CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 3

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). *CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 3*. Department of Civil Engineering, Aalborg University.

Hourly Consumption Profiles of Domestic Hot Water for Finnish Apartment Buildings

Kaiser Ahmed [1,*], Petri Pylsy [1, 3], Jarek Kurnitski [1, 2]

[1] *Aalto University, Department of Civil and Structural Engineering, Finland*
[2] *Tallinn University of Technology, Faculty of Civil Engineering, Estonia*
[3] *The Finnish Real Estate Federation, Finland*
**Corresponding author: Rakentajanaukio 4 A, FI-02150 Espoo, Finland; E-email: kaiser.ahmed@aalto.fi*

Abstract

The hourly profile of domestic hot water (DHW) is required for system sizing and energy simulations. This paper addresses the hourly DHW profiles for Finnish apartment buildings. The hourly consumption of 191 occupant during one year data were processed. Hourly profile for August, November and January had similar consumption pattern and monthly variation of consumption were also illustrated. Higher variation of consumption was noticed during peak hours and 90% of consumption variation were in between the range of 0-20 L/per./hour. The average consumption during peak and non-peak hours were 3.6 and 1.5 L/per./hour respectively. To understand the effect of the number of occupants on hourly peaks five profiles were drawn for one person, 3 people, 10 people, 31 people and 191 people group. All profiles followed similar DHW consumption pattern and a specific selection procedure was applied for a number of good candidates in order to select the most representative real consumption data based profile for each group. The results revealed higher evening peaks compare to morning peak and smaller groups had a higher peak consumption values compared to large groups. The obtained profiles accompanied by scaling factor can be used with monthly consumption factor of DHW to deliver the hourly profile for any month. Average DHW ratio was 0.31 and varied from 0.10 to 0.39, but was not sensitive to hourly consumption.

Keywords - Domestic hot water, hourly profile, DHW ratio

1.0 Introduction

Domestic hot water (DHW) accounts the second largest use of energy, next to space heating, in Finnish buildings [1]. Almost 72% of DHW volume are consumed by the residential building and rest of them are used in small and large scale office buildings [2]. Washing, bathing, laundry, drinking and cleaning are the main purposes of DHW usages. Experience has shown that DHW consumption depends on many factors such as user behavior, occupancy rate, demographic location, climate condition, user age, income, appliance quality etc. The average daily consumption of DHW for Finnish and Swedish are 46 and 33 L/per./day respectively [3, 4]. Considering the consumption variation during a year authors developed monthly consumption factor for Finnish residential building in [5] which summary is shown in table 1. Furthermore, hourly DHW consumption pattern seems to be unique characteristic for every country. Germans consume higher DHW at morning and lower during evening whereas Finnish people consumption pattern are opposite [6].

Vine et al. investigated DHW hourly consumption of four low income apartment buildings in California. The obtained profile was drawn based on hourly average of 15 units DHW consumption for a short duration [7]. In another study [8], hourly water consumption profile was drawn by summing up the consumption of all end uses. This result was obtained based on statistical data of user in household and each end uses information i.e., frequency of occurrence, flow intensity and duration. In this study, authors have applied different approach. Authors are considered each apartment hourly basis consumption from smart metering system and exact occupant number. The information of each end uses were not available. Hourly profiles were drawn based on selection of actual representative consumption profiles of induvial occupants. The results show real peaks which were strongly damped when larger groups of occupants were analyzed.

2.0 Method

2.1. Description of target building and apartments

The study is accomplished based on the actual hourly consumption of domestic hot water (DHW) and cold water (DCW) data from 86 Finnish apartments. All apartments with 191 occupants belong to one large rental apartment building which is located in Helsinki, Finland. Table 2 lists the apartment number, apartment type and family size.

Table 2: Apartment number, apartment type and family size in building

Apartment type	No	Occupancy in apartment	No
One room apartment	2	One person occupied	24
Two room apartment	20	Two people occupied	31
Three room apartment	27	Three people occupied	15
Four room apartment	30	Four people occupied	15
Five room apartment	7	Five people occupied	1

Most of the Finnish population are living in Helsinki, Tampere and Turku which are covered by climate zone 1 and 2. The annual average outdoor temperature of climate zone 1 and 2 are 5.3 and 4.6 °C respectively. The study data represents well the majority of Finnish population, however some Northern part of Finland having extreme winter may apply different profiles of DHW. The obtained profile with monthly correction factor from [5] could consider as hourly user profile of DHW for Finnish apartment building. The required heating energy for space heating and DHW was supplied by the central district heating system of all rented apartments. The required energy for DHW was measured in kWh. The data was collected from 01.05.2014 to 30.04.2015 with 1 hour interval period. According to Finnish building code the minimum and maximum value of supply water temperatures are 55 and 65°C respectively which are usually in the range between 55 to 60 °C. In this study, the maintenance staff confirmed that the supply water temperature compliance with the minimum Finnish building code value of 55°C [9]. Each apartment had two individual meter which was taken readings of DHW and DCW separately. Occupants were using DHW for bathing, shower, body washing and kitchen facilities. Each apartment also own dishwasher and washing machine but those were not connected with DHW but DCW.

2.2. Data measurements

The accuracy level of measurement devices was good i.e., ± 2 %. The measured data were stored in a database with a resolution of 1.0 liter. The individual smart water metering system provided measurement for each apartment as follows

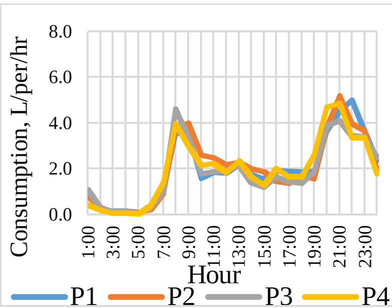
- Cumulative meter readings of hourly consumption of DHW for each apartment in liter.
- Cumulative meter readings of hourly consumption of DCW for each apartment in liter.

Authors consider month of November and August as representative month of summer and winter DHW consumption. Furthermore, some data cleaning are also accomplished during data processing work. Data is not taken into account if the apartment was vacant for whole month or daily average consumption of individual was less than 20 liter/per./day.

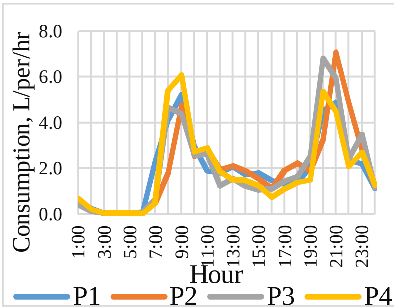
2.3. Data analysis

Hourly basis data of 86 apartments were separated according to month of November, August and January. Cumulative meter readings of hourly consumption of DHW and DCW for each apartment in liter for month of November were processed. The data presents the apartment hourly consumption which is further divided by the number of occupant from respective apartment. Occupants were numbered properly for proper identification. The daily consumption sum of each day from 1.11.2014 to 30.11.2014 for individual occupant was calculated. Daily basis consumption (L/per/day) of November (30 individual days) were calculated. Afterwards an average of 30 days was calculated to get the daily average of November. The number of occupants are 191 which eliminates to 164 and ensured minimum daily consumption of 20 L/per./day. 164 occupants hourly consumption data from 1.11.2014 to 30.11.2014 are separated based on individual hour i.e., 1.0 hour to 24 hours. The average of each hour of 164 occupants were obtained which presents the hourly profile of daily consumption for month of November.

The authors have formed 5 different random groups of 1 person group, 3 people group, 10 people group, 31 people group, and 191 people group. For one person hourly consumption profile authors considered 164 occupants individual profile. 15 profiles closest to the average daily consumption were selected for further analyses. Among these 15 profiles 4 good candidates were selected based on similarity with the shape of the average consumption profile representing the hourly consumption profile for 1 person group. For 3 people group, authors used Excel RAND function to randomly pick three occupants among 164 occupants and to form 3 people groups. The total number of combination was 164 and each group had own profile that was accomplished from the hourly average of 3 occupants. Among 164 profiles 15 profiles were selected which have nearly similar daily consumption to average of all occupants daily consumption. Again 4 different candidates were chosen which represent hourly consumption profile for 3 people group. The same procedure was followed to draw the user profile of DHW for 10 people group and 31people group. The random selection procedure was repeated 3 times in order to be sure that the selection of groups will not affect the results.



(a)



(b)

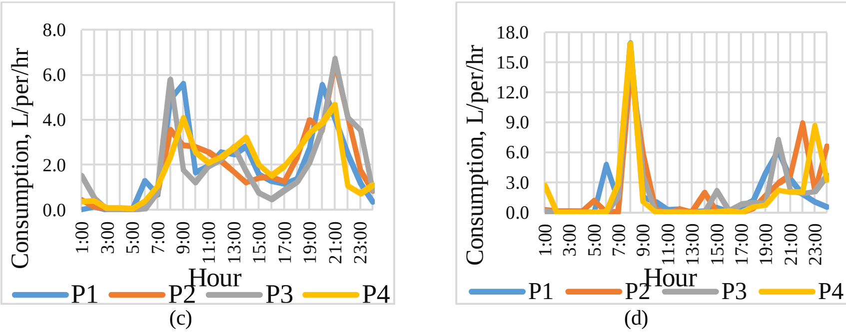


Figure 1: Similar candidates of November for group a) 31 people, b) 10 people, c) 3 people, and d) 1 person.

The daily consumption of DHW for each month was obtained by multiplying the monthly consumption factor with annual daily average. Afterward, scaling factor has assigned for each group which further multiply with hourly consumption of respective group. The following equation was used to form scaling factor

$$Scaling\ factor,\ SF_{i,d} = \frac{Annual\ daily\ average * Monthly\ consumption\ factor}{Daily\ average\ of\ specific\ group}$$

Furthermore, domestic cold water hourly profile of 164 occupants for month of November has drawn. The hourly ratio of DHW to DCW (total) is calculated by using the following equation

$$Hourly\ ratio = \frac{Hourly\ consumption\ of\ DHW}{Hourly\ consumption\ of\ DTW}$$

Where, DTW is consumption of total water (Hot + Cold).

3.0 Result and discussion

The result was drawn based on the hourly DHW and DCW consumption of 191 occupants from 86 Finnish apartments in Helsinki region. The hourly consumption data during one year was find representative because of similar average consumption values compared to larger and longer data set of [5]. However, the quality of proposed profile might be increased if authors could manage couple of consecutive year data. It was found higher variation of DHW consumption during a day than in previous study [5]. Similar findings are also observed in this study where daily consumption is varied from 0 – 300 L/per./day during data processing of individual data set of 191 occupants.

Table 1 DHW monthly consumption factor for Finnish apartment building

Annual average consumption, L/per./day	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
43	1.105	1.04	1.033	1.005	0.977	0.895	0.88	0.964	0.969	0.98	1.111	1.041

Table 2: Hourly consumption factor of different groups for month of November.

	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	0:00
191 Per.	0.47	0.17	0.07	0.07	0.03	0.10	0.50	1.95	1.65	1.09	1.20	1.12	1.13	0.88	0.71	0.76	0.82	0.85	1.06	1.97	2.51	2.09	1.82	0.98
31 Per.	0.45	0.14	0.06	0.06	0.04	0.12	0.55	1.82	1.77	0.81	0.94	0.92	1.10	0.89	0.78	0.97	0.95	0.94	0.94	1.87	2.30	2.54	1.85	1.20
10 Per.	0.21	0.06	0.03	0.03	0.01	0.04	0.34	2.37	2.22	1.31	1.33	0.63	0.79	0.62	0.53	0.56	0.73	0.84	1.29	3.46	3.02	1.23	1.78	0.59
3 Per.	0.83	0.28	0.01	0.01	0.01	0.03	0.44	3.10	0.96	0.65	1.03	1.20	1.51	0.93	0.41	0.25	0.47	0.66	1.13	1.92	3.60	2.20	1.89	0.47
1 Per.	0.02	0.00	0.00	0.00	0.00	1.58	0.38	5.57	0.92	0.83	1.50	1.46	0.57	0.47	0.77	0.98	0.53	0.64	1.35	3.06	1.53	0.96	0.55	0.32

The data was analyzed to quantify the hourly variation of DHW. In morning peak (7.00 to 9.00) and evening peak (20.00 to 22.00) the consumption rates varied from 0 to 78 L/per./hour. Some common behavior were also noticed such as low consumption rate during 11.00 to 16.00 hours, almost no consumption from 1:00 to 5:00 hours and high consumption rate during morning and evening peak hours. The average during peak and non-peak hours were 3.6 and 1.5 L/per./hour respectively. In figure 2 is shown the frequency distribution at peak and non-peak hours.

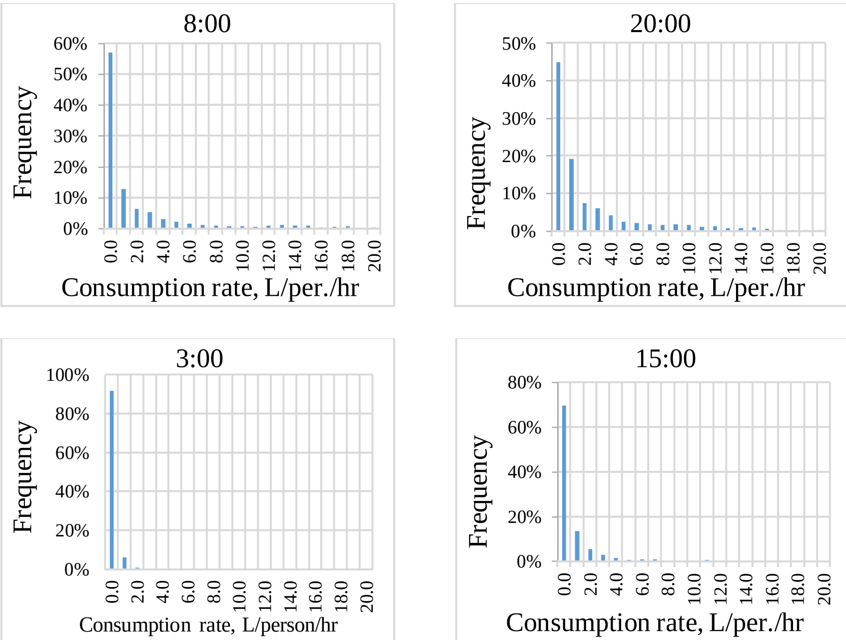


Figure 2: Frequency distribution at peak hours of 8 hour, 20 hour and non-peak hours of 3 hour, 15 hour for month of November.

Almost 90% of consumption were kept in between the range of 0 to 20 L/per./hr. during the measured period. Some cases the deviation was noticed more than 10 times higher than the average one however the probability of occurrence was very low. The frequency of consumption is important to design the system as well as making a connection with renewable energy sources. The frequency of DHW consumption for month of November is shown in table 2.

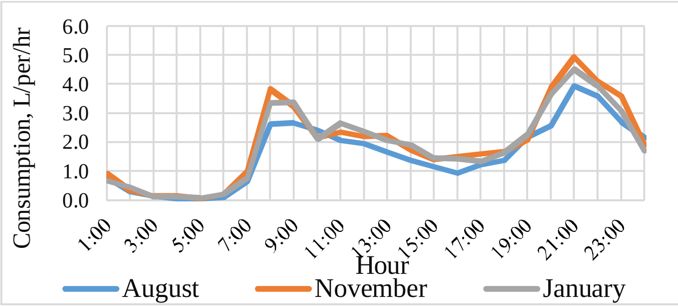


Fig. 3 Hourly average consumption profile for month of August, November and January

The hourly consumption during November was found higher compared to August and January. In addition, hourly consumption patterns were nearly similar for all the months. Because the average profile of a large group is dampened and smoother, hourly profiles for different group sizes were drawn in order to explain properly the hourly variations. The hourly profiles of small groups could able to estimate more preciously the consumption of any number of occupant. For instance if designers would like to design the DHW system for 7 occupants or 100 occupants, they could easily choose 10 person group or 191 person group profile respectively. In figure 4 is shown the proposed profiles of different groups for month of November.

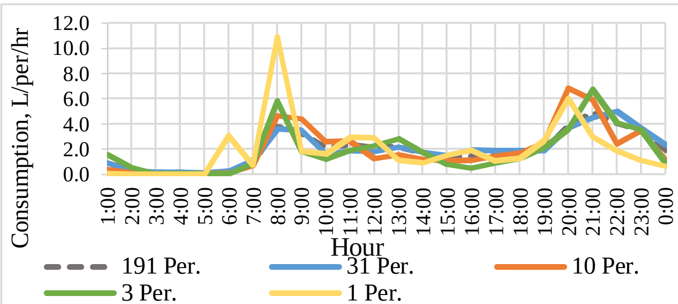


Figure 4: Proposed profiles of different groups for month of November

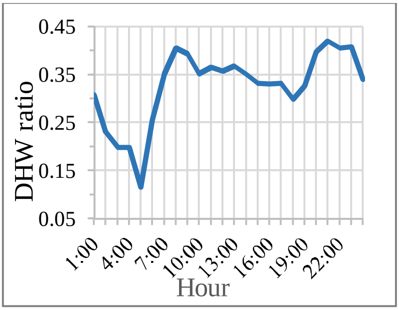
In method section the selection criteria for each profile was described briefly. Selected candidates (most close to average daily consumption) of each profile group were compared to the pattern of average profile of 191 people. The candidates which had the best similarity with average profile were selected as representative ones for studied 5 groups. Similarity was assessed based on morning and evening peak ratios, peak times and durations which are the main parameters describing the shape of profiles. Daily consumption of selected candidates was scaled with daily average consumption for month of November (table 1) and individual factor was assigned for each hour of different group. Scaled hourly consumption factors of groups for month of November are shown in table 2. Hourly consumption values for each hour can be calculated from Table 1 and 2 data as follows:

$$Average\ hourly\ consumption_m = \frac{Annual\ average * Monthly\ factor_m}{24}$$

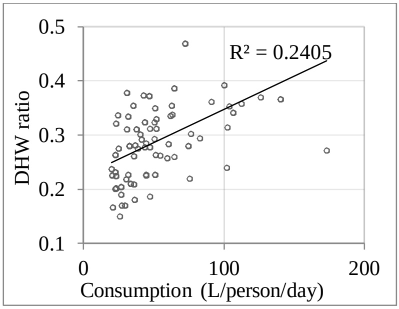
$$Consumption\ at\ any\ hour_{i,g} = Average\ hourly\ consumption_m * Hourly\ factor_{i,g}$$

Where, 'm' is month of year, 'i' is hour during a day and 'g' is group.

The ratio of DHW to total water may be important information for energy calculations. The ratio of DHW to total water of November and hourly DHW ratio as a function of specific consumption are shown in figure 5.



(a)



(b)

Figure 5: (a) Ratio of DHW to cold water (total) (b) Hourly DHW consumption ratio as a function of specific consumption for month of November

The common finding was a higher hourly consumption ratio during peak hours of the day. For lowest consumption hours the ratio was low. Most cases occupant used low volume of DHW for hand washing during that period. At that condition the initial water temperature are relatively cold while it starts to deliver but it adjust within couple of second. Furthermore, DHW ratio was not clearly dependent on hourly consumption of shown in the figure.

4.0 Conclusion

Hourly DHW consumption rate was derived based on measured data from 86 apartments with 191 occupants. The following conclusion can be drawn

- Daily average consumption (L/per./day) was nearly similar to previous study. The average consumption pattern during a day had nearly similar pattern for August, November and January.
- DHW hourly consumption followed the lognormal distribution and consumption were in between 0-20 L/per./hour. Average consumption of peak and non-peak hour were 3.6 and 1.5 L/per./hour respectively.
- Five different group consumption profiles were derived to describe the hourly consumption as a function of number of occupants. Smaller group had a higher peak consumptions compared to larger groups. Derived profiles allow to design DHW systems for any number of occupant.
- The obtained profiles can be use with monthly consumption factors (Table 1) to generate the hourly profile of all months.
- An average DHW ratio was 0.31 but significant variance (0.10 - 0.39) was found during a day.

Acknowledgment

K.V. Lindholms Stiftelse foundation is acknowledged for financial support and Finnish Real Estate Federation Kiinteistöliitto for DHW data.

References

[1] J. Hakala, "Energy consumption in households 2014," Edita Publishing Oy, 2014.

[2] "Water supply Statistics," Statistics Netherlands, Rijswijk, 2007.

[3] "Suomen rakentamismääräyskokoelma osa D3," Rakennusten energiatehokkuus, Helsinki, 2003.

[4] "Regelsamling för byggande BBR-2012," Sweden, 2012.

[5] K. Ahmed, P. Pylsya and J. Kurnitski, "Monthly domestic hot water profiles for energy calculation in Finnish apartment buildings," *Energy and Buildings,* vol. 97, no. 15 June 2015, p. 77–85, 2015.

[6] IEA, "Energy conservation in buildings and community systems programme" 2007.

[7] E. Vine, R. Diamond and R. Szydlowski, "Domestic hot water consumption in four low-income apartment buildings.," *Energy,* vol. 12, no. 6, p. 459–467, 1987.

[8] E. J. M. Blokker, J. H. G. Vreeburg ja J. C. v. Dijk, ”Simulating Residential Water Demand with a Stochastic End-Use Model,” *Journal of Water Resources Planning and Management,* osa/vuosik. 136, nro 1, 2010.

[9] ”Suomen Rakentamismääräyskokoelma D1,” Kiinteistöjen vesi-ja viemärilaitteistot Määräykset ja ohjeet, Helsinki, 2007.