

Manual

DHWcalc

Tool for the Generation of Domestic Hot Water (DHW) Profiles on a Statistical Basis

Version 1.10 (2003)

Ulrike Jordan, Klaus Vajen

*Universität Kassel
Institut für Thermische Energietechnik
Solar und Anlagentechnik
D - 34109 Kassel
solar@uni-kassel.de*

The program can be downloaded free of charge from <http://www.solar.uni-kassel.de>

It was developed within the scope of the Solar Heating and Cooling Program of the International Energy Agency (IEA-SHC), Task 26: Solar Combisystems, with financial support by the German Federal Ministry of Economics and Labour (BMWA).

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

DHWcalc

Manual

There are no specific hardware requirements to run DHWcalc. To start the program, the executable program file *DHWcalc_xxx.exe* needs to be started. All output files will be saved in the directory of the executable.

1. Introduction

DHWcalc is a program to generate **Domestic Hot Water (DHW)** profiles. The generated profiles are text-files, containing a list of flow rate values for each time step. For single-family houses, most values of the list equal to zero, with only few non-zero flow rate-values in between, distributed over the total duration. An example of a three day-period of a DHW-profile for a single-family house is shown in Figure 1.

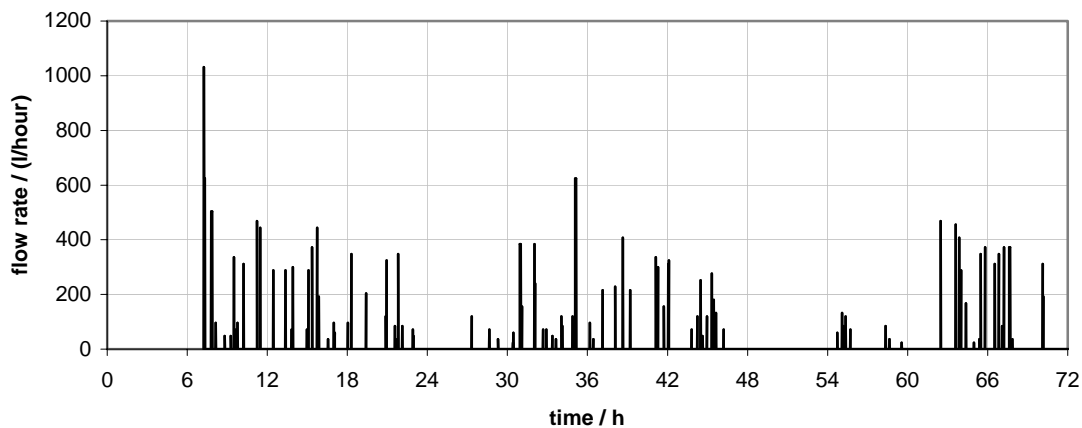


Fig. 1: Example of a DHW-profile for a single-family house. Time step: 1 min.

The program distributes DHW draw-offs throughout the year with statistical means, according to a probability function. Both, reference conditions for the draw-offs (flow rates, durations, etc.) and reference conditions for the probability function (daily probabilities for draw-offs etc.), can be set by the user.

To run the program, double-click the *DHWcalc_xxx.exe* -file.

The program starts with a main form. It contains edit-boxes and drop-down menus for settings like duration of the profile, start day, time step duration etc. Additionally, it contains two buttons to open windows for draw-off and probability-function settings.

To run the program, the button Generate Loadprofile needs to be pressed.

2. Interface Description

2a. Main Window

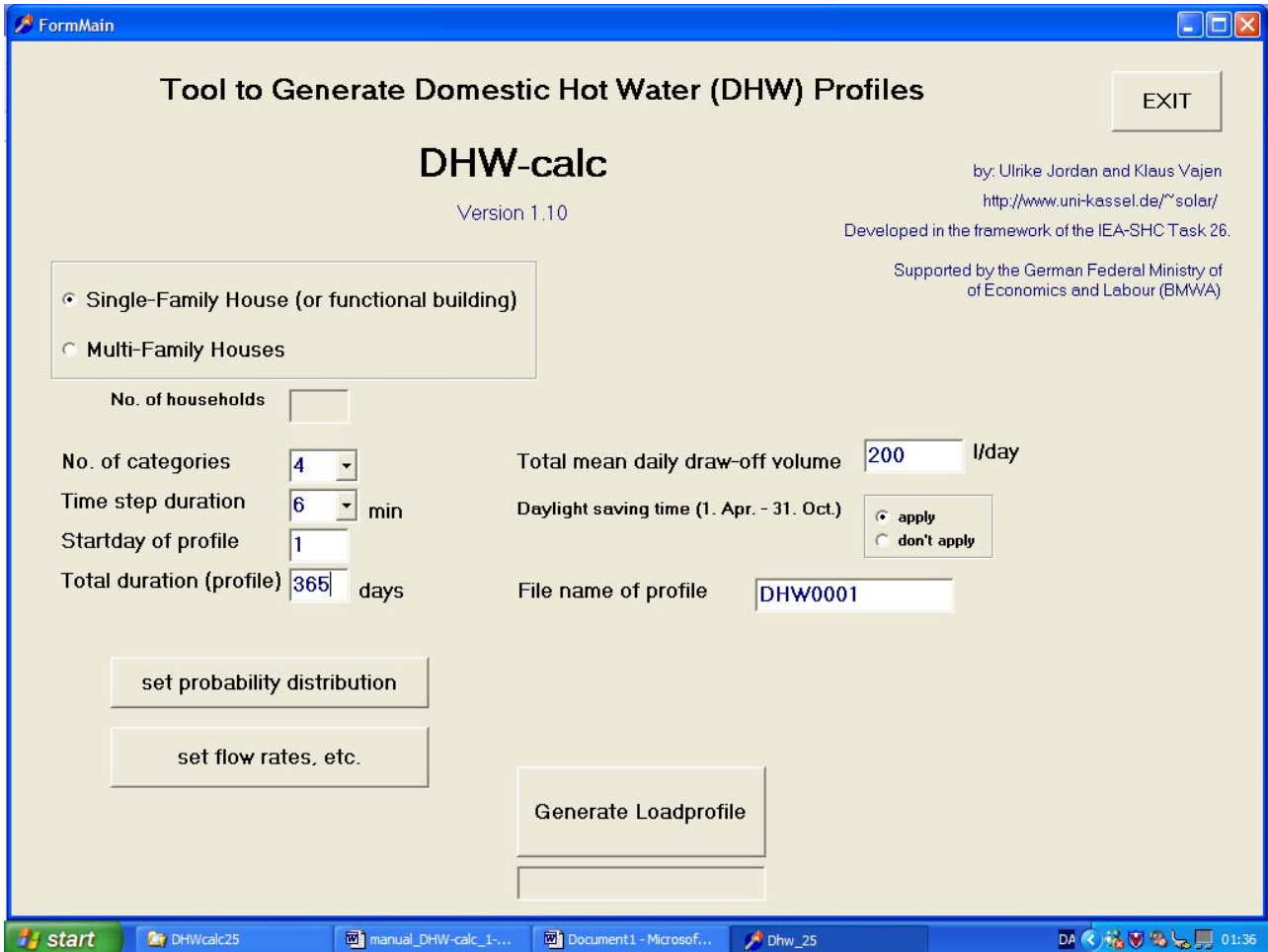


Fig. 2.1: Main Window: *FormMain*.

The window consists of

- a radio-buttons to choose between the options single/multi-family houses,
- three boxes and two drop-down menus to edit profile parameters,
- a box to edit a filename,
- a radio-button for the option to apply the European daylight saving time,
- two buttons to open windows for further parameter settings,
- a button to start the generation of a profile,
- list-boxes to show some output values, and
- a box to exit the Main Window.

NB: The boxes in the upper part of the window need to be filled out **before** reference conditions are set for probabilities and flow-rates in the other windows. If the properties in the main window are changed after probability distributions or flow rates have been set, it might be necessary to apply the settings again. In this case the texts ‘set flow rates’ or ‘set probability distributions’ will appear in the box below the Generate Loadprofile-button.

The following reference conditions can be defined:

- **Single or Multi Family House:** The only distinction between single and multi-family houses made in the program, is concerning holiday-periods taken into account. The differences are described in the section *Probability Function Window*. All settings for the holiday periods are to be made in the form *ProbForm*, which opens when the button *Set Probability Distributions* is pressed. If the button *Multi Family House* is checked, it can be specified how many households are taken into account (which equals to the number of holiday periods). If it is not specified, the number of household is set to the default value of one.
- **Number of categories:** Up to four categories with different flow rate levels, durations and frequencies can be defined. The settings are made in forms that open when the button *Set Flow Rates* is pressed. (For further descriptions see section: *Flow Windows*.)
- **Time step duration** in minutes: Marks the minimum time interval between two draw-off starts and hereby the minimum time duration of a draw-off. The profile consists of an integer value of the flow rate in litre/hour for each time step in the total profile duration. Only fixed values between 1 and 60 minutes can be chosen. The draw-off durations (to be defined in the Flow Windows) need to be multiple integers of the profile time step.
- **Start day of the profile:** The profile can start on any day of the year. The start day affects the seasonal probabilities for draw-offs. Jan. 1st is regarded as the first day of the year. Start day 1, 2, .. means, the first weekday of the profile is a Monday, Tuesday, .. , respectively.
- **Total duration (profile)** in days: Duration of the DHW-profile (usually 365 days). Determines the size of the output file. The number of values for the flow rate given in the load profile output file equals to the total duration (in minutes) divided by the time step duration.
- **Total mean daily draw-off volume** in litre/day. For multi-family houses not the mean daily draw-off volume per household, but the **total** draw-off volume has to be entered.
- **File name of profile:** The file name must only consist of letters and numbers. The four output files names are extended to *filename_DHW.txt*, *filename_Vdot.txt*, *filename_log.txt*, and *filename_sum.txt*. For further information concerning the output files see section 3 of this manual.

To exit the program, press the button at the upper right corner of the window.

2b. Probability Distribution Window

To spread the flow rates throughout the time period for the profile, the cumulated frequency method was applied. This method is based on the integral function of a probability function. The method is described in section 3.1.

The probability function of draw-offs is described by the product of probability functions for seasonal, daily, and week-daily variations of DHW-consumption:

$$p(t) = d_{\text{day}}(t) \cdot p_{\text{weekday}}(t) \cdot p_{\text{season}}(t) \cdot p_{\text{holiday}}(t)$$

Fig. 2.2: Probability distribution window.

The following reference conditions can be defined:

Probability during the day: One out of three options can be chosen:

1.) Default distributions:

This is a pre-defined probability distribution based on Gaussian and step functions as shown in figure 2.3. Four categories of loads are defined. For two categories (small and medium draw-offs) a constant probability for draw-offs is assumed during daytime and nighttime, respectively. For the other two categories (shower and bath) Gaussian distributions with peaks in the morning and evening, respectively, are defined to describe the probabilities during the day. Each category-profile is generated separately and superposed afterwards.

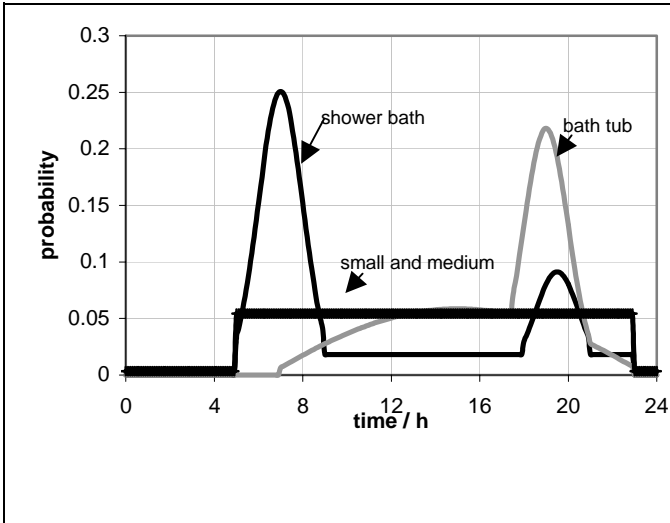


Fig. 2.3: Probability distribution load in the course of the day.
 Category 1 and 2: For small and medium draw-offs the probability is distributed equally between 5:00 and 23:00 h.
 Category 3: Bath
 Category 3: Shower

Fig. 2.4: Window to define the daily probability distributions as two different step functions, one for weekdays, the other one for weekend-days for up to 6 time period each.

!!! Attention !!!
The standard daily probability distributions as shown in Fig. 2.5 can only be chosen if the number of categories set in the main form is set to 4.

2.) Step functions for weekdays and weekend-days: Figure 2.4

Two daily probability step functions can be defined with this option, one for weekdays and one for weekend-days. Therefore the probability for a draw-off at a certain time of each day is equal from Monday to Friday, and it is equal on Saturdays and Sundays.

Up to six time-step intervals can be defined for each period. The values in the yellow windows p_{step} show the part of the mean daily draw-off volume for each time interval in percent of the total mean daily draw-off volume. The values in the boxes increase, when either the corresponding time interval is enlarged or the scroll bar next to the box is moved to the right.

p_{step} are calculated with:

$$p_{step}^i = \frac{\Delta t_{step}^i \cdot pos^i}{\sum_{j=1}^6 (\Delta t_{step}^j \cdot pos^j)}, \quad \text{with } i, j = 1..6 \text{ and } pos^i \in [0,100]$$

pos^i : scroll bar position of the six time steps i with values between 0 and 100.

Δt_{step}^i : time step intervals, time 2 (white time box) – time 1 (grey time box)

If the radio-button at the top of the window is set to **use scroll bars**, the boxes on the right side of the scroll-bars can not be edited.

3.) Step functions for each day: Figure 2.5

The third option provides the possibility to apply special consumption patterns, which differ much for the different days of the week, e.g. for sport halls or hospitals.

A mean draw-off volume (in litres) can be set for each hour of the week.

When the default-button is pressed the values are set as shown in Figure 2.5.

When the apply-button is pressed or when the window is closed, the values are normalized, to reach the right value for the total draw-off volume. (In the example shown in Figure 2.5 to 1400 l/week, mean daily draw-off volume: 200 l/day).

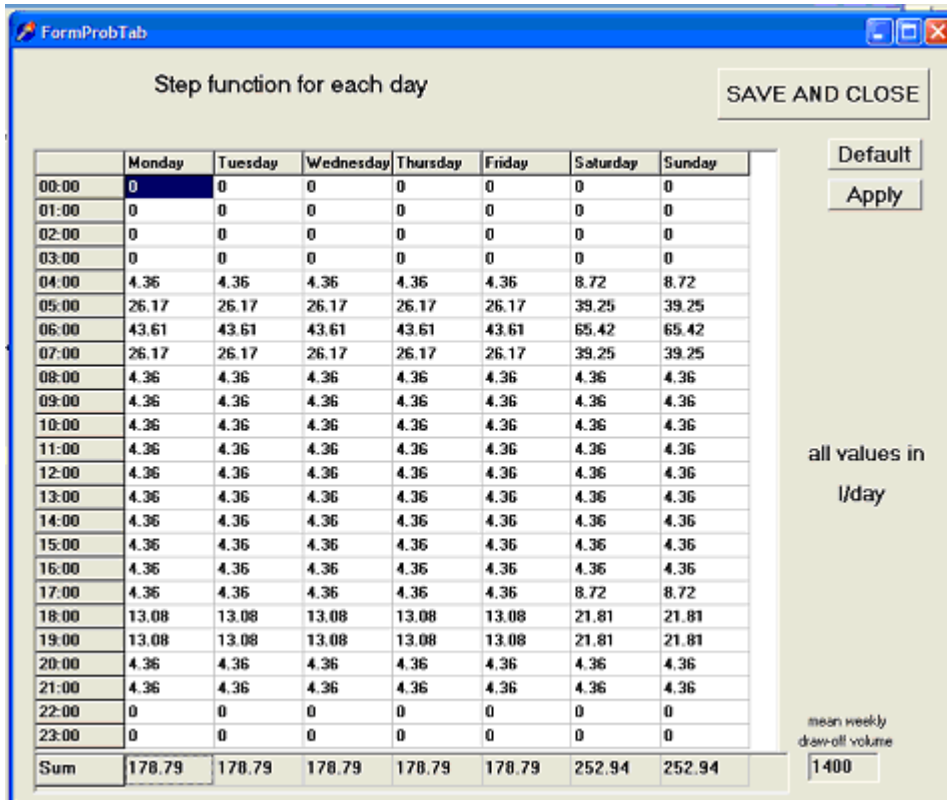


Fig. 2.5: Window to define the daily probability distributions as a different step function for each day of the week with a step size of 1 hour.

Probability weekend-day/weekday: Proportion of mean draw-off volume on weekend-days compared to weekdays. Range: 0 .. 300 %.

Example:

$$\frac{P_{\text{weekend-day}}}{P_{\text{weekday}}} = 120 \quad \text{and} \quad \bar{V}_{\text{day}} = 200 \text{ l/day}$$

$$\Rightarrow \quad \text{Daily mean draw-off volumes:} \quad \bar{V}_{\text{Mon}} = \bar{V}_{\text{Tue}} = \bar{V}_{\text{Wed}} = \bar{V}_{\text{Thu}} = \bar{V}_{\text{Fri}} \approx 189 \text{ l}$$

$$\bar{V}_{\text{Sa}} = \bar{V}_{\text{Su}} \approx 227 \text{ l}$$

The value can be set either with the scroll bar or it can be typed into the box.

If the daily step functions are selected the Probability Weekend-day/Weekday should be set to 100.

Seasonal Variations

Seasonal variations are described by a sine function with a period of 365 days. The amplitude of the sine function and the day of the year at which the sine maximum occurs can be set (Figure 2.6).

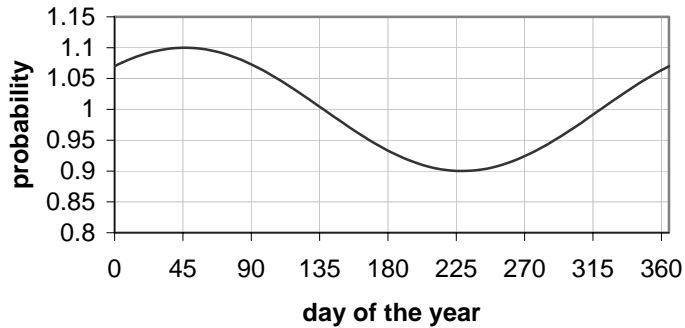


Fig. 2.6: Example for a sine function to describe the seasonal variation of the probability.

Default settings
Amplitude: 10 %;
Position of maximum: Day 45

Holiday periods

For single-family houses up to three periods can be defined. During these periods the DHW consumption is usually reduced to zero. If a non-zero, but reduced DHW consumption should be taken into account during these periods, the reduced portion (percentage of the regular probability for draw-offs at that day) needs to be set in the edit-box situated at the bottom of the window. Overlapping periods are regarded as a regular holiday period.

To change the start- and end-dates of the holiday periods, the drop-down buttons need to be enabled with the check buttons placed below.

For multi-family houses a long period (of usually a few months) marks the whole period within which holidays are taken into account for each household of the house. The holiday duration for each household can be specified in the edit-box next to the start- and end- date buttons. The start date for each single holiday duration is generated with the random generator.

2b. Flow Windows

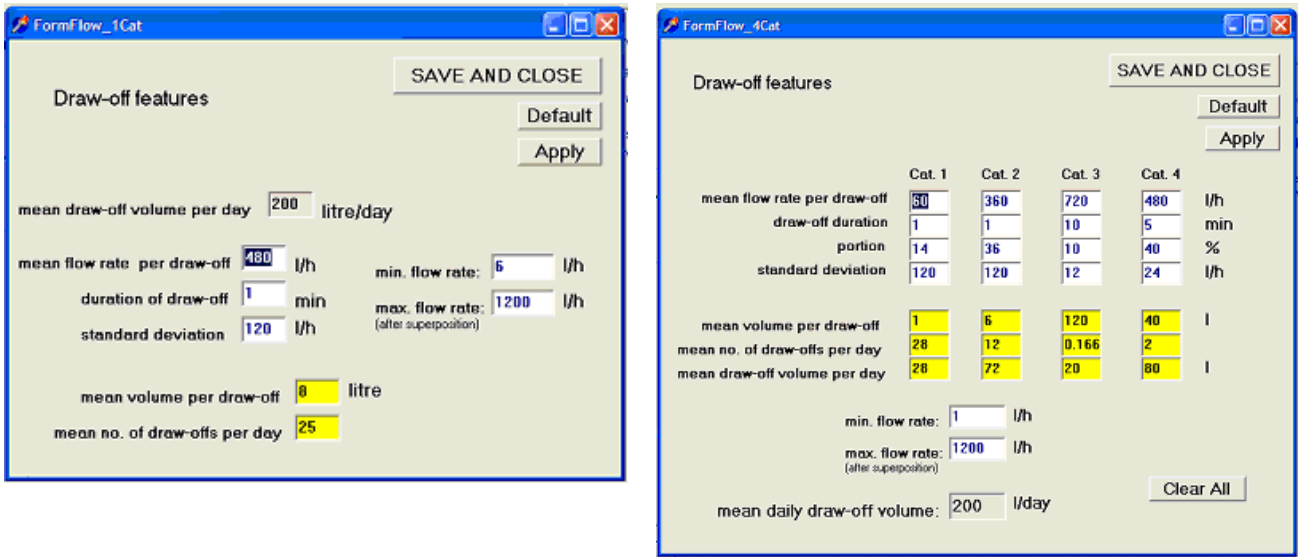


Fig. 2.7 a) and b): Flow Windows to specify flow rates, draw-off durations and the standard deviation of the Gaussian distribution of flow rates for one draw-off category (a) or for up to 4 draw-off categories (b).

If the button **Set flow rates** is pressed on the main window and **Number of categories** is set to **1** for the draw-off *FormFlow_1Cat* (Fig. 2.7a) will open.

With this option only one interval of flow rates with a fixed duration can be chosen.

If **Number of categories** is set to **4**, *FormFlow_4Cat* (Fig. 2.7b) will open. In this case up to four flow rate-intervals and draw-off durations can be chosen, as well as the distribution of the total draw-off volume among the four categories.

Only the white boxes can be filled in. The value for the mean daily draw-off volume is only shown for information purposes in this window. It must be set in the main window **before** the Flow window is opened. The values in the yellow boxes are calculated automatically. In some cases they are not calculated immediately. Then, the apply button can be used to show the recent values. However, the use of the apply button is optional. All the recent values are stored automatically if the window is closed.

The following reference conditions can be defined:

- **Mean flow rate:** Peak of the Gaussian curves, shown in Figure 2.8.
- **Draw-off duration:** Must be a multiple integer of the profile time step.
- **Standard deviation of the Gaussian functions:** Determines the width of the Gaussian curves.
- **Minimum flow rate**
- **Maximum flow rate:** For multi-family houses, the total maximum flow-rate (sum for all households after superposition)

and for 4 categories additionally:

- **Portion:** Percentage of volume assigned to each category.

For each category a mean flow rate is defined. The values of the flow rates for the profile are spread around the mean value with a Gaussian-distribution:

$$prob(\dot{V}) = \frac{1}{\sqrt{2\pi}\sigma} \exp \frac{-(\dot{V} - \dot{V}_{mean})^2}{2\sigma^2}$$

with σ : standard deviation

A flow rate step size of 0.1 l/min = 6 l/h is defined by the program.

In Figure 2.8 the flow rate distributions are shown which are applied, if the option ‘DHW standard distribution’ is chosen. The curves show Gaussian flow rate distributions for four categories. The categories represent small and medium draw-offs, shower, and bath. In the figure, the total duration of draw offs during a year is shown as a function of the flow rate.

Default values for 4 categories:

mean flow rates: 0, 6, 8 and 14 l/min, respectively;

standard deviations (for all categories): 2 l/min;

durations of draw-offs: 1, 1, 5, 10 min, respectively.

The minimum and maximum flow rate is determined by twice the standard deviation σ :

$$\dot{V}_{min} = \dot{V}_{mean} - 2 \cdot \sigma \quad \text{and} \quad \dot{V}_{max} = \dot{V}_{mean} + 2 \cdot \sigma .$$

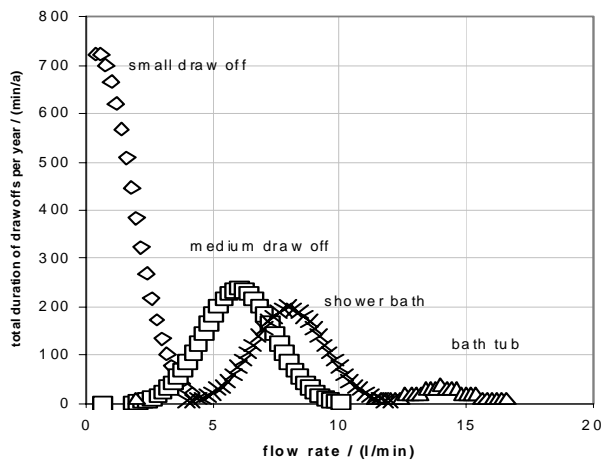


Fig. 2.8: Example for flow rate distributions for four categories.

3. Mathematical Description: Cumulated Frequency Method

The transient probability function is calculated as the product of daily, weekly, seasonal probability distributions and the holiday step functions for every time step:

$$p(t) = p_{\text{day}}(t) \cdot p_{\text{weekday}}(t) \cdot p_{\text{season}}(t) \cdot p_{\text{holiday}}(t)$$

with:

$p_{\text{day}}(t)$ is the function of the distribution during the day. Three options can be chosen:

- 1.) A superposition of Gaussian functions as shown in figure 2.5.
- 2.) Two step functions, one applied on weekdays, the other one on weekend-days. Up to six time intervals can be defined for the step functions (see form in Figure 2.6).
- 3.) A step function can be defined for each day of the week with a step size of 1 hour (see form in Figure 2.7).

$p_{\text{weekday}}(t)$ is a function to take into account different mean draw-off volumes on weekdays compared to weekend-days.

For example, if the scroll bar for the Probability Weekend-day/Weekday is set to 1.2, it follows

$$p_{\text{weekday}}(t) = \begin{cases} 0.95 & \text{for } t \in \text{weekday} \\ 1.14 & \text{for } t \in \text{weekend} \end{cases}$$

$p_{\text{season}}(t)$ is described as a sine function.

The integral $I(t)$ over the probability function $p(t)$ from the start time t_{min} to the time t is then normalized.

$$I(t) = \int_{t_{\text{min}}}^t p(t) dt$$

For each draw-off a random value with $\text{ran} \in [0,1]$ is generated.

The time step t in which each draw-off occurs is then given by the dependent variable of the integral function: $\text{ran} = I(t)$ (see figure 3.1).

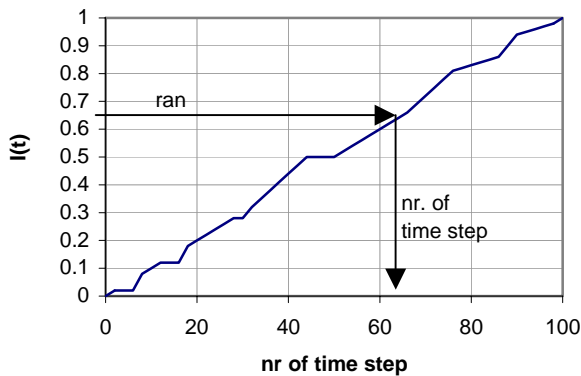


Fig. 3.1: Cumulated frequency method: Random values for each draw-off are distributed over the time period according to the probability integral function $I_p(t)$.

The European Daylight Saving Time ('summer time') is not taken into account in the listing of *Filename_sum.txt*. Due to the fact that the daily probability distributions are shifted by one hour during the summer months, the values in the list of the hourly draw-off volumes do not reflect the daily probability distributions exactly.

The file *Filename_log.txt* supplies information about all input data supplied by the user. An example logfile is shown below.

LOGFILE DHW0001_log.txt

for a single family house
Total duration: 2 days
Start day : 1. day of the year
Mean daily draw-off vol.: 200 l/day
No. of categories: 1
Time step duration: 15 min

FLOW RATE SETTINGS

Mean flow Rate: 60 l/h
Duration of draw-off: 15 min
standard deviation: 12 l/h
min. flow rate: 6 l/h
max. flow rate: 1200 l/h

PROBABILITY FUNCTION SETTINGS

Step function probability distribution for weekdays + weekend-days

Mean DHW-volume tapped during 6 time periods:

weekdays

time period ratio of daily DHW-volume

22:00-06:30 2 %

06:30-07:30 50 %

07:30-12:00 6 %

12:00-13:00 16 %

13:00-18:00 6 %

18:00-22:00 20 %

weekend-days

time period ratio of daily DHW-volume

23:00-07:00 3.8 %

07:00-09:00 47.5 %

09:00-15:00 7.1 %

15:00-17:00 23.8 %

17:00-20:00 3.6 %

20:00-23:00 14.3 %

Ratio of the mean daily draw-off volume tapped
on weekend-days/on weekdays: 120 %

Seasonal Variations:

Sine amplitude: 10 %

Day of sine maximum: 45

Holiday Periods:

Relative consumption during holiday periods: 0 %

5. Examples of daily draw-off volumes

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

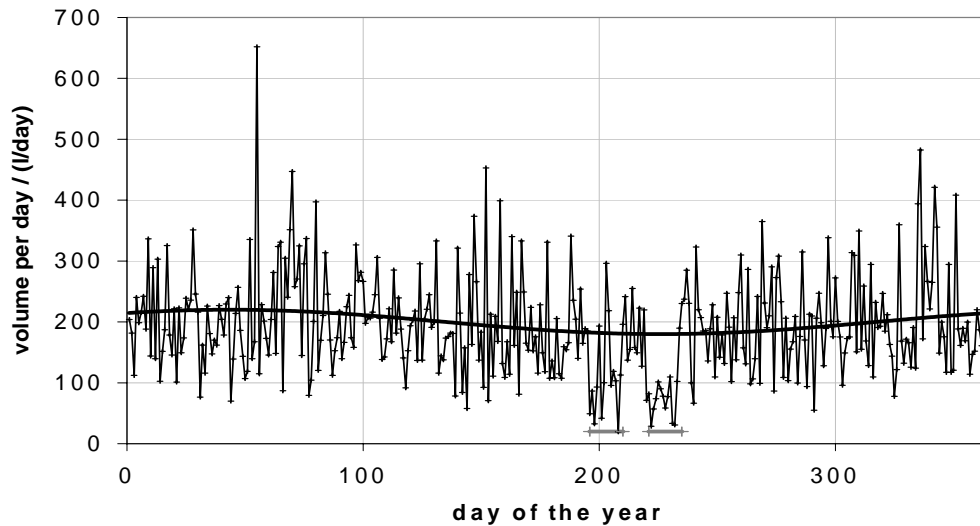


Fig. 5.1: Distribution of draw-off volume per day during the year (mean value on holidays: 100 l/day, on other days: 200 l/day.). The sinus function, used to calculate the probability during the course of the year with an amplitude of 20 l/day (10% of the mean daily draw-off volume) is shown with a solid 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 (marked with gray lines).

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

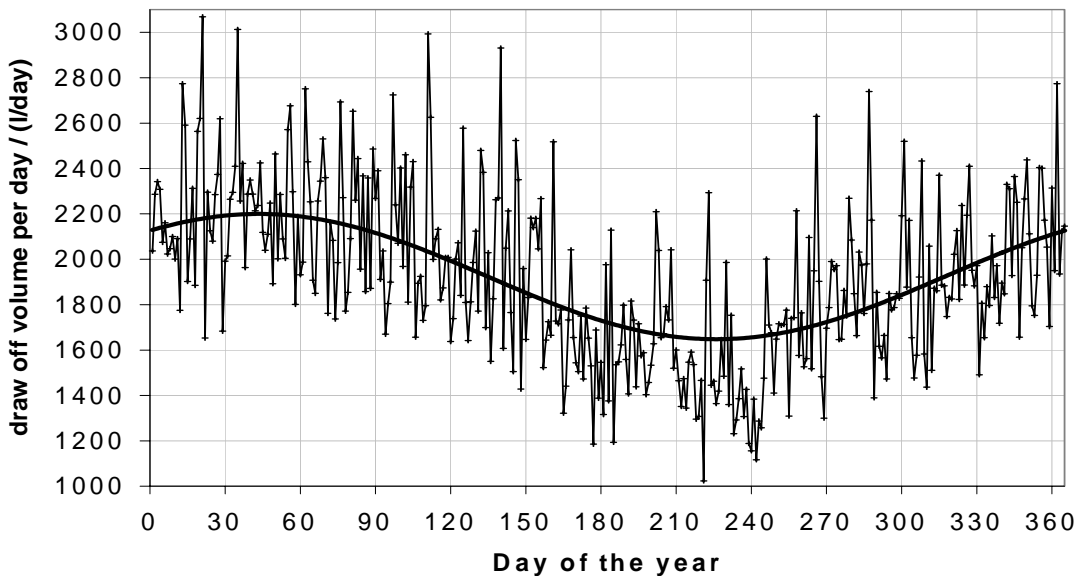


Fig. 5.2: Distribution of the total draw-off volume per day during the year for a ten-family house (mean value: 2000 l/day). Solid line (sinus function): average consumption in the course of the year. Two weeks holidays between June 1st and Sept. 30th for each household.