburban areas, but also primarily due to a significant increase in the living space [27]. In Finland the differences in the living space per capita are not huge, especially if the communal spaces in the apartment buildings would be divided according to the number of residents. Myors et al. (2005) actually report the highest energy use related to high-rise urban core apartment buildings [28]. According to them the efficiency of an apartment building decreases quickly when the height increases due to high operational energy requirements. One explanatory factor in their study is the decrease in the average household size towards the more urbanized areas, as is the case in Finland as well.

There are uncertainties related to the analysis. We combined three different data sets to create an overall picture of the energy use in Finnish households. It might be that calculating the communal building energy based on the housing management fees and rental payments overestimates or underestimates that share, especially the share embedded in the rental payments. A comparison of the household purchases data and the statistics on the finances of housing companies would indicate a relatively good comparability, but deviations are still possible. Yet a more significant uncertainty relates to the assessment of energy from firewood, which was taken from a totally separate data. Further, the presented renewables–non-renewables analysis is subject to uncertainty as we were forced to use the Finnish average energy production fuel distributions for all the areas. In reality there are significant variations in the fuel mixes between individual power plants which might cause certain area to deviate from the presented patterns. Finally, it can be argued that heat and electricity consumption should not be summed and compared. Primary energy coefficients could be one possible solutions to increase the robustness of the analysis from this perspective. In the future this kind of extension to the study should be conducted, but the fact that approximately 70% of the district heat in Finland is produced as CHP production adds complexity to such an analysis as well.

5. Conclusions

The primary conclusion based on the study is that the actual energy use cannot be estimated solely based on the theoretical characteristics of a residence. Two factors, the different incentives to save on energy and the communal building energy, that doesn’t show in the direct energy use of a household, significantly narrow down the differences between households living in different types of contexts. Secondly, the most reliable level in energy use analyses might be the per capita level instead of household and the results also suggest that the traditional per m2 measurement of energy consumption is misleading. In the study we depicted how the different functional units return very different outcomes, the household level leaving the less urbanized areas worse off as the average household sizes tend to increase as the level of urbanization decreases. Finally, in addition to the incentives to save energy in detached houses, a significant share of the annual heat requirements seem to be produced with own firewood burning. The amount of renewable fuels should thus be analyzed when comparing the energy use of the residents of different types of buildings and residential areas.

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