Comparison of Residential Energy Consumption in Different Geographical Areas and Relevance for Environmental Policy

Rolf André Bohne¹, Lizhen Huang¹ and Annemie Wyckmans²

1. Department of Civil and Transport Engineering, Norwegian University of Science and Technology, Trondheim 7491, Norway

2. Department of Architectural Design, History and Technology, Norwegian University of Science and Technology, Trondheim 7491, Norway

Abstract: Residential energy consumption is varying considerably worldwide. In order to understand these variations, and thus design effective policies for energy reductions, one needs a better understanding of the different drivers behind these variations. A comparison of geographical areas with similar climate and socio-economic conditions has shown significant variations in residential energy consumption across otherwise comparable case studies. This research paper aims to identify cultural and historical parameters that contribute to these significant variations, including economic, environmental and social traditions related to local availability of natural resources. Furthermore, the transferability of these parameters is evaluated, taking into consideration local legislation and planning documents, and historic and socio-economic accessibility of resources. It is evaluated to which degree these parameters can be transferred and included into building assessment tools and policy documents for planning and transformation of sustainable urban neighborhoods.

Key words: Residential energy use, income, culture, climate zones, policy.

1. Introduction

Shelter and warmth—they are as essential as food for survival. Adequate living space and warmth increase the quality of human health, which is a main result of human wealth. Yet one can not get shelter and warmth without consuming natural resources.

A better understanding of cultural drivers and the socio-spatial relations they create may help indicate successful paths for transition towards more energy and resource efficient buildings districts and cities that provide a high quality of life for all of their users. The character of residential buildings and neighborhoods is inherently related to quality of life issues such as security and comfort, identity and heritage, status and

property [1]. Quality and appearance of people's own homes and the neighborhood in which they reside, as well as the standard of local services, further determine quality of life [2]. Local character includes, amongst others, the presence of natural and human history, the morphology of the settlement, the nature of the routes that pass through it, and the people and communities living in or near the area [3].

The construction and management of buildings, districts and cities is thus an important economic sector that influences people's daily lives in a profound manner. In addition, it also exerts a large impact on energy and resource consumption, biodiversity, climate change mitigation and adaptation. In order to reduce this impact, renovation of existing buildings is crucial: The annual growth rate of new buildings added to the housing stock in the EU27, for example, is estimated at around 1%-1.5% of the housing stock per year, while the number of buildings

Corresponding author: Rolf André Bohne, Ph.D., research fields: environmental impact assessment of buildings and building components, resilience and sustainable development of neighborhoods and cities. E-mail: rolf.bohne@ntnu.no.

removed from the stock only amounts to about 0.2%-0.5% of the housing stock per year [4]. Unfortunately, few components and services are developed for the renovation market.

In addition, there is lack of holistic building models in which installation of components, service and maintenance is managed as a whole, centered around users' needs, preferences and behavior. Houses typically need to be sufficiently robust to incorporate a myriad of changes in the daily lives of their occupants: "Homes are the steadiest changers, responding directly to the family's ideas and annoyances, growth and prospects, etc.. Reality-based change is constant and relentless. Babies arrive, become kids, become older kids, leave; dependent aging relatives arrive, die; money comes, money goes; divorce hovers; careers change; everybody keeps on maturing in their tastes and activities" [5].

Current energy services do not reach optimal performance in terms of balancing basic human needs and individual preferences with resource and cost efficiency [6]. The Leipzig Charter on sustainable European cities declared that "we need to tackle the combined challenges of climate change adaptation, mitigation and resource efficiency while ensuring cultural diversity and establishing high quality in the fields of urban design, architecture and environment (2007) [7]. The United Nations Environment Programme recently concluded that "(due to) deeply-rooted attitudes and practices relating to how people establish patterns of comfort and efficiency, etc. understanding the economic and psychological rationale of decisions made by individuals and

institutions is increasingly recognized as fundamental to achieving energy-efficiency improvements in buildings" [8].

Dwellings perform differently from region to region. Energy consumption is impacted by climate and socio-economic factors, as indicated in Table 1 and Fig. 1.

Compared with other spatial factors, the most significant considerations are climatic conditions, including local temperature, humidity and ambient natural light. There is a clear need to take climatic conditions into consideration when a building's energy efficiency is evaluated. In this paper, the authors do a comparative analysis of residential energy consumption between geographical areas with similar climate and socio-economic conditions.

This paper will discuss residential energy consumption in regions with similar climate and economic situation, but with different cultural backgrounds. The authors will use data from two climate zones while taking temperature as the key factor in the Köppen Climate Classification system Table 2 [9].

2. Differences within the Same Income Group and Climate Zone

To identify indications of how culture may influence residential energy consumption, the authors have compared different countries with comparable economical and climatic conditions, but with different cultural background. In this paper, the authors compare four countries from two different climate zones, with each other.

Table 1 Summary of impacts on residential energy use.

	Dimensions	Key determinants	Related subdivision	Characters
Exogenous	Environment	Temperature, sun light, precipitation	Heating/cooling, lighting	Long term, most local, least flexible
	Socio-economic	Price and availability of fuels and appliances, cultural preferences	All	Medium term, political
Endogenous	Socio-economic	Income, household size, age structure, occupants' behavior, habit (norms, value)	All	Medium term, local, less flexible
	Technology	Efficient energy technology	All	Short term, flexible, global

Comparison of Residential Energy Consumption in Different Geographical Areas and Relevance for Environmental Policy

Fig. 1 Subdivision of energy consumption in residential buildings in selected places.

2.1 OECD-Europe versus New Zealand in Climate Zone Cb

The climate, income and culture of New Zealand are comparable to OECD-Europe countries in climate zone Cb. However, residential energy consumption per capita in OECD-Europe is quite a bit higher than New Zealand (Fig. 2), while they have the same decreasing trend in personal and dwelling floor area energy intensity. There are some facts that could explain this phenomenon. Firstly, the largest portion of New Zealand household energy consumption is space heating at 34%, then hot water at 29%, and refrigeration, other appliances, lighting and range (cooking) at around 10% each [10]. New Zealand is not a high-income country by OECD standards, New Zealanders are not extravagant with home heating and low indoor temperatures are common [11]. An international energy agency report [12] notes that on a climate-corrected basis, New Zealand had the lowest residential sector energy use per capita in comparison with Australia, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Sweden, the United States and the United Kingdom. New Zealand had the lowest space heating

intensity—measured as energy per square meter per degree day—of all the countries studied by 1995. According to the New Zealand Census in 2001 and 2006, nearly 3% of people used no heating at all [13] and almost a third of households had an average winter temperature below the WHO's (World Health Organization's) healthy indoor temperature minimum of 18 °C. Isaacs et al. [10] conclude that mean daily living room temperatures were close to 16 °C excluding the Southern South Island and bedrooms are on average slightly colder than living room and little heated. Secondly, the biggest part of housing stock in most OECD countries was built between 1946 and 1970 [14]. For example, 47.2% houses in Germany and 30.9% in Netherlands were constructed in that period. In New Zealand, the percentage of houses that were built earlier than 1970 decreased from 70% in 1999 to 55% in 2005 [15]. Since April 1, 1978, the addition of thermal insulation has been a mandatory requirement for New Zealand houses. Thus post-1978 houses have lower average heat losses and require about 20% less energy to heat to the same temperature [10]. Also in Europe houses become insulated during this period, but the building stock is much older, that is—the building stock is less insulated on average.

Table 2 Description of climate symbols and defining criteria.

Type	Description	Criterion
A	Equatorial climates	$T_{min} \geq +18^{\circ}\text{C}$
Bh	Arid climates with hot steppe/desert	$P_{ann} < 10 \text{ Pth}$ and $T_{ann} \geq +18^{\circ}\text{C}$
Bk	Arid climates with cold steppe/desert	$P_{ann} < 10 \text{ Pth}$ and $T_{ann} < +18^{\circ}\text{C}$
Ca	Warm temperate climates with hot summer	$-3^{\circ}\text{C} < T_{min} < +18^{\circ}\text{C}$ and $T_{max} \geq +22^{\circ}\text{C}$
Cb	Warm temperate climates with warm summer	$-3^{\circ}\text{C} < T_{min} < +18^{\circ}\text{C}$ not a and at least 4 $T_{mon} \geq +10^{\circ}\text{C}$
Cc	Warm temperate climates with cool summer and cold winter	$-3^{\circ}\text{C} < T_{min} < +18^{\circ}\text{C}$ not b and $T_{min} > -38^{\circ}\text{C}$
Da	Snow climates with hot summer	$T_{min} \leq -3^{\circ}\text{C}$ and $T_{max} \geq +22^{\circ}\text{C}$
Db	Snow climates with warm summer	$T_{min} \leq -3^{\circ}\text{C}$ not a and at least 4 $T_{mon} \geq +10^{\circ}\text{C}$
Dc	Snow climates with cool summer and cold winter	$T_{min} \leq -3^{\circ}\text{C}$ not b and $T_{min} > -38^{\circ}\text{C}$
Dd	Snow climates with extremely continental	$T_{min} \leq -3^{\circ}\text{C}$ not b and $T_{min} < -38^{\circ}\text{C}$
EF	Tundra climate	$0^{\circ}\text{C} \leq T_{max} < +10^{\circ}\text{C}$
ET	Frost climate	$T_{max} < 0^{\circ}\text{C}$

a Hot summer $T_{max} \geq 22^{\circ}\text{C}$;

b Warm summer not a and $T_{mon10} \geq 4^{\circ}\text{C}$, T_{mon10} = number of months where the temperature is above 10°C ;

c Cold summer not (a, b or d);

d Very cold winter not (a or b) and $T_{min} < -38^{\circ}\text{C}$.

Fig. 2 Comprising of OECD-Europe versus New Zealand from climate zone Cb.

Comparison of Residential Energy Consumption in Different Geographical Areas and Relevance for Environmental Policy

Fig. 3 Comparing of USA (Ca) versus Japan from climate zone Ca.

2.2 USA versus Japan in Climate Zone Ca

Another interesting comparison within OECD countries can be made between Japan and USA (climate zone Ca) with similar living level, but different cultural traditions. Residential energy consumption per m^2 in Japan is somewhat less than USA. The average value from 1990 to 2005 in Japan is $129.8 \text{ kWh}/(\text{m}^2 \cdot \text{year})$ compared $160.5 \text{ kWh}/(\text{m}^2 \cdot \text{year})$ in USA. While compared with the time series from 1990 to 2005, USA has made more improvement in dwelling energy efficiency (Fig. 3). Household size in these two countries is nearly the same (about 2.6 persons/household), but the dwelling size is quite different. The average dwelling size per capita in Japan is half that of the USA value. The household size decreased while the dwelling size

increased in the past two decades in these two countries. That means that the increase in residential energy efficiency due to building technology improvement is severely weakened by the concurrent rise in dwelling size.

In addition, residential energy consumption per capita in USA is more than double to Japan (Fig. 3a). The main reason for this huge difference comes from energy end-use patterns, which are deeply affected by traditional cultures. Japanese and other Asian countries have a good tradition in saving. Japanese tend to heat only one room when they are at home [16], while Americans tend to heat the whole house even though their houses are much bigger than those in other countries. In a similar pattern, most occupants only use artificial lighting in the room in which they reside and tend to turn off the lights when they leave

the room or house in Japan. The average temperature for washing clothes in western countries is 40-60 °C while eastern countries households wash their clothes in room temperature. Furthermore, the residential energy per capita in Japan slightly increased from 1990 to 2007, while the residential energy per capita in USA showed a decreasing trend. This phenomenon is mainly due to the result of the Japanese culture changing to a more western lifestyle—including energy use [17]—even though both cultures are introducing more energy efficiency household appliances and buildings. It is a strong indication of the cultural role in energy consumption.

3. Conclusions and Discussions

Residential energy consumption is varying considerably worldwide. In order to understand these variations, and thus design effective policies for energy reductions, one needs a better understanding of the different drivers behind these variations.

A starting point for such understanding is the study of comparable areas in term of income and climatic conditions. In this paper, the authors have shown that residential energy consumption is varying considerably, despite relatively equal climatic and economic conditions in different parts of the world. Comparison of statistical data suggests that cultural indicators and particularly their development over time, influence residential energy consumption of individual households and society as a whole. These cultural indicators can on the one hand be linked to building type and age and the historical development of building practice in local societies. Such variations are decreasing due to globalization of economy, building industry and lifestyles. In addition, increasing income and comfort standards appear to influence energy and resource efficiency in a negative manner, particularly in cultures that have a large tradition of energy saving.

The study does also point towards another interesting feature of how the authors collect and

present available data. Most often data are presented as kWh/m², not kWh/capita. The difference, as shown in Fig. 3, is dramatic. Identifying the impact of these divergent indicators of effectiveness is crucial in order to address and avoid the rebound effect, where “efficiency gains from a new technology are undermined by increase in consumption of the resource involved” [8]. A per m² energy performance target, does not limit the total energy usage in buildings—unless a per capita (design) limit is enforced. Also, as per capita floor space decreases, energy consumption per m² increases, due to the basic need for hot water and cooking. Policies should be designed in such a manner that one facilitates residential building design with the overall lowest energy usage per capita. In this regard, one also needs to look at the bigger picture, and include infrastructure and transportation on a per capita basis in further studies, in order to design effective policies. If such holistic approach is pursued, necessary policies can be designed for the creation of sustainable neighborhoods.

Last, the study shows the importance of addressing existing building in climate change mitigation. Already the authors have existing technologies that enables people to build buildings with an average energy use for floor heating of less than 15 kWh/m²yr⁻¹, more than a factor of 10 down from the existing energy use. But the real potential lies within the renovation and refurbishment of existing buildings, as well in technologies for the control of energy usage, such as light and heating control. However, according to a recent study by the ECEEE [18], “despite some excellent initiatives and approaches to improving the energy performance of existing buildings, the immense potential for cost effective energy saving and carbon reduction is unlikely to be achieved without a combination of: strong policy drivers, effective financing schemes and increased propensity among building owners/occupiers to take action.” More profound knowledge of local cultural drivers can help

set up targeted performance-driven programs for large-scale implementation of energy efficient renovation of residential buildings.

Acknowledgments

This paper has been written in the project “knowledge base and tools for development and management of a sustainable infrastructure”. The authors acknowledge the financial support from the Research Council of Norway. The authors also acknowledge the anonymous referee for the constructive suggestions.

References

- [1] K. Dovey, *Becoming Places*, Urbanism/Architecture/Identity/Power, Routledge, London, 2010.
- [2] A. Creedy, C. Zuidema, G. Porter, G. De Roo, *Towards Liveable Cities and Towns*, Guidance for Sustainable Urban Management, <http://www.eukn.org/dsresource?objectid=149541> (accessed Apr. 23, 2013).
- [3] D. Walton, *Urban Design Compendium*, English Partnerships, London, 2nd ed., 2007, <http://www.newham.gov.uk/nr/rdonlyres/9974efa4-359a-4734-a8c9-fb0d81d90e8f/0/udc.pdf> (accessed Apr. 23, 2013).
- [4] Ad-hoc Industrial Advisory Group, 2010 Energy-Efficient Buildings PPP, Multi-annual Roadmap and Longer Term Strategy, http://www.ectp.org/cws/params/ectp/download_files/36D1191v1_EeB_Roadmap.pdf (accessed Apr. 23, 2013).
- [5] S. Brand, *How Buildings Learn: What Happens after They Are Built*, Penguin Books, New York, 1995.
- [6] R. Haas, J. Watson, W. Eichhammer, Transitions to sustainable energy systems—Introduction to the energy policy special issue, *Energy Policy* 36 (2008) 4009-4011.
- [7] Leipzig Charter on Sustainable European Cities, European Council of Ministers, May 24, 2007, http://www.eukn.org/E_library/Urban_Policy/Leipzig_Charter_on_Sustainable_European_Cities (accessed Apr. 23, 2013).
- [8] P. Rode, R. Burdett, Cities: Investing in energy and resource efficiency, in: United Nations Environment Programme UN, 2011, pp. 452-493, <http://www.unep.org/greeneconomy/GreenEconomyReport/tabid/29846/Default.aspx> (accessed Apr. 23, 2013).
- [9] M. Kottek, J. Grieser, C. Beck, B. Rudolf, F. Rubel, World map of the Koppen-Geiger climate classification updated, *Meteorologische Zeitschrift* 15 (3) (2006) 259-263.
- [10] N. Isaacs, K. Saville-Smith, M. Camilleri, L. Burrough, Energy in New Zealand houses: Comfort, physics and consumption, *Building Research and Information* 38 (5) (2010) 470-480.
- [11] P. Howden-Chapman, H. Viggers, R. Chapman, D. O’Dea, S. Freeand, K. O’Sullivan, Warm homes: Drivers of the demand for heating in the residential sector in New Zealand, *Energy Policy* 37 (9) (2009) 3387-3399.
- [12] L. Schipper, M. Grubb, On the rebound? Feedback between energy intensities and energy uses in IEA countries, *Energy Policy* 28 (6-7) (2000) 367-388.
- [13] Census Data of Population and Dwellings 2006, Statistics New Zealand, Wellington, 2006, <http://www.stats.govt.nz/Census/2006CensusHomePage/QuickStats/quickstats-about-a-subject/housing/heating-fuels.aspx> (accessed Apr. 23, 2013).
- [14] K. Dol, M. Haffner, *Housing Statistics in the European Union 2010*, OTB Research Institute for the Built Environment, Delft University of Technology, Delft, 2010.
- [15] New Zealand 2005 House Condition Survey, BRANZ Ltd. Study report No. 142, BRANZ Ltd, Porirua, 2005.
- [16] H. Wilhite, H. Nakagami, T. Masuda, Y. Yamaga, H. Haneda, A cross-cultural analysis of household energy use behaviour in Japan and Norway, *Energy Policy* 24 (9) 795-803.
- [17] H. Nakagami, Lifestyle change and energy use in Japan: Household equipment and energy consumption, *Energy* 21 (12) (1996) 1157-1167.
- [18] Steering through the Maze # 4, Capturing the Collective Knowledge Base on Building Retrofit, A report, European Council for an Energy Efficient Economy, 2011, http://www.eceee.org/press/New_maze_guide/eceee_steering4.pdf (accessed Apr. 23, 2013).