The Reference Framework for System Simulations of the IEA SHC Task 44 / HPP Annex 38

Part A: General Simulation Boundary Conditions

A technical report of subtask C

Report C1 Part A

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IEA Solar Heating and Cooling Programme

The *International Energy Agency* (IEA) is an autonomous body within the framework of the Organization for Economic Co-operation and Development (OECD) based in Paris. Established in 1974 after the first "oil shock," the IEA is committed to carrying out a comprehensive program of energy cooperation among its members and the Commission of the European Communities.

The IEA provides a legal framework, through IEA Implementing Agreements such as the *Solar Heating and Cooling Agreement*, for international collaboration in energy technology research and development (R&D) and deployment. This IEA experience has proved that such collaboration contributes significantly to faster technological progress, while reducing costs; to eliminating technological risks and duplication of efforts; and to creating numerous other benefits, such as swifter expansion of the knowledge base and easier harmonization of standards.

The *Solar Heating and Cooling Programme* was one of the first IEA Implementing Agreements to be established. Since 1977, its members have been collaborating to advance active solar and passive solar and their application in buildings and other areas, such as agriculture and industry. Current members are:

Australia	Finland	Singapore
Austria	France	South Africa
Belgium	Italy	Spain
Canada	Mexico	Sweden
Denmark	Netherlands	Switzerland
European Commission	Norway	United States
Germany	Portugal	

A total of 49 Tasks have been initiated, 35 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition to the Task work, a number of special activities—Memorandum of Understanding with solar thermal trade organizations, statistics collection and analysis, conferences and workshops—have been undertaken.

Visit the Solar Heating and Cooling Programme website - **www.iea-shc.org** - to find more publications and to learn about the SHC Programme.

Current Tasks & Working Group:

Task 36	*Solar Resource Knowledge Management*
Task 39	*Polymeric Materials for Solar Thermal Applications*
Task 40	*Towards Net Zero Energy Solar Buildings*
Task 41	*Solar Energy and Architecture*
Task 42	*Compact Thermal Energy Storage*
Task 43	*Solar Rating and Certification Procedures*
Task 44	*Solar and Heat Pump Systems*
Task 45	*Large Systems: Solar Heating/Cooling Systems, Seasonal Storages, Heat Pumps*
Task 46	*Solar Resource Assessment and Forecasting*
Task 47	*Renovation of Non-Residential Buildings Towards Sustainable Standards*
Task 48	*Quality Assurance and Support Measures for Solar Cooling*
Task 49	*Solar Process Heat for Production and Advanced Applications*

Completed Tasks:

Task 1	*Investigation of the Performance of Solar Heating and Cooling Systems*
Task 2	*Coordination of Solar Heating and Cooling R&D*
Task 3	*Performance Testing of Solar Collectors*
Task 4	*Development of an Insolation Handbook and Instrument Package*
Task 5	*Use of Existing Meteorological Information for Solar Energy Application*
Task 6	*Performance of Solar Systems Using Evacuated Collectors*
Task 7	*Central Solar Heating Plants with Seasonal Storage*
Task 8	*Passive and Hybrid Solar Low Energy Buildings*
Task 9	*Solar Radiation and Pyranometry Studies*
Task 10	*Solar Materials R&D*
Task 11	*Passive and Hybrid Solar Commercial Buildings*
Task 12	*Building Energy Analysis and Design Tools for Solar Applications*
Task 13	*Advanced Solar Low Energy Buildings*
Task 14	*Advanced Active Solar Energy Systems*
Task 16	*Photovoltaics in Buildings*
Task 17	*Measuring and Modeling Spectral Radiation*
Task 18	*Advanced Glazing and Associated Materials for Solar and Building Applications*
Task 19	*Solar Air Systems*
Task 20	*Solar Energy in Building Renovation*
Task 21	*Daylight in Buildings*
Task 22	*Building Energy Analysis Tools*
Task 23	*Optimization of Solar Energy Use in Large Buildings*
Task 24	*Solar Procurement*
Task 25	*Solar Assisted Air Conditioning of Buildings*
Task 26	*Solar Combisystems*
Task 27	*Performance of Solar Facade Components*
Task 28	*Solar Sustainable Housing*
Task 29	*Solar Crop Drying*
Task 31	*Daylighting Buildings in the 21st Century*
Task 32	*Advanced Storage Concepts for Solar and Low Energy Buildings*
Task 33	*Solar Heat for Industrial Processes*
Task 34	*Testing and Validation of Building Energy Simulation Tools*
Task 35	*PV/Thermal Solar Systems*
Task 37	*Advanced Housing Renovation with Solar & Conservation*
Task 38	*Solar Thermal Cooling and Air Conditioning*

Completed Working Groups:

CSHPSS; ISOLDE; Materials in Solar Thermal Collectors; Evaluation of Task 13 Houses; Daylight Research

IEA Heat Pump Programme

This project was carried out within the Solar Heating and Cooling Programme and also within the *Heat Pump Programme*, HPP which is an Implementing agreement within the International Energy Agency, IEA. This project is called Task 44 in the *Solar Heating and Cooling Programme* and Annex 38 in the *Heat pump Programme*.

The Implementing Agreement for a Programme of Research, Development, Demonstration and Promotion of Heat Pumping Technologies (IA) forms the legal basis for the IEA Heat Pump Programme. Signatories of the IA are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the IA collaborative tasks or “Annexes” in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and work plans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex. The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

The IEA Heat Pump Centre

A central role within the IEA Heat Pump Programme is played by the IEA Heat Pump Centre (HPC). Consistent with the overall objective of the IA the HPC seeks to advance and disseminate knowledge about heat pumps, and promote their use wherever appropriate. Activities of the HPC include the production of a quarterly newsletter and the webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the IEA Heat Pump Programme and for inquiries on heat pump issues in general contact the IEA Heat Pump Centre at the following address:

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Visit the Heat Pump Programme website - **http://www.heatpumpcentre.org/ -** to find more publications and to learn about the HPP Programme.

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Executive Summary

In Subtask C of the joint IEA Solar Heating and Cooling Programme Task 44 and Heat Pump Programme Annex 38 (T44A38), different concepts for solar and heat pump heating systems are evaluated based on annual system simulations. For these system simulations, common boundary conditions have to be defined in order to ensure that different performance obtained by the simulation of different system concepts are not a result of different boundary conditions used for the simulation. These common boundary conditions are described in the reference framework for system simulations presented in Part A of this report. Part B of this report describes the definition of the reference space heat loads based on the definition of reference buildings and heat distribution systems (Dott et al. 2013).

The base climates used for the simulation framework are Strasbourg (moderate), Helsinki (cold) and Athens (warm). In addition to these, Davos is used for an extreme mountainous climate and Montreal for an extreme continental climate. The permission has been obtained from Meteotest (Switzerland) to use these Meteonorm climate data-sets for work within T44A38. A mitigation factor of 0.5 has been defined for the estimated wind speed on the collector surface in comparison to the meteorological wind speed.

For the simulation of ground heat exchangers, reference ground properties are defined together with standard heat exchanger design (e.g. number and lengths of probes) for the climates of Strasbourg and Helsinki.

The domestic hot water load is based on the EU mandate M/324 tapping cycle M. In order to be suitable for the use in annual simulations, adaptations have been made in order to introduce one bath tub tapping per week, the dependency of hot water demand on the cold water temperature of each location and annual fluctuations.

In order to compare results of these boundary conditions implemented on different simulation platforms, monthly parameters and heat load distribution curves have been defined. A spreadsheet is provided for download on the internal task website where the results of the reference simulations performed with TRNSYS 16.1 can be compared with the results of the implementation of these boundary conditions on any simulation platform.

1 Introduction

In Subtask C of the joint IEA Solar Heating and Cooling Programme Task 44 and Heat Pump Programme Annex 38 (T44A38), different concepts for solar and heat pump heating systems are evaluated based on system simulations. For these system simulations, common boundary conditions have to be defined in order to ensure that different performance obtained by the simulation of different system concepts are not a result of different boundary conditions used for the simulation. The definition of a reference framework for the system simulations in T44A38 include the definition of climates, domestic hot water loads, ground properties and reference ground heat exchanger design. Space heat loads are based on the simulation of buildings and heat distribution systems that are documented in (Dott et al. 2013).

2 Climates and weather data

A summary of the reference climatic conditions that will be used in T44/A38 is given in Table 1. Monthly values are shown in Appendix A. These values are close to, but not identical to, the monthly values proposed in the EN standards for the evaluation of heat pump performance (reference). The reason for this is that the time-resolution of the values shown in the EN standards is months, whereas at least an hourly resolution is needed for system simulation. Hourly values that match exactly the monthly data in the EN standards could not be obtained. Instead, hourly values generated with Meteonorm are used (Meteotest 2009).

Table 1: Key values for different climates used in T44/A38.

Location	Lat. °	Long. °	Alt. m	$\theta_{amb,D}$ °C	$\bar{\theta}_{amb}$ °C	$\Delta\theta_{amb}$ K	$\tau_{Tamb,shift}$ h	$I_{tot,45S}$ kWh/m2a
Strasbourg	48.55N	7.63E	150	-10.0	11.0	9.3	319	1227
Athens	37.9N	23.73E	15	-1.0	18.4	9.4	641	1708
Helsinki	60.32N	24.97E	53	-19.0	5.6	11.5	497	1177
Davos	46.82N	9.85E	1590	-18.0	2.8	8.4	545	1748
Montreal	45.50N	73.62E	133	-24.0	7.4	15.1	533	1587

The permission has been obtained from Meteonorm to use this data ***for the work within the IEA Task 44 / Annex 38 “Solar and Heat Pump Systems” for all participants, under the premises of correct citation of the source of the data whenever it is used:***

Meteonorm 6.1.0.9, Global Meteorological Database for Engineers, Planners and Education, Software and Data on CD-ROM, Meteotest, Bern, Switzerland, 2009**.**

and:

"The permission of Meteotest for using Meteonorm climate data for simulations within the IEA-SHC Task 44 / Annex 38 is gratefully acknowledged."

3 Space heating loads

The Building description that is the base for the definition of the space heating load can be found in a separate document (Dott et al. 2013). The different buildings that will be simulated correspond to heat loads (climate of Strasbourg) of

- 15 kWh/m^2a (SFH15)
- 45 kWh/m^2a (SFH45)
- 100 kWh/m^2a (SFH100)

All European participants will use hydraulic heat distribution systems. However, Task participants from Canada will want to use air-based heat distribution systems. Therefore, the reference air-based distribution system will be defined by the Canadian participant(s).

4 Ground properties and ground coupling losses

Physical ground properties are needed for ground heat exchangers and for ground coupling losses of the building. The physical properties assumed for T44/A38 are listed in Table 2. The average conductivity of 2 W/mK will be used for all base cases.

Table 2: Ground properties for the simulation of the Task44 reference conditions.

conductivity of the ground, good ground	λ_{grd}	3	W/mK
conductivity of the ground, average ground (base case)	λ_{grd}	2	W/mK
conductivity of the ground, bad ground	λ_{grd}	1	W/mK
density of the ground	ρ_{grd}	2500	kg/m3
specific heat capacity of the ground	cp_{grd}	800	J/kgK
geothermal gradient	G_t	0.025	K/m

The method for the calculation of the undisturbed ground temperature and the ground coupling losses of the building can be found in the Appendix of the Reference Building description.

5 Reference ground heat exchangers

Apart from the properties of the soil, the dimensioning of the ground heat exchanger (GHX) also has an influence on the simulated performance of ground source heat pumps. Naturally, simulation studies that aim at the evaluation of the performance of a particular type of GHX that differs from the standard GHX described in this section will need to perform simulations with their particular GHX. The influence of this GHX on the simulation result may then be evaluated by comparing it with the results from the standard GHX defined here. Simulation studies that aim for the comparison of the "above ground" solar and heat pump system alone without the effect of different ground heat exchanger solutions will need to use the standard GHX defined here in order to eliminate as much as possible differences in the resulting performance that may arise from different dimensioning of the GHX.

The standard simulation uses vertical borehole heat exchangers with double-U pipes and the properties specified as shown in Table 3.

Table 3: Borehole heat exchanger properties that are independet of the number and length.

borehole diameter	0.18	m
inner diameter of pipes	0.026	m
specific heat capacity of the filling material	1.65	kJ/kgK
density of the filling material	2000	kg/m^3
heat conductivity of the filling material (lambda)	2.0	W/mK
specific heat of the fluid / heat carrier / brine	3860	kJ/kgK
density of the brine	1035	kg/m^3
heat conductivity of the brine (lambda)	0.449	W/mK
kinematic viscosity of the brine	6.5×10^{-6}	m^2/sec

The number and length of the boreholes are different for each building and each climate. Standard values used for T44/A38 simulations have been derived based on a maximum heat extraction of 50 W/m for Strasbourg and 42 W/m for Helsinki. Resulting borehole lengths of more than 100 m have been converted to multiple boreholes of less than 100 m using conversion factors from VDI 4640-2 (2001, p. 18). The resulting number and length of the boreholes are shown in Table 4 for the climates of Strasbourg and Helsinki. It is not assumed that ground source heat pumps will be used for the climate of Athens. Details of the assumptions made can be found in Appendix D.

Table 4: Number and length of borehole heat exchangers for the different locations and buildings.

		Strasbourg			Helsinki		
		SFH15	SFH45	SFH100	SFH15	SFH45	SFH100
Max. heat extraction	kW	3.5	4.2	7.0	3.5	5.6	10.5
boreholes realised	**m**	**49**	**84**	**2 x 90**	**75**	**2 x 95**	**4 x 95**

6 Domestic hot water load

Hot water draw off profiles are based on the EU mandate M/324 tapping cycle M (CEN/TC113N380 2003) and (FprEN 16147 2010), corresponding to an average draw off of 140 L/d at 45 °C (cold water 10 °C) or 5.845 kWh/d (2133 kWh/a). The following adaptions have been made to the standard tapping cycle M:

- Replacement of the evening shower by a bath tub filling for every seventh day of the simulation.
- Reduction of all tapped energies such that an average of 5.845 kWh/d is reached again over the seven days of the week.
- Replacement of the different temperature requirements stated in the standard by one temperature for each tapping that has to be reached at the outlet of the hot water system at all simulation timesteps.

The resulting tapping cycle tables for days 1-6 and for day 7 are shown in appendix C.

The influence of the site-specific average cold water temperatures ($\overline{\theta}_{cw,loc}$) is accounted for by the calculation of a location specific energy demand for each hot water tapping ($Q_{dhw,loc}$).

Eq. 1 $$Q_{dhw,loc} = Q_{dhw,std} \cdot \left(\frac{\theta_{dhw,set} - \overline{\theta}_{cw,loc}}{\theta_{dhw,set} - 10K} \right)$$

Where $Q_{dhw,std}$ is the average standard hot water energy demand for a particular tapping given in Table 7 of Appendix C. The site specific cold water temperature is assumed to be equal to the average ambient temperature of each site ($\overline{\theta}_{cw.loc} = \overline{\theta}_{amb}$).

The variation of the DHW energy demand over the year (less consumption in summer for various reasons) can be approximated with an adaption of each hot water tapping energy with the time of the year.

Eq. 2 $$Q_{dhw,i} = Q_{dhw,loc} \cdot \left\{ 1 + x_{dhw,amp} \cdot COS\left(\left[\tau_i - \tau_{dhw,shift} \right] / 365d \cdot 2 \cdot \pi \right) \right\}$$

Where ($x_{dhw,amp} = 20\%$) is the amplitude of the sine-curve for the variation of the DHW energy demand, τ_i is the time of the year the tapping occurs in days, and $\tau_{dhw,shift} = 40d$ is the time between the first of January and the day where the maximum of the DHW energy demand is expected.

The minimum temperature that has to be achieved is 45°C for all tappings except for the dishwashing (55°C). Detailed information on the background of the DHW load profile is given in Appendix C.

7 Solar thermal system simulations

Standard simulations are performed with a collector tilt of 45 ° oriented towards south (azimuth = 0°). The wind speed on the collector plane is taken as half of the meteorological wind speed from the climate data (relevant only for uncovered collectors).

Eq. 3 $$v_{wind,coll} = 0.5 \cdot v_{wind}$$

Long wave radiation exchange between uncovered collectors and the ambient may be calculated based on the same effective sky temperature T_{sky} that is used for the calculation of building heat losses presented in Appendix B of Part B of this report (Dott et al. 2013). For inclined absorber surfaces, the effective view temperature T_{view} should be taken instead which is defined according to the view factor between the sky and the asbsorber and between the ground and the absorber. For an unobstructed horizon these view factors are functions of the absorber inclination β as shown in Eq. 4.

Eq. 4 $$T_{view} = \frac{1+COS\left(\beta\right)}{2} \cdot T_{sky} + \frac{1-COS\left(\beta\right)}{2} \cdot T_{amb}$$

The pipe lengths for the collector field are 15 m each for the flow and return line. The diameter is to be chosen based on the maximum mass flow rate of the collector field and the insulation properties are to be taken from common insulation material. Heat losses of the collector pipes are to be calculated towards a temperature that corresponds to the average of the ambient temperature and the room temperature inside the building. Heat lost from the collector pipes are not counted as heat gain for the building.

Heat losses of the solar thermal storage are to be calculated towards 15 °C.

8 Symbols

cp_{grd}	specific heat of the ground, J/kgK
G_t	geothermal gradient, K/m
$I_{tot,45S}$	total irradiation on the 45° sloped south facing plane, kWh/m^{2}a
$Q_{dhw,loc}$	energy of a DHW tapping at a specific location, J
$Q_{dhw,std}$	energy of a DHW tapping for the reference cold water of 10 °C, J
$Q_{dhw,i}$	draw off energy of a specific tapping, J
R_{tot}	total resistance of the floor, m^{2}K/W
$\theta_{amb,D}$	design ambient temperature for the heating system, °C
T_{sky}	effective sky temperature, K
T_{amb}	ambient (outdoor) temperature, K
T_{view}	effective view temperature of the absorber, K
U_{floor}	heat transfer coefficient of the floor, W/m^{2}K
$x_{dhw,amp}$	amplitude of the sine-curve that fits the hot water consumption fluctuation over the year, %

β	inclination of the absorber surface (0° = horizontal)
$\Delta\theta_i$	amplitude of the sine-curve that fits the annual inside temperature variation, K
$\tau_{dhw,shift}$	time between the first of January and the maximum DHW energy demand of the year (usually the coldest temperature from the mains inlet).
τ_i	time of the year, d
$\overline{\theta}_{amb}$	annual average of the ambient (outdoor) temperature, °C
$\overline{\theta}_i$	annual average of the inside temperature, °C
$\overline{\theta}_{cw}$	annual average of the cold water temperature, °C
$\theta_{dhw,set}$	temperature setpoint for domestic hot water, °C
λ_{grd}	thermal conductivity of the ground, W/mK
v_{wind}	meteorological wind speed from climate dataset, m/s
$v_{wind,coll}$	wind speed on collector surface, m/s
ρ_{grd}	density of the ground, kg/m^3
τ_i	time of the year, d
$\tau_{dhw,shift}$	time-lag between the first day of the year and the coldest water from the mains, set to 40 days for T44A38, d
$\tau_{Tamb,shift}$	time lag between the first day of the year and the coldest ambient air temperature according to the sine-curve that fits the ambient air temperatures over the year, h

9 Bibliography

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Appendix A – Working group boundary conditions

Working Group members Boundary Conditions and Platform Independence of the IEA SHC Task 44 / HPP Annex 38:

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Appendix B – Details on climate data

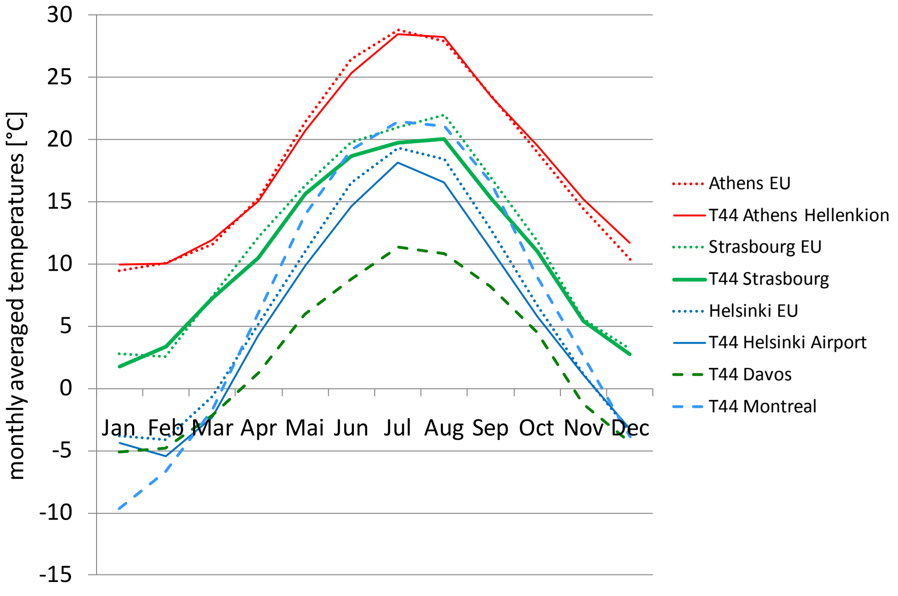

Figure 1: Comparison of monthly averaged temperatures for the Task 44 climate data of Strasbourg, Athens, Helsinki, and Davos with the data published in (EC 2010/30/EU 2010).

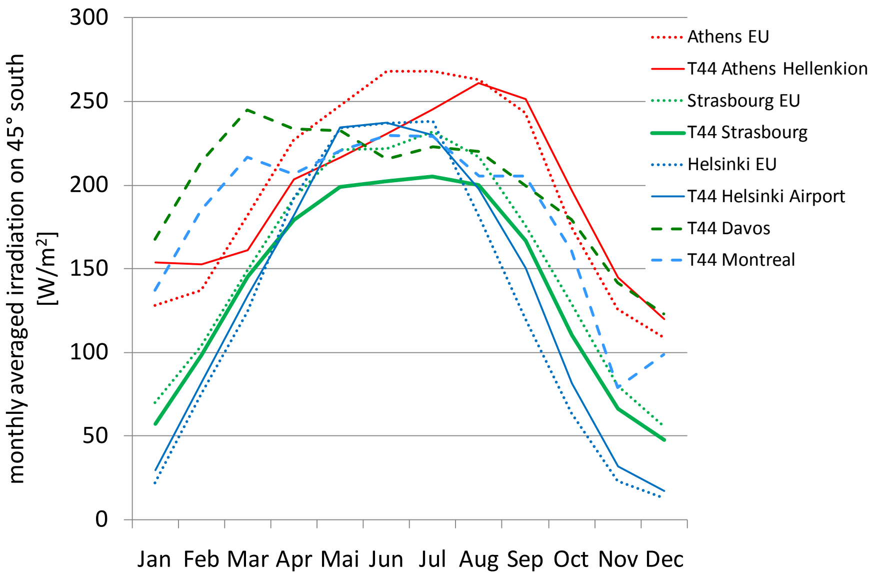

Figure 2: Comparison of monthly irradiation averages for the Task 44 climate data of Strasbourg, Athens, Helsinki and Davos with the climate data published in (EC 2010/30/EU 2010).

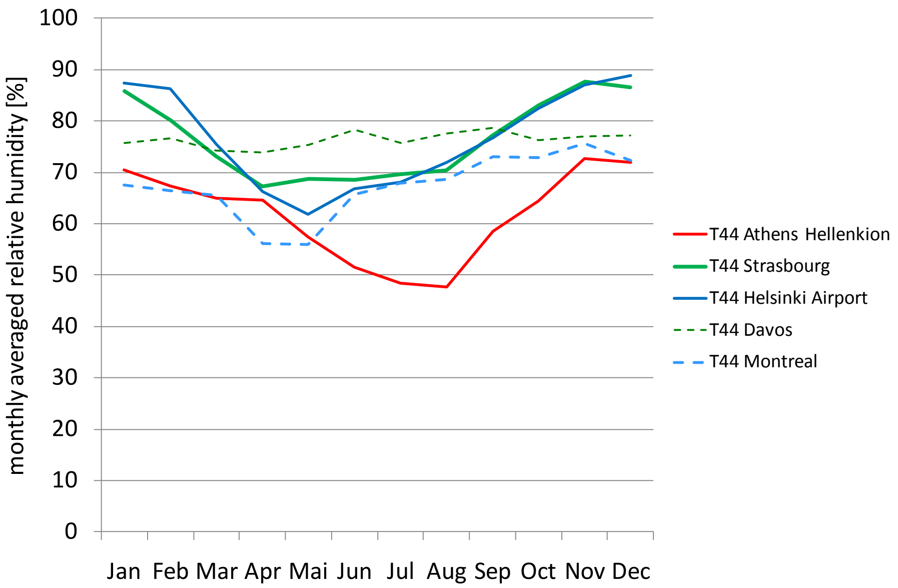

Figure 3: Comparison of monthly averaged relative humidity for the Task 44 climate data of Strasbourg, Athens, Helsinki and Davos. No relative humidity data is available from (EC 2010/30/EU 2010).

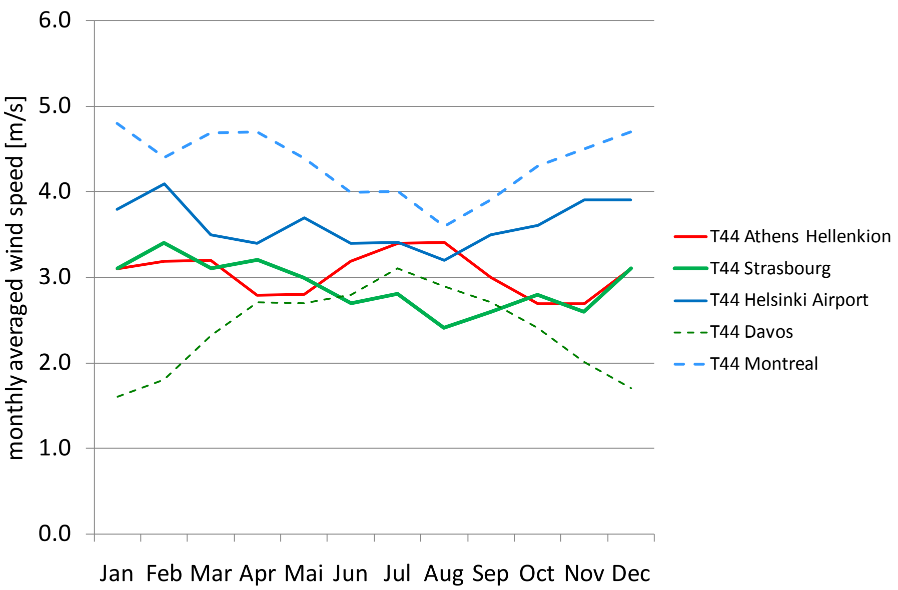

Figure 4: Comparison of monthly averaged wind speeds for the Task 4 climate data of Strasbourg, Athens, Helsinki and Davos. No data for wind speeds available from (EC 2010/30/EU 2010).

Table 5: Monthly averages of ambient (outdoor) temperatures and of the average total irradiation on the 45° sloped plane.

	ambient temperature [°C]					average total irradation on 45° slope [W/m^2]				
Month	**Strasb.**	Helsinki	Athens	*Davos*	*Montreal*	**Strasb.**	Helsinki	Athens	*Davos*	*Montreal*
JAN	**1.8**	-4.4	10.0	*-5.1*	*-9.6*	**57**	30	154	*168*	*137*
FEB	**3.4**	-5.5	10.0	*-4.8*	*-6.7*	**99**	82	152	*214*	*185*
MAR	**7.2**	-2.3	11.9	*-2.1*	*-1.7*	**145**	134	161	*245*	*217*
APR	**10.5**	4.3	15.0	*1.3*	*6.1*	**179**	182	204	*234*	*206*
MAY	**15.6**	9.9	20.8	*6.0*	*13.9*	**199**	234	217	*233*	*221*
JUN	**18.7**	14.7	25.4	*8.8*	*19.2*	**202**	237	231	*215*	*230*
JUL	**19.7**	18.2	28.5	*11.4*	*21.4*	**205**	230	246	*223*	*229*
AUG	**20.1**	16.5	28.2	*10.8*	*21.1*	**200**	198	261	*220*	*205*
SEP	**15.2**	11.2	23.5	*8.2*	*16.6*	**167**	150	252	*200*	*205*
OCT	**11.0**	5.8	19.5	*4.6*	*9.0*	**111**	82	196	*180*	*161*
NOV	**5.4**	1.1	15.2	*-1.2*	*2.6*	**67**	32	145	*142*	*79*
DEC	**2.8**	-3.2	11.7	*-4.3*	*-3.9*	**48**	17	120	*123*	*99*

Table 6: Monthly averages of wind speed and relative humidity

	wind speed [m/s]					relative humidity [%]				
Month	**Strasb.**	Helsinki	Athens	*Davos*	*Montreal*	**Strasb.**	Helsinki	Athens	*Davos*	*Montreal*
JAN	**3.1**	3.8	3.1	*1.6*	*4.8*	**85.9**	87.4	70.6	*75.8*	*67.6*
FEB	**3.4**	4.1	3.2	*1.8*	*4.4*	**80.1**	86.2	67.3	*76.6*	*66.4*
MAR	**3.1**	3.5	3.2	*2.3*	*4.7*	**73.1**	75.4	65.0	*74.3*	*65.5*
APR	**3.2**	3.4	2.8	*2.7*	*4.7*	**67.2**	66.3	64.7	*74.0*	*56.2*
MAY	**3.0**	3.7	2.8	*2.7*	*4.4*	**68.7**	61.8	57.4	*75.4*	*55.9*
JUN	**2.7**	3.4	3.2	*2.8*	*4.0*	**68.5**	66.7	51.6	*78.2*	*65.7*
JUL	**2.8**	3.4	3.4	*3.1*	*4.0*	**69.7**	68.1	48.5	*75.7*	*67.8*
AUG	**2.4**	3.2	3.4	*2.9*	*3.6*	**70.5**	72.0	47.6	*77.5*	*68.6*
SEP	**2.6**	3.5	3.0	*2.7*	*3.9*	**77.2**	76.7	58.5	*78.7*	*73.1*
OCT	**2.8**	3.6	2.7	*2.4*	*4.3*	**83.0**	82.4	64.4	*76.2*	*72.8*
NOV	**2.6**	3.9	2.7	*2.0*	*4.5*	**87.7**	87.1	72.8	*77.1*	*75.6*
DEC	**3.1**	3.9	3.1	*1.7*	*4.7*	**86.7**	88.8	71.9	*77.2*	*72.3*

Appendix C – Domestic hot water loads

Data compiled by several authors indicate that the average hot water energy demand of 8.4 kWh/d assumed in previous studies (e.g. IEA-SHC Task 32) does not reflect the average hot water consumption of European families of today anymore. Mack et al. (1998) compiled data from 22 multifamily houses (MFH) and concluded that the average daily energy consumption was 4 kWh or 70 liters at 60 °C per day and apartment. For the case of Denmark (Knudsen 2002) found that the average hot water draw off for a one family household has decreased from 200 L/d in 1989 to 100 L/d in 1996, without specifying the hot water temperature this refers to. (Thür et al. 2006) compiled data from the Austrian CEPHEUS projects that show that the average energy demand for DHW in 53 passive house standard MFH apartments was about 4.4 kWh/d. On the other hand, data compiled from 13 single family houses (11 Denmark, 2 Austria) show an average consumption of 8.2 kWh/a. The current efforts of the European Union to harmonize test methods for hot water stores with the mandate M/324 (CEN/TC113N380 2003) suggest an average draw off for a single family that corresponds to 100 L/d at 60°C or 5.845 kWh/d.

Supported by this data, an average draw off of 140 L/d at 45 °C (cold water 10 °C) or 5.845 kWh/d (2133 kWh/a) was chosen for the IEA T44/A38, which is in line with the recent EU efforts for harmonizing test methods (tapping cycle M). Since tapping cycle M does not include a bath tub tapping, but it is considered crucial that the DHW supply system is able to provide enough capacity to fill a bath tub, each 7th day the evening shower is replaced by a bath tub draw off. In order to keep the average of 5.845 kWh/d, all draw offs of all days are reduced by about 6%.

Hot water energy demand is usually not constant over the whole year. Three factors of influence can be distinguished:

1. The temperature of the cold water from the mains is usually not constant, but shows a minimum in late winter and a maximum in late summer.
2. It has been claimed that the water consumption habit is such that more hot water is consumed on colder (winter) days than on warmer (summer) days. This may lead to a difference in energy consumption in the order of +/- 10%
3. Depending on the country, people tend to take more vacation in summer months than in winter months. The effect of this is difficult to estimate and likely to be dependent on the culture of each country.

If data from several apartments is analyzed together, the influence of different consumption habits can usually not be distinguished clearly from the influence of vacation. Figure 5 shows the measured monthly averages of the daily hot water energy demand in percent of the yearly average of the daily hot water energy demand for four different studies dating from 2004 to 2010. The difference between the different curves in this figure is surprisingly small. It can be concluded that the energy demand shows a maximum in February with about 22% more than average and a minimum in July and August with about 29% less than average. This includes the influence of cold water temperatures, vacation, and consumption habits, and is in agreement with earlier studies performed on multifamily houses by Mack et al. (1998) that showed +/- 25% for February and August.

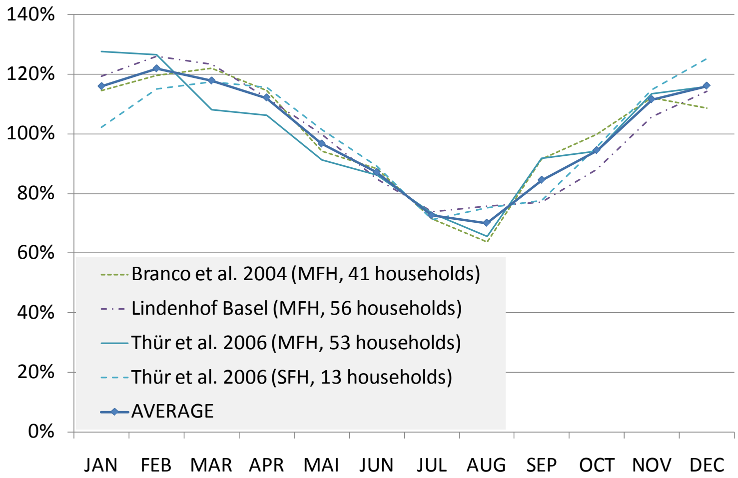

Figure 5: Measured monthly averages of the daily hot water energy demand in percent of the yearly average of the daily hot water energy demand (without energy demand for circulation).

Figure 6 shows a comparison between the average shown in Figure 5, the proposed energy demand variation for Task44/Annex 38 and the values from the IEA-SHC Task 32. It can be seen that the proposed profile corresponds well with the values from the literature. The difference between the proposed values and the observed values for the months of August and July is currently only 14%, corresponding to about four days of vacation for each of these two months. If the effect of vacation should be considered, the average daily consumption on the other days must be increased in order to preserve the annual average, and $x_{dhw,amp}$ might have to be decreased in order not to get too large differences between the months of February and July/August.

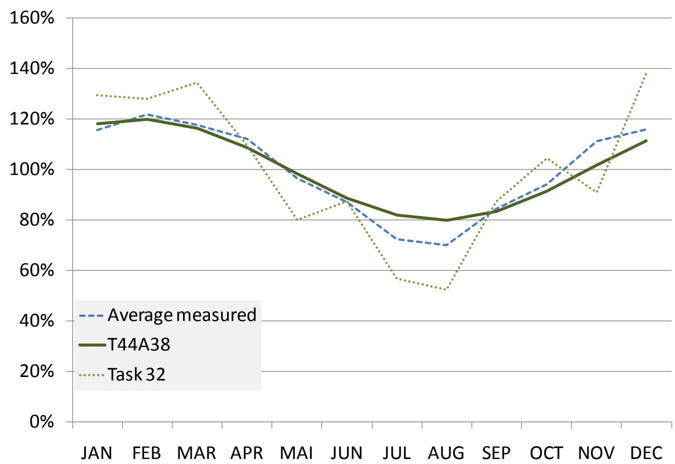

Figure 6: Monthly averages of the daily hot water energy demand in percent of the yearly average of the daily hot water energy demand (without energy demand for circulation) for the average of four different field studies (Average measured) and the proposed curve for Task 44 / Annex 38 (T44A38), compared to curves from IEA-SHC Task 32.

The hot water draw off profile was adapted from M/324 tapping cycle M (CEN/TC113N380 2003) and (FprEN 16147 2010). The following adaptations have been made:

- Since cold water temperatures are different for different locations, an absolute temperature requirement of 45 °C is used instead the „delta-T desired“ and „Min. dT for counting useful Energy” mentioned in (FprEN 16147 2010). A minimum of 45 °C is assumed for all draw offs except the ones for dishwashing (55°C). If this temperature is not achieved, then the remaining temperature difference will be counted as direct electric heater input with a penalty factor of 1.5.
- Since every seventh day a bath tub tapping of 3.52 kWh replaces the evening shower tapping of the load file, the energy of each tapping has been reduced by approximately 6% in order to maintain the annual average tapping energy of 5.845 kWh/d.

Table 7: Tapping cycle for days 1-6, based on M/324 cycle M.

Nr.	start time (h:min)	Energy $Q_{dhw,std}$ (kWh)	Type	Flow Rate (L/h)	Min. Temp. $\theta_{dhw,set}$ (°C)
1	07:00	0.100	S	240	45
2	07:15	1.315	Sh	600	45
3	07:30	0.100	S	240	45
4	08:00	0.100	S	240	45
5	08:15	0.100	S	240	45
6	08:30	0.100	S	240	45
7	08:45	0.100	S	240	45
8	09:00	0.100	S	240	45
9	09:30	0.100	S	240	45
10	10:30	0.100	FC	240	45
11	11:30	0.100	S	240	45
12	11:45	0.100	S	240	45
13	12:45	0.300	DW	240	55
14	14:30	0.100	S	240	45
15	15:30	0.100	S	240	45
16	16:30	0.100	S	240	45
17	18:00	0.100	S	240	45
18	18:15	0.100	HC	240	45
19	18:30	0.100	HC	240	45
20	19:00	0.100	S	240	45
21	20:30	0.700	DW	240	55
22	21:15	0.100	S	240	45
23	21:30	1.315	Sh	600	45
Total		5.530			

Table 8: Bath tub replacing the evening shower on each 7th day.

23	21:30	3.520	Ba	600	45

S = Small; Sh = Shower; FC = Floor cleaning; DW = Dish washing; HC = Household cleaning; Ba = Bath tub

Appendix D – Determination of borehole lengths

Table 9: Details of the calculation of the number and length of borehole heat exchangers for the different buildings in Strasbourg and Helsinki.

		Strasbourg			Helsinki		
		SFH15	**SFH45**	**SFH100**	**SFH15**	**SFH45**	**SFH100**
Max. space heat load	kW	1.8	4.1	7.3	3.1	6.3	10.9
DHW load	kW	0.5	0.5	0.5	0.5	0.5	0.5
Max. total load	kW	2.3	4.6	7.8	3.6	6.8	11.4
Max heating power	kW	3.5	6	10	4.5	9	15
COP at design cond.	-	3.3	3.3	3.3	3.3	3.3	3.3
Max. heat extraction	kW	2.4	4.2	7.0	3.1	6.3	10.5
Max. spec. heat extraction	W/m	50	50	50	42	42	42
borehole length [a)]	m	49	84	139	75	149	249
boreholes realised	**m**	**49**	**84**	**2 x 90**	**75**	**2 x 95**	**4 x 95**

[a)] *for a single borehole*

Appendix E – Changelog

2012-12-07 MH changed units in table 5 from erroneous kWh/m^2 to averaged W/m^2

2013-11-08 MH corrected referencing errors (automatic cross-referencing of word)