Identifying Socioeconomic and Cultural Patterns in the Heat Consumption of Copenhagen Households

Ida Maria Reiter, Research assistant, cand.tech.
Henning Sten Hansen, Professor, dr. scient.
Institute for Planning at AAU-CPH

Abstract

This paper explores spatial correlations between the heat consumption and the socioeconomic and cultural characteristics of households in the City of Copenhagen. The purpose is to analyse how the social, cultural, and economic structures affect heat consumption differences in the city and to find out which household types need political targeting in order to reach the goal of a 20 % decrease in the Copenhagen heat consumption in 2025 compared to 2010. Using a combination of choropleth maps, Pearson's R, and regression analyses, the total effects as well as direct effects of socioeconomic and cultural variables on heat consumption per capita are analysed in order to better understand heat consumption patterns. A life-cycle pattern is found to describe heat consumption per capita, but it is challenged by the existence of an income divide between a new generation of wealthy families with small children living in newer, semi-detached houses with better energy labels and non-western ethnic people tending to have low income. The income divide affects the economic motivations and options for decreasing heat consumption per capita.

Keywords: Household heat consumption, Copenhagen, socioeconomic factors, cultural factors, Pearson's R, regression analysis

1. Introduction

Countries and cities around the world aim at reducing CO_2 emissions to the atmosphere in order to reduce global warming, to become less dependent on scarce and competitive energy resources (Sovacool & Blyth, 2015), as well as to become green and sustainable in order to attract companies and citizens (Aboulkheir, 2011). Denmark has within the last decade introduced an ambitious goal of reaching CO_2 neutrality in year 2050 by having Denmark's entire energy supply, including electricity, heating, industry, and transportation, covered by renewable energy (Sovacool & Blyth, 2015). The City of Copenhagen has set its ambition even higher than the national ambition, since it aims at achieving CO_2 neutrality already in year 2025 (the City of Copenhagen, 2012). However, the City of Copenhagen defines CO_2 neutrality in another way than the national strategy in that it will by year 2025 produce and distribute to surrounding areas more renewable energy than it consumes, to make up for the fact that its transport sector will still depend on fossil fuels (the City of Copenhagen, 2012).

To reach the goal of CO2 neutrality, the City of Copenhagen not only focuses on moving towards a CO2 free energy production, but it also focuses on decreasing energy consumption. One of the strategies to meet the 2025 goal is to decrease heat consumption with 20 % by year 2025 compared to year 2010 (the City of Copenhagen, 2012). Since the household sector causes more than half of the heat consumption of the City of Copenhagen (The City of Copenhagen, 2015), it is particularly relevant to reduce the heat consumption of the household sector.

To be able to turn the heat consumption practices of households in a more energy-reducing direction, it is important to explore correlations between socioeconomic and cultural factors and heat consumption (Gram-Hanssen, 2014). Within the last decade, an increasing number of studies around the world have made use of regression-based models based on specific geographic regions for the purpose of finding correlations between socioeconomic and cultural factors and heat consumption (e.g. Hansen, 2016; Estiri, 2016; Hsu, 2015; Gram-Hanssen, 2014; Lenzen et al, 2006). By exploring such correlations, a new focus has recently been given attention by Hansen (2016) and Estiri (2016); the tendency for socioeconomic and cultural factors to have indirect effects on heat consumption through dwelling choices and to have direct effect on heat consumption through practices, the sum of which is called total effects.

Therefore, the purpose of this paper to investigate direct as well as indirect effects of socioeconomic and cultural variables on heat consumption within the City of Copenhagen, to reflect upon the knowledge that this indirect and direct effect perspective can provide for understanding heat consumption differences in a specific geographic region. First, socioeconomic and cultural variables that theoretically affect heat consumption, either directly or indirectly, will be deduced to create a model of explanatory factors. Second, data will be introduced in order to represent the variables that are most important according to theory. Third, a combined strategy of using regression, Pearson's R, and choropleth maps to find the specific direct and indirect effects will be introduced. Fourth, relevant patterns of correlations based on the found direct and indirect effects will be analysed and discussed.

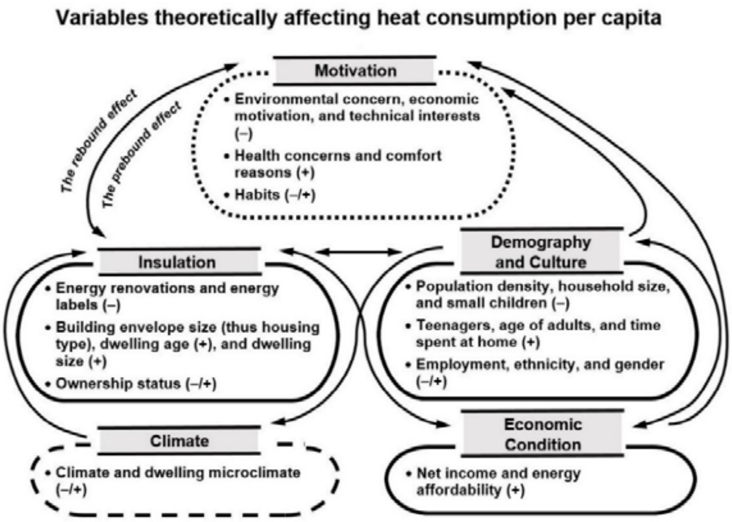
2. Theory

While finding correlations between household characteristics and heat consumption is an effort gaining increasing attention (Gram-Hanssen, 2014), many articles focus more broadly on energy consumption, which combines heat consumption with electricity consumption (e.g. Estiri, 2016; Hsu, 2015; Bhattacharjee et al, 2014, Lenzen et al, 2006). It is common for energy consumption studies, including heat consumption studies, to use multiple linear regression to build models with multiple variables based on socioeconomic and cultural data to explain energy consumption (e.g. Hansen, 2016; Gram-Hanssen, 2014; Lenzen et al, 2006; Petersen & Gram-Hanssen, 2005). So far, only a few studies that use multiple linear regression to find correlations between socioeconomic variables and energy consumption take place in Denmark, and no study focuses on Copenhagen alone. A regression study by Lenzen et al (2006) and another by Hansen (2016) focus on describing energy consumption within Danish households. A third regression study by Petersen and Gram-Hanssen (2005) narrows its focus to detached houses in Aalborg. The Danish studies as well as studies from other countries are in the following section used to deduce variables that theoretically explain heat consumption.

2.1. Five variable themes explaining heat consumption

By combining the findings from the reviewed energy consumption articles, the model in figure 1 is developed containing variables that theoretically influence heat consumption per capita. The climate variables are not socioeconomic in nature. They affect the second theme; insulation related variables, which are indirectly socioeconomic, since they reflect household choices in that households have chosen which building to live in and chosen the degree to which the insulation abilities of the building are maintained (Hansen, 2016). The last three themes are directly socioeconomic or cultural in nature; economic variables, demographic and cultural variables, as well as heat saving motivations.

Figure 1: The figure shows variables explaining heat consumption per capita according to literature, divided into five themes. Climate is not socioeconomic or cultural in nature (hence its dashed circle). Motivation is difficult to measure (hence its dotted circle). The arrows represent which themes influence each other.



Climate-related variables

The climate-related variables can be divided into *climate* and *dwelling microclimate*, where the latter is the temperature conditions locally around buildings, described by factors such as solar access, natural ventilation, street and building form, and vegetation density (Bhattacharjee et al, 2014). In the cooler Danish climate, insulation of buildings is very important in order to decrease the need for heating.

Insulation-related variables

Energy renovations is a means to improve the *energy label* (Bhattacharjee et al, 2014), the latter of which reflects the expected energy standard of a building due to the Danish Energy Labelling scheme (Hansen et al, 2013). *Dwelling type* matters for heat consumption, since the insulation degree is typically lower for detached houses than for apartments (Lenzen et al, 2006). *Dwelling* size is also important for the insulation level and the need for heating, often measured as residential floor area (Bhattacharjee et al, 2014). Fourthly, the energy standard of buildings has increased in time due to modified Building Regulations, causing the *construction age* trend that older buildings have a lower energy standard than newer buildings (Estiri, 2016; Petersen & Gram-Hanssen, 2005). The *ownership status* of the building can also affect the heat consumption by influencing the economic motivation to renovate (Petersen & Gram-Hanssen, 2005). Furthermore, a rebound effect has often been shown to exist, stating that people living in more insulated dwellings tend to care less about saving heat (Gram-Hanssen, 2014). The opposite effect, the *prebound effect*, has also been stated as an important factor for studies to look into; the tendency that people living in old, poorly insulated houses seem to actively care for saving heat (Gram-Hanssen, 2014).

The economic condition of households

Variables representing the economic condition of households have proved to be very important for describing heat consumption per capita (Bhattacharjee et al, 2014; Petersen & Gram-Hanssen, 2005). Bhattacharjee et al. (2014) describes the economic condition of households to be the interconnection of income and monetary expenditure. The economic condition of a household affects the economic motivation to save energy and to energy renovate (Bhattacharjee et al, 2014). *Energy affordability* is a variable that describes energy prices in relation to income level, but it does not take other expenses into account (Bhattacharjee et al, 2014). A more common variable to use as a simpler estimate for the economic condition is net income (e.g. Estiri, 2016; Hansen, 2016; Petersen & Gram-Hanssen, 2005).

Demography and culture

A focus on heat consumption per capita allows one to investigate how the heat consumption of individuals changes with the household constellation (Lenzen et al, 2006). A larger *household size* and a denser *population density* can be expected to decrease heat consumption per capita, since more people in a room adds to the natural heating of the room (Petersen & Gram-Hanssen, 2005). However, the household constellation can overshadow the *household size* effect. The *number of children* in a study in Aalborg proved to decrease heat consumption per capita, while *teenagers* in apartments were the exception in the study; they had a larger heat consumption than adults and thus increased heat consumption per capita (Petersen & Gram-Hanssen, 2005). Due to comfort reasons, the age of the adults in the household also affects heat consumption (Bhattacharjee et al, 2014; Lenzen et al, 2006; Petersen & Gram-Hanssen, 2005). Elders need higher indoor-temperatures, spend more time at home, and renovate less, for which reason they consume more heat (Bhattacharjee et al, 2014).

Demographic and cultural variables that studies have found difficult to measure are *time spent at home*, *employment*, *gender*, and *ethnicity* (Estiri, 2016; Bhattacharjee et al, 2014; Lenzen et al, 2006). Ethnicity was found to be statistically nonsignificant in a Danish heat consumption study by Petersen & Gram-Hanssen (2005). However, in another Danish study by Hansen (2016), households with at least one member haven migrated to Denmark statistically significantly decreased heat consumption with a factor of -0.005 ($p < 0.01$) (Hansen, 2016).

Motivations affecting heating patterns

The last theme, motivations to save energy for heating, consists of complex variables that are difficult to measure in quantitative studies based on regression (Gram-Hanssen, 2010). *Environmental* concerns can theoretically cause households to act in a more energy saving manner (Bhattacharjee et al, 2014; Gram-Hanssen, 2010). One indicator for environmental concern is the degree to which households vote for 'green' political parties. A comprehensive survey by Stubager et al (2016) have gathered the view from voters in regards to how 'green' the political parties were considered to be at the Danish general election in 2015. The more than thousand voters in the survey have provided a green score to each individual Danish political party on a scale from 1 to 5, where 1 is the greenest. The survey result shows a clear divide of the parties into three groups of different average 'greenness' scores; *green parties (Å, Ø, F), medium green parties (B, A), and low green parties (C, O, V, I)* (Stubager et al, 2016).

A driver for saving energy that certainly has proved strong is economic motivation. Buyers have proved willing to pay more for houses with better energy labels and thus a better energy standard in a study by Hansen & Kragh (2013), creating the fundament for an *economic motivation* to energy renovate. Besides an economic motivation, *habits*, *health concerns*, *comfort needs*, as well as a *technical interest and knowledge* in regards to managing the heating system affect individual heating behaviour (Gram-Hanssen, 2010).

Variables from all the four direct and indirect socioeconomic themes, excluding the climate-related theme, will be represented in this paper in order to find direct as well as indirect effects of the variables on heat consumption. *Energy labels, dwelling type, residential area per capita* as *dwelling size*, and *construction age* will represent the insulation-theme. *Net income* will represent the economic condition of households. The demographics and cultural theme will be represented by the *household size*, the presence of age intervals in different subdistricts, and the percentage of *non-western ethnic people*. Lastly, the variable *environmental concern*, will be represented by the voting patterns during the Danish general election of 2015.

3. Data

In order to find data to represent the four direct and indirect socioeconomic themes, the Technical and Environmental Administration from the City of Copenhagen provides the insulation-related variables based on data from the Danish Building and Housing Register (BBR) and energy labels, while the Finance Administration from the City of Copenhagen provides direct socioeconomic and cultural data from Statistics Denmark. Since the study area is limited to the City of Copenhagen that only has one district heating provider, HOFOR (The Greater Copenhagen Utility), it has been considered acceptable to represent the economic condition of households with the variable net income. *Net income*, which is income after tax, is included as a family-weighted income variable calculated by Statistics Denmark in five intervals *(<100,000 DKK; 100,000-200,000 DKK; 200,000-300,000 DKK; 300,000-400,000 DKK; >=400,000 DKK). Environmental motivations* are included by examining the spatial distribution of the percentages of votes at the Danish general election in 2015 for the three different 'greenness' groups of political parties in Stubager et al (2016) with data from Statistics Denmark.

The heat consumption is calculated as the heat consumption per capita at subdistrict level. The calculation is based on the dwelling sizes registered in BBR for each building multiplied standard values provided by HOFOR. The standard values describe the average actual heat consumption for one square meter floor area and they are based on heating degree-days corrected actual heat consumption for the City of Copenhagen in the period May 2014 to April 2015. The standard values do not change between subdistricts, but they change with dwelling type and construction age. Standard values have been provided for both apartments and detached houses, separated out on different construction age intervals. Assumptions are made for the standard values of other residential dwelling types registered in BBR. University halls were assumed to have the same standard values as apartments, whereas semi-detached houses and residential homes for children and elders were assumed to be in between detached houses and apartments in values. The standard values have not been provided here for copyright reasons, but their matrix structure is provided in table 1.

Table 1: Structure of the standard values (actual average of kWh/m2) provided by HOFOR

		Intervals of construction years by HOFOR				
		Before 1960	**1860-1972**	**1973-1979**	**1980-2000**	**After 2000**
Dwelling types in BBR	**Apartments**	Provided	Provided	Provided	Provided	Provided
	Detached houses	Provided	Provided	Provided	Provided	Provided
	University halls	Estimated	Estimated	Estimated	Estimated	Estimated
	Terraced or semi-detached houses	Estimated	Estimated	Estimated	Estimated	Estimated
	Residential homes for elderly people and orphanages	Estimated	Estimated	Estimated	Estimated	Estimated

3.1. The resolution and quality of the data

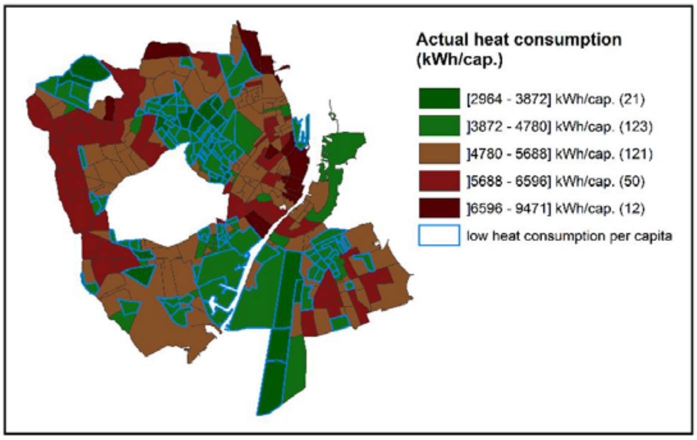
As already stated, BBR-data is used to calculate heat consumption at subdistrict level from the standard values and used to provide the insulation-related variables. Since all building owners are required by law to ensure correct registrations of their residence properties in the BBR-register, a relatively high degree of correctness of the data can be expected. To avoid exposing sensitive individual information, all data are aggregated to subdistrict level (in Danish called *rode*). The aggregation removes some of the noise and patterns in the data, which decreases the quality of the data (Estiri, 2016). The subdistricts do neither have similar area sizes nor similar population sizes, but were created in 1871 for tax collection. A third of the subdistricts are aggregated further to ensure at least 800 people per subdistrict. Furthermore, the varying sizes of the polygons obstruct a solely visual interpretation of the data, since the polygons with a larger area catch the eye of a map viewer more easily than smaller areas, despite the fact that the smaller areas occasionally contain more people in total and per square meter than the larger areas. Since the heat consumption is not first and foremost spatially aggregated, but averaged after dwelling type and construction age interval, the spatial patterns that might have existed in the data due to local household heating behaviour have been blurred. The heat consumption data cannot reflect whether some households in a specific geographic region decide to only heat up parts of their dwelling. If they have decided to do so, their smaller heat consumption will only influence the size of the relevant standard value. Therefore, the focus is more on heat consumption differences arrived from different housing choices than from individual household behaviour.

4. Methods

The ordinary least square model with the highest adjusted R2 will be found with the insulation-related variables that directly influenced the categorization of the heat consumption standard values; *construction age interval, dwelling type, residential area per capita,* and *energy labels*. To examine direct effects of the other socioeconomic and cultural variables, the iterative process of stepwise regression will be used to see whether these other variables can improve such a model (Lenzen et al, 2006). The order of the other variables to be tested is here chosen to be a Pearson's R ranking, starting with the variable with the highest Pearson's R-relation with heat consumption per capita.

For a visual exploration of direct and indirect effects on heat consumption, the socioeconomic and cultural variables will be presented on choropleth maps created in ArcMap with coloured borders representing the polygons with low heat consumption. Low heat consumption is defined as standardised heat consumption per capita values of less than -0.5 standard deviations. To give an overview of the data to be explained, the heat consumption per capita for each district is mapped in figure 2. The classification theme to divide the socioeconomic and cultural variables into classes is a manually created scale for the data in percentages to make them comparable, and a hybrid equal interval method, described by Brewer and Pickle (2002), is used for the non-percentages data. Counts of polygons for each class are provided in the legends to compensate for the fact that the visually larger areas draw more attention from the map reader.

Figure 2: The calculated heat consumption per capita for each subdistrict based on HOFOR's standard values



5. Results

5.1. Finding direct effects of socioeconomic and cultural variables

The regression analysis, presented with two models in table 2, confirms that insulation-related variables have important direct effects on heat consumption per capita, which is not so surprising, given that it can be deduced from the way the heat consumption standard values were divided into classes by HOFOR. However, the regression analysis also reveals that net income and certain *age intervals* have important direct effects on heat consumption per capita. Model 1 has the highest adjusted R2 with random residuals and statistically significant variables. It shows that older children (*age 6-17*) and family-weighted *very high net* income tend to increase heat consumption per capita and *age 0-5* tend to decrease it, even after correcting for the influence of the insulation-related variables. The standard error is relatively high for age 0-5, indicating that this variable is internally heterogeneous. Model 2, on the other hand, has relatively low standard errors of all its variables, while its adjusted R2 is almost as high as in model 1. *Age 0-5* is here replaced with the tendency for *age 65+* to increase heat consumption per capita.

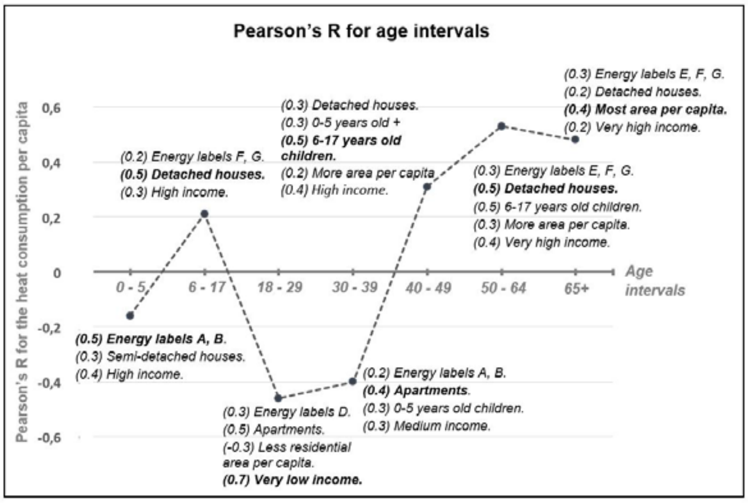
Table 2: OLS model 1 and OLS model 2 based on stepwise regression. They explain average actual heat consumption per capita at subdistrict level. Significance levels: *p < 0.05 and **p < 0.001. Residuals are random. The bold variables are variables that statistically significantly explain more than the basic model, which has an R2-adjusted of 0.927.

Model 1 R^2-adjusted = 0.937 (an increase of 0.010). Koenker Statistics** indicates non-stationarity.			**Model 2** R^2-adjusted = 0.936 (an increase of 0.009). Koenker Statistics** indicates non-stationarity.		
Variable	*Standardized coefficient*	*Standard error*	*Variable*	*Standardized coefficient*	*Standard error*
Residential area per capita	0.77**	3.30	Residential area per capita	0.76**	3.67
The percentage of detached houses	0.33**	0.59	Buildings constructed after year 2000	-0.34**	0.89
Buildings constructed after year 2000	-0.32**	1.04	The percentage of detached houses	0.33**	0.61
Buildings constructed in 1980-2000	-0.14**	1.80	Buildings constructed in 1980-2000	-0.15**	1.83
Children/teenagers of age 6-17	0.13**	4.44	**Children/teenagers of age 6-17**	0.10**	3.90
The percentage of semi-detached houses	0.09**	0.76	The percentage of semi-detached houses	0.08**	0.79
Family-weighted very high income	0.07*	2.78	**Family-weighted very high income**	0.07*	2.82
Children of age 0-5	-0.07*	8.42	**Age 65 years old and older**	0.05*	2.74

5.2. A life-cycle and a generation pattern

After having established that income and age add further to the explanation of heat consumption per capita than insulation-related variables alone, it is important to examine, whether income and age correlate with each other and other socioeconomic and cultural variables, which have indirect effects on heat consumption (Hansen, 2016). The total effects of age intervals prove to be very relevant for describing heat consumption differences. A life-cycle pattern seems to exist, as illustrated in figure 3. The figure shows that the age intervals *0-5, 18-29, and 30-39* years old tend to decrease heat consumption per capita (negative Pearson's R), while the age intervals *6-17, 40-49, 50-64,* and *65+* years old tend to increase it (positive Pearson's R). Thus, the heat consumption per capita increases with the age of the adults as well as increases with the age of the children in the household. The age intervals and their influence on the heat consumption per capita are also related to other socioeconomic and cultural factors. Older adults in families with older children tend to live in the fringes of the city in detached houses, the dwelling type that correlates most with the poorest energy labels; *E, F, and G*. The same families that tend to live in detached houses tend to have a higher *income* and have *more residential area per capita*, all while they tend to consume more energy for heating. The tendency for high heat consumption per capita is particularly clear for age *50-64* and age *65+*. The reason that *age 50-64* correlates more with heat consumption than age *65+*, could be related to the fact that people of *age 50-64* tend to live more in *detached houses* and have older children and teenagers (*age 6-17)*, as well as they tend to have very high net income *(>=400,000 DKK)* to a higher degree than age *65+*.

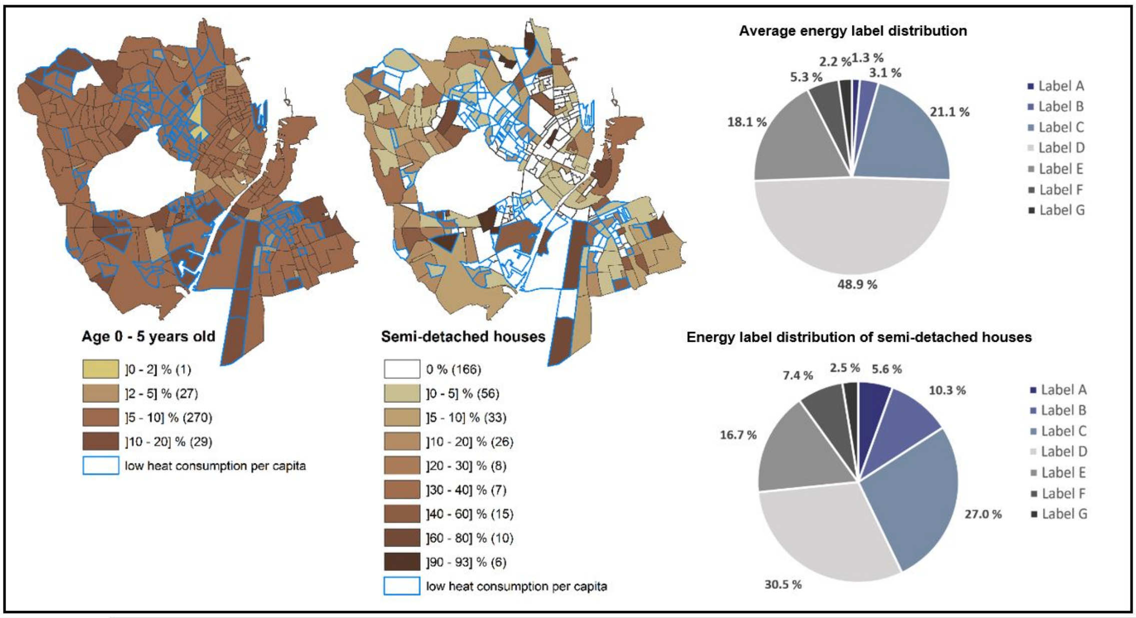
Figure 3: Pearson's R calculated for each age interval and its relation with the heat consumption per capita (the Y-axis), as well as Pearson's R calculated for its relation with other socioeconomic variables (each number in brackets).



When examining figure 3 once more, it is interesting that *age 0-5* is the only age interval that mostly tend to live in *semi-detached houses*. This dwelling type has the highest percentage of buildings with energy label A, B, and C, in fact higher than average as indicated in figure 4. Furthermore, semi-detached houses have the highest percentage of *buildings constructed after year 2000.* Combining this information, *age 0-5* could indicate a generation shift towards the tendency for families with small children to choose newer houses with a better energy label. It is not necessarily the case that they are more environmental aware. Another option is that these families have better housing options when choosing a family house than their older generations due to improved Building Regulations. A visual examination of how *age 0-5* correlates with l*ow heat consumption per capita* as well as with the distribution of *semi-detached houses* is shown in figure 4.

When comparing *age 0-5* with *age 30-39*, of which the latter tend to correlate with *age 0-5* to a certain degree, the dwelling type difference between the two classes span an *income* divide. People of *age 30-39* tend to live in *apartments* and earn *medium net income (200,000-300,000 DKK)*, while the families with children of *age 0-5* tend to live in semi-detached houses and earn a high net income *(300,000-400,000 DKK)*, as seen in figure 2. If a generation shift is on the way represented by the trends describing *age 0-5,* it is thus a generation shift that excludes many medium and lower income families from the advantages of better energy labels.

Figure 4: The distributions of age 0-5 and of semi-detached houses. The two circle-diagrams show that semi-detached houses have a higher percentage of the better energy labels; A, B, and C than the average energy label distribution for all dwelling types.

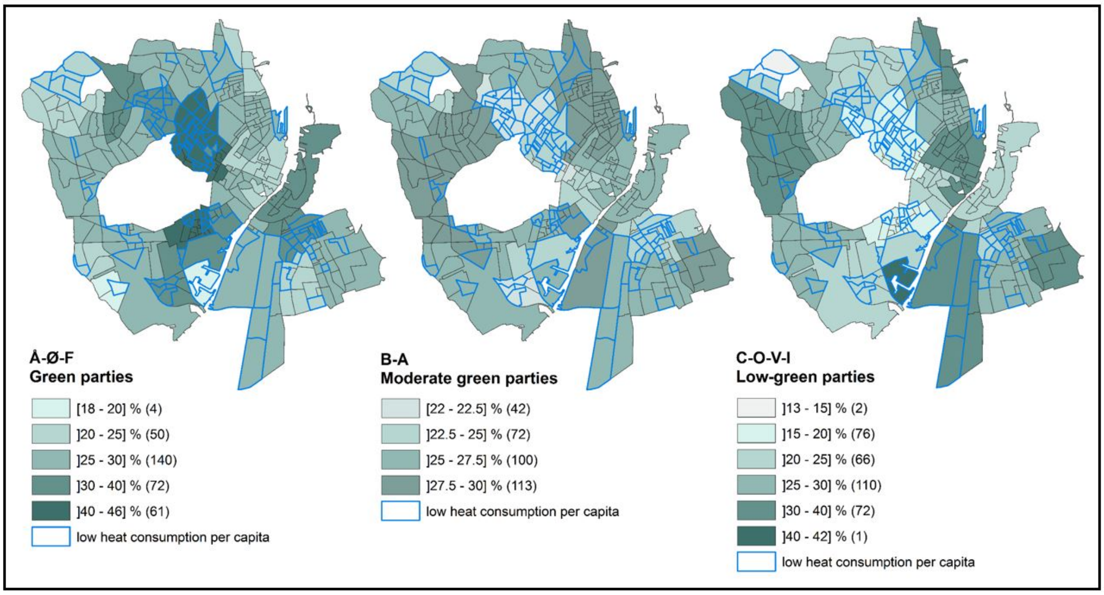


5.3. Distribution of green political votes and ethnic inheritance

The votes for the *green political parties* is another variable with a clear total effect on heat consumption in that the variable *green votes (Å, Ø, F)* decreases heat consumption with a Pearson's R of -0.36, while *moderate green votes (B, A)* and *low-green votes (C, O, V, I)* increase heat consumption per capita with Pearson's R of respectively 0.42 and 0.45. The vote-variables are mapped in figure 5. They have some resemblance with the life-cycle pattern in figure 3 in that the *green party votes* correlates positively with young and medium-aged adults (*age 18-29: 0.36; age 30-39: 0.41)*, with *apartments* (0.41), and with *very low net income* (0.38). On the other hand, the *low-green votes* correlates positively with older people (*age 40-49*: 0.20; *age 50-65*: 0.39; *age 65+*: 0.36), older children (*age 6-17*: 0.13), *detached houses* (0.29), *more residential area per capita* (0.41), *high net income* (0.45), and with *very high net income* (0.45), while the moderate green votes correlates positively with older people (age 40-49: 0.39; age 50-65: 0.27; age 65+: 0.23), older children (age 6-17: 0.25), detached houses (0.14), more residential area per capita (0.35), high net income (0.45), and with very high net income (0.40). The total effect of *green votes* seems thus to be that people voting for green parties tend to have a lower energy consumption per capita, a pattern following the age distribution.

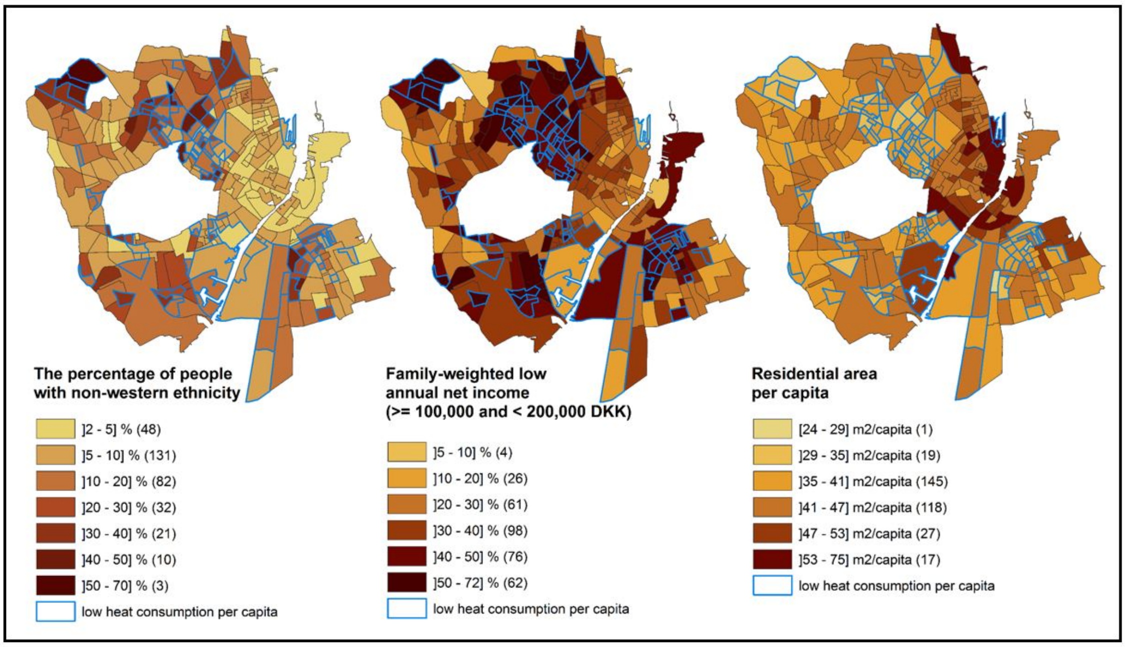
Despite the similarities between the pattern of green votes and the life-cycle pattern, the green vote pattern does not appear to bear a resemblance with the potential generation shift of *age 0-5*. *Age 0-5* neither correlates with *green votes* (0.02) nor *low-green votes* (-0.01), but only correlates to a small degree with *moderate green votes* (0.16).

Figure 5: The distributions of green votes. High percentages of low-green and medium green votes only occasionally overlap with low heat consumption per capita.



A cultural pattern not related to the life-cycle pattern occurs when examining the total effects on heat consumption of the percentage of people with a non-western ethnicity. The percentage of people with a non-western ethnicity correlates highly with a low heat consumption per capita (-0.48), which is visualized in figure 6, and correlates negatively with the *low-green* votes (-0.29) and the *moderate green votes* (-0.37). The figure furthermore illustrates that the percentage of non-western ethnicity correlates positively with family-weighted *low net income* (0.75) and correlates negatively with *residential area per capita* (-0.50). Thus, a tendency is illustrated for people with a non-western ethnicity to be relatively poor and have little space per capita, leading to a lower heat consumption per capita. People of *age 0-5* in *semi-detached houses* as well as people of *non-western ethnicity* thus both tend to decrease heat consumption, but assumingly due to different reasons.

Figure 6: The percentage of non-western ethnic people tend to decrease heat consumption per capita. It also correlates positively with family-weighted low net income and correlates negatively with residential area per capita.



6. Discussion

The fact that both direct and total effects on heat consumption per capita have been found from socioeconomic and cultural variables shows that socioeconomic and cultural variables matter in the explanation of heat consumption, and that household practices need to be understood better and taken into consideration in the process of decreasing heat consumption.

6.1. Including age-based heat consumption targeting

The fact that age was found to be important both as a direct effect on heat consumption per capita, but also indirectly through its total effect related to the life-cycle perspective, reveals the relevance for an age-based targeting in regards to political initiatives and campaigns related to household heat consumption. In particularly, families with older children *(age 6-17)* and *age 65+* seem to need targeting through political campaigns and economic strategies from the City of Copenhagen. Households with these characteristics seem at subdistrict level to have a direct tendency for higher heat consumption per capita. For *age 65+*, the higher heat consumption per capita might be comfort-related. Bolius has used data from Statistics

Denmark to show that *age 60+* has a remarkably higher heating bill, both in households with singles and households with couples (Mulvany, 2016). The age pattern also fits the renovation motivation tendency found by Mortensen et al. (2015) that elders are less interested in renovating their homes, whereas younger householders are more interested in renovations (Mortensen et al, 2015). For the elders, the long prospects in renovating houses might be the highest challenge to overcome from a planning perspective. For families with older children that live in detached houses with a higher heat consumption than expected, information campaigns of how to limit heat consumption with knowledge fostered directly from the everyday experiences of the families might be a needed strategy. It should be followed by strategies that try to release the potential for energy renovations of detached houses, where a high percentage of poor energy labels still exists.

6.2. An income divide and the danger of segregation

Net income is similarly to *age* important for understanding heat consumption differences, given its direct effect that increases heat consumption per capita. Despite the overall tendency for a life-cycle pattern, income differences do not solely follow adult age differences. An income divide that is not related to age is emphasized by the tendency for a generation shift and for ethnic differences in regards to heat consumption.

The fact that the smaller children *(age 0-5)* correlate with *high income* and tend to live in newer, *semi-detached houses* in Copenhagen indicates that a class of wealthy families with small children inhabits new buildings with better energy standards. When examining current moving patterns for Copenhagen, more families with children move out of Copenhagen than move into or internally in Copenhagen (The City of Copenhagen, 2014). However, the absolute number as well as the percentage of families with children that live in Copenhagen still increase, which is a tendency that started around 1995 (The City of Copenhagen, 2014). At the same time, the average income level in Copenhagen has increased since 2000 together with an increase in the income differences. Affordable living options are thus limited for the households with lower income (The City of Copenhagen, 2014). This indicates that among the families with children, the ones staying in Copenhagen are the wealthier families. *Age 0-5* seems to reflect the staying class with their tendency to live in newer semi-detached houses and have *high income*. In the couple of years following the financial crisis of 2008, many families with children stayed in the city, indicated by a short-lasting tendency for families with children to move internally in Copenhagen to a higher degree than moving out of Copenhagen (Andersen, 2016). The trend gave way to the idea of a new generation that highly prioritise the city as living location (Andersen, 2016). However, the trend has changed again with changes in the economic cycle (Andersen, 2016), and a study by the Danish Building Research Institute shows that many Danes still wish to live in detached houses with more residential space and a garden (Kristensen & Andersen, 2009). Despite the high attractiveness of detached houses in the fringes of the city and in the suburbs, the study also showed that the wish to live in the centre of the city increased from 9 % in 2001 to 19 % in 2008, reflecting the tendency in the period to construct new buildings on attractive urban areas near the harbour (Kristensen & Andersen, 2009). *Age 0-5* reflects how a new generation of wealthier families with children has embraced the new attractive building offers and that these new buildings enable a decrease in heat consumption per capita due to better energy standards. The fact that income increases heat consumption per capita in the found regression models underlines that not all wealthy households in Copenhagen live in these semi-detached houses.

When wealthier families embrace the new city areas and the income differences within the City of Copenhagen increases, it leaves the tendency for lower-income households to gather in the areas with lower housing prices and social housing (The City of Copenhagen, 2014). The tendency for people of same socioeconomic and cultural inheritance to concentrate in certain areas has increased since the millennium (The City of Copenhagen, 2014). The tendency is reflected in the finding that people of *non-western ethnicity* were found in this study to live in concentrated areas of Copenhagen that correlate with *low income* and *less residential area per capita.* Both people of *non-western ethnicity* and *age 0-5* correlate with low heat consumption per capita, but assumingly due to different reasons. Whereas the *non-western ethnicity* can be expected to save heat due to *less residential area per capita* and due to the theoretical *prebound effect*, the generation of *age 0-5* can be thought to save heat due to better energy standards.

Summing up, the non-age related income divide creates differences in the options for saving heat, but not in the tendency to save heat overall. Economy and economic motivations clearly matters in regards to choosing houses with better energy standards, but not in regards to decreasing heat consumption through housing choices overall. The generation of *age 0-5* only correlates to a small degree with *moderate green party votes* and not with *green party votes*, indicating that environmental awareness might not matter much in regards to choosing houses with better energy standards. However, environmental awareness does have a total effect that decreases heat consumption per capita through its relation with the life-cycle pattern.

6.3. Further analysis suggestions

When looking at the two models found to explain heat consumption per capita, the variables included as well as their direction seem to overall fit well with the similar models in the studies described in the theory section. However, the two models have impressively high explanation powers, which can be related to the fact that heat consumption was calculated from heat consumption averages that were based on *construction age* and *dwelling type*, which naturally must have removed noise from the models. Non-aggregated or spatially aggregated heat consumption data could be used in future studies to examine how heat consumption is related to individual household heating behaviour, and how individual heating behaviour is related to environmental awareness.

Furthermore, the assumption that the actual heat consumption values of semi-detached houses are in between the values of apartments and of detached houses might be erroneous. To counteract the tendency for higher income to increase heat consumption per capita, information regarding actual heat consumption for semi-detached houses ought to be obtained and looked into in future studies.

7. Conclusion

Following Hansen (2016) and Estiri (2015), this study examines direct as well as total effects of socioeconomic and cultural variables on heat consumption, applied to a specific geographic region; the City of Copenhagen. The paper illustrates that while direct effects can show the direct influence of variables on heat consumption and the size of the influence, indirect effects can illuminate patterns of connected variables such as the tendencies for a new wealthy generation with small children (age 0-5) and non-western ethnic people to decrease heat consumption, but due to different reasons.

Relatively high family-weighted income and old age have been found to have statistically significant direct effects on heat consumption per capita after building characteristics-based insulation-related variables have been accounted for, even though the standard values used to calculate heat consumption have been averaged after construction age and dwelling type, which has blurred behaviour-related heat consumption differences. The direct effects could potentially be even higher, if spatially aggregated heat consumption data is used instead to reveal heat consumption behaviour, which is a task for future studies to investigate.

Moving to total effects in order to find patterns of socioeconomic and cultural influences, a life-cycle pattern seems to exist in that heat consumption, income, the number of children, and the residential area per capita increase with age. The total effect of voting for green political parties correlates with the life-cycle pattern, indicating the tendency for green political party votes to decrease heat consumption per capita. Especially older children, elders, and people with very high net income tend to increase heat consumption. Planners can thus focus on these household types in their strategies in order to make it easier for these household types to decrease heat consumption and renovate more.

The total effects of the different age intervals as well as the total effect of non-western ethnicity reveal an income divide affecting the motivations to decrease heat consumption per capita. Whereas the people with non-western ethnicity can be expected to limit their heat consumption per capita for economic reasons and due to less residential space per capita, the generation of wealthy families with small children living in new, semi-detached houses can be thought to limit their heat consumption due to better energy standards. The new generation of families with small children (age 0-5) does not seem to reflect a high degree of environmental awareness. Economic motivation, on the other hand, are of huge importance for understanding heat consumption differences. Copenhagen needs to plan towards decreasing heat consumption per capita, but risks at the same time to exclude the lower income households in the city from the advantages of better energy labels. Future studies based on less aggregated or spatially aggregated data need to take a closer look at the potentials for decreasing heat consumption inherent in the new semi-detached houses, inherent in energy renovations, and in better management of the heating systems, while examining the consequences for the socioeconomic and cultural differences within the city.

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