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Monthly domestic hot water profiles for energy calculation in Finnish apartment buildings

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ABSTRACT

Domestic hot water (DHW) profile is required to estimate energy use and system design. Few onsite data and simulation-based studies are available in literature focusing on hourly profile, individual consumption with seasonal variation and occupant number. This paper investigated onsite DHW daily consumption in 182 Finnish apartments with 379 occupants during two consecutive years. DHW monthly consumption rates and monthly consumption factors for full week, weekdays, and weekend were derived allowing of calendar months variation. The average consumption was 43 L/person/day whereas maximum and minimum consumptions were noted, respectively in November and July. The variation was observed between weekdays and weekend too, being mostly in the range of 20–70 L/person/day and DHW ratio varied from 0.3 to 0.5. Higher consumption trend during November to February were noticed whereas opposite behavior was observed during May to July. Apartment's size affected specific consumption and smaller apartment consumption was higher by factor of about 1.5. The obtained profiles effect on the energy use was tested with dynamic simulation of solar thermal system. The derived monthly profile increased delivered energy by 4.7% compared to simulation without monthly variations. The weekday and weekend consumption variations did not have significant effect on delivered energy.

1. Introduction

Residential building sector has consumed 16–50% of total energy at national level in most of the countries [1], which is also responsible for higher emission of greenhouse gas. Domestic hot water (DHW) is accounted a large percentage of it. In United Kingdom, almost 20% of domestic energy is used for DHW purposes [2]. Residential buildings have consumed 72% of total DHW volume where as 12% and 16% are required for small and large-scale office users [3]. The key purposes such as washing, bathing, laundry, drinking, and cleaning are noted. The consumption rate depends on many primary functions such as occupant behavior, occupancy rate and number, demographic condition, appliance, ownership, etc. [4]. In addition, life style and personal comfort have played a significant role. Thus, it is observed higher fluctuation of consumption among apartments and buildings. Sometime it is hard to understand the actual reason of unpredictable fluctuation and consumption variation from apartment to apartment or household.

The importance of occupant number on DHW consumption was discussed by Merrigan [5] in briefly. He found a linear relationship of this two and added 45 L/day for each additional person where the occupant number was above 2. Another study also found the same relation between occupant number and total hot water use [5]. Parker [6] noticed occupant number as the key determinants of DHW consumption and importance of occupancy pattern for modeling of domestic energy consumption [7]. In another study, Evarts and Swan [8] found higher DHW consumption for household of three people or less. It also noticed lower consumption rate when the household was occupied with four person or more [8]. Furthermore, ownership, income, age, activity have great influence on DHW consumption. The consumption of energy in case of using appliances, lighting, DHW was depended on the activity of the apartment residents [9]. According to the Canadian Mortgage and Housing Corporation [10] Canadian senior's buildings consumed less than 44% DHW compare with the standard family apartment buildings. Other finding had noticed the presence of the

Abbreviations: HVAC, heating ventilation and air condition; DHW, domestic hot water; RE, renewable energy; WD, week day; WE, weekend; IDAICE, IDA indoor climate and energy.

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Table 1
Domestic hot water (DHW) consumption rate of apartment buildings in Nordic countries.

	L/person/day
Finnish [18]	46.0
Estonian [19]	40.3
Swedish [20]	33.0
Danish [21]	20.0
Norwegian [22]	40.0

children caused higher consumption rate of DHW [11]. Foekema and Engelsma [12] also concluded the relationships in between age and frequency of use, age and shower duration, penetration rate, and household size in Dutch buildings. Sometimes higher consumption is observed in owner occupied apartments [13]. However, it is hard to identify the actual number of occupant, age, income due to privacy, and personal problem.

Many studies found different consumption rate for different nationality, which are quite different from each other. Becker and Stogsdill [14,15] studied on nine North American apartments and found the consumption rate was 239 L/day/apartment. During investigation of this study also considered the seasonal variation, ownership, and occupant ages. Canadian house hold consumption was recorded 236 L/day and per capita use was varied from 47 to 86 L/day, which was based on the number of person [16]. In another Canadian study concluded that typical Canadian household consumed 208 L/day and individual average was 67 L/day [4]. VTT drew a conclusion on six Finnish households' consumption. The finding was reported 135 L/day by each household and 43 L/day for individual occupant [17]. The geographical location might be the important parameter of DHW consumption. In Table 1 is shown individual average consumption of Nordic and Baltic country.

The hourly DHW consumption profile is different for different country, i.e., every country has its own hourly DHW profile. The hourly profile depends on the local custom and tradition. The water consumption for Dutch people during sleeping hours, peak hours, and rest of the hours are respectively, 1.5%, 65%, and 33.5% [23]. The Finnish people consume higher DHW at evening and lower during morning [17] whereas Germans are behaving in reversely. In another investigation found the relation between the appliance and the water consumption [24]. Clothes washer, dishwasher event also count as a higher impact on water consumption and energy use, which are positively related with the household size and wealth class [12,25]. The previous statement also validated by Widen et al. [26]. They had shown the variance of hourly basis profile of shower, kitchen work, and wash stand during weekdays and weekend for detached and apartment house [26]. Another important dominating factor is local climate condition and seasonal variation, which are correlated to consumption volume and required energy to heat up supplied water. Goldner [11] described the impact in New York City and showed the increment of consumption volume around 10% and 13% from summer to fall and summer to winter, respectively. It was also shown the variation of consumption during weekdays and weekend which was noted almost 7.5% [11]. In another study by Bouchelle and Parker [27] had commented the increment of 30% consumption on coldest winter days compare to the mildest days in Florida. The behavior was quite significance for Australian weather which pointed out almost 30–48% of DHW consumption variation [28].

The previous study had shown the effect of different factors on DHW consumption, reason for variation, hourly profile of different countries. The conclusion was based on the short period of duration, consumption rate for full apartment without consideration the exact number of occupants and their status, expression of consumption rate in term of energy instead of average occupant consumption volume, absence of monthly variation, etc. In addition, most of the cases results had drawn based on the simulated model instead of real onsite data. Yao and Steemer [2] had drawn a conclusion regarding the importance of exact figure of daily consumption and occupant information for generating DHW profile. The implementation of obtained profile was discussed very shortly which could be integrated with renewable energy sources in broad sense. Lamnatou et al. [29] had made the life cycle analysis (LCA) of building's integrated solar thermal system and showed the benefits in term of energy efficiency and environmental impact. In addition, the optimum efficiency of solar thermal system depends on the storage capacity, occupancy rate, tilt angle of panel, and geographical location [30].

Table 2
Apartment type in buildings A–D.

	Building A	Building B	Building C	Building D
One room apartment	6	–	30	14
Two rooms apartment	6	30	18	20
Three rooms apartment	9	4	3	12
Four rooms apartment	4	4	3	10
Five rooms apartment	2	4	3	–
Number of apartments	27	42	57	56

Table 3
Actual occupant number in apartment of buildings A–D.

Occupancy in apartment	Building A	Building B	Building C	Building D
One person occupied apartment	6	19	37	22
Two people occupied apartment	10	13	12	13
Three people occupied apartment	4	3	2	7
Four people occupied apartment	4	2	1	12
Five people occupied apartment	3	3	2	1
Six people occupied apartment	–	2	3	–
Total number of occupants	69	89	99	122

This paper has drawn the monthly DHW user profile for Finnish residential apartment building with consideration of monthly, weekdays, and weekend variation factors for whole year. The profiles are prepared from onsite data of 182 Finnish apartments during two consecutive years and are based registered on occupant number in apartments. The result shows the seasonal variation of DHW consumption as well as obtain individual monthly factor for different months. The arithmetic mean consumption rate and the consumption variations are also calculated. In addition, consumption ratio of DHW to cold (total) water consumption is calculated for all months. Obtained monthly profiles are prepared to be included to Finnish building code. A solar thermal simulation example is run to show the effect of obtained profiles on delivered energy of top-up heating.

2. Method

2.1. Target buildings and apartments

The study is accomplished based on the actual consumption data of 182 Finnish apartments with 379 occupants. Around 24% of occupants were less than 18 years old whereas the rest of occupants were more than 18 years old. Exact data of age, gender, and income scales was not possible to collect because of being privacy-protected data. Apartment type and social structure of the tenants are reported in Tables 2 and 3.

Two consecutive year's daily basic data sets of domestic hot water and cold water were used to draw the user profile of DHW