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Residential energy consumption patterns and the overall housing energy requirements of urban and rural households in Finland

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ABSTRACT

In this study, we analyze holistically the residential energy consumption patterns and the overall housing energy requirements of urban and rural households in Finland. We study separately three of the most common types of housing—apartment buildings, row-/terraced houses, and detached houses—and include private and the communal building energy as well as the amount of energy consumed by free-time residences. With this study, we add perspective to the ongoing discussion on the sustainability of urban versus rural living and that of different housing types. We employ Household Budget Survey data from Statistics Finland and data from the Finnish Forest Research Institute (Metla) to extract the actual energy purchases and convert them into energy units. Our key findings include five perspectives: (1) behavioral differences seem significant between different housing modes; (2) each housing mode appears to be less energy-intensive in rural areas; (3) including indirect energy purchases is essential when comparing different housing modes; (4) unit-of-analysis (m^2, capita, household) selection strongly affects the results; and (5) the energy mixes vary significantly between the studied building types, changing from the predominance of non-renewables in apartment buildings to that of renewables in detached houses, which in turn has interesting carbon footprint implications.

1. Introduction

Increasing the energy efficiency of the building stock is currently one of the key climate change mitigation strategies throughout the world [1]. This focus is well grounded, as building energy use accounts for as much as 30–40% of the global energy requirements [2]. In many studies, especially in the northern countries, but elsewhere as well, residential energy consumption has also been found to constitute the largest or at least one of the largest sources of energy demand and GHG emissions of a household (e.g., [3–7]). Improving the energy efficiency of the residential building stock is thus one important action category since the housing stock qualities inevitably have a significant impact on the operational energy requirements. For example, all new residential buildings within the EU must be "Nearly Zero Energy Buildings" by the year 2020 according to current plans. In Finland the target year has been set to 2017, which means a very rapid change within the next few years. A more energy efficient building stock would reduce the GHG emissions as such, but it would also support increased renewable energy production.

Consequently, residential energy use has been widely studied. In general, less densely built urban areas with low-rise buildings have been reported to increase energy requirements [8–15]. This has significantly contributed to the current predominance of high-density and apartment building-based living as the major sustainability objective in urban planning in all of the developed countries.

Room for making new contributions to the issue of residential energy consumption still exists from at least three perspectives. First, when the energy requirements of different building types are assessed, standard occupancy rates and similar user behavior across all the building types are often assumed (e.g., [14–16]). However, Wright [17] suggests that, "*Current models with standard occupancy predict that energy use will be strongly related to size and built form, but surveys of real homes show only weak correlations, across all types of dwelling.*" Thøgersen and Grønhøj [18] support this statement, concluding that "*household members' electricity saving effort makes a difference for a private household's electricity consumption*", Likewise, Branco et al. [19] present a case study from Switzerland where the measured energy consumption is 50% higher than the predicted energy consumption due to, for example, higher-than-predicted indoor temperatures. Although several other studies have also tackled this issue (e.g., [7,11,20,21]), by no means has the saturation point been exceeded. Second, many studies treat energy performance merely as a function of the physical

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qualities of a building, with the square meter often as the functional unit (e.g., [22–26]) (see also Sartori and Hestnes [27] for a review of 60 cases). This approach omits users entirely, and while it has significant value in many other applications, it may lead to biased estimations of the actual energy consumption in a certain building due to varying occupancy rates and user behavior. Third, while certain studies have used actual consumption data to assess energy consumption in different building types (e.g., [8,9,12,13]), they typically cannot differentiate the impacts of behavioral differences or explicitly compare building types due to the data not being detailed enough. The same applies to the studies focusing on overall household energy consumption and the embodied energy related to different consumption categories (e.g., [7,28–33]). Adopting a broader scope, Weber and Perrels [34] get closer to making this kind of comparison and suggest that lifestyle-residential energy relationships are complex and difficult to capture in simple energy requirement modeling, but they do not compare the different building types.

There are many reasons for the actual rate of consumption to deviate from the theoretic efficiencies, but one potentially important reason has to do with the differences in fiscal incentives, which may promote very different user behavior. For instance, Kyrö et al. [35] suggest that the residents of an apartment building with district heating, whose heating and cooling energy payments are often embedded in the housing management or rental payments, may have little incentive for energy efficient behavior. Similarly, Linden et al. [21] report having found 2 °C higher indoor temperatures in Sweden for buildings with commonly paid energy costs, and Haas et al. [36] suggest that residents living in detached houses are much more sensitive to prices than those living in apartment buildings in Austria. These findings actually also relate to a whole new perspective in building energy efficiency, namely managerial efficiency in multi-family buildings, which Baumann [37] and Kyrö et al. [38] discuss to some extent, but which otherwise has received little attention thus far.

Furthermore, energy consumption in apartment buildings should not be assessed solely based on the actual living space since communal spaces actually generate a significant share of the overall energy use [35]. Similarly, many standard operation and maintenance activities are relatively energy intensive, adding to the communal energy demand in apartment buildings. Finally, when the energy requirements are assessed from the demand perspective, possessed living spaces and other space used outside the primary residence should be taken into account as well. Denser city living may represent a tradeoff between living space and possessing a free-time residence, but it may just as well have to do with having a wider availability of diverse service spaces around the apartment [39].

This study adds a new perspective to the above-mentioned academic discourse by analyzing holistically the residential energy consumption patterns of Finnish households. Furthermore, we contribute to the discussion on the energy requirements of urban and rural living by separating the two area types in the study. We also look into the differences in the energy consumption of households living in different types of housing by discussing apartment buildings, row-/terraced houses and detached houses separately. In addition to direct energy consumption, our analysis takes into account the communal and private energy costs embedded in housing charges as well as the amount of energy consumed by free-time residences with respect to households living in different area and with different housing modes. We employ Household Budget Survey data by Statistics Finland and data from the Finnish Forest Research Institute (Metla) to assess the energy consumption rates. We will demonstrate that the theoretical differences between different types of buildings disappear or are greatly reduced when actual consumption data are utilized and the communal energies taken into account. Furthermore, we demonstrate that urban living results in more energy consumption when each housing type is compared across urban and rural areas. On the other hand, differences in fuel mixes between the different building types remain large, which raises interesting discussion topics and further research issues from the sustainability perspective.

The paper is structured so that Section 2 deals with the research design, data, and methods used, while the results are presented in Section 3 and then discussed in Section 4 together with an evaluation of the uncertainties. The key conclusions are presented in Section 5.

2. Research design

2.1. Utilized data

Three separate data sets were utilized in the study to extract the housing energy consumption rates for average residents in the areas under study. The primary data set is the Household Budget Survey (HBS) 2006 by Statistics Finland [40], which provides data on the annual housing energy purchases for primary homes and free-time residences based on different types of energy and fuels as well as the housing management and rental payments, including embedded energy expenditures. The 2006 data are the most recent HBS data available in Finland. The single-period, cross-sectional survey includes the consumption rates of 4007 Finnish households (0.2% of all Finnish households). The survey mode is a single-stage, stratified cluster sample survey designed to be representative of Finnish households. The data contain probability weight coefficients to correct the non-response bias. The data follow the international COICOP classification system, in which data are divided into approximately 1000 categories and sub-categories. The data provide a wide selection of background variables, such as area and housing types, for sampling and descriptive purposes.

The second data source employed in the study is Statistics on the Finances of Housing Corporations (SFHC) in Finland, which was also provided by Statistics Finland [41]. This data were used to extract the energy payments embedded in the housing management charges and rental payments presented in the HBS data. Different distributions were utilized for apartment building residents and row-/terraced house residents. The third data set from Metla [42] was employed to assess the energy content of domestic firewood use in primary homes and in free-time residences, which has previously been shown to have a significant influence in the Finnish context [43]. Table 1 depicts the data sources and the utilized categorization.

2.2. Sample characteristics

For the purposes of the study, the HBS data is divided into urban and rural households and also according to the housing type, with a three-level categorization of apartment buildings, row-/terraced houses and detached houses. The sampling was done according to the background information reported in HBS. Statistics Finland utilizes a three-level categorization of the municipalities in Finland according to the degree of urbanization: Cities, semi-urban areas and rural areas. In the study, cities form the urban category and semi-urban and rural municipalities form the rural category. Table 2 shows some of the main characteristics of the samples.

2.3. Research process

The research process consisted of five steps:

Table 1
The data sources and the coverage of the utilized data.

Energy type	Utilized categories	Data source	Data coverage
Direct energy purchases	Home electricity	HBS	Energy purchased directly by the household
	Heating oil	HBS	
	Firewood	HBS	
	District heat and hot water	HBS	
Indirect energy purchases	Housing management charges	HBS	Heat and communal building energy paid within housing charges
	Rental payments	HBS	
	Embedded energy shares	SFHC	
Firewood use	Volumes of firewood use by housing type	Metla	Firewood use in detached and row-/terraced houses

Table 2
The main characteristics of the utilized six samples.

Area/characteristics	Urban areas			Rural areas		
Definition (stat.fi)	"municipalities in which at least 90% 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 less than 90% of the population lives in urban settlements and in which the population of the largest urban settlement is less than 15,000"		
Sub-samples	Detached house	Row-/terraced house	Apartment building	Detached house	Row-/terraced house	Apartment building
N (households)	836	315	1198	1229	237	169
Average family size	2.75	2.19	1.65	2.62	1.76	1.57
Disposable income (€/a)	50,600	38,400	28,000	39,800	25,100	20,200
Primary heating modes (%)						
Electricity	50	29	2	38	35	2
District heat	12	62	91	2	44	78
Oil	26	7	5	22	20	18
Wood	7	–	–	22	–	–
Other	5	2	2	16	1	2
Living space (m^2)						
Per household	128.0	80.2	58.3	124.8	62.8	55.0
Per capita	46.6	36.6	35.4	47.7	35.7	35.0
Free-time residence in possession (%)	31	23	19	25	18	11

1. Extracting the average direct energy purchases for the different samples from the HBS data;
2. Extracting the average housing management charges and rental payments from the HBS data and disaggregating them for the embedded energy purchases;
3. Replacing the HBS data on firewood with the more comprehensive data on firewood provided by Metla;
4. Converting the expenditure data to quantities of energy use;
5. Analyzing the results.

During the first phase of the process, we extracted COICOP category 4.5, "Electricity, gas and other fuels," from the HBS data for the six selected samples. The data was then re-ordered according to the different energy types or fuels listed in Table 2 and the type of residential space, primary home or free-time residence. Next, we separated the average housing management charges and rental payments from the HBS data for primary homes and free-time residences. Using the SFHC data, the housing management charges for apartment buildings and those paid by row-/terraced house residents were disaggregated into shares of electricity, heat, and other. Heat was then further disaggregated based on the primary heating type distributions within each sample. Although the differences are small, we utilized different cost profiles for apartment buildings and row-/terraced houses. For free-time residences, the Finnish averages were utilized since the data does not reveal their types. It was assumed that residents of detached houses pay all of their energy costs separately and that the housing charges consist only of managerial and maintenance activities. Table 3 depicts the shares of energy payments embedded in the housing management charges.

Regarding the rental payments, we assumed that the housing management charges are equal in rental buildings and owner-occupied buildings. Thus, we assumed that the rental payments contain the same housing management charges as those paid by owner-occupants. Based on this assumption, we extracted the average housing management charge for each sample from the average rental payment and calculated the sample average according to the share of rent payers in each sample. After this, the above-mentioned disaggregation process was applied to the assessed housing management charges in order to extract the embedded energy purchases. Tables 4 and 5 show the direct and indirect energy purchases for primary homes and free-time residences.

For free-time residences, the purchases are shown in a less detailed form, including only direct and indirect shares, since they only constitute a minor share of overall energy purchases.

For the third action, we replaced the firewood expenditure data with the quantity data provided by Metla [42], but we utilized the expenditure distribution data to weight the average usage reported by Metla. This was done for two reasons. First, no price data for firewood for the reference year 2006 is available. Second, the Metla survey focuses on firewood and thus very likely returns more accurate estimations than the HBS data where the reported value only provides an estimation for the respondent since the majority of firewood is a person's own or benefit-in-kind firewood. Metla's data contain quantity-based figures for firewood used in detached

Table 3
The shares of energy payments embedded in the housing management charges (%).

Shares of energy in the housing management charge (%)	Apartment buildings	Row-/terraced houses	Finnish average
Electricity	4	5	4
Heat	23	25	24

Table 4
Direct and indirect energy purchases for the primary home of an average household in each sample (€/a).

Expenditure (€/household/a)	Urban			Rural		
	Detached	Row/terrac.	Apartment	Detached	Row/terrac.	Apartment
Direct energy purchases						
Home electricity	1058	512	202	1019	473	218
Heating oil, etc.	418	7	1	326	1	0
Firewood	150	11	0	306	3	0
District heat	106	197	132	37	153	119
Total	1733	726	335	1688	629	337
Indirect energy purchases						
Housing management charges	100	1199	952	2	803	660
Housing fees paid within rents	120	537	1000	76	620	953
Of which						
electricity	–	86	74	–	71	61
district heat	–	382	431	–	244	306
oil and other	–	50	27	–	110	72
Total	–	519	531	–	425	439
Overall energy purchases	1733	1245	866	1688	1055	776

Table 5
Direct and indirect energy purchases of an average household for free-time residences in each sample (€/a).

Purchase value (€/a)	Urban			Rural		
	Detached	Row-/terrac.	Apartment	Detached	Row-/terrac.	Apartment
Direct energy purchases	91	68	58	66	62	33
Indirect energy purchases	20	10	13	21	7	13
Overall energy purchases	111	78	71	87	69	46

houses and row-/terraced houses as well as in free-time residences in Finland. According to the data, firewood use constitutes 40% of the heating energy demand in detached houses in Finland and, on average, 4.6 m^3 of wood is burned per annum in detached houses. The weighted consumption is thus 3.0 m^3 in urban areas and 6.2 m^3 in rural areas. The respective quantity is 1.8 m^3 in free-time residences, while in row-/terraced houses it is only 0.3 m^3 per household. Energy consumption in free-time residences was weighted according to the data in Table 1, which is based on the number of people who possess free-time residences.

We used two data sources when converting the monetary and quantity data into energy units. The consumer price data for energy purchases was retrieved from Statistics Finland for electricity, district heat and oil [44]. For oil, a single spot-market price was used for all the samples, but different prices were used for electricity and district heat for the different customer types. Regarding the district heat prices, the apartment buildings are assumed to be smaller on average in the rural sample and thus the price is slightly higher. The heat content of firewood (mixed type) was taken from Alakangas [45]. In addition, an average efficiency of 50% was assumed for domestic fireplaces. Table 6 presents the conversion factors.

3. Results

3.1. Primary homes

3.1.1. Consumption per household

The results comply with earlier studies that have reported lower emissions from apartment buildings in comparison to detached houses when the functional unit is an average household and only primary homes are taken into account. The overall average energy use per household increases from approximately 12,600 kWh/a in apartment buildings in rural areas and 15,500 kWh/a in urban areas for the same building type to 22,500 kWh/a and 23,300 kWh/a, respectively, in detached houses in the same areas. The difference is thus significant. Row-/terraced houses fall in between these two ranges, but they are closer to apartment buildings in terms of their overall energy usage. Interestingly, the energy use seems to be lower in rural areas for each of the three housing types, as shown in Fig. 1A.

3.1.2. Consumption per resident

Fig. 1B shows the results on a per capita basis. Quite often, the differences in household size are not taken into account, but as Table 2 already implied, apartment buildings are mainly occupied by adult households while families with children tend to live in the low-rise areas. When the differences in household sizes are accounted for, the overall differences in energy consumption are only a fraction of those listed above and no clear patterns exist across the two area types. Interestingly, in urban areas the energy consumption per capita increases from detached houses to row-/terraced houses and further to apartment buildings, while in rural areas apartment buildings remain as the most energy efficient type of housing.

On the one hand, it is desirable to reduce energy consumption and achieve higher levels of energy efficiency in order to cut down on the environmental burdens related to energy use. Thus, it is also important to compare the various types of technology related to energy production and the average energy mixes since their impact can be just as high. Among our samples, the energy mix actually varies significantly both within the two area types and to some extent also when the same housing types are compared across the area types, as depicted in Fig. 1A and B. Electricity use was predominant in both detached house samples in which it serves as the dominant primary heating mode (see Table 2). Firewood and heating oil accounts for the next largest shares of energy consumption. In apartment buildings and row-/terraced houses, district heating accounts for the largest share of energy consumption. In terms of electricity use, far more electricity is used in row-/terraced houses than in apartment buildings.

In many studies concerning building energy, the unit of analysis is energy consumption per m^2. This kind of comparison gives an additional perspective for our study. In theory, apartment buildings with a lower external wall area/living space ratio should

Table 6
The conversion factors utilized in converting the monetary and quantity data into energy units.

Purchased energy	Urban			Rural		
Average price (cent/kWh)	Detached	Row-/terrac.	Apartment	Detached	Row-/terrac.	Apartment
Electricity	8.9	10.2	12.0	9.4	10.2	12.0
Heating oil	6.41	6.41	6.41	6.41	6.41	6.41
District heat	5.05	4.72	4.41	5.05	4.72	4.65
Firewood (m^3/a)						
Primary home	3.0	0.3	–	6.2	0.3	–
Free-time residences	0.28	0.21	0.17	0.23	0.16	0.10
Firewood energy content	1875 kWh/m^3					

appear as the most energy efficient. Here, the results do not fully support the theory-based hypothesis. Apartment buildings in urban areas seem to have the highest per m^2 energy consumption: 266 kWh/m^2/a. In rural areas, row-/terraced houses have the highest levels of energy consumption when using this metric: they average 251 kWh/m^2/a. When taking into account both area types, clearly the most energy efficient homes seem to be detached houses; they use 182 kWh/m^2/a in urban areas and 180 kWh/m^2/a in rural areas.

One additional observation from the energy production side is that if only purchased energy is taken into account (with own or benefit-in-kind firewood omitted), the differences at the household level are significantly reduced, while detached houses are by far the most energy efficient on a per capita basis. There is no consensus regarding how to measure the greenhouse gas emissions from residential firewood combustion, and while there are other harmful emissions from firewood combustion, like particulate matter, this perspective on energy consumption in the different housing modes is interesting, although still an open question.

3.2. Free-time residences

Owning a summer home or so-called free-time residence is common in Finland as Table 2 shows. Since they offer complementary living spaces to a person's primary home, the energy requirements for maintaining and operating them should be taken into account when attempting to understand housing energy consumption rates with respect to different types of living. According to our data, owning and using free-time residences pertains quite strongly to more affluent families with children; thus those families living in low-rise types of housing in both types of areas. In addition, more free-time residences are owned by the city. Regarding the free-time residences, the average per household energy use increases from 870 kWh/a in apartment buildings in rural areas and 1120 kWh/a in apartment buildings in urban areas to 1560 kWh/a and 1770 kWh/a, respectively, in detached houses in rural and urban areas. Row-/terraced houses again fall in between these two ranges. The relative share energy use that free-time residences add to the overall amount of energy consumption by both urban and rural households was quite close in all the samples, varying from 6 to 7%.

When looked at on a per capita basis, the situation becomes more complex. In urban areas, it is actually those people living in apartment buildings who use the most energy with respect to their free-time residences, while in rural areas those living in row-/terraced houses do so, although the differences are significantly reduced at the household level. Still, the functional unit is again a highly important factor. Table 7 shows the related energy usages of free-time residences when using the two functional units.

3.3. Overall energy consumption, renewable and non-renewable fuels

Overall, when combining primary residences and free-time residences, urban households consume more energy than rural households for each of the three housing types. In addition, the overall energy consumption in both urban and rural areas increases for people living in row-/terraced houses and detached buildings in comparison to apartment buildings.

On a per capita basis, however, the differences are significantly smaller, and in detached and row-/terraced houses the urban residents actually consume slightly less energy. In apartment buildings, the amount of energy consumed by urban residents still exceeds that consumed by rural residents. Interestingly, the highest consumption rate was found for those living in apartment buildings in urban areas, but all of the samples fall within a margin of 1500 kWh/a, as shown in Table 8.

Since, in addition to overall energy consumption, the energy mixes vary significantly between the samples, as shown in Section 3.1, it is interesting to estimate the shares of energy produced by renewable and non-renewable fuels. To provide a rough estimation, we assumed that all Finnish households consume the national

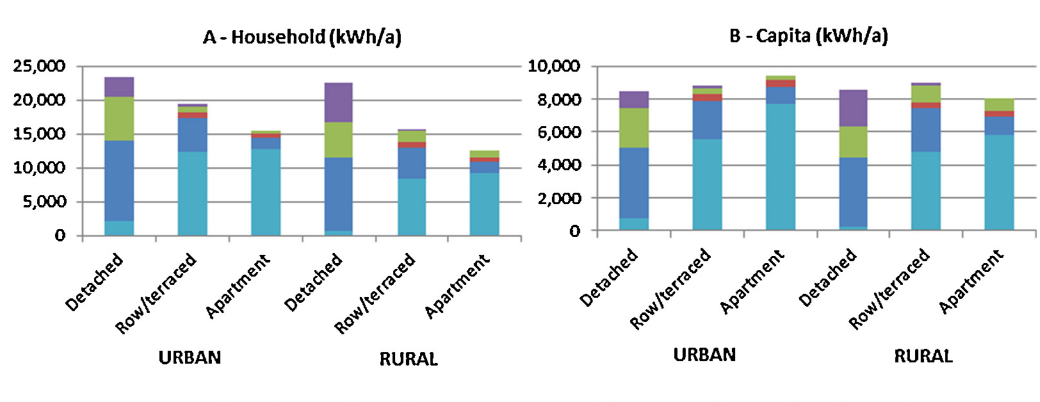

Fig. 1. The average per household and per resident energy use in the two area types and the three housing types in Finland.

Table 7
Energy consumption related to free-time residences.

Free-time residence energy (kWh/a)	Urban			Rural		
	Detached	Row-/terrac.	Apartment	Detached	Row-/terrac.	Apartment
Per household	1770	1270	1120	1560	1220	870
Share (%) per household	7	6	7	6	7	6
Per capita	640	580	680	600	690	560

Table 8
The overall energy consumption (primary homes and free-time residences) among the residents of urban and rural areas in Finland on a per household and a per capita bases.

Overall housing energy (kWh/a)	Per household		Per capita	
	Urban	Rural	Urban	Rural
Detached houses	25,090	24,030	9130	9180
Row-/terraced houses	20,560	16,970	9400	9650
Apartment buildings	16,600	13,450	10,090	8570

average electricity and district heat (whenever district heat is consumed). We used the most recent available data instead of the base year of our study, 2006, to avoid errors from potential changes in the fuel mixes since 2006. In 2011, the national average fuel mix of electricity production consisted of 34% renewables, 34% fossil fuels (coal, natural gas, oil) and peat, and 32% nuclear power [46]. The dominant mode of district heat production in Finland is combined heat and power (CHP). In an average district heat production fuel mix in Finland, approximately 75% of the mix is non-renewable (coal, natural gas, oil and peat) and 25% is renewables [46].

In Fig. 2, the overall energy use in the different samples is depicted in terms of renewable, non-renewable, and nuclear shares, including the residence-specific combustion of firewood. According to this rough estimation, the share of non-renewables is the highest for the residents of apartment buildings due to the high share of predominantly non-renewable-based district heat as the primary heating mode. The share of non-renewables is the lowest in detached houses, where close to 50% of energy is generated using renewable fuels.

4. Discussion

The purpose of this study was to analyze the energy consumption patterns and the overall housing energy requirements of urban and rural households in Finland. We also studied three different housing types in both urban and rural areas, namely apartment buildings, row-/terraced houses, and detached houses, and we included communal energy as well as the energy consumption related to free-time residences.

While residential energy consumption rates have already been studied extensively, we see room for new contributions to exist, especially for studies taking into account the behavioral aspects of energy consumption. Our study contributes to this discussion and adds some interesting angles with respect to the situation in Finland. Our key findings include five perspectives:

(1) Our analysis suggests that including indirect energy purchases into the analysis is very important. For apartment buildings in Finland, these purchases represent a share of more than 50% of the average household's annual energy purchases and more than 70% of their energy use.
(2) The functional unit of analysis is extremely important. We demonstrated that while on a household level the detached housing mode appears to be by far the most energy intensive, the differences are greatly reduced when the differences in household sizes are taken into account. Interestingly, in both types of areas the detached housing mode of living also appears to be the most efficient in terms of the amount of energy consumed per square meter, which implies that behavioral differences do exist. In addition, if firewood is not taken into account, the differences substantially decrease at the household level, while on a per capita and per square meter basis the energy consumption rate is lowest in detached houses in both urban and rural areas.
(3) According to our results, each of the housing types is less energy-intensive in rural areas in comparison to the respective mode in urban areas. This is an interesting perspective to add to the ongoing discussion on the sustainability of urban versus rural living.
(4) Since free-time residences offer complementary living spaces in addition to primary homes, they should be included in the assessments as well. With respect to our study, free-time residences contributed the most to the amount of energy used of households living in detached houses; however, on per capita basis the differences disappear due to much smaller household sizes in apartment building.
(5) The energy mixes vary significantly between the samples, with some interesting implications. CHP production is a highly desirable alternative to fossil-fuel-based electricity production, but in our rough estimation, those living in apartment buildings consume far fewer renewable fuels as a total share of their energy consumption in both area types. How to judge the implications of this is a complicated issue, but it is clear that the allocation method adopted for balancing the environmental burdens between electricity and heat in CHP production play an important role. Furthermore, while CHP production is not tied to fossil fuels, in Finland at the moment these fuels form a vast majority of the fuel mix and thus greatly reduce the potential advantages of CHP production.

Based on the results of the study, occupancy rates actually seem to be one focal issue. In comparison to studies that have reported significant increases in energy consumption in lower density areas, in our study differences in occupancy rates explain a large share of the differences. Fuller and Crawford [14] and Stephan et al. [15] in particular report that rapidly increasing living space is a key factor in the increasing energy requirements of those living in less dense areas. VandeWeghe and Kennedy [9], despite a lack of supporting data, argue that living space is a key explanation for differences in energy consumption rates. Likewise in Finland, the smallest living spaces are found in the densest areas; however, on a per capita basis the differences remain moderate (see Table 2). Furthermore, when the common spaces in apartment buildings are allocated to residents, the differences become negligible. Heinonen et al. [47] has also shown from a greenhouse gas perspective that economies of scale effect have a strong effect on energy consumption rates, especially regarding housing-related emissions, and that the theoretical differences in building types may thus easily be overshadowed by differences in the average household sizes.

With respect to the impact of the behavioral differences between the studied samples, an explicit assessment is not possible, but a clear indication of such differences can be seen. First,

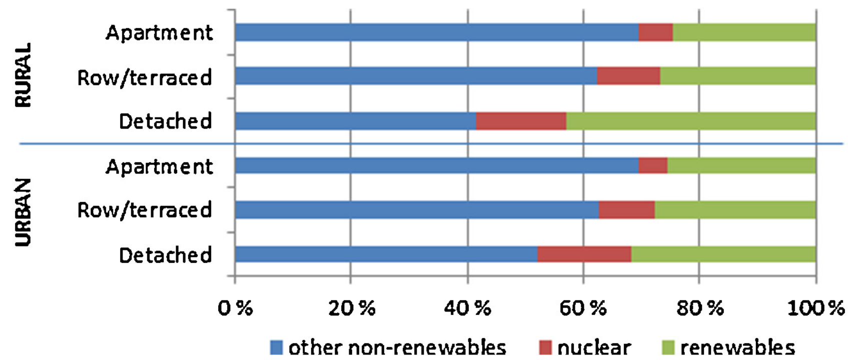

Fig. 2. The distribution of the overall energy use in nuclear power, other non-renewables and renewables based on the production fuels.

the highest energy efficiency per square meter found in detached houses strongly suggests that significant differences exist. In theory, apartment buildings with a lower ratio of external wall and roof area per square meter of living space should be the most energy efficient in comparison to both row-houses and detached houses. For example, the class limits for the same energy efficiency class in the Finnish energy certification system for residential buildings are significantly stricter for apartment buildings than for other types of housing [49]. Second, when making an urban–rural comparison, rural households consume less energy in each type of housing than urban residents. Urban households also spend more on energy purchases with respect to each type of housing, which cannot be explained by prices or living spaces. These findings suggest that behavioral differences exist as well between urban and rural households and not only between residents living in different types of buildings. Finally, the significant amount of firewood used in detached houses can also be interpreted as a clear behavioral difference, especially since fireplaces are predominantly only secondary heating systems.

Our findings on the behavioral differences leave a lot of room for further research with additional data sources, however. For example, in the future it would be an interesting issue for another study to find out if similar indoor temperature differences exist as those reported by Linden et al. [21] when studying the situation in Sweden. In addition, the heating modes should be studied in more detail. Currently, the category listed as “Other” accounts for 16% of all heating in detached houses in rural areas, as shown in Table 2. While the data do not reveal what these other sources are, we can assume that the majority of them are air-source and ground-source heat pumps, which actually show up as reduced heat purchases. Our data also show that disposable income seems to follow the energy consumption patterns quite closely (see Table 2). Previously, Guerra Santin et al. [11], among others, found that income is an important factor in residential energy consumption. Several studies have also shown that income level correlates with one’s overall energy requirements (recently, e.g., Wiedenhofer et al. [7]). It is obvious that income affects housing choices, but since there are no significant differences in the living spaces in the respective types of housing between the area types, it is not evident that income level would significantly explain the differences in energy consumption rates between the same types of housing in urban and rural areas.

Finally, in high-rise apartment buildings there are factors related to operating energy requirements that may quickly reduce any efficiency advantages. In an earlier study, Heinonen and Junnila (2011) [43] found that the operation and maintenance energy requirements narrow the gap between apartment buildings and detached houses. Likewise, Myors et al. [48] have provided an example of how the efficiency advantage of apartment buildings disappears along with increasing height due to increasing operational energy requirements and decreasing household sizes. Thus, it is not that surprising in the end that our assessment results in relatively small differences in energy requirements when the functional unit is per capita.

As always, uncertainties exist in the presented analysis. These can be divided into three categories: Uncertainties related to the utilized data, uncertainties arising from the employed assessment methods and adopted assumptions, and uncertainties related to the interpretation of the results. First, there are risks involved when combining three different data sets for the analysis. In particular, our estimates of the communal building energy use based on the housing management fees might potentially lead us to either underestimate or overestimate the expenses from one sample to another. The statistical data [41] has been tested against actual housing company financial statements [35,38], but since it only differentiates apartment buildings from row-/terraced houses without offering a specific geographical location perspective, the potential effects of price-level differences cannot be captured. However, the statistical data do separate the Helsinki Metropolitan Area, the most expensive area in Finland, from other areas, and given the fact that the difference between the Helsinki Metropolitan Area and the rest of the country is not significant, this potential source of bias should not compromise the results. Another issue has to do with the reported costs and their level of accuracy in the HBS data. Since the sample sizes reported in Table 2 seem plausible and the categories taken from the HBS data should belong to the most reliable category since the respondents should truly know these costs, we assume that the risk related to this uncertainty is relatively minor as well. Second, we made some important assumptions related to the method of extracting the housing management fees from the reported rental payments. Again, it is possible that the assumptions led to errors in the extracted costs, but the direction or magnitude of these cannot be estimated properly with the available data. Third, since we had no better option than to use the Finnish average energy production data for all of the samples, the analysis on the division between renewable and non-renewable fuels is very rough at best. Actually, the differences between the production fuels amid certain power plants might mean that a certain sample does not follow the detected patterns. Additionally, in some cases heat and electricity should not be directly compared. Including primary energy coefficients could be a solution for increasing the strength of this type of analysis in the future. However, the fact that more than 70% of district heat in Finland is produced as CHP increases the complexity of such an analysis significantly. Finally, the adoption of a per capita metric as the primary functional unit has its strengths but also its deficiencies. The per capita metric does not enable theoretical analyses based on buildings' characteristics. Furthermore, per capita comparisons are more complex in nature, since factors like daily occupancy can significantly impact the results. A combination of different metrics is thus often needed. To reduce this uncertainty, we have presented and discussed the key results using different metrics. However, such additional metrics as a cubic meter would be informative, but could not be used due to data restrictions.

5. Conclusions

The most important conclusion from the study is that the theoretical characteristics of a building form an unreliable basis for estimating the actual energy consumption. Three factors, the significantly different occupation rates, the varying incentives for energy efficient behavior, and the inclusion of communal building energy, can easily exceed the energy efficiency differences arising from the various building types. In addition, we suggest that a per capita metric be used as the functional unit in energy use analyses in addition to the household or traditional per m^2 metric. In the study, we showed the important role played by the unit-of-analysis in determining energy use rates. The results can be totally different from those obtained when using per household, per capita, or per square meter perspectives. Finally, the energy mixes may vary even more than the energy consumption rates. Thus, if the underlying target is to find ways to reduce the environmental burdens resulting from energy production, attention should be paid to the fuels being used as well.

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