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Simulating energy consumption and greenhouse gas emissions in Finnish residential buildings

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Global warming is an ever increasing problem and greenhouse gas emissions from anthropogenic sources are on the rise. Residential buildings account for a nearly a fifth of the energy consumption in Finland. In order to properly understand the different factors effecting energy consumption and the consequent greenhouse gas emissions were simulated for a district in Tampere. Simulation is an important method to see the effects of different actions without the need for field testing. Three different scenarios were also tested to determine the outcome of different actions to reduce energy consumption and emissions. The first scenario was replacing the heating sources in direct electrically heated detached homes with wood heating, the second scenario was installing heat pumps into every home that used direct electrical heating and third was to test the effect of different internal temperatures on every house's heat consumption. The results show that the apartment building are the greatest net consumer of energy and producer of emissions, but the energy and emission intensity is largest for detached and attached homes. The most successful method of reducing emission was scenario one. Scenario three was the best scenario to reduce total energy consumption. These results have a wide range of practical application such as city planning, individual user's energy decisions and predicting nationwide greenhouse gas emissions.

Keywords	Greenhouse gas emissions, Energy consumption, Simulation

Contents

1 Introduction

1.1 Residential building stock as a contributor to climate change in Finland

The residential stock in Finland is one of the largest consumers of energy, representing just over 16%, a total of 223 PJ of energy, of the total energy consumption in 2011 [1]. As a member of the European Union, Finland is bound to the greenhouse gas emission targets established by the union. The main approach in climate change policy is known as the 20-20-20 targets, which establish three goals to be obtained by its member states by the year 2020 [2]:

- “A 20% reduction in EU greenhouse gas emissions from 1990 levels; [2]”
- “Raising the share of EU energy consumption produced from renewable resources to 20%; [2]”
- “A 20% improvement in the EU's energy efficiency. [2]”

Beyond the EU targets, the goal of Finland's energy policy is generally to stop the rise of and bring about a decrease in energy usage in the country. This goal is set about to be achieved through a number of objectives, such as: promoting free energy markets, promoting energy efficiency and conservation, developing less-greenhouse-gas-producing energy sources, promoting bio-fuels and other local energy sources, maintaining a high level of technology in the energy sector, and having secure and diverse sources of energy[3]. In order to effectively reduce energy consumption and greenhouse gas emissions in the residential sector it is necessary to understand how energy is consumed in households and where the greatest need for improvement lies.

1.2 Energy consumption in the residential sector

Energy consumption within the residential sector depends greatly on geographic location, built form of the buildings, and occupancy behavior [4].

1.2.1 Geographic location

The geographic location of a dwelling is highly influential in the energy demand of the dwelling. The location determines the climate in which the dwelling is located, its immediate surroundings, daylight hours, as well as access to certain fuels (e.g. whether it is near a district heating source, gas hookups, etc.). Climate affects several parameters that can influence home energy consumption: outdoor temperatures, solar radiation levels, wind speed and air humidity [5]. In Finland, temperature has the strongest impact on heating and cooling demands; this is especially true during the winter (January, February, March, and December). Temperature and solar radiation are equally important during the summer (May, June, July, and August) while air humidity and wind speed have minor influences on heating and cooling demand, with wind speed being more significant of the two [5].

One method of taking climate into account during modeling is the use of climate zones. There are different methods of determining climate zones, for example using the average outdoor air temperatures. Using the average annual temperatures, Finland has four climate zones as seen in Figure 1, with climate zone one being the warmest and four the coldest. Heating degree days (HDD) and cooling degree days (CDD) are another method of using climate data and represent a method of determining the heating or cooling demand of buildings. Degree days are method to compare energy consumption (either for heating or cooling) for the same building in different parts of the year, or similar buildings in different locations. HDD are based on the idea that the heating energy consumption is proportional to difference between the internal and external temperatures. HDD are the monthly sum of the difference between the daily indoor and outdoor temperatures. The most common heating degree day is S17, which assumes the daily average difference between the indoor and outdoor temperatures is 17ºC. [6]

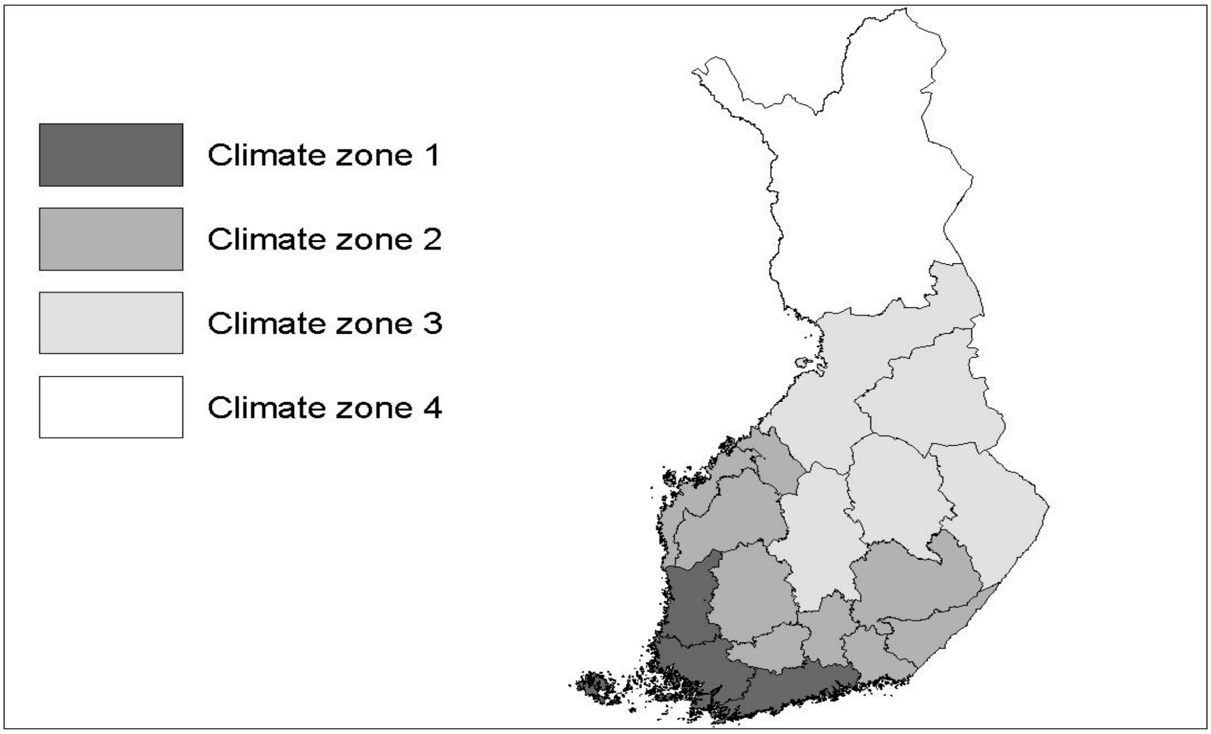

Figure 1 Finland's four climate zones [5]**.**

The direct surroundings of a dwelling impact energy consumption in the case of shade coverage. During summer-time shade can reduce the cooling need, while during winter shade may increase the heating requirements by blocking solar gains [7]. Shade can be provided by trees, window awnings, or other buildings.

Energy demand in cities is influenced by the urban heat island phenomenon, caused by man-made alterations of the environment: the thermal properties of the built environment, urban morphology, and the use of heat producing energy within the urban areas [8]. Short-wave radiation is stored during the day and is transformed into long-wave radiation which is remitted throughout the evening, consequently creating an area of increased daily temperatures (7,8). Due to the increased temperatures, cities use more electricity than neighboring rural areas for cooling, but decreased electricity for heating during the winter [8].

1.2.2 Built form

Wright [4] defines built form as the type of building, floor area and volume, its layout, insulation, and air infiltration and ventilation rates, all of which are related to the age of the dwelling. These are all important in determining the efficiency of the dwelling with respect to heat demand (total volume), losses (insulation level), and production (domestic hot water, space heating, electrical equipment, etc.). Electricity consumption is also related to a dwelling's built form, for example the daily electric lighting energy-consumption in kWh/day can be equated as proportional to the dwelling floor area, m^2 [9].

Naturally the building type, the floor area and volume would have an influence in the amount of energy consumed by the building. The larger the building the more energy is required to heat the structure. Shared walls, roofs, and floors of attached and apartment buildings also allow reduction of energy loss because of the reduction in the area that is exposed to the outside environment.

The positioning of the building with respect to the sun's orientation is one example of how building layout influences energy consumption. Windows allow the largest amount of solar radiation to enter a building, and a house should be designed to capture this free energy by positioning windows so that solar gains are minimized during the summer months (to reduce cooling demand), and maximized during the winter months (to reduce heating demand). Because the angle of the sun changes throughout the year the majority of the home's glazed surfaces should be facing southward (in the northern hemisphere). Jaber and Ajib [10] show how orientation for homes in Jordan can influence the amount energy for heating and cooling. Homes with a western, eastern and northern orientation required respectively 436 kWh, 268 kWh, and 196 kWh more energy than a southward orientated home. With Finland’s far northern location it can be expected that the effect of the window position is also highly important.

One of the most important aspects of built form is the U-value. A U-value represents the amount of heat that is transferred through the building's structure. Different parts of the building (windows, walls, roof, floor, and doors) all have different U-values and therefore different heat conductions; a lower U-value rating is better and represents less heat transfer through the material [11]. The U-value unit is expressed as $W/m^2 K$. A U-value of 1 $W/m^2 K$ corresponds to 1W of heat loss per $1m^2$ of the surface for every degree difference between the inside and outside temperatures [11]. The U-value is calculated from the thermal conductivity of the material and the material's thickness, as seen in Equation 1[11], where λ is thermal conductivity and d is thickness of the material.

$$\text{U value} = \frac{\lambda}{d} \tag{1}$$

Insulation is a material that restricts the amount of heat that flows through the house, and is essential in keeping the U-values low. Insulation is represented using a slightly different value, the R-value, which is the thermal resistivity of the material. R-values are the inverse of the U-values, as seen in Equation 2 [11].

$$R = \frac{1}{U} = \frac{d}{\lambda} \tag{2}$$

The standards for U-values for newly constructed homes in the Nordic countries are presented in Table 1.

Table 1 U-value standards for Nordic countries. All values are in W/m2K. Overall value is calculated in order to allow comparisons. Overall values are a sum of ceiling, wall and floor, and 0.2*window U-value [3]

	Component U-values [W/m2 K]				Overall U-values	
	Ceiling	Wall	Floor	Windows	Overall	Average
Denmark	0.15	0.2	0.12	1.5	0.77	0.77
Finland	0.15	0.24	0.15-0.24	1.4	0.91	1.01
Norway	0.13	0.18	0.15	1.2	0.71	0.8
Sweden	0.13	0.18	0.15	1.3	0.72	0.72

Air exchange can occur through either air leakages, when air enters uncontrolled through the building envelope, or through controlled ventilation, such as natural or mechanical ventilation systems. A large amount of energy is expended in air exchange because of the need to heat and cool the incoming air, as well as the loss of heat with escaping air. The air leakage rate depends on the leakage area in a dwelling, the weather, and the physical condition of the dwelling [12].

1.2.3 Occupancy and behaviour

Occupants' energy use behavior is highly important for the energy use of a dwelling (4,13). However, many models typically only predict the energy efficiency and quality of dwellings by using standards of use, rather than the actual energy consumption which requires taking into account human attitudes and behavior [14]. Five different attitudes and behaviors towards energy/heat consumption in the Netherlands have been determined by Van Raaji and Verhallen [15]: conservers, average users, spenders, cool dwellers and warm dwellers. Conservers had small ventilation and low mean inside temperature. Average users had modest values for both ventilation and temperature. Spenders used high levels of ventilation and high temperatures. Cool dwellers had high levels of ventilation, with cool temperatures, and warm dwellers were the opposite with moderate ventilation and high temperatures. The behavior of the occupant thus has a major impact on the energy demand of a dwelling.

Rebound is also important in energy modeling. Rebound is the result when improved energy efficiency leads to an increase in energy spending. Two types of rebound exist, direct and indirect. Direct rebound is a cost-benefit relationship, while indirect rebound means that savings allow households to use money for other energy consuming activities outside of the home [14]. Rebound shows that even though the built form may be developed to reduce energy consumption of homes, the occupants' behavior, such as purchasing new equipment that uses more energy, heating the home to a higher temperature, or expending energy outside the home, may override any energy savings achieved by the increased heating efficiency.

1.3 Greenhouse gas emissions from heat and electricity production

There are four major greenhouse gases (GHG): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and halocarbons (gases containing bromine, chlorine and fluorine). Because of human activities the concentration of these gases in the atmosphere has increased drastically over the last few hundred years; the burning of fossil fuels is one of the major causes of the rise [16]. Because GHG have different chemical structures which affect their lifetime and the chemical's absorption of infrared energy, they each have different global warming potentials. The global warming potential (GWP) is a measure of the how much energy a gas will absorb during its lifetime [17]. In order to easily compare the GWP of these different gases an index was created, called the carbon dioxide equivalent index. The carbon dioxide equivalent sets the GWP of carbon dioxide to 1 and all other values can be easily compared to it; the GWP of methane is 21 and nitrous oxide is 310 over a hundred year period [18]. The GWP of different gases are often normalized to a single unit to better understand and quantify the difference between emissions. This is called carbon dioxide equivalent (CO_2 e) and uses carbon dioxide as the reference value. Carbon dioxide equivalent takes different gases into account when determining the emission factors: carbon dioxide, methane, perfluorocarbons, and nitrous oxide to name a few.

1.3.1 Emissions from residential space heating sources

The residential sector represents 16% [1] of Finland's whole energy consumption, which is largely attributable (85%) to the space heating requirements. In all of Europe, Finland has one of the largest needs for space heating. A number of options exist for space and water heating in Finland: wood, light oil, heavy oil, district heating and electricity. Electrical heating makes up about one third of the residential space heating requirements, and in 2011 wood represented 23% of the fuel used for all space heating [1]. A number of factors determine how much energy and carbon equivalent a fuel produces: the heat of combustion, the efficiency of the heating system, and whether it was produced sustainably, to name a few. The carbon equivalent emissions for different fuels can be seen Table 3 in chapter 2.3.

1.4 Energy saving potential in the residential sector

Energy efficiency is a reliable, quick and clean way to save energy, reduce environmental damage, and slow the pace of global warming [19]. A number of methods exist to reduce the amount of energy a building or user consumes: building retrofitting, fuel switching for space heating to provide more efficient, cleaner burning heating options, innovations in and for the home to reduce energy usage of certain technologies, and feedback systems to inform the user of their energy consumption in order to allow them to make an informed decision on their energy usage.

1.4.1 Retrofitting

Retrofitting stands for ensuring the building's preservation through improvements in the existing structure, and maintenance and implementation of energy efficient technologies. Retrofitting in residential homes is typically centered on the improvement of the thermal envelope, which keeps the indoor air separate from the outdoor air, but can also include machinery and plumbing as well. The thermal losses through the envelope occur mostly through the floor, roof, walls, windows and doors, and ventilation/air infiltration. The amount of potential energy savings can vary depending on location but often considerable savings are possible. In Milan it was estimated that a reduction of nearly 25% is possible when considering only the thermal envelope [26], and in Finland an estimated 20% savings can be achieved by 2050 [20].

Insulation is a material that reduces the air flow, and consequently the heat flow between the inside and outside air. Insulation occurs throughout the home; it's in the walls, ceiling, and floor. There are a number of different insulation types, such as foam insulation, blown-in loose insulation, or blanket rolls. Not all insulation need occur in the structure; insulating heating systems, such as domestic hot water heaters, can help reduce heat loss [21]. Though the thickness of the insulation reduces the amount of heat lost, as seen in Equation 2, there is a limit on the effectiveness of increased insulation. In a Hong-Kong high-rise it was shown that increasing the insulation layer beyond 50 mm would provide insignificant reduction in the cooling load [22]. Insulation also works better in some areas than others. Increasing the insulation during a refurbishment in an old home in Serbia showed that greater energy savings occurred while insulating the walls (nearly 9.7 GJ/year), compared to insulating the ceiling (0.89 GJ/year), lowering the ceiling (1.89 GJ/year), as well as combination of the two (4.89 GJ/year) [23].

Ventilation is required in all homes to remove polluted air and allow clean air inside, but with this transfer heat is lost along with it. Methods to recover this lost heat exist in the form of heat exchangers that remove heat from the air as it leaves and heats up incoming air. They are capable of capturing around 70 percent of the heat in the air. Air leakage maintenance through sealing can also reduce heating. Windows, doors, electrical outlets and switches are typical locations for air leaks because these create passageways to the outside by making holes in the buildings thermal envelope [21].

Windows are essential parts of the building, and a minimum size is required for comfort levels, as well as providing light and passive solar gains into the building. Typically 25 percent of a home’s heat is lost through windows [10]; this is done primarily by two means: conduction through the glass and convection via gaps in the seams that typically develop years after the windows have been installed due to movement of the house. Convection via seems can be remedied simply by the application of the appropriate sealant, but the conduction is an inherent property of the windows. The U-values can vary widely due to how windows are constructed, with thickness, the number of panes, the size of the window and the nature of the gas used to fill the space between panes as factors. When comparing the U-values for a single versus a double pane window [24]. The location of the windows also plays a large role in managing heat loss. Having smaller sized windows facing North and West, with larger facing the South and East allowed for the minimum heating demand in homes in Jordan [10]. Overhangs over south facing windows can reduce summer solar gains, and deciduous trees can also have the added benefit of allowing the winter sun inside [10][21]. Finnish homes can utilize this information by reducing the size of north facing windows, which receive no direct sunlight or utilizing deciduous trees that do not block the winter sunlight. Think carefully if these results are relevant for Finland/this thesis.

Walls in un-insulated homes account for nearly half of the heat loss [25]. The U value standards for walls in Finnish homes are worse than other structural areas of the buildings at 0.24 W/m^2 (floors can range from 0.15-0.24 W/m^2) [1]. Possible reasoning for extra heat loss through walls is thermal bridging. Thermal bridging is the transfer of heat at a much higher rate in a specific area than through another. This occurs because of way walls are constructed. Walls in homes are typically constructed out frames of wood and steel, with supports spaced throughout the wall, these are called studs, as well as convergences of walls. Thick, dense materials such as wood and steel allow heat to pass through easier than the insulation around them [26].

Heat loss through the roof occurs because of convection which allows the heat to rise through the ceiling’s insulation and into the attic. U-values for Finnish homes, and in all Nordic countries, are some of the best in Europe and the standard U-value in a Finnish building's roof is 0.15 W/m^2 [3]. Another option besides increasing or changing the insulation layer is a green roof, which is a vegetation layer (as well as the supporting layers) that is constructed on top of a building. These roofs offer an opportunity to reduce the amount of heat loss through a roof as well as a range of other environmental benefits. Castleton et al. [27] reviews a series of experiments with green roofs and concludes that green roofs do reduce cooling and heating requirements. The vegetation layer acts as an extra layer of insulation, effectively reducing the heat flow through roofs during both the summer and the winter seasons. Though green roofs have proven effective, their efficiency is most pronounced in buildings where the roof's U-values are high, often occurring in older homes or in countries with limited policy on building energy efficiency design. When comparing residential roofs in Finland to residential roofs in Athens, Greece with U-values ranging between 0.26-0.4 W/m^2 [27] the usefulness for energy savings from green roofs would most likely be lower compared to the rest of Europe due to having such higher U-values.

Electrical appliances consume one of the smallest shares of a home's electricity, about 15 percent of the total consumption, but between the years 2000 and 2030 it is estimated that their share of energy consumption will grow to 27 percent for EU homes [28]. A number of methods to reduce appliance energy consumption exist such as eco-design and energy labeling. Energy labeling allows consumers to be aware of their purchasing and energy saving potentials. However, despite the growing use of energy saving appliances, energy consumption from appliances continues to grow because of lifestyle choices (i.e. increased number of electrical appliances, or amount of time using appliances) [28].

1.4.2 Fuel switching

With space heating (from all buildings) representing around 22% of all energy consumed in Finland (data obtained from Statistics Finland) the choice of how that heat is produced has great consequences on the amount of energy consumed and consequent greenhouse gas emissions. There are a number of different choices when considering replacement of a heating system, such as a system with a higher efficiency (heat pumps), or fuel which has less or no carbon dioxide equivalent emissions (renewable energies).

Renewable energies provide electricity and heat to the residential building stock without greenhouse gas emissions and are key to reducing GHG emissions in residential buildings [29]. Common renewable energy sources used in residential buildings are solar power, wind power, and wood or bio-fuels. For example, solar energy can be utilized either for electricity using photovoltaic panels (PV-panels) or for heat production with solar water heaters. By utilizing horizontally mounted PV-panels in Finland, it is possible to generate 700-800 kWh/kWp in the south and 630-700 kWh/kWp in the north; with an optimal angle, the efficiency increases by 9-26%, bringing levels in northern Finland up to 760 kWh/kWp [30]. Solar water heaters are devices that heat water using solar energy, and then the water is transferred into the domestic hot water system. In northern Europe it is possible to reach energy savings in domestic hot water around 75% when compared to gas, oil, or electrically heated water, and create large CO_2 savings due to reduced energy consumption [29].

Heat pumps are a technology that uses electricity to raise the temperature of different heat sources to produce useable heat for buildings. There are three different heat pump types, determined by the source of heat: air source, water source, and ground source. Air source heat pumps retrieve heat from the outside air and transfer this heat via a fluid, typically a refrigerant. These are typically the least efficient heat pumps and are most suited to working in mild and moderate climates, whereas water and ground source heat pumps are more efficient and are able to work in colder climates. Regardless of the type, heat pumps can save as much as 40% of the electricity needed for heating [31]. Because of the high efficiency and energy savings compared to direct electric heating and other heating sources, heat pumps are capable of reducing the GHG emissions from space heating. These savings depend on the electricity mixture used to run the heat pump, i.e. fossil fuel, nuclear, or renewable produced electricity. Applying ground source heat pumps in Germany showed that CO_2 emission savings of at least 35% could be achieved, or 1.8 to 4 tons of CO_2 for one unit a year, depending on the electricity mixture, compared to an approximate 10 tons of CO_2 emitted per person [32].

1.4.3 Innovations

An innovation here means the adaptation of existing technology to improve a home's energy efficiency by the users. Innovations come in different forms, e.g. through altering the design, modifications, or adding features to an existing technology.

Users in Finland have modified commercial heat-pumps, typically air source heat pumps, to increase suitability for the Finnish climate, increase efficiency and reduce energy consumption. The modifications range from constructing new heat pumps, "new-to-world designs" such as a double source heat pump using both ground and air heat, heat pumps made to work in temperatures as low as -25°C, and different methods of distributing heat in the home [33].

Ornetzeder and Rohracher [34] discuss the role of individual users and user groups have in the improvement of solar heating technology, residential biomass heating systems and a sustainable building project in Austria through the 1980s and 1990s. Commercial solar heating technology has adopted many of its current technology from user modifications, such as a special glass cover sealing, and roof-integrated collectors, which improved the efficiency of the systems. Biomass heating systems integrated two important technologies that improved the safety, a method to reduce wood chip swelling, and efficiency, through more advanced electronic control system, with the help of users. Finally, in planning a residential construction area, the private firm Forum Vauban created groups of future residents to help in design and planning of the area, and were able to introduce innovative building concepts to reduce the energy consumption and environmental impacts of the residences.

1.4.4 Feedback systems to reduce energy consumption

Feedback on energy consumption allows users to see the consequences of their behavior and lifestyle choices on energy consumption. The increased awareness may result in altered behavior of the consumer and consequently in reduced energy consumption in the house [35].

Darby [35] describes how feedback can come in a variety of forms: direct feedback (available immediately, such as meter reading or through display monitors); indirect feedback (processed data, such as monthly billing); and inadvertent feedback (learning by association). Different levels of savings exist for each type, for example an average savings of 5-15% can be achieved in homes when occupants have direct feedback on energy consumption, compared to savings of 0-10% for an indirect feedback method.

The most effective feedback systems must 1) capture consumer attention, 2) show link between actions and consequence, and 3) appeal to different consumer groups with methods such as cost savings, sustainability, emission reduction [36]. These three points show that having a real-time breakdown on energy usage, such as appliance usage, is essential for energy conservation [35-37]. With enough knowledge on specific consumption rates, users may choose substitutes of inefficient appliances or limit their usage [37].

1.5 Basic concepts in modelling energy consumption and greenhouse gas emissions

A wide variety of models exist to determine the energy consumption of residential buildings, but they tend to fall within two hierarchical approaches, the top-down and the bottom-up [38-40]. The difference between these two approaches is determined by the type of data each approach uses. Aggregate data are high level data created by combining different individual data sets and are often not very detailed; disaggregate data are detailed data from a single source. The top-down approach uses aggregate data to determine sub-systems of consumption, whereas the bottom-up approach uses disaggregate data to look at the base components and calculate the overall consumption for a dwelling [38]. Figure 2 presents a simplified perspective behind residential energy consumption approaches.

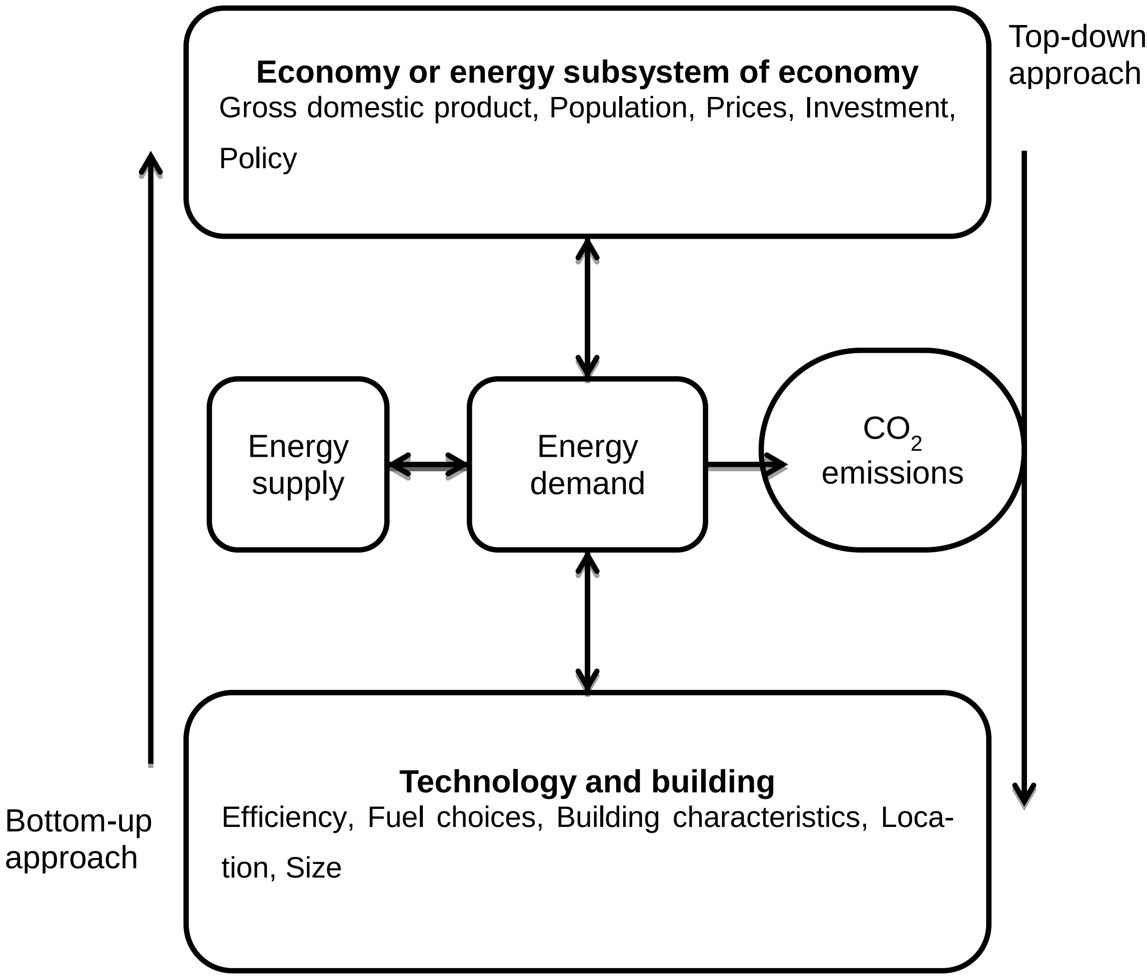

Figure 2 Residential energy modeling (adapted from [39]**)**

The top-down approach models energy consumption by taking into account processes in the economy/government, population changes, or investment into various energy projects. which have an influence on energy demand. In the top-down approach, the residential sector is seen as an energy sink [40]. This means that the residential sector only accepts incoming energy and does not contribute to energy production. The top-down approach is used primarily for determining the effect of change on the energy demand in the residential sector due to outside influences. The primary models used are the econometric and technological models. Econometric models use economic data, such as price and income, and focus on the relationship between energy and the economy; technological models look at a variety of characteristics about the houses themselves, such as technological progress and saturation of various energy technologies in the market [38].

The bottom-up approach focuses on specific features of the residential stock or a technology and how they can influence energy demand. The bottom-up method uses data from real houses to calculate energy consumption and create samples or archetypes of houses that are then used to represent a larger group, such as on a municipal or national level [38]. These samples are meant to represent dominant house types based on certain criteria, such as year of construction and heating fuel type, and are determined through different multivariate statistical methods, such as cluster analysis. The bottom-up method relies on quantitative disaggregated data that represents anything less than the whole system [39]. As with the top-down approach, there are two different methods: statistical and engineering (a.k.a. physical). The statistical method relies primarily on regression-based analysis, but neural networks are also commonly applied to residential energy models [41]. The engineering method uses formulas with parameter values derived from different sources, such as from literature, for different energy aspects of houses (domestic hot water, space heating, lighting, etc...) in order to estimate energy consumption [38].

Energy demand affects all categories by influencing the economy (for example by fuel price fluctuations), technology (demand for more efficient, cleaner technology), energy supply, and greenhouse gas emissions [39]. Even though Figure 2 shows that each approach uses unique characteristics to determine the energy consumption and subsequent CO_2 emissions, models need not follow such a strict interpretation and can employ different components from each method.

1.5.1 Comparison between the model approaches

The major advantages and disadvantages of both the top-down and bottom-up approaches are presented in Table 2. These comparisons do not make a distinction between the different modeling options for each approach; rather it provides a summary of the total positives and negatives for both approaches.

Table 2 Comparisons between top-down and bottom-up modeling approached [39]

Top-down approach	Bottom-up approach
Advantages: • Aggregated data is easier to obtain and manage than disaggregated data. • Historic data lends certainty to results, because of stability of residential energy val-	**Advantages**: • Useful in determining the effects of energy saving technologies and processes. • Passive gains, for example from the sun or inhabitants, can be included in the model.

ues • Allows simplified models and ease of development because of limited detail. • Useful in determining national energy strategies or economic impacts on energy system.	• Data is physically measureable. • Able to estimate least-cost combinations of energy technologies.
Disadvantages: • Difficulty in managing dramatic shifts, such as from emerging technologies, because of reliance on historical data. • Aggregated data make it more difficult to narrow the scope, usually only allowing a focus on national/city-wide models. • Historical data may not be able to represent climate change and its impacts.	**Disadvantages**: **1.** Requires large data sets in order to run the model. This data can be difficult to obtain, and makes replication difficult because of limited access. **2.** Models are often complex, because of required calculations. **3.** Human behavior and economy are poorly represented.

The right choice of approach is dependent on the type of data one has (aggregated versus disaggregated), and what one is interested in modeling (economy versus technology).

1.5.2 Other important aspects in modelling

Besides the advantages and disadvantages discussed above, Kavgic et al. [39] describes how the level of data disaggregation can play a big role in modeling. High levels of data aggregation provides results that may be too broad, while lower levels of aggregation require larger data sets and may require more assumptions in the data in the case of missing values or estimations .

Transparency of both the model, and the data itself, is highly important. Model replication and proper use is limited without access to the data and proper explanations of model algorithms [39]. de Vos et al. [42] discussed a few causes for a model's lack of transparency and reproducibility: size and complexity, and the lack of incentives for modelers to be transparent. Models tend to increase in complexity in order to improve realism, but a model in itself is a simplification of real world processes, therefore it is necessary to find a balance between complexity and abstraction. Models are not often properly described or detailed for different reasons: fear of model failure, releasing of intellectual property, and the time-demand of such detailing. Incentive, in the form of requests or obligation, by peers and journals may lead to increased model transparency [42].

For both top-down and bottom-up approaches, uncertainty plays a large role in understanding and interpreting the results. Uncertainties arise from a number of sources, for example assumptions are often made with the data either due to missing information or for simplicity. With assumptions one introduces an error into the model. Measurement errors also occur with data and its influence on the results can be difficult to estimate. Another source of error is determining the entailment between the inputs and outputs [43]. A sensitivity analysis is "The study of how uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input [44]." The traditional method for performing a sensitivity analysis is to change one parameter value in the model at a time and see the effect this has on the model results [45]. Sensitivity analysis is an important part of modeling, and because of the level of complexity that many energy system models deal with, it allows the modeler to test and present the reliability of their model to the user.

1.6 Aims of study

The purpose of this study was to model the energy consumption and greenhouse gas emissions from the Finnish residential building stock in order to better understand their relationship, to determine what causes the differences greenhouse gases emissions between different buildings, as well as to see if there is any opportunity for energy saving measures within the building stock. To accomplish this I utilized a model which is based on the physical characteristics of houses. I then fitted the model to a detailed data set of residential homes obtained from the Finnish government's population center. I focused the research on a case study area as a means to obtain a representative sample of Finland's residential buildings.

2 Materials and Methods

The methodology is first presented with a description of the case area (buildings, area, and environment) information. This is followed by a run-down of the workings of the data set and model which were utilized. The method for testing the sensitivity analysis is described as well as the alternative heating scenarios. These allow a look at how the model works when key parameters are altered. Finally, the assumptions and uncertainties in the data are presented to allow for criticism of the methods.

2.1 Case area

I tested the model performance with data from the small district of Kaukajärvi, Tampere in Finland, as seen in Figure 3. Kaukajärvi has an annual mean temperature, mean precipitation and mean wind speed are 4.4°C, 598 mm, and 3.2 m/s, respectively [46].

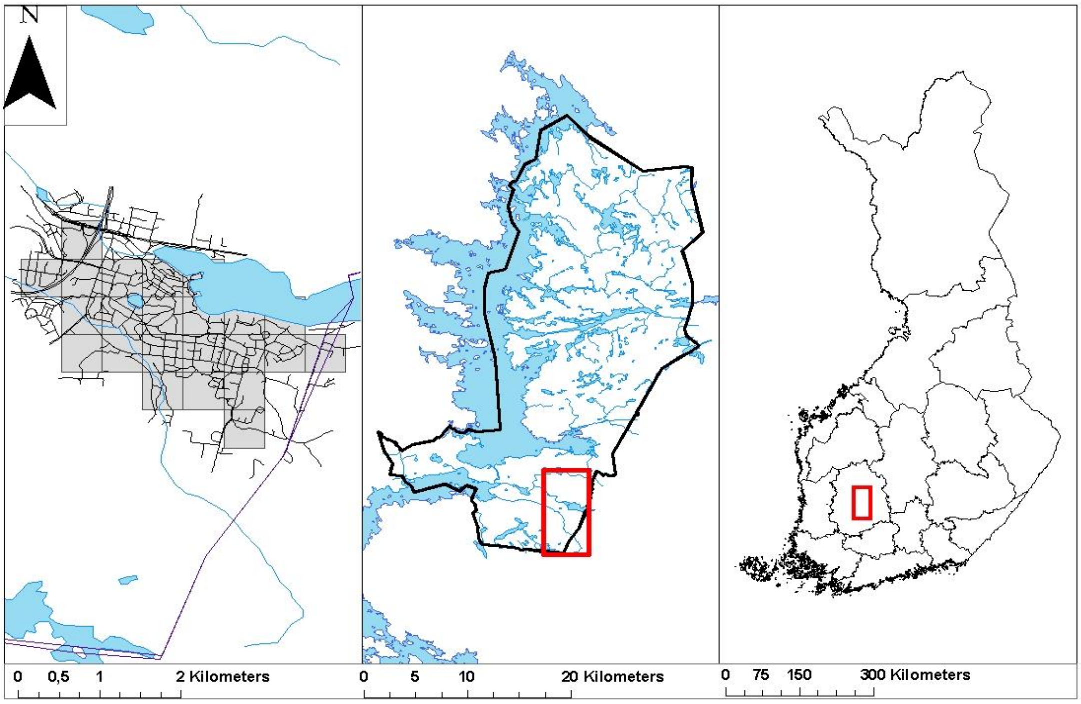

Figure 3 Location map for Kaukajärvi (left), Tampere (middle) in Finland

The district was chosen because it was felt that it has a representative sample of the different house types, with a total 723 residential dwellings of which 382 are detached homes, 187 are attached homes and 154 are apartment buildings. The district has a population of nearly 11 000 inhabitants.

2.2 Data

The Population Register Centre of the Finnish government maintains data sets on over three million dwellings and almost three million residents. This data set is called the

Building and dwelling register or BDR and it maintains data for a number of years. The information contained within the data set is obtained through cooperation between municipal building authorities, local register offices, and building owners [47].

For this research I utilized the most recent dataset at the time, BDR 2010. BDR 2010 contains information sampled in December 2010. We utilized two different datasets under the umbrella name of BDR 2010: building data and population data, for the Kaukajärvi district located in the city of Tampere, Finland. This area was chosen because it was felt it was a good representation of Finnish residential areas. There were a total of 723 permanently occupied dwellings used from the data. For each dwelling we were interested in a building-specific identity code, the municipal sub-area, the building type/purpose of use, the year of construction, the number of residents, the size (volume and floor area), the original heating source, and the location coordinates.

2.3 Ekorem model for calculating energy consumption

The Ekorem model is a bottom-up engineering model used for calculating Finland's building stock energy use, CO_2 equivalent-emissions, and energy saving potential. The model was developed in Tampere University of Technology, in the Energy and Life-Cycle Research Group. The calculations are based on section D5 (2007) of the National Building Code of Finland: "Calculation of power and energy needs for heating of buildings [20,48]. The model is capable of calculating the energy and water consumption of multiple building stocks (i.e. industrial, commercial, public, etc.), but for the purpose of this research the scope was limited only to the energy consumption and CO_2 equivalent emissions from the residential stock.

The model assumes that the age of a building translate into U-values, ventilation rates and other parameters which affect energy consumption, and requires buildings to be divided by year of construction into five-year age groups (-1920, 1921-1925, 1926-1930, 1931-1935, 1936-1940, 1941-1945, 1946-1950, 1951-1955, 1956-1960, 1961-1965, 1966-1970, 1971-1975, 1976-1980, 1981-1985,1986-1990,1991-1995-1996-2000, 2001-2005, 2006-2010 and 2011-). The model utilizes different parameter values for three residential house types: detached houses, attached houses, and apartment buildings. The house type is important to include in the model because along with age it largely determines the built form. House hold electricity use, for example,. lighting and appliances, is calculated in the model based on the dwelling's area and building type. The house type also determines the internal temperature the model uses: 21° for detached houses, 22° for attached houses and 22.5° for apartment buildings. The model takes into account the heating source by incorporating nine different primary heating sources, each with their own heating efficiencies and carbon dioxide equivalent emissions (Table 3). Household electricity represents the emission value for electricity used for non-heating purposes. Passive gains are also considered; these include solar gains, gains from people, and gains from hot water. The main inputs provided to the model were building volume, area, number of residents, and the primary heating source, which were available from the BDR 2010. The main outputs are the gross energy consumption and CO_2 equivalent values for a building.

Table 3 Primary heating source CO_2 equivalents used in the Ekorem model [49]**.**

Heat Source	CO_2 equivalent (g Co2 eq./kW)
Wood	18
Light oil	267
Heavy oil	279
Gas	202
Coal and Peat	370
Electricity	400
District heating	226
Geothermal	400
Other	300
Household electricity	204

Both electricity and geothermal sources share the same CO_2 eq. value. This is because the geothermal heat pumps run on electricity, as well as the direct electric heating, the difference arises in the higher efficiency of the geothermal heat pump. The model does not take into account possible additional heating sources such as air-source heat pumps.

For each house type the average heat loss of the building's features (floor, roof, wall, window, doors, and ventilation) was calculated for the Kaukajärvi district using the Ekorem model [20,48]. This was done using the respective U values, the share of the façade that each feature occupies, and the volume of the stock by age group. For ventilation, heat recovery systems of the stock were taken into account. Hot water consumption was based on the estimated hot water consumption (m^3 of water/$m^2$of the dwelling), the share of this water which is heated to 50ºC, along with the ratio of volume to area of the dwelling.

2.3.1 Sensitivity analysis

A sensitivity analysis was performed on the model to test which input parameter was the most sensitive to change, and therefore has a greater role in the outcome of the results. Volume, area, population, the U-values for different structural components of the buildings, and the emission factors for the different heating options were the input parameters tested. The model was re-run for each parameter separately with a small increase (5%) in the value for each building in the chosen parameter, while others remained constant.

2.3.2 Alternative heating scenarios

Three alternative heating scenarios were tested with the model. The first scenario is the wood heating scenario, which replaced direct electrical heating with wood as the primary heating source in detached houses. Only detached houses were chosen because of the unlikeliness that row houses and apartment buildings could install fireplaces. Wood was chosen because it is an abundant resource in Finland, and because it is a renewable resource if properly managed, thus allowing the possibility to produce far less greenhouse gas emissions.

The second scenario was the efficiency scenario, in which it was attempted to determine the role that the efficiency of the heating source plays in energy consumption. Direct electrical heating was chosen because it is the second most used heating source, and alterations to its efficiency are possible by home owners by different methods, such as installing a heat pump. All house types were chosen, because it is plausible that an air-source heat pump could be installed in all types of buildings. Because of the varying efficiencies of heat pumps, as well as the impact that outside temperature has on their efficiencies, three different efficiencies were chosen to be tested. Because the efficiency of direct electrical heating within the model is 100%, three different efficiencies were chosen: 150%, 175%, and 200% as the efficiencies simulated in order to test for the affects of varying efficiencies. These efficiencies are the ratios between the input and output from the direct electrical heating device, not the coefficient of performance (COP).

In the third scenario, it was attempted to take into account human behavior and heating. Here I simulated what the effect would be in Kaukajärvi if the internal building temperatures were to be reduced by a single degree in all buildings. Each building type had its internal temperature lowered by a single degree, and then raised a single degree. The cool and warm temperatures chosen were 20° and 22° for detached houses, 22° and 23° for attached houses, and 22.5° and 23.5° for apartment buildings.

2.4 Used programs

All calculations were done with the freeware statistical program R, version 2.15.0 [50], all tables and graphs were created using Microsoft Excel 2007, while all spatial visualizations were created with the commercial geographic information system program ESRI ArcMap, version 9.3.1 [51]. In ArcMap, the coordinate system Finland Zone 3 was used along with the Gauss-Kruger projection.

2.5 Data assumptions

In order to utilize the BDR 2010 data into the Ekorem model it was necessary to make several assumptions: primary heating source, house type, volume, population, and the year of construction. These assumptions arose mostly due to what format the model required the data set to be in, missing values, and differences between the two data sets (population and housing).

The primary heating source information available in the data is what the house was either originally constructed with, or the current heating source if it was necessary to obtain permission from the city to change the heating source. Hence, information on any secondary source of heating, for example wood heated stove or fireplace, or an air-heat pump, both common secondary heat sources, is not included in the data. If these secondary heating sources were to be utilized into the model it would likely show a reduction in energy consumption and emissions.

Each dwelling has a specific three digit building type code in BDR. In order to run the model each building type was placed into one of three groups, because they shared similar characteristics. Detached house consisted of three different house types: "single-family residences", "two family residences", and "other small houses"; Attached houses consisted of three house types: "row house", "attached houses", and "loft houses"; Apartment buildings are only one house type, "other apartment buildings."

Not all of the BDR dataset is complete; missing or unexplained values exist, and in the case of volume there were ten dwellings with missing information. In order to correct this, a conversion factor was used that was provided along with the model. The conversion factors are based on house type and year of construction and are multiplied with the gross floor area of the building to produce a volume.

In seventeen dwellings there was no information on the number of residents. To correct this, a conversion factor was created based on the average of people per square meter in the BDR 2010 data set. A conversion rate of 0,022 people/m^2 was used. This was then multiplied by the buildings gross floor area to obtain a value for the number of residences for the missing dwellings.

For two dwellings, the year of construction was given a value of zero. These dwellings were treated as though they were older and fell into the year group of up to and including 1920, this is based on advice given by the data managers.

3 Results

The results are presented in three different sections. First, where the average heat loss from each house type occurs, secondly, the energy consumption and energy intensities were calculated and are presented, and finally, the CO_2 emissions of Kaukajärvi, as both total emissions, and the emission intensity are presented.

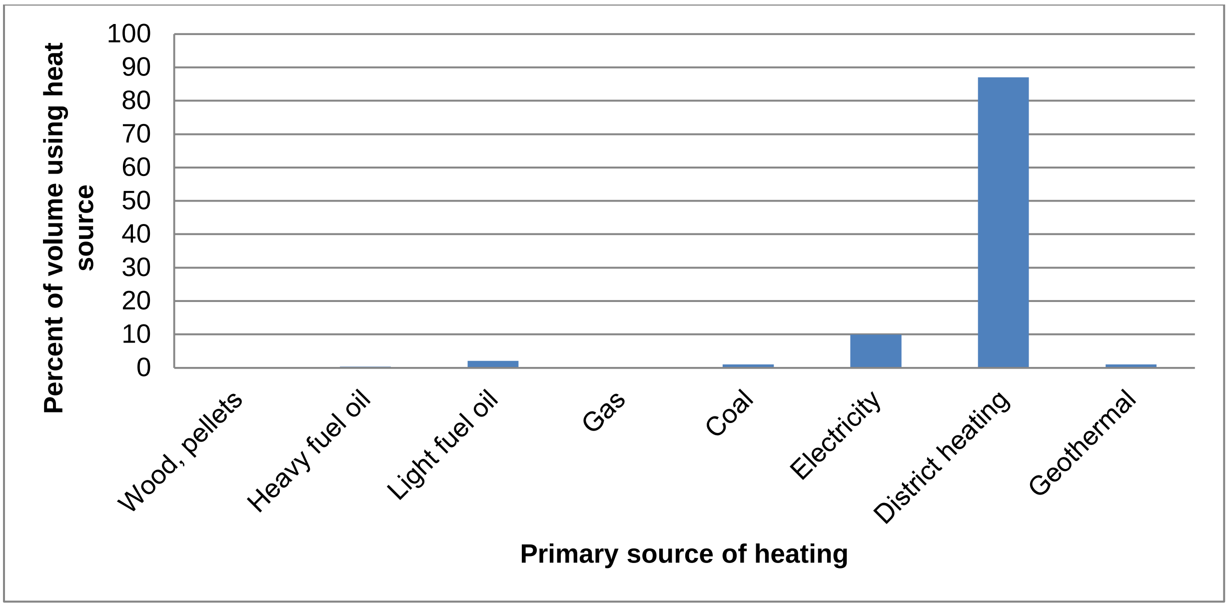

Figure 4 The distribution as a percentage of building stock volume by primary heating sources in Kaukajärvi.

Kaukajärvi's residential fuels are quite clearly dominated by district heating, followed by electric heating (Figure 4). These fuels represent 87%, and 9.9% respectively of the fuels used and together make up nearly 97 percent of the fuels used in the residential sector by volume. District heating dominates the district, because of the large amount of large apartment houses in the area which all utilize district heating. Both wood and gas are absent, while coal and other each make up much less than 1% of the heating sources in Kaukajärvi. The spatial distribution of these heating sources is presented below in Figure 5, which shows the number of dwellings within each square that use a particular heating source, normalized by the total number of dwellings. The size of the bar is not representative of the number of dwellings present, because of the normalization to the number of dwellings in the grid square. This figure allows for a comparison of the heating source usages

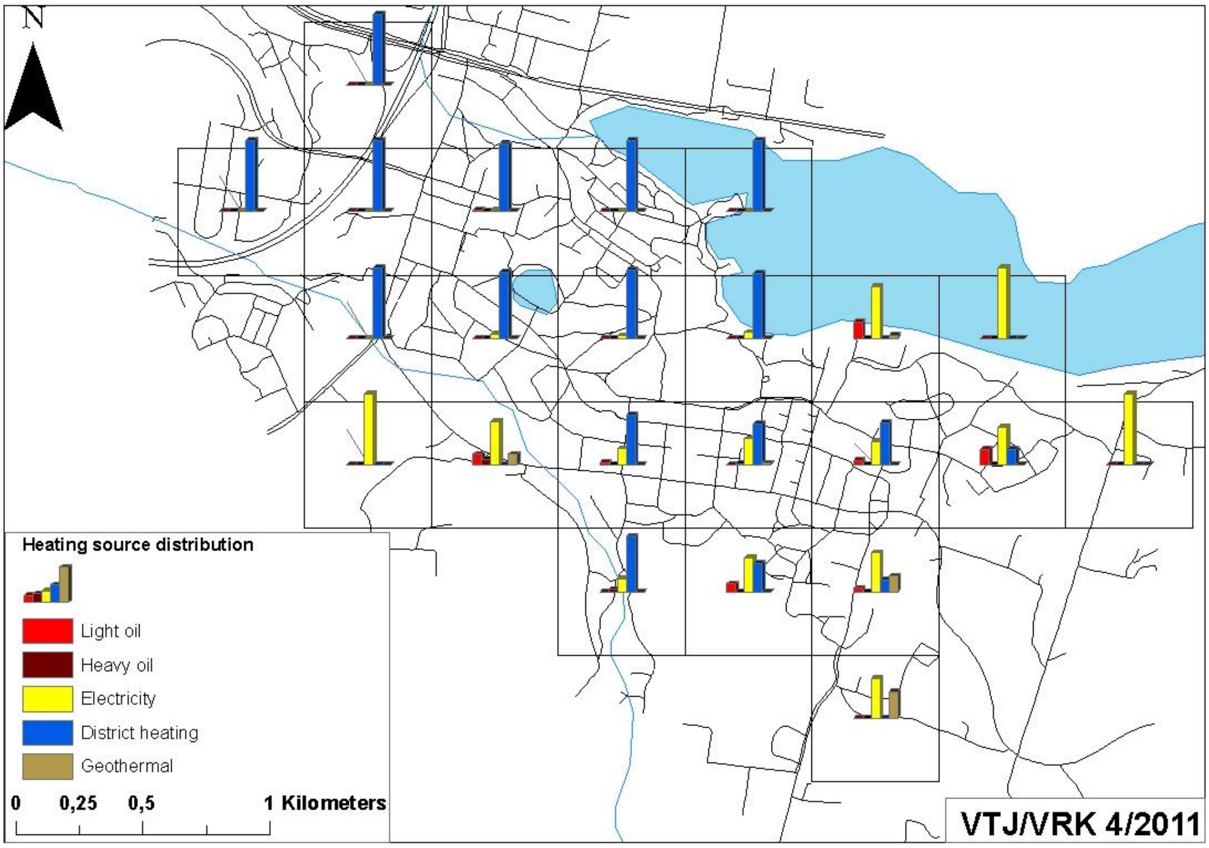

Figure 5 Heating source distribution normalized by the number of dwellings per 500 m^2.

The spatial distribution of fuels is essential when trying to understand the emissions and emission intensities. In Fig. 5 one can see that the north section, where the majority of apartment buildings are located, is dominated by district heating, while there is more variation in the southern half of the map, with more detached houses. Row houses are spread throughout the district.

3.1 Heat loss in the residential stock

The heat loss of each residential house type was calculated in order to compare where the largest source of heat loss occurs (floor, roof, wall, window, doors, and ventilation). Figure 6 show the respective cumulative heat loss for the whole of Kaukajärvi in GWh/a for detached houses, attached houses, and apartment houses normalized by the number of houses in each house type.

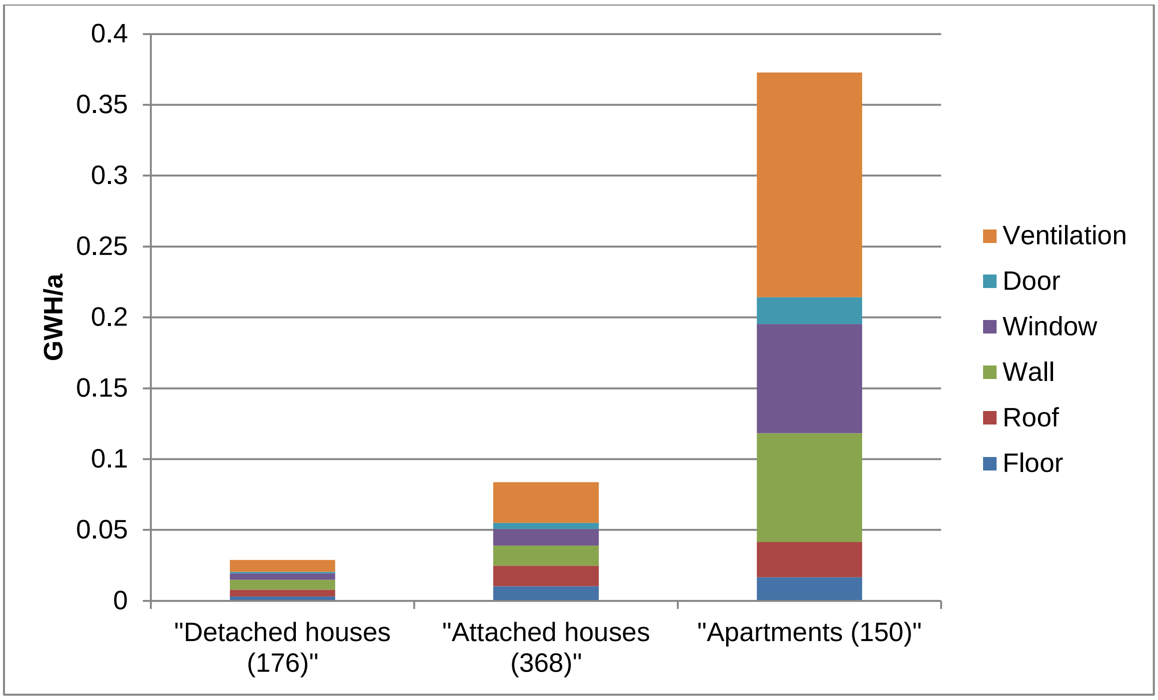

Figure 6 Heat loss from detached houses, attached houses, and apartment buildings through the specified building feature and normalized by the number of buildings built within that house type. The count is given in brackets after the age group.

Because of the larger share of apartment building space (volume and area) there is a larger proportion of heat loss occurring in that sector. For apartments heat loss primarily happens through ventilation (36%) and windows (33%) while all other features all account for less than 10%. In detached houses the greatest amount of heat loss (33%) occurs in the windows, followed by ventilation (23%), and in decreasing order the roof, walls, floor, and doors. Heat loss in attached houses is rather equally split between most features, besides doors, falling between 15% for the floor and 24% for windows.

Figure 7 shows the combined heat loss through the specified building feature in GWh/a of all three house types with the dwellings divided by their year of construction and normalized to the number of buildings in the respective age group. The buildings were normalized in order to allow for a comparison and to not be distorted by the large number of buildings built in the latter part of the century.

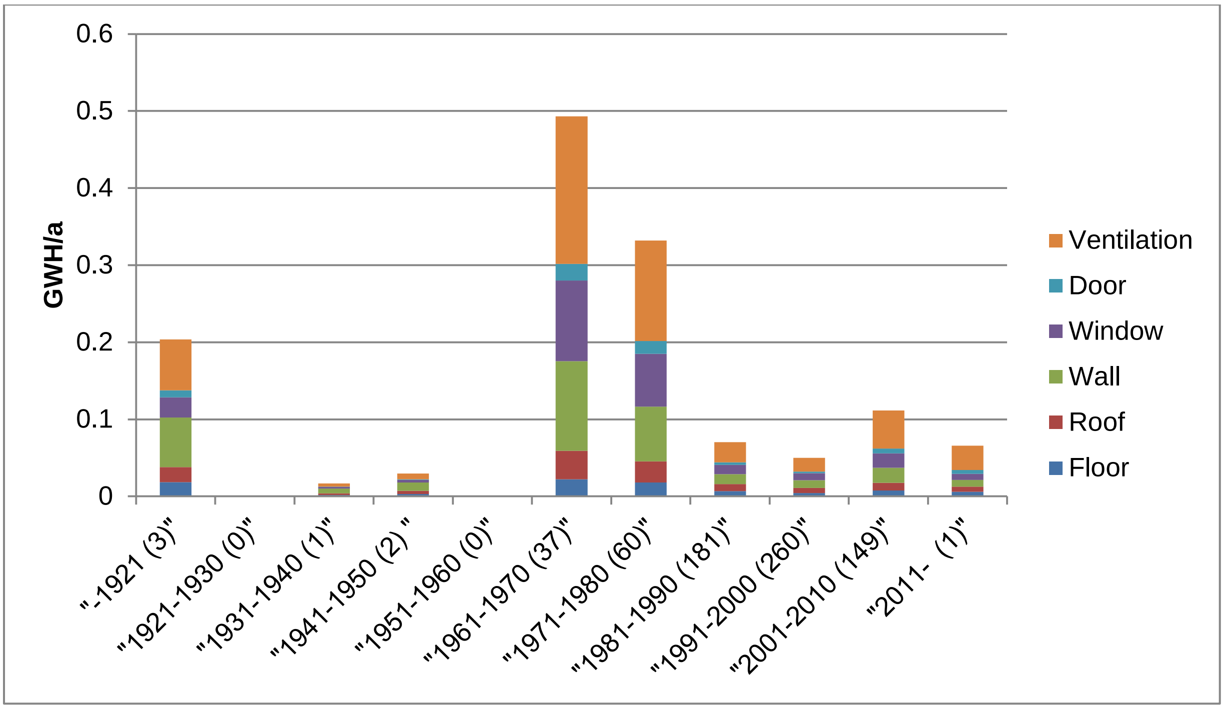

Figure 7 The combined heat loss of all house types separated by their year of construction through the specified building feature and normalized by the number of buildings built within a decade. The count is given in brackets after the age group.

The vast majority of heat loss happens in buildings built between the 1960s and 1980s and before the 1920s. Heat loss through the specified building features are similar to what Figure 6 shows and is discussed above.

Ventilation represents a large proportion of heat loss for all three building types, with total values over 20 GWh/a in apartment buildings, and 3-5 GWh/a for detached and attached houses. Table 4 shows the heat recovery values for ventilation obtained through the model.

Table 4 Calculated heat recovery values for Kaukajärvi using Ekorem (20,48) **negative values represent the amount of energy saved.**

Heat Recovery (GWH/a)			
	Detached houses	**Attached houses**	**Apartments**
-1921	-6.07E-05	-	-6.12E-04
1921-1930	-	-	-
1931-1940	-1.01E-05	-	-
1941-1950	-3.65E-05	-	-
1951-1960	-	-	-

1961-1970	-	-1.11E-03	-2.47E-02
1971-1980	-3.10E-04	-1.86E-03	-3.54E-02
1981-1990	-5.25E-02	-1.56E-02	-1.38E-02
1991-2000	-3.08E-01	-2.70E-02	-4.89E-02
2001-2010	-2.08E-01	-1.29E-01	-1.09E+00
2011-	-	-1.40E-02	-

Heat recovery is one method to reduce the heat loss from ventilation, but according to the rates obtained in the model, little has been done. Heat recovery from all house types is low and represents about one fourth of the energy lost in ventilation for all house types.

3.2 Energy consumption

The energy consumption of Kaukajärvi was simulated and is presented in Table 5. The table presents a breakdown by consumption means (space heating resource used and the household electricity), as well as by the housing types. Heating sources not used in Kaukajärvi were excluded from the table.

Table 5 Energy consumption for Kaukajärvi (GWh/a). Household electricity is not included in heating energy total. Values represented with a dashed line mean that there was no use of that heating source for that housing type

	Energy consumption for residential stock in Kaukajärvi (GWh/a)									
	Household electricity	**Light oil**	**Heavy oil**	**Coal/peat**	**Electricity**	**District heating**	**Geothermal**	**Other**	**Heating energy total**	**Gross energy consumption**
Detached houses	3.79	1.50	0.05	0.02	5.87	0.81	0.19	0.03	8.48	12.27
Attached houses	4.48	0.05	0.22	-	0.31	11.32	0.02	-	11.92	16.39
Apartment	16.31	-	-	-	-	49.72	-	-	49.72	66.02
Total	24.58	1.55	0.27	0.02	6.18	61.85	0.21	0.03	70.11	94.69

District heating is the largest consumer of energy, followed by household electricity and electric heating. Heavy oil, coal/peat, geothermal and other represents less than 1% respectively. Heating energy makes up 74% of the total energy consumed in the district. Apartments consume the most energy, of which all heating energy is district heating. Energy consumption for both row houses and detached houses is more diverse and much lower than for apartment buildings.

Figure 8 shows the distribution of primary heating sources and the overall energy intensity for Kaukajärvi. The squares are 500 by 500 meters which are provided for privacy of the residents.

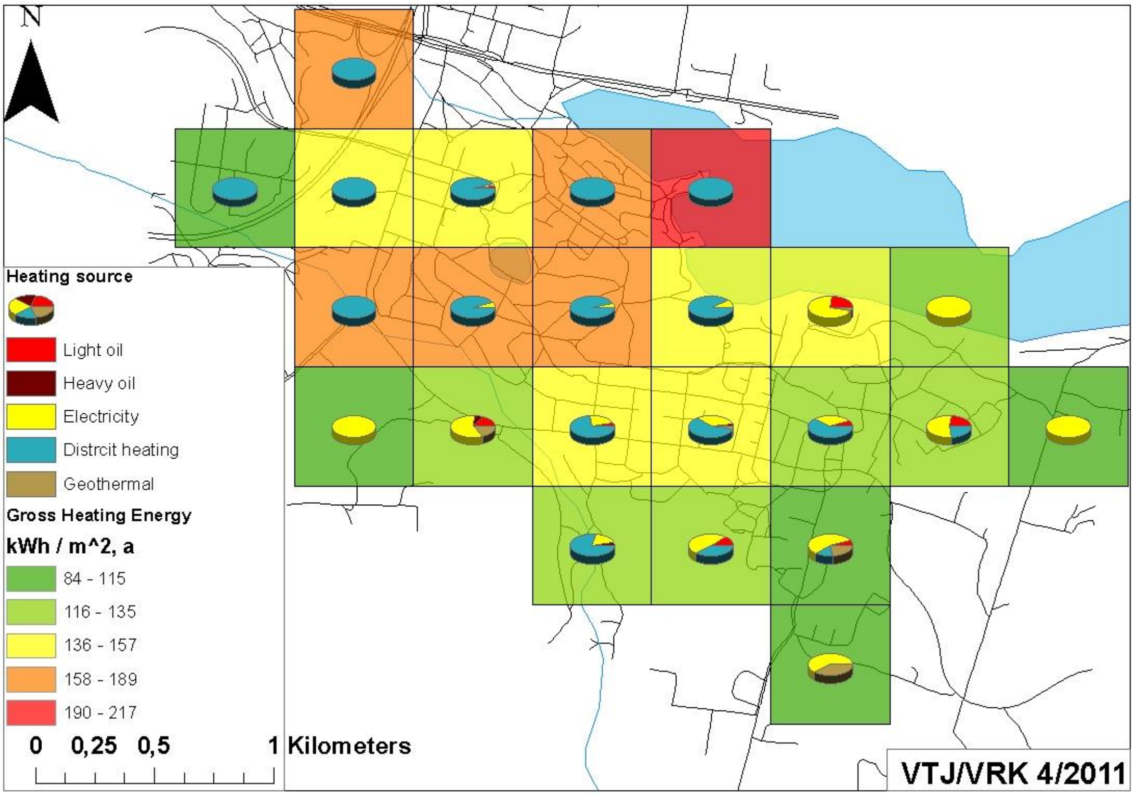

Figure 8 Primary heating source distribution and gross energy intensity map for Kaukajärvi.

Although the spatial heating distribution was shown in Figure 5, it is provided here to allow one to compare the heating source with the energy intensities of the buildings. The energy intensity is highest in the center and north of the district, while being the lowest in the south and east.

3.3 Greenhouse Gas Emissions

The total greenhouse gas emissions are presented below in two different figures. Figure 9 presents the emissions separately for all three house types, as well as the combined emissions, while Figure 10 present the emission intensities (kg CO_2/ m^2) for all residential buildings. The images are presented in a 500m x 500m grid in order to maintain privacy of the home owners.

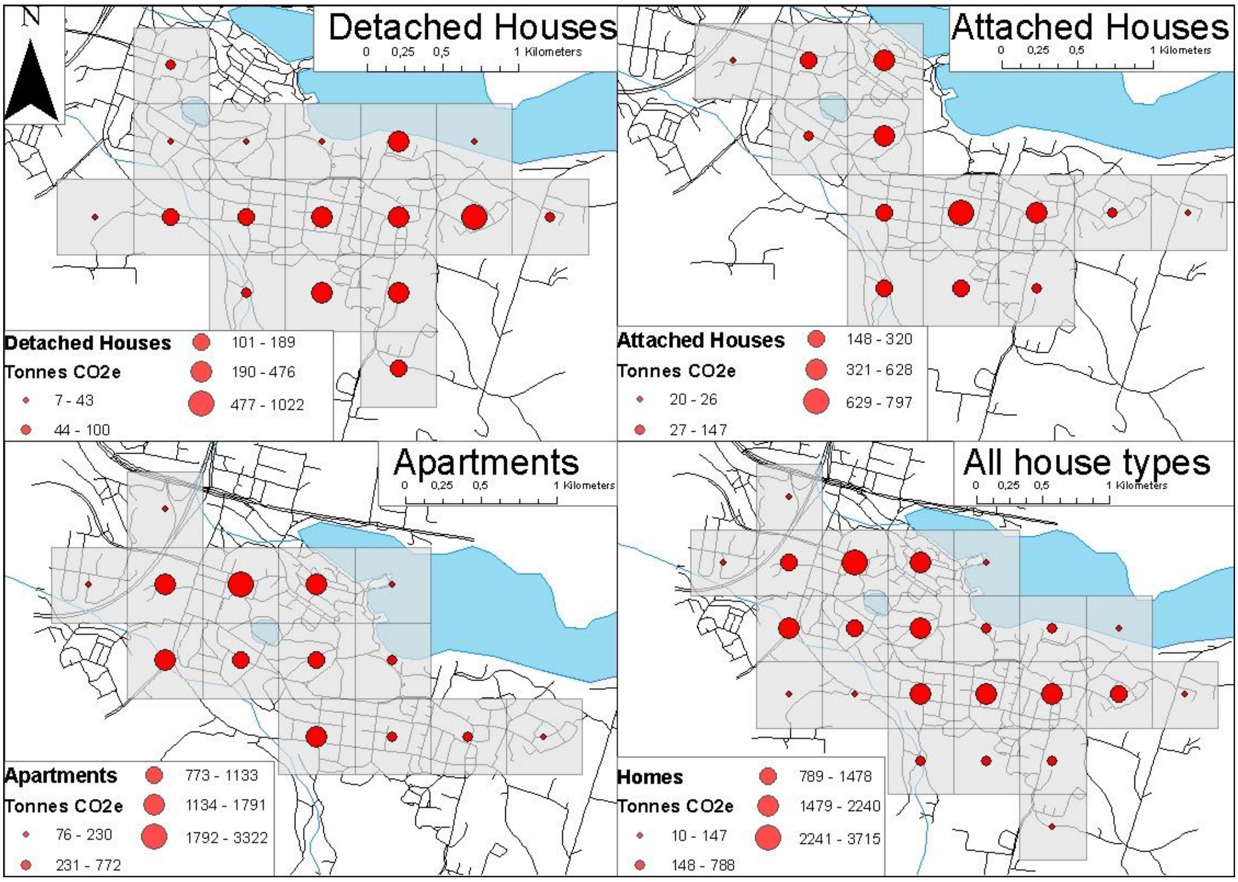

Figure 9 CO_2 equivalent emissions values for detached houses (top left), attached houses (top right), apartment buildings (bottom left), and for all house types (bottom right). They are presented in 500-500 meter grids. Circle size represents emissions, and varies between each picture.

Emission values in Figure 9 are represented as graduated circles, with the size of the circle representing the amount of emissions. The figure indicates where the highest emissions are located. Most detached houses are located in the east of the district, explaining the high emission values for that area. Attached houses are more spread throughout the district, where as apartment buildings occur mainly in the north and west of the district. Apartment buildings represent the largest total value of emissions, up to 3 322 tons of CO_2, whereas detached houses have the lowest emissions, with as low as 7 tones of CO_2. The total emission, seen on the bottom right, represents the sum of all homes in the grid cell. The total emissions for all house types and the entire district are shown in Table 6.

Table 6 Greenhouse gas emissions for Kaukajärvi

	GHG emissions (tones of CO_2e)
Detached houses	3814
Attached houses	3678
Apartments	14563
Total	22055

Figure 10 shows the sum of emission intensities for all house types in kg CO_2/m^2. Emission intensities are presented in order to normalize the emissions due to the large areas of apartment buildings, and attempt to show a comparison of emissions, rather than their magnitudes. Figure 10 is presented as gray-scale choropleth map, with black representing the highest emission intensities.

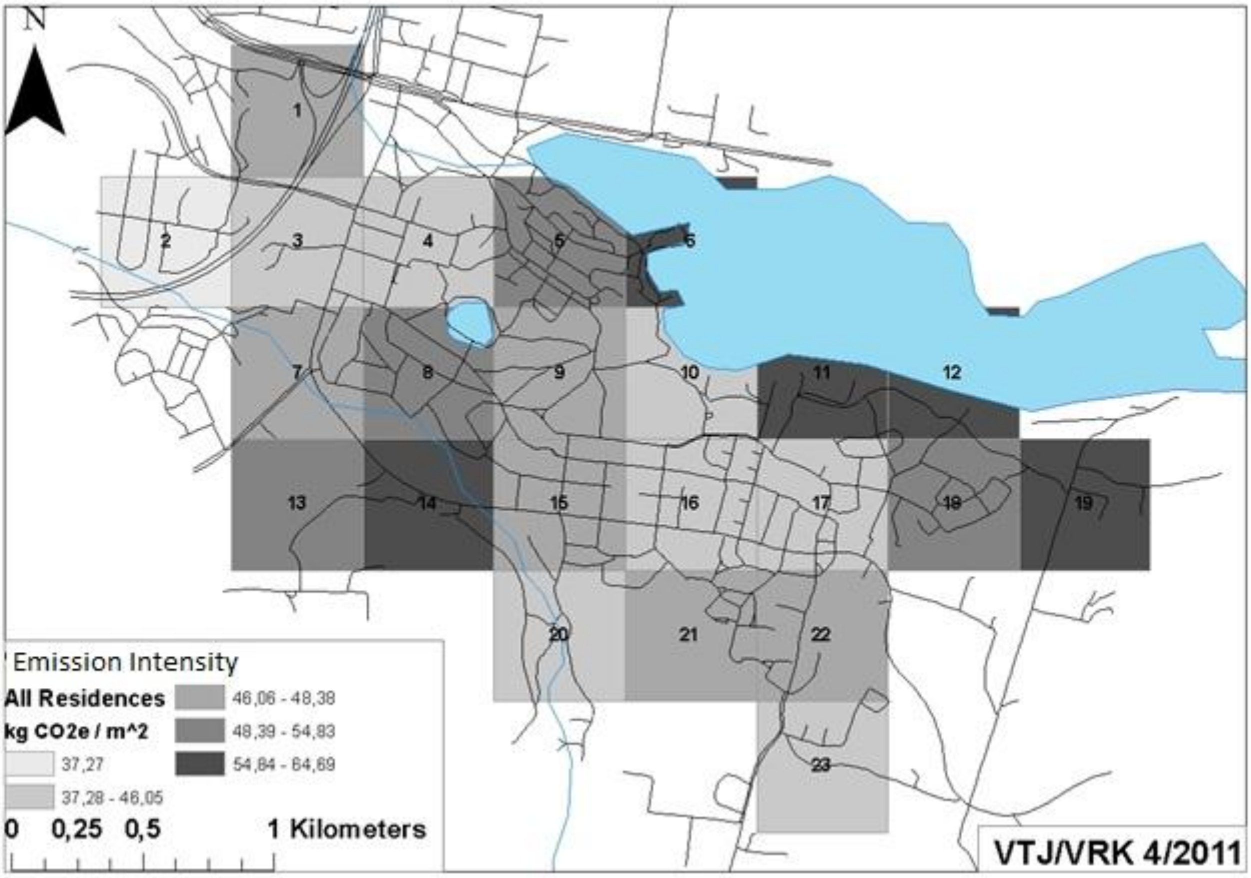

Figure 10 The emission intensity [kg CO_2e / m^2] for all residential buildings in the Kaukajärvi district.

The figure shows that the largest emission values are located around the lake's shore, in cells 6, 11, and 12, as well as in the South-East, cell 14. In cells 11, 12, and 14 there are only detached houses present, while in cell 6 there is only a single apartment building.

3.4 Sensitivity analyses

The sensitivity analysis results are presented in amount of change in total emissions in Table 7. The table shows that the parameter most sensitive to change is the volume of the buildings, followed by the emission factor for district heating at 3.2% and the area and the emission factor for household electricity at 1.1%.

Table 7 Sensitivity analysis with variation of 5% from original.

Sensitivity analysis	
Input parameter	**Emissions change (%)**
Volume	4.1
Area	1.1
Population	0.2
Emission factor (district heating)	3.2
Emission factor (household electricity)	1.1
U-values of structures	<1

Besides volume, the two emission factors, and the area, all other parameters were below 1% and therefore not very sensitive to change. The other emission factors were quite small, being below 0.5% and are therefore not presented. U-values were all below 1% and are therefore presented together.

3.5 Alternative heating scenarios

Scenario one (wood heating) and scenario two (Efficiency) are presented along with the original scenario below in Table 8.

Table 8 Alternative heating scenarios. Results are presented for energy consumption and greenhouse gas emissions.

Scenario	Energy consumption (GWH/a)	Emissions (tones of CO_2e)
Original	70,1	22 055
Scenario 1 (Wood)	74,6	19 846
Scenario 2 (Efficiency 150%)	67,8	21 148
Scenario 2 (Efficiency 175%)	67,3	20 925
Scenario 2 (Efficiency 200%)	66,9	20 757
Scenario 3 (Cool)	66,3	21 109
Scenario 3 (Warm)	74,0	23 001

Scenario 1 shows that though there is actually slightly more energy consumed (though there is naturally a decrease in electrical energy due to wood replacing electricity in detached homes), the emissions are reduced for the whole district by 14% to be 19 846 kWh . In Scenario 2 the emissions are reduced by only 10% to be 21 109 for the most efficient choice. Naturally there is a decrease in both energy consumed and the emissions in scenario 2 from the 150% efficiency to the 200%. The difference in emissions from 150% and 200% is only 2%. Scenario three shows that there is a ¨change of 4% when internal temperatures are changed for either positive or negative. With lower internal temperatures, it is also possible to lower the net energy consumption in the district.

4 Discussion

The energy consumption and greenhouse gas emissions were modeled in residential buildings using a bottom-up model that enabled the utilization of real data for houses in Kaukajärvi, a district in Tampere. The results were the calculated energy consumption and greenhouse emissions for each house in the district. The results show that the most important aspects of energy consumption and emissions were the chosen fuel type, the volume of the house, and the house type. Further, this showed how different parts of the built form were responsible for heat loss. Finally it was possible to show that spatial relationships are essential for proper planning in order to plan for energy saving and reduced emissions in the residential sector.

4.1 Primary heating source influence on consumption and emissions

Energy consumption in Kaukajärvi is dominated by district heating; this is especially true for apartment buildings of which all use district heating. Direct electrical heating is the second most common and is present in attached houses. Other heating sources exist in the area but are inconsequential when compared to district heating and electricity, as seen in Figure 4. The different emission factors for different fuels lead to different levels of emissions. The efficiency of the heating source also influences the consumed electricity. It is seen on chapter 3.4.3 that changing fuel sources (as seen in scenario 1) brought about a decrease in emissions, and increasing efficiencies (scenario 2) can reduce energy consumption and emissions. In chapter 3.4.2, there is evidence that the emission factors themselves can alter the results with even small changes. Although only district heating was a sensitive parameter, this is likely attributable to the high number of buildings that utilize district heating compared to other fuel choices, such as electricity and light fuel oil. Therefore, the emission factors and efficiency of the dominant heating source has a larger effect and is therefore more sensitive to changes.

4.2 Volume

Volume appears to be an influential parameter concerning energy consumption. Larger houses require more energy to heat, and have a larger surface area leading to an overall larger heat loss compared a smaller building as seen in Table 5. Apartment buildings account for a larger volume than all detached and attached houses combined, and thus require more energy to heat. Volume is also more sensitive to change, bringing about the largest variation in Table 7, much larger than population and area. This is important because the volume had to be estimated for 10 buildings, thus leading to a source of error. If the model encompasses more buildings, more houses would most likely need their volume calculated leading to a greater degree of error.

4.3 House type

Though apartments represent the largest source of energy consumption and emissions, Tables 5 & 6, their emission intensity is lower than detached and attached houses, Figure10. Apartments are located primarily in the north of the district while detached houses are in the south and attached houses are dispersed throughout the district. The emission intensity was determined by the kilograms of CO_2e per square meter of the building. Detached buildings have smaller area, therefore allowing a larger emission intensity than the apartment buildings with a larger area. Detached and attached house also use high emission heating sources (e.g. electricity, light fuel oil) than the apartment buildings leading more emissions for equivalent energy consumption. This is important because it means that for a much smaller area there are proportionally more emissions produced than for a larger building.

4.4 Heat loss through building structure

Heat loss occurs throughout the entire building structure, but the results presented in Figures 6 and 7 show that s certain aspects of the building lead to greater heat loss than others. Ventilation and windows provide the predominant area for heat loss throughout the building stock, though it does differ between building types. Renovation efforts aimed at energy efficiency could utilize the model in order to determine what efforts would prove the most effective for reducing heat loss throughout the building. It appears that the district utilizes near to no method of heat recovery (Table 4). If apartment buildings were to increase their heat recovery abilities, this could possibly save large amounts of energy, especially if this effort was focused on buildings built between 1960 and 1980. In detached and attached houses it would be easier to focus renovation efforts on windows because of the easy of replacing them and the amount of energy that is lost through them. Performing the sensitivity analysis on the U values showed that there was only a small change in the energy consumption and emissions. This would suggest that though there is significant heat loss through walls and windows changes in U values would produce little difference. This could be due to two things. First, and most likely, is that the change is so small that little effect can be achieved. The second is that the U values are already so low that changing them produces little difference.

4.5 Uncertainty in the data

A few known sources of uncertainty are inherent in the BDR dataset used. The first is that there is a ± 100 m coordinate marginal. Because of this error, the houses could be located in different blocks in the maps, introducing an error into the geographic analyses. Another error arises from the need to calculate certain input parameters (volume, area or population). By calculating the values from a conversion factor, the values are most likely not true, but assumed to be close to the truth. This can have an impact on the results of the model. Finally, it is possible that the heating source data is either out of date or inaccurate possibly due to residents changing heating systems without obtaining appropriate permits. Alternative heating sources, such as wood heating and heat pumps, are possible for residential homes.

5 Conclusion and future work

Modeling the energy consumption and greenhouse gas emissions of buildings enables a wide range of users to enact means to reduce consumption, lower emissions and choose the better ways to plan and develop buildings, cities and even countries. Focusing my research on a small district of the city in Tampere shows that the model can be successfully used for local developers and managers for planning local areas. The model allows one to see the effects of the chosen heating sources, house types, as well as building features while the integration of geographic information systems takes into account the spatial layout of the district to help not only visualize the results, but also provide a deeper understanding of the role of geography and spatial relationships that are essential in planning an environment that is more sustainable by providing insight into what is already present in an area (heating sources, accessibility for fuels, access to renewables).

The Ekorem model is an engineering-based model, meaning it utilizes the physical attributes of buildings to predict consumption and emissions. Although this is an important and useful method, it lacks any behavioral aspects that have can have a large effect on energy consumption. Though I attempted to rectify this with my temperature scenario, greater strides could be made towards integrating different behavioral patterns when it comes to energy consumption. One area of future research would be to find a method to incorporate behavioral energy use patterns into the model, thus enabling a greater accurate simulation of energy consumption. Another possible expansion for the model would be to include air pollution emissions based on energy consumption and the primary heating source. Such a model would be able to predict health hot spots and possible environmental damage due to energy choices in the home.

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