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A METHODOLOGY TO GENERATE REALISTIC RANDOM BEHAVIOR PROFILES FOR SPACE HEATING AND DOMESTIC HOT WATER SIMULATIONS

J. De Schutter[1*], I .Verhaert[2], M. De Pauw[1]

[1]Thomas More Kempen, Kenniscentrum Energie, Geel, Belgium
[2]University of Antwerp, Antwerpen, Belgium

ABSTRACT

To simulate the performance of a heat production for space heating and domestic hot water (DHW) in residential buildings, a realistic behavior profile of the habitants is needed next to inputs like building characteristics, weather data and heat production parameters. To take into account habitants presence and simultaneity on domestic hot water demand, stochastic presence and DHW demand profiles were generated. In order to obtain random, but realistic profiles, available and gathered statistic data out of inquiries on water use and family profiles are used, next to in situ measurements which completed the data and validated the profiles.

With this method it is possible to generate static arrays, starting from occupancy profiles, based on habitants per dwelling, habitants general profile and present tapping points per dwelling which can be used as an input for building simulations.

KEY WORDS: domestic hot water, collective heating systems, behavior profiles

1. INTRODUCTION (Details for Submitting Paper)

Collective heating systems reappear more frequently in residential buildings, more precisely the central heating systems with one primary distribution circuit and substations in each apartment. An important reason is the fact that collective systems make the integration of renewable energy much easier. Moreover, collective systems permit to reduce the installed power for DHW. Thanks to an increased rate of insulation, peak demand for space heating (SH) is becoming significantly lower than peak demand for domestic hot water (DHW) generation. Within single dwellings or apartments combined heater (for SH and DHW), this leads to oversized installation for space heating.

To compare collective with individual heat production on energy use and comfort by simulation, realistic behavior profiles of the habitants are needed, which can be used as a static input for simulation models. These behavior profiles give an overview of presence of the habitants and DHW needs, and can vary on composition per dwelling, behavior of the habitants and present DHW tapping points.

2. PRESENCE

The first step in simulating behavior profiles is to simulate the presence of the inhabitants. The presence of the inhabitants will be the base for the further simulated profiles, as the adjustment of the room thermostat, the internal heat gains and the domestic hot water profiles of the given dwelling. In this paper we focus on the simulation of the behavior profiles according to presence and DHW.

*Corresponding Author: f.author@affiliation.com

2.1 Dwelling types In order to restrict the number of dwelling types, a limited list of choices is generated.

Table 1 - Types of dwellings

dwelling	No. Of inhabitants	Adult No. 1	Adult No. 2	Child No. 1	Child No. 2
1	1	unemployed	/	/	/
2	1	employed	/	/	/
3	2	unemployed	employed	/	/
4	2	employed	employed	/	/
5	3	unemployed	employed	school-going	/
6	3	employed	employed	school-going	/
7	4	unemployed	employed	school-going	school-going
8	4	employed	employed	school-going	school-going
9	2	unemployed	unemployed	/	/

For each person of a certain dwelling, the presence will be determined on a daily base.

2.2 Determining the presence As a simplification, a dwelling will be considered as 1 temperature area, so no difference will be made between the different rooms of a dwelling. Distinction is made as follows: A person can be 'present and awake', 'absent' or 'present but asleep'. As humans are inclined to hold on to certain habits, each person has some kind of a 'fixed' pattern, with a difference between week days and weekend days. This means that for each person for example the average hour of waking up on a week day is determined once, and in a later stadium, some scattering on this value will be admitted.

2.3 Procedure The procedure to determine the presence for the members of a certain dwelling is as follows:

Step 1: At the start of the simulation, average times of the days are fixed for each member of a dwelling.

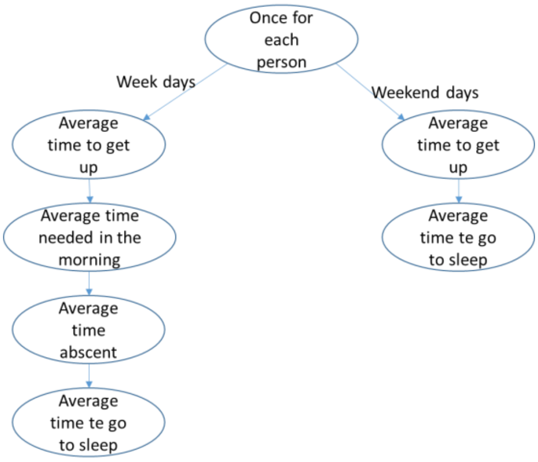

Figure 1 – Average times of the day

For every step, the average times are randomly determined by random generation according to a cumulative normal distribution.

For example, the average time to get up on a weekday for a working person without a school-going child is at 7 a.m, according to a survey, held on 700 dwellings. The standard deviation is +/- 24 minutes. This gives the following course:

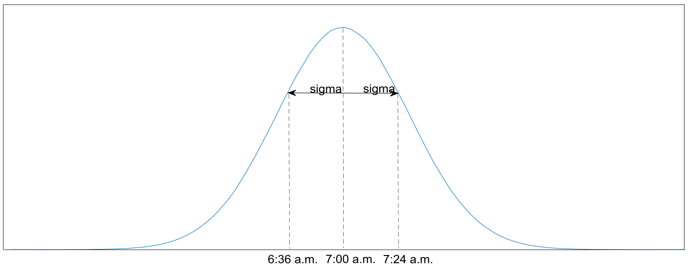

Figure 2 – Normal distribution

Transforming this normal distribution to a cumulative curve will graphically show the method. On the cumulative curve, a random generator will generate a number between 0 and 1, which can be projected on the cumulative curve. Projecting on the X-axis will provide the average time of waking up for that person.

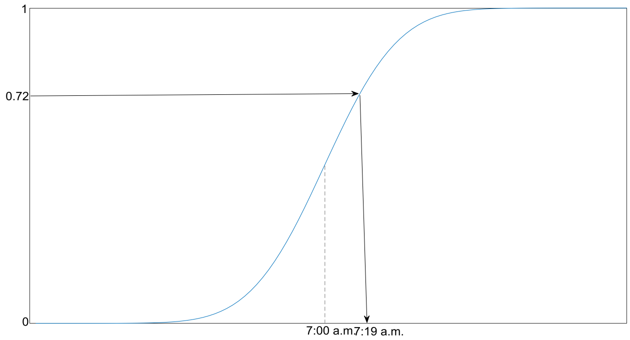

Figure 3 – Cumulative normal distribution and generating time

Each value to be determined has his own curve, based on the survey, and validated by a research held by the VUB in Brussels (http://www.tijdsonderzoek.be/ [1]).

Step 2: For each day of the simulation period, the real times of that day are determined per person. For the example above, a person with an average time to get up at 7:19, the normal distribution will be as follows:

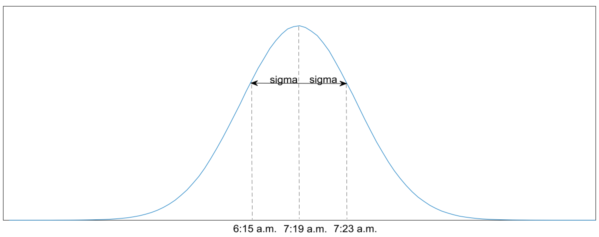

Figure 4 - Normal distribution for real time of waking up

Also here, each value to be determined has his own curve, based on the survey. This is done according to the following flow chart:

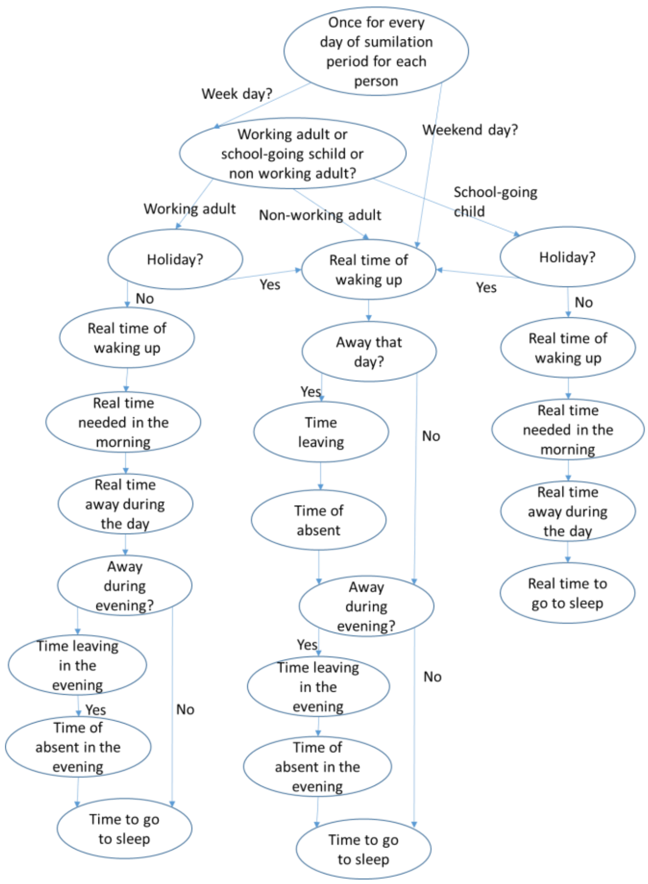

Figure 5 - Determining the real times of a habitant for one day of the simulation period

Remarks:

- If adults have a school-going child, the average time to wake up cannot be later than 7:30 a.m.
- The average time to get up from a school-going child is the same as the average time to wake up from the longest sleeping adult
- Average time to leave for school for a school going child cannot be later than 8:00 a.m.
- Every member of a dwelling has 30 holidays which will be considered as (50/50)
  - A weekend day
  - A day of total absence

3. DOMESTIC HOT WATER

3.1 Procedure A requirement profile for the use of domestic hot water (DHW) will be generated on the level of the tapping points. The requirement profile consists a temperature profile and a flow profile. There's a link between the DHW requirement profile and the presence profile. This means that there can only be a DHW need when at least 1 habitant is present and awake. There is a maximum of 7 tapping points per dwelling: 1 bath, 2 showers, 2 bathroom tapping point and 2 kitchen tapping points. There are 4 types of tappings defined:

- Personal hygiene. This can be divided in
  - Bathing moments (in bath)
  - Shower moments (in a shower or in bath (if indicated))
- Dishwashing. These tappings always happen on one of the kitchen tapping points.
- Cleaning (house or car). These tappings can happen on one of the two bathroom- or one of the two kitchen tapping points.

- Other tappings. All small DHW tappings such as hand washing, shaving, kitchen cleaning, … These tappings can happen on one of the two bathroom- or one of the two kitchen tapping points.

For every dwelling, the tapping pattern is generated randomly for each of these 4 types of tappings. These types of tappings can be characterized by:

- Number of tappings during 1 day (dependent on the number of habitants of that dwelling)
- For every tapping
    - Time of the day (only if at least 1 habitant is present and awake)
    - Tapping point where tapping takes place
    - Desirable length of the tapping
    - Desirable flow and mixing temperature of the tapping

Step 1: The number of tappings is determined depending on the number of habitants. For example, for a dwelling, consisting of 2 persons, the chance is 8.0% that no tapping for personal hygiene (bath or shower) will take place that day. The chance that 1 tapping for personal hygiene will take place is 47.1%, etc.

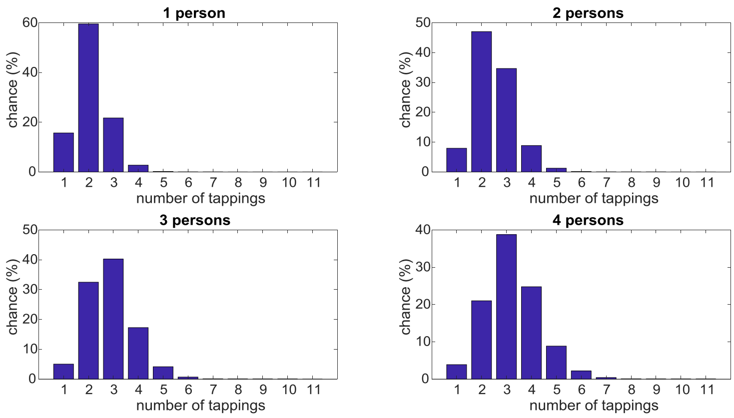

Figure 6 - chance on a number of tappings for personal hygiene (bath or shower) depending on the number of persons in a dwelling

Again, the chance profiles are converted to cumulative chance profiles, where a random number can be generated. This random number can be projected on the cumulative chance curve and will give the number of tappings for personal hygiene for that specific day. For example, if the generated random number for a specific day is 0.22 (22%), the number of tappings for personal hygiene for a dwelling of 2 persons equals 2. For tappings for personal hygiene, there are 2 types of tappings: shower tappings or bath tappings. Whether a tapping for personal hygiene is a shower or a bath, depends.

- If a dwelling only has a shower, but no bath, every tapping for personal hygiene is a shower
- If a dwelling has a shower and a bath, a tapping for personal hygiene can be a shower as well as a bath. The ratio ‘bathing moments/showering moments’ is depending on the number of dwelling habitants. This is based on the results of the survey. A higher number of habitants (or more children) gives a higher percentage of bating moments.

Table 2 - ratio of bathing moments

# habitants per dwelling	ratio of bathing moments (%)
1	12,3
2	17,1
3	21,8
4	26,6

- If only a bath is available, it is supposed that the bath is used as a shower as well, so the same dividing between showering moments and bathing moments as above is used.

Step 2: For every tapping, the moment determine of the day when the tapping takes place, is determined. The moment when certain tappings are more likely to take place, depends on different factors:

- The presence of the habitants. DHW tappings can only take place when at least 1 habitant is present and awake.
- The type of day. Week days have a different profiles then weekend days.
- The type of tapping (bath, shower, dish wash, cleaning, others). For example, the chance on a shower is bigger in the morning. Dishwashing is more likely to take place in the evening. To meet this requirement, a weighing factor graph is given for every tapping. For the example of a shower, we see the graph on the figure below.

  This means that, if somebody is present and awake somewhere between 6:00 a.m. and 8:00 a.m., chances are 5 times higher that this person will take a shower, compared to the fact that this person should be at home between 10:30 am and 18:00 a.m. So for a certain day, the weighing factor over that day can be multiplied with the presence during that day, which gives the actual chance curve for determining the time of a shower for that day.

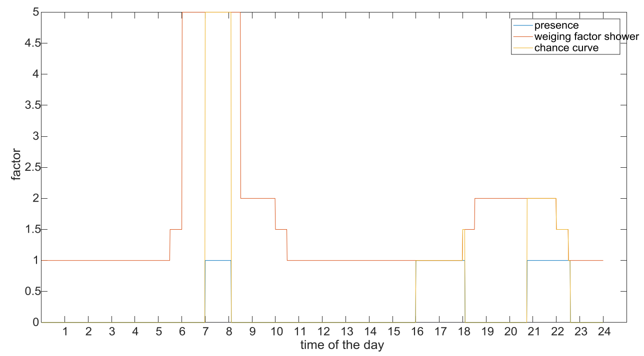

Figure 7 - chance curve for shower tappings for a certain day

This chance curve can again be transformed to a cumulative chance curve for this specific day.

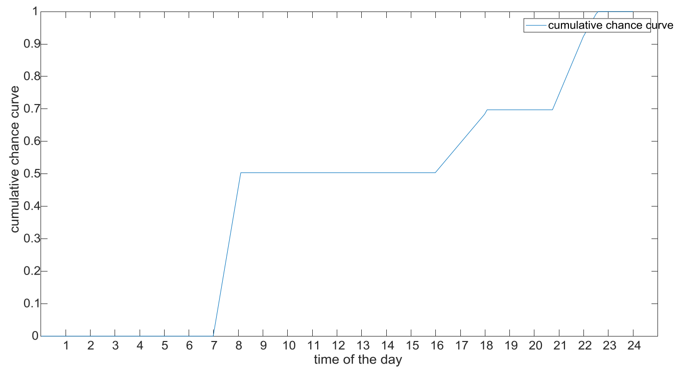

Figure 8 - cumulative chance curve for shower tappings for a certain day

On this curve, again, a random number between 0 and maximum can be generated, which gives the actual time when the shower takes place. Note that this chance curve changes for every type of tapping and for every day of the simulation period.

Step 3: The tapping point where the tapping takes place, is determined. If for every type of tapping (personal hygiene, dishwashing, cleaning, others) the number of tappings per day is determined, the tappings can be divided over the tapping points.

- Tappings for personal hygiene
  - Bathing moments: will always take place in the bath
  - Showering moments: can take place in 1 of the 2 showers (if 2 available) or in the bath (if used as a shower). It's possible to give priority to 1 of the showering points. In that case, this shower will have 80% of the showering moments. In the other case, showering moments will be divided equally over the different showering points.
- Dishwashing: Only on the kitchen tapping points. If there are 2 kitchen tapping points, 80% of the tappings is foreseen for the first kitchen tapping point
- Cleaning: equally devided over the available kitchen and bathroom tapping points
- Other tappings: equally devided over the available kitchen and bathroom tapping points

If, on the moment the tapping should take place, another tapping already takes place on this tapping point, the following hierarchy is followed:

- Of another tapping point is available where this tapping can take place, the other taping point will be chosen
- If no other tapping point is available for this certain tapping, a new time for the tapping will be chosen

Step 4: The length of a tapping can be determined using the same method as described above. A skewed normal distribution is used in this case. For example, for showering moments, the shape of the curve is as follows:

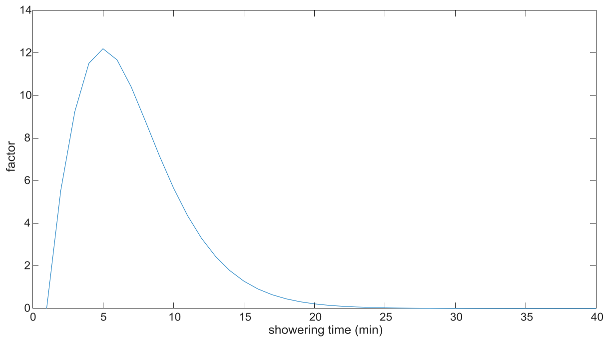

Figure 9 - skewed normal distribution for determining showering time

Determining the showering time is done, using the same method as described earlier.

Step 5: The desired flow and temperature of the tapping is determined. The desired mixed flow and temperature are related. The desired mixed flow is dependent on the position of the lever of the tapping point, but also on the characteristics of the tapping point. For example, a rain shower will have a higher standard water flow then a normal shower or a water-saving shower. The desired mixed flow is determined by using normal distribution curves, depending on the tapping point (bath, rain shower, normal shower, water-saving shower, bathroom faucet, kitchen faucet). The desired temperature is depending on the type of tapping. For example, the average desired temperature for showering is 38°C, for bathing, the desired temperature will be slightly higher. The desired hot water flow can be calculated from the desired flow, the desired mixing temperature, the cold water temperature (depending on the time of the year, between 5 and 15°C) and the hot water temperature (standard 60°C), using the formula:

$$Q_{DHW} = Q_{mix} * (\frac{T_{mix} - T_{cold}}{T_{DHW} - T_{cold}})$$

- with:
  - $Q_{DHW} = hot\ water\ flow\ [liter/minute]$
  - $Q_{mix} = desired\ mixed\ water\ flow\ [liter/minute]$
  - $T_{mix} = desired\ mixed\ water\ temperature\ [°C]$
  - $T_{cold} = cold\ water\ temperature\ [°C]$
  - $T_{DHW} = delivered\ hot\ water\ temperature\ [°C]$

2.3 Results As an example of a result, you can see a DHW tapping profile underneath for a 1 person dwelling, living in an apartment with 1 shower (no bath), 2 bathroom valves and one kitchen valve. The flow is given as the wanted mixed water flow [l/min], the mixed water temperature is always 38°C, except for the kitchen tapping (dish wash) it is 45°C. The lengths depends from 15 seconds (shortest bathroom tapping) over 32 minutes (a short shower in the morning) to 8 minutes (the dish wash).

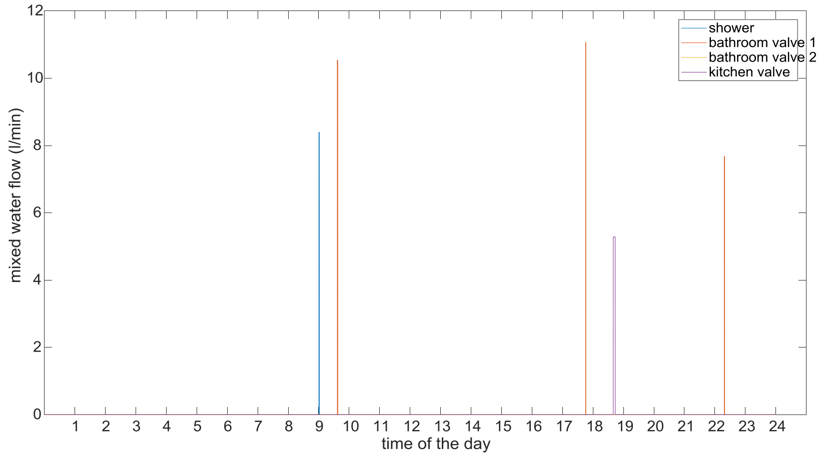

Figure 10 - Example of DHW tapping profile

4. CONCLUSIONS

The method as described above generates realistic behavior profiles, concerning presence and domestic hot water use. These behavior profiles can be used as a static input for space heating and DHW simulations in collective housing buildings and to compare different heating methods on energy and comfort parameters.

ACKNOWLEDGMENT

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[1] http://www.tijdsonderzoek.be/, VUB Brussels (2013)