Realistic Domestic Hot-Water Profiles

in Different Time Scales

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The profiles are distributed by the authors under the email address: solar@physik.uni-marburg.de.

The authors would appreciate any remarks and comments, as well as information about papers and reports, for which the profiles have been used.

Realistic Domestic Hot-Water Profiles in Different Time Scales

Sets of load profiles for the domestic hot water demand for a period of one year in the time scales of 1 min, 6 min, and 1 hour are described in this paper. Each profile consists of a value of the DHW flow rate for every time step of the year. For the cold water temperature distribution during the year, a local profile should be used.

In order to take into account fairly realistic conditions, a **time step of one minute** was chosen in the first place. In order to carry out simulations with time steps higher than 1 min, an additional set of profiles in a time scale of **6 min** was generated. The reference conditions concerning the distribution of the draws were chosen similar to those of the 1 min profiles.
A third set of profiles in an **hourly time scale** was generated for the purpose to simulate large solar heating systems with a simulation time step higher than 6 min. Due to the fact that the flow rates become very small when calculating mean values, the flow rates may not be regarded as realistic for small and medium sized solar heating systems.

The values of the flow rate and the time of occurence of every incidence were selected by statistical means.

For TRNSYS simulations the following profiles should be used:
(Δt_{sim} : simulation timestep, $\Delta t_{DHWprofile}$: time scale of DHW load profile)

$$\Delta t_{sim} \leqslant 1 \text{ min} \quad \Rightarrow \quad \Delta t_{DHWprofile} = 1 \text{ min}$$
$$1 \text{ min} < \Delta t_{sim} \leqslant 6 \text{ min} \quad \Rightarrow \quad \Delta t_{DHWprofile} = 6 \text{ min}$$
$$\Delta t_{sim} > 6 \text{ min} \quad \Rightarrow \quad \Delta t_{DHWprofile} = 1 \text{ hour}$$

The basic load in each set of DHW profiles is 100 litres/day. The profiles are generated for higher demands in dual order (100, 200, 400, 800 liters ..), with different initial random values. In this way, it is possible to get a load profile for any multi-family house very easily by superposition.

Content:

1. DHW Load-Profiles in a One-Minute Time Scale

For the IEA-Task 26 simulation studies, a mean load volume of 200 litres per day was chosen for a single family house. A short sequence of the profile is shown in figure 1.1.

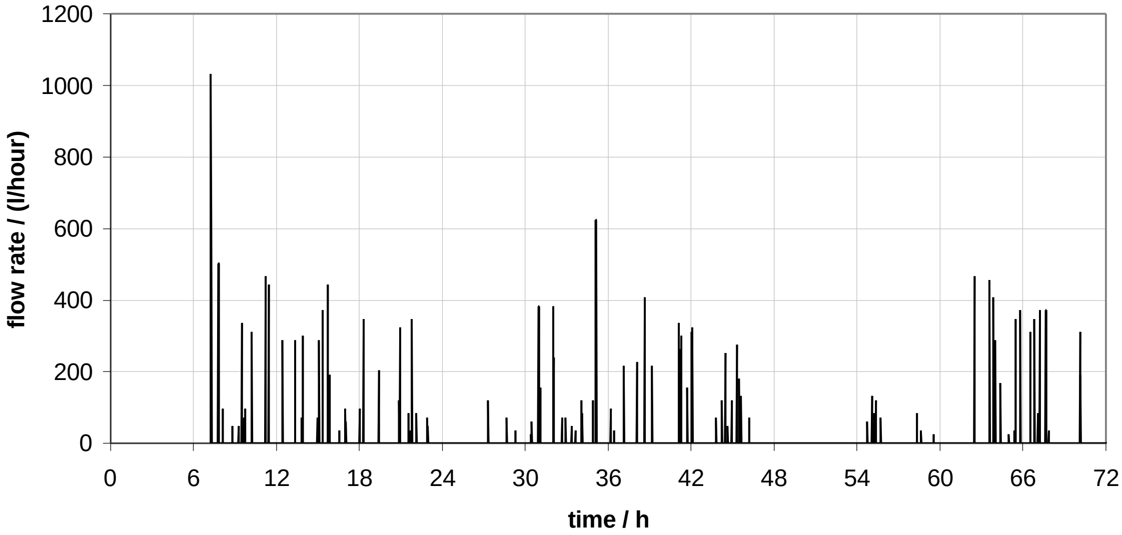


Figure 1.1: Load profile of 72 hours, Jan. 1st – 3rd (200 l/day).

Basic Assumptions

Four categories of loads are defined. Every category-profile is generated separately and superponed afterwards.
For every category a mean flow rate is defined. The actual values of the flow rates are spread around the mean value with Gauss-Distribution (figure 1.2):

$$prob(\dot{V}) = \frac{1}{\sqrt{2p}\, s} \exp \frac{-(\dot{V} - \dot{V}_{mean})^2}{2s^2}$$

The values chosen for s , for the duration of every load, and for the medium number of incidences during the day are shown in table 1.

Flow rates in steps of 0.2 l/min = 12 l/h are taken.

A probability function, describing variations of the load profile during the year (also taking into account the (European) daylight saving time), the weekday, and the day is defined for every category.
The Accumulated Frequency Method is used to distribute the incidences described by the probability function among the year.

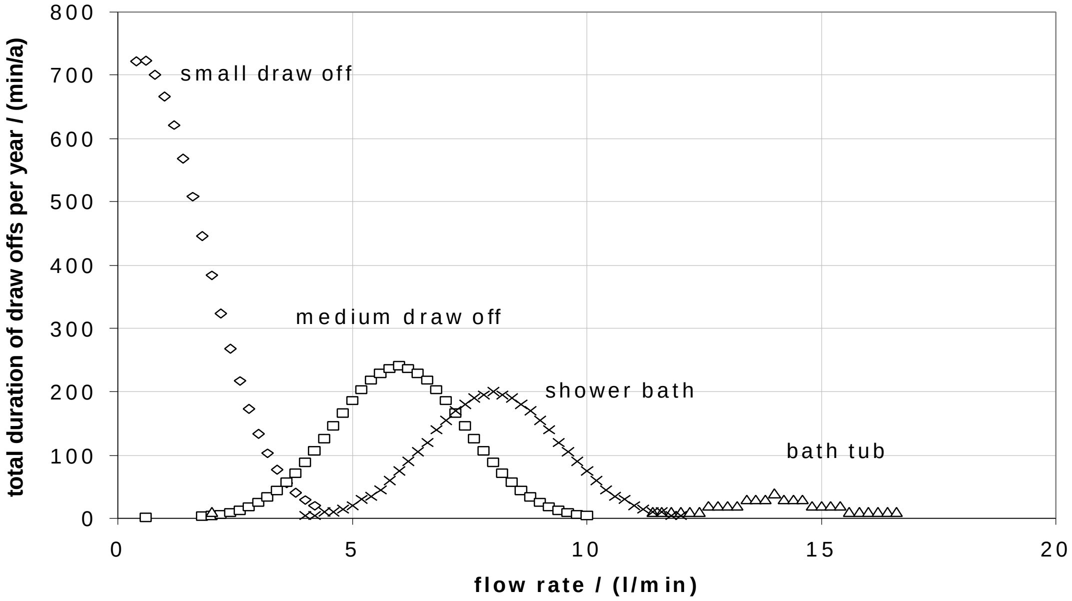


Figure 1.2: The total duration of draw offs during a year is shown in dependence of the flow rate. The number of draw offs with a certain flow rate are distributed as a gaussian function (e.g. 702 showers during the year with a duration of 5 minutes each). **Discretisation of flow rates: 0.2 l/min.**

The following assumptions are made:

- the mean load is 200 l/day
- four categories to describe the different types of loads are defined:
  - cat A: short load (washing hands, etc.)
  - cat B: medium load (dish-washer, etc.)
  - cat C: bath
  - cat D: shower

assumptions made for every specific category
for

- the mean flow rate	Vdot
- the duration of one load	duration
- the nr. of incidences (loads) per day	inc/day
- the statistical distribution of different flow rates	sigma

=> (for a basic average day)

- the mean volume of each load	vol/load
- the total volume (for every category) per day	vol/day
- portion of volume from the total volume (200 l/day)	portion (=^ percentage)

	cat A: short load	cat B: medium load	cat C: bath	cat D: shower	Sum
Vdot in l/min	1	6	14	8	
duration in min	1	1	10	5	
inc/day	28	12	0.143 (once a week)	2	
sigma	2	2	2	2	
vol/load in l	1	6	140	40	
vol/day in l	28	72	20	80	200
portion	0.14	0.36	0.10	0.40	1

Table 1: Assumptions and derived quantities for the load profile.

The maximum energy of one draw off is:

14 l/min * 10 min * 1.16 Wh/(kgK) * 35 K = 5680 Wh

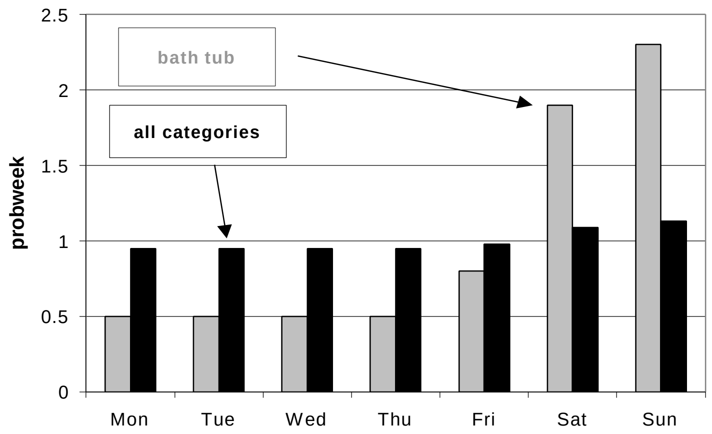
(suggested max. heat demand according to DIN 4708: P = 5820 Wh)
Table 1 is based on a few research studies about DHW-consumption patterns in Switzerland and Germany, investigated by measurements of the electrical power of el. DHW-burners, measurements of temperatures or flow rates or by a representative telefon research study (e. g. /Loose91/,/Nipkow99/,/Real99/,/Dichter99/). (Thank you very much to Peter Vogelsanger Jean-Marc Suter for the swiss studies !)

Probability function

prob = prob(year) * prob(weekday) * prob(day) * prob(holiday)

- The course of probabilities during the year is described by a sinus-function with an amplitude of 10 % of the average daily discharge volume (see /Mack98/). => ***prob(year)***

- The non-equal distribution of DHW-consumption during the weekdays is only applied on the category bath (cat. 3). This was done due to the results of research studies (e.g. /Dichter99/). The probability-function probweek for taking a bath (grey columns) and the mean distribution for the total volume per day (black columns) are shown in figure 1.5.



- **Figure 1.5**: probability-function only for category 3 (bath), and mean value of the weekly distribution of all categories (medium load: 100 %, load Mon-Thu: 95 %, Fri: 98 %, Sat. 109 %, Sun.: 113 %). => ***prob(weekday)***

- The assumptions for the **daily distribution** used, are shown below:

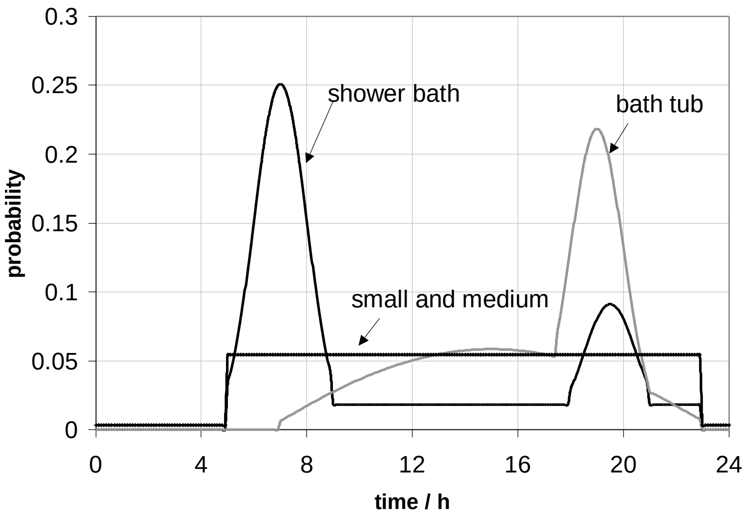


Figure 1.6: Probability distribution of the DHW-load in the course of the day. For a short and medium load is distributed equally between 5:00 and 23:00 h. => ***prob(day)***

- Holidays are taken into account in two ways:

1.) A period of two weeks of no DHW-consumption between June 1st and Sept. 30th is taken into account for a household with a total load of 100 l/day. The starting-day of the holidays is given by a random number. The initialization of the random number generator is set in the way, that the holidays for a one family house with a load of 100 l/day starts at Aug. 1st. For a one family house with a load of 200 l/day (Task26) the DHW-load is reduced by 100 l/day in two periods. The duration of both periods is 2 weeks, starting on Jul. 14th and Aug. 8th, respectively. In multifamily houses the number of reduced DHW-load periods is given by the average daily load volume devided by 100 l/day. Therefore, for the multifamiliy house modeled in Task26, 20 periods are taken into account.

2.) The distribution of the DHW-consumption during the year is described by a sinus-function with an amplitude of ± 10 % of the average daily discharge volume. This variation takes into account less consumption during the summer than during the winter in general (/Mack98/ found a variation of ± 25%, due to variations of the cold water temperature of ± 5 K (± 14 %) and variations of the consumption patterns). Due to the two weeks of holidays described in (1.), variations of ± 3.8 % are induced.

The probability term in order to descibe a load reduction of 100 l for periods of 14 days is given by:

$$prob(holiday) = \frac{mean\ volume\ of\ \ daily\ load - reduced\ \ volume}{mean\ volume\ of\ \ daily\ load}$$

In case of a mean volume of 200 l/day, the possible values for prob(holiday) are

- prob(holiday) = ½ between Jul. 14th .. Jul.28th and Aug. 8th .. Aug. 22nd,
- prob(holiday) = 1 else

If the two periods were overlapping, probholiday would be equal to zero during that period.

The total number of periods with a reduced load is given by the *mean volume of daily load/100.*

=> yearly volume taken into accound:

one-family house	=>	73 000 litres (= 365 days * 200 l/day)
five-family house	=>	365 000 litres (= 365 days * 200 l/day * 5)

NB:

The unit of the flow rates is litres/hour.
Format: The new Pascal-format is LongInt, the TRNSYS (Fortran)-Format for the DataReader TYPE 9 is **(F6.0)**.

The following profiles are available (May 2000):

	mean daily DHW-volume in litres/day
01DHW001.txt :	100
01DHW002.txt :	200
01DHW004.txt :	400
01DHW008.txt :	800
01DHW016.txt :	1600
01DHW032.txt :	3200

The influence of DHW profiles in a 1 min scale were investigated e.g. in /Frei00, Jordan00, Knudsen01/.

One-family house: Daily load in the course of the year:

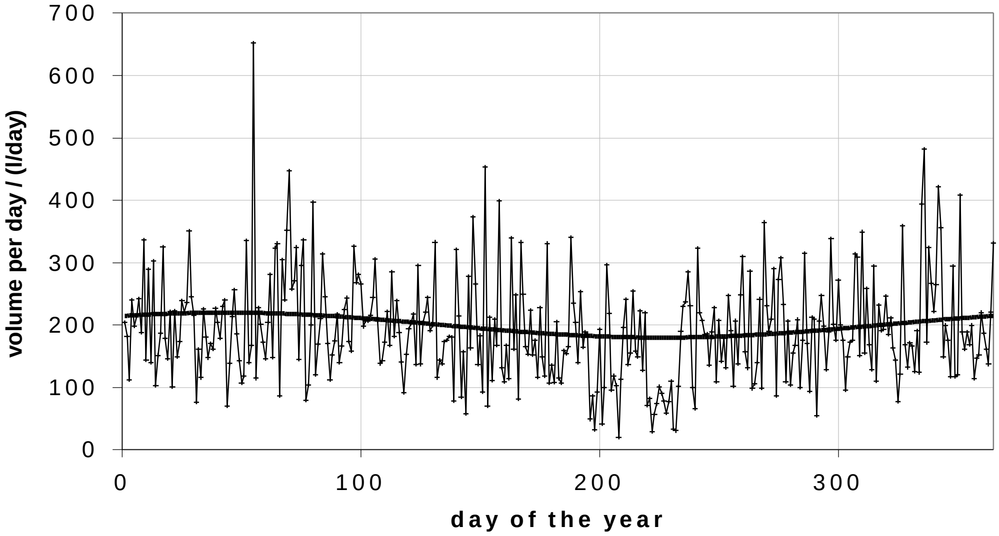


Figure 1.3: Distribution of draw-off volume per day during the year (mean value on holidays: 100 l/day, on other days: 200 l/day,). The sinus function, used to calculate the probability during the course of the year with an amplitude of 20 l/day ($\pm 10\,\%$) is shown with a solid line. Two periods of reduced discharge are taken into account, between Jul. 14th (196. day) and Jul.28th and between Aug. 8th (221. day) and Aug. 22nd .

Ten-family house: Daily load in the course of the year:

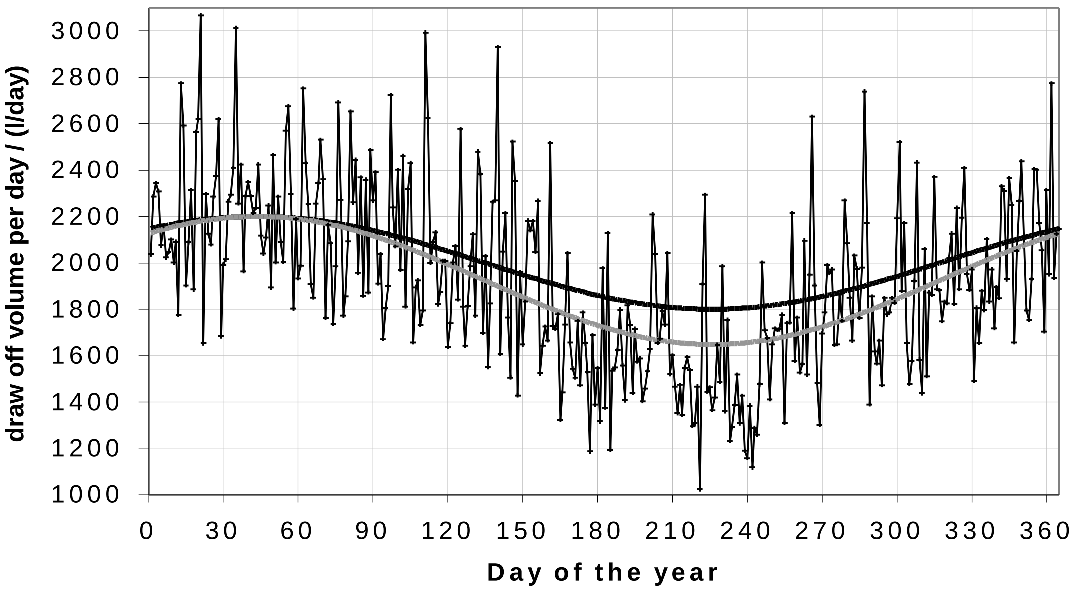


Figure 1.4: Distribution of the total draw-off volume per day during the year for a ten-family house (mean value: 2000 l/day). Upper solid line (sinus function): amplitude = 200 l/day ($\pm 10\,\%$), lower solid line (sinus function): amplitude = 13.8 %, with 3.8% due to two weeks holidays between June 1st and Sept. 30th for every household.

2. DHW Load-Profiles in a Six-Minute Time Scale

For the six-minute profiles only draws with a duration of 6 minutes are taken into account (for the one minute profiles durations of 1, 5, and 10 min were considered). This means, that only one category of loads is defined for the 6 min profiles, representing all types of draws (small and medium draws, shower bath and bath tub filling).

For simulations with a timestep of 6 min it would also be possible to take mean values of the one-minute profile. However most of the mean values are very small. Therefore we would propose to take the presented profiles which are based as far as possible on the assumptions made for the one-minute profiles.

As an example a sequency of the profile of one week is shown in figure 2.1.

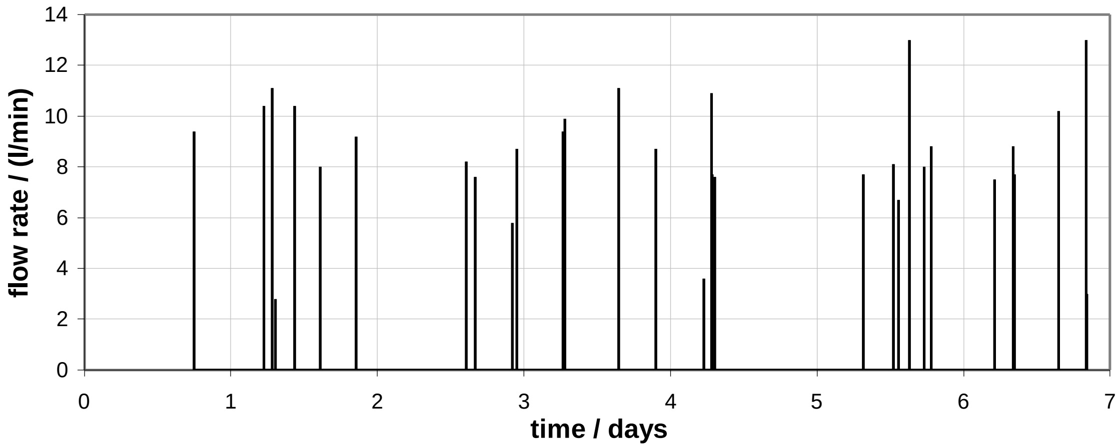


Figure 2.1: One week sequency of a DHW-Profile in a 6-minute time scale.

The values of the flow rates are spread around the mean value with Gauss-Distribution as shown in figure 2.2:

$$prob(\dot{V}) = \frac{1}{\sqrt{2p}\,s} \exp \frac{-(\dot{V} - \dot{V}_{mean})^2}{2s^2}$$

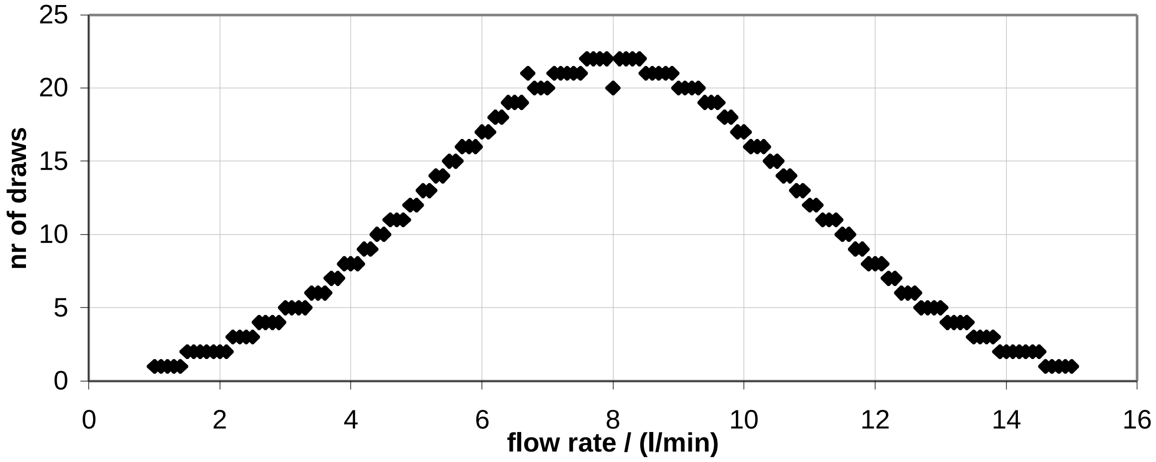


Figure 2.2: DHW-Profile in a 6-minute time scale: Nr of draws in dependence of the flow rate. The deviations from the Gaussian function are due to the descretization of the flow rate.

A probability function, describing variations of the load profile during the year (also taking into account the (European) summer time), the weekday, and the day is defined in the same way as for the one minute profile.
Also the probability distribution is based on the relations that were chosen for the one-minute profile. The functions were multiplied with the portion of the volume of each category defined for the one-minute profile (see figure 1.6). E. g. the distribution of probabilities during the day (figure 2.3) is calculated as:

probday = 0.14 * probday(small) + 0.36*probday(medium) + 0.4*probday(shower) + 0.1*probday(bath tub)

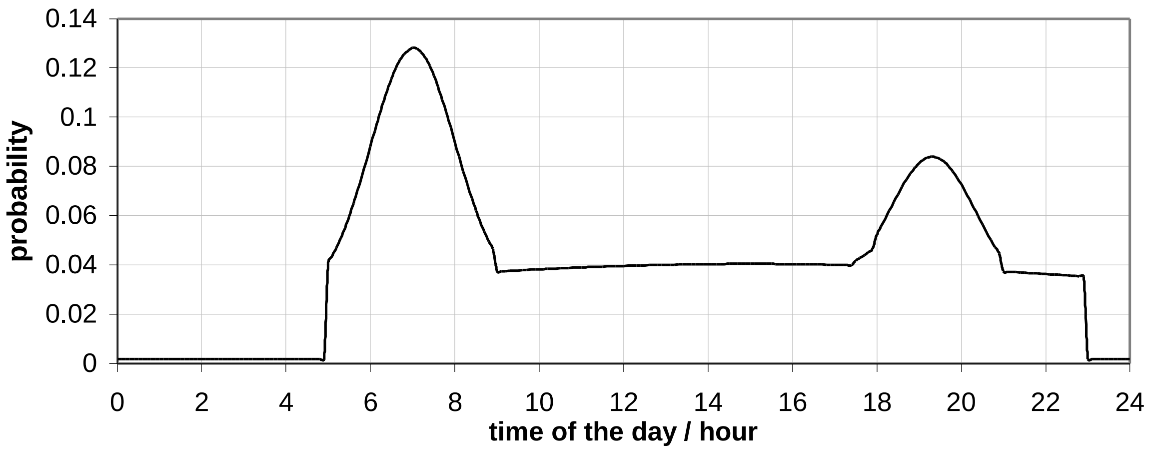


Figure 2.3: DHW-Profile on a 6-minute time scale: Distribution of probabilities during the day.

Variations during the year are described as a sine-function with an amplitude of 10 %. Variations of the probability of draw offs per day at different weekdays are:

Monday .. Thursday	0.9
Friday	1.0
Saturday, Sunday	1.2

The following assumptions are made for the 200 l/d- profile:

total load volume	73 000.2*	l/a
=> mean load	≈200	l/d
mean flow rate	8	l/min
min. flow rate	1	l/min
max. flow rate (single draw)	15	l/min
max. flow rate (superposition)	23.9	l/min
=> max. energy demand of one draw	5822**	Wh
discretization of flow rates	0.1	l/min
duration of each load	6	min
sigma	4	
total no of draws	1521	/a

* Due to the descretization of the flow rates of 0.1 litres/min, only multiple values of 0.6 litres are possible for the total volume.

** The maximum energy of one draw is:

23.9 l/min * 1 kg/l * 6 min * 1.16 Wh/(kgK) * 35 K = 5822 Wh.

(Suggested max. heat demand according to DIN 4708: Q = 5820 Wh

=> $\dot{V}_{\max} = 23.9\ l\,/\,\mathrm{min}$).

In figure 2.4 the daily draw off volumes are shown for all generated profiles in a 6 min time scale. Weekly variations of the load are shown clearly (a higher DHW demand during the weekend) as well as the seasonal variations of DHW consumption.

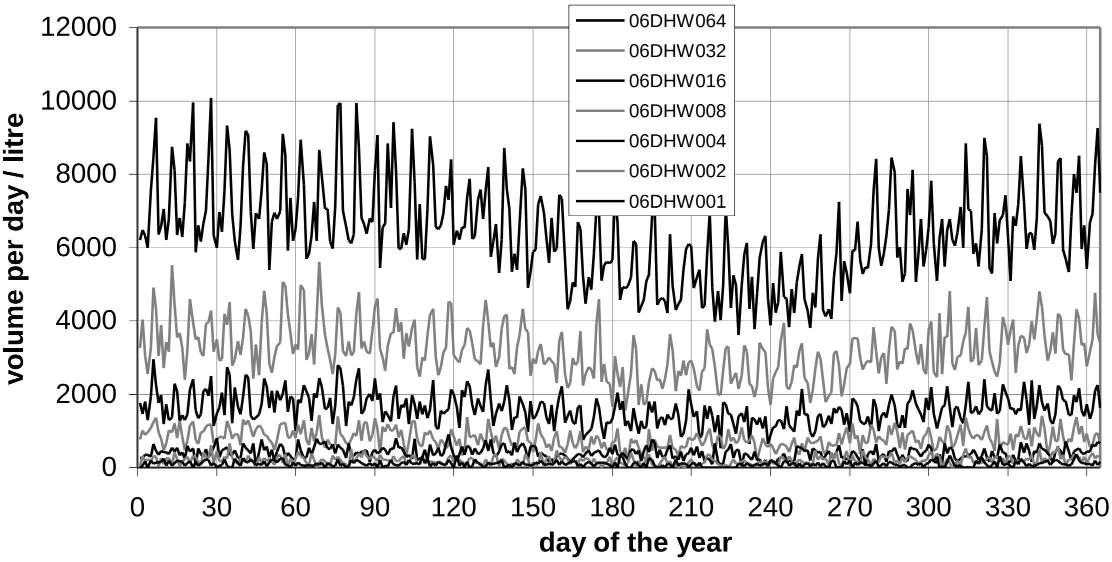


Figure 2.4: DHW volume per day for profiles with a mean daily draw off volume of up to 6400 litres.

NB:
The unit of the flow rates is litres/hour.
Format: TRNSYS (Fortran)-format for the DataReader TYPE 9 is **(F6.0)**.

The following profiles are available (May 2001):

		mean daily DHW-volume in litres/day
06DHW001.txt	:	100
06DHW002.txt	:	200
06DHW004.txt	:	400
06DHW008.txt	:	800
06DHW016.txt	:	1600
06DHW032.txt	:	3200
06DHW064.txt	:	6400

3. DHW Load-Profiles on an Hourly Time Scale

The DHW- load profiles in a time scale of one hour are produced by taking hourly mean values of the 6 min profiles. This is done only for the purpose to simulate large solar heating systems with a time step of one hour. Due to the fact that the flow rates become very small when calculating mean values, they may not be regarded as realistic flow rates. However, the effect of ‚smearing out' the DHW draw offs becomes smaller for an increasing total load.

As an example, the flow rates during the January period are shown in figure 3.1a) and b) for the 6 min and the 1 hour profiles for a mean daily load volume of 6400 litres.
Whereas the shapes of the curves are quite similar, the flow rates differ significantly. The ratio of the highest flow rate of the 6 min profile (3714 l/h) to the highest flow rate of the 1 h profile (1547.4) in this period is about 2.4. This ration increases even to about 6.7 for a mean daily load volume of only 200 litres.

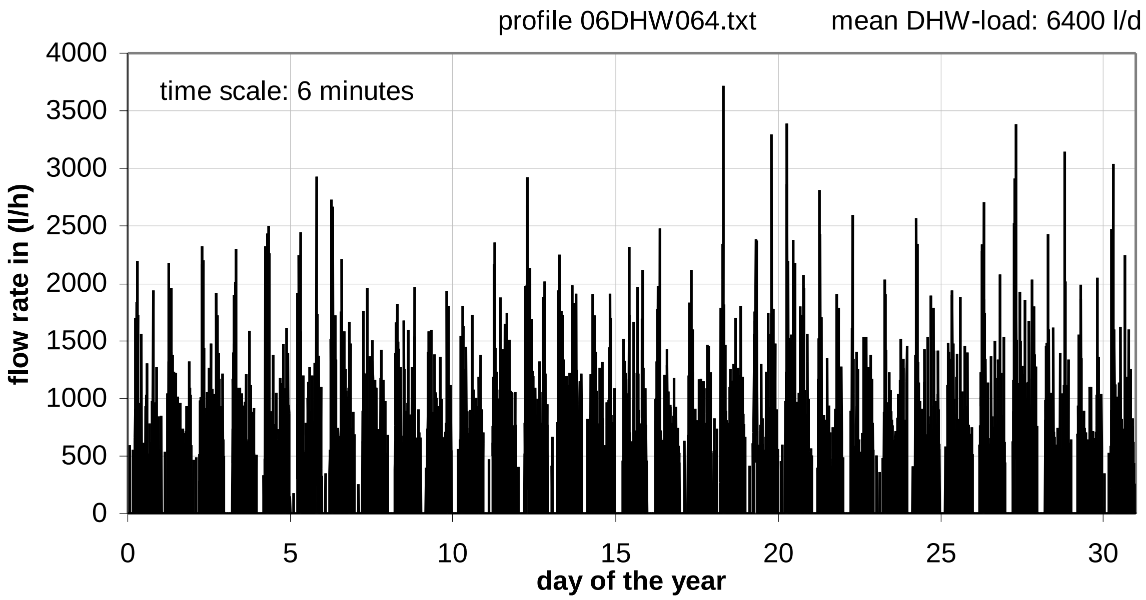


Figure 3.1a : Sequence of the 6 min DHW profile (Jan 1. to 31.) with a mean daily DHW-load volume of 6400 litres (file 06DHW064.txt).

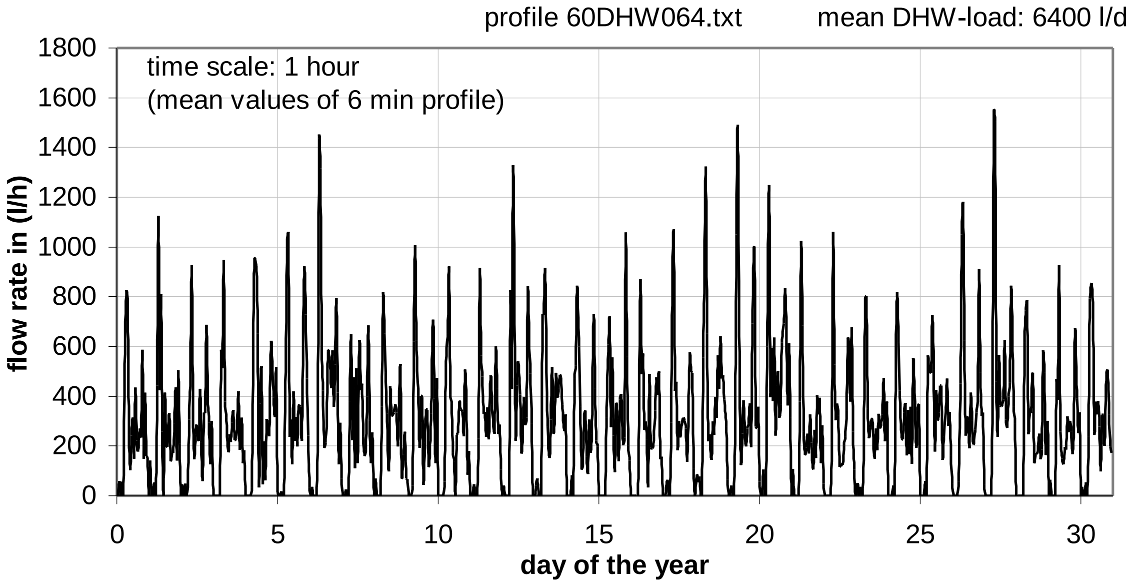


Figure 3.1b : Sequence of the 1 hour DHW profile (Jan 1. to 31.) with a mean daily DHW-load volume of 6400 litres (file 60DHW064.txt).

NB:

Different format than for 1 min and 6 min profiles !!

The unit of the flow rates is litres/hour.
Format: The TRNSYS (Fortran)-format for the DataReader TYPE 9 is **(F7.1)**.

The following profiles are available (May 2001):

	mean daily DHW-volume in litres/day
60DHW001.txt :	100
60DHW002.txt :	200
60DHW004.txt :	400
60DHW008.txt :	800
60DHW016.txt :	1600
60DHW032.txt :	3200
60DHW064.txt :	6400

4. Superposition of DHW Load-Profiles

The DHW profiles that are described in the previous sections were generated for mean daily load volumes in multiple integers of 100 litres in dual order (100, 200, 400, 800 liters ..). Due to the fact that the statistical generator was initialized differently for every profile, it is possible to superpone the profiles. Therefore profiles for mean daily load volumes in multiple integers of 100 litres can be produced by superposition.

With the ***SUPERPON.EXE*** load profiles with the following file names can be superponed:

01DHWxxx.txt (1 min time scale), or
06DHWxxx.txt (6 min time scale), or
60DHWxxx.txt (6 min time scale).

xxx stands for the mean daily load devided by 100 (e.g. for 200 l/day: 06DHW002.txt), the number at the beginning for the time scale in minutes.

Definitions:

- **Original files** contain load profiles, which are generated with a differently initialized random generator. They have been delivered in dual order: 01DHW001, 01DHW002, 01DHW004, etc.
- **Standard files**: original files and files made by superposition of original files, using every original file no more than once.

(Original) Load profiles with a mean daily load of up to 3200 l/day are given with a 1 min time scale, (original) profiles with a mean daily load of up to 6400 l/day are given for a 6 min and 1 hour time scale. Therefore, standard files can be produced by superposition with a mean daily load of up to 6300 or 12700 l/day in 100 l/d intervals.
Up to 14 files may be superponed at one run.

In order to superpone profiles, the mean daily load of the files to be superponed needs to be typed in (see example below). The output file will be written into the same dirctory as the input files. If standard files are created, the output file name will be made automatically.
If non-standard files are created, the output file name needs to be typed in (it shall not get the same name as a ‚standard‘ profile !),

- if ‚non-original‘ load volumes (e. g. 300 ℓ/d) are used as source file or
- if (for research purposes) the same mean daily load is used more than once.

If identical files are superponed, the output profile may be regarded to be less realistic (‚non-standard file‘).

When the program is started, the following questions will occur on the screen (comments are written in *italics*). The *superpon.exe* shall be started **in the same dirctory** that contains all input files.

Example 1:

Double click ***superpon.exe***:
Time step of DHW profile in minutes ?
(1, 6, 60), < return >
1
Mean daily flow volume (in litres) of the load profile to be superponed ?
(100, 200, 400, 800, 1600, 3200), < return >
100
Mean daily flow volume (in litres) of the load profile to be superponed ?
(100, 200, 400, 800, 1600, 3200), < return >
200
Mean daily flow volume (in litres) of the load profile to be superponed ?
(100, 200, 400, 800, 1600, 3200), < return >
<return>
Please wait !
10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Total load during the year = 109500 litres
= 365 days * 300 l/day
New file: 01DHW003.txt

Example 2:

Double click ***superpon.exe***:
Time step of DHW profile in minutes ?
(1, 6, 60), < return >
6
Mean daily flow volume (in litres) of the load profile to be superponed ?
(100, 200, 400, 800, 1600, 3200), < return >
100
Mean daily flow volume (in litres) of the load profile to be superponed ?
(100, 200, 400, 800, 1600, 3200), < return >
100
Mean daily flow volume (in litres) of the load profile to be superponed ?
(100, 200, 400, 800, 1600, 3200), < return >
100
Mean daily flow volume (in litres) of the load profile to be superponed ?
(100, 200, 400, 800, 1600, 3200), < return >
<return>
Two or more identical files will be superponed !
Please type in a new file name (not standard file name) for a file with a load volume of 300 l/day (without path name or extension)

06DHWA03 {e. g. „A“ instead of „0“ !}

Please wait !
10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Total load during the year = 109500 litres
= 365 days * 300 l/day
New file: 06DHW**A**03.txt

Example 3:

Double click ***superpon.exe***:
Time step of DHW profile in minutes ?
(1, 6, 60), < return >
6
Mean daily flow volume (in litres) of the load profile to be superponed ?
(100, 200, 400, 800, 1600, 3200), < return >
300
The given daily load volume does not belong to an original file !

Mean daily flow volume (in litres) of the load profile to be superponed ?
(100, 200, 400, 800, 1600, 3200), < return >
100
Mean daily flow volume (in litres) of the load profile to be superponed ?
(100, 200, 400, 800, 1600, 3200), < return >
<return>
Please type in a new file name (not standard file name) for a file with a load volume of 400 l/day (without path name or extension)

06DHWB04 {e. g. „B“ instead of „0“ !}

Please wait !
10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Total load during the year = 146000 litres
= 365 days * 400 l/day
New file: 06DHW**B**04.txt

5. List of References

/DIN 4702/ *Heizkessel: Ermittlung des Norm-Nutzungsgrades und des Norm-Emissionsfaktors*, Deutsches Institut für Normung.

/DIN 4708/ *Zentrale Wassererwärmungsanlagen. (1) Begriffe und Berechnungsmethoden. (2) Regeln zur Ermittlung des Wärmebedarfs von Trinkwasser in Wohngebäuden. (3) Regeln zur Leistungsprüfung von Wassererwärmern in Wohngebäuden*. Deutsches Institut für Normung.

/Dichter99/ Ernst Dichter: *Dusch- und Badeverhalten. Bericht zu einer Repräsentativumfrage*, Eidgenössische Drucksachen- und Materialzentrale, Bern, 1999.

/Dittrich72/ A. Dittrich, B. Linneberger, W. Wegener: *Theorien zur Bedarfsermittlung und Verfahren zur Leistungskennzeichnung von Brauchwasser-Erwärmern*, HLH 23, Nr. 2, 1972

/Frei00/ U. Frei, P. Vogelsanger, D. Homberger: *Domestic Hot Water Systems: Testing, Development, Trends*, in: CD-ROM of the Third ISES Europe Solar Congress EuroSun00, Copenhagen, Denmark, 2000.

/Jordan00/ U. Jordan, K. Vajen: *Influence of the DHW-profile on the Fractional Energy Savings – A Case Study of a Solar Combisystem*, in: CD-ROM of the Third ISES Europe Solar Congress EuroSun00, Copenhagen, Denmark, 2000.

/Knudsen01/ Søren Knudsen: *Consumers‘ Influence on the Thermal Performance of Small DHW Systems – Theoretical Investigations*, 9th International Conference on Solar Energy in High Latitudes, NorthSun, Leiden, The Netherlands, 2001, in press.

/Loose91/ Peter Loose: *Der Tagesgang des Trink-Warmwasser-Bedarfes*, HLH 42, Nr. 2, 1991.

/Mack98/ Michael Mack, Christiane Schwenk, Silke Köhler: *Kollektoranlagen im Geschoßwohnungsbau – eine Zwischenbilanz*, 11. Internationales Sonnenforum, Tagungsband, pp. 45-52, Köln 1998.

/Nipkow99/ Jürg Nipkow: *Warmwasser-Zapfungsverhalten. Schlussbericht.* Industrielle Betriebe der Stadt Zürich, Zürich, 1999.
http://www.stadt-zuerich.ch/kap08/energieberatung/s_50.html#Warmwasser-Zapfungsverhalten

/Real99/ Markus Real, Jürg Nipkow, Lukas Tanner, Bruno Stadelmann, Fredy Dinkel: *Simulation Warmwassersysteme. Schlussbericht Forschungsprogramm Wasser*, Eidgenössische Drucksachen- und Materialzentrale, Bern, 1999.