DIPARTIMENTO DI
ARCHITETTURA, INGEGNERIA DELLE
COSTRUZIONI E AMBIENTE COSTRUITO
ABC

POLITECNICO DI MILANO

Hourly Dynamic Calculation Engine based on EN ISO 52016 Standard implemented in TERMOLOG Software.
BESTEST according to ANSI/ASHRAE 140-2011 Standard

FINAL REPORT

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Prof. Luca Sarto

Summary

1 Scope of work

Logical Soft has entered into a research contract with the Department of Architecture, Built Environment and Construction Engineering (ABC) of Politecnico di Milano to provide technical-scientific support in the implementation of the hourly dynamic calculation model proposed by EN ISO 52016 Standard in TERMOLOG Software.
The research program consists in the realization of a series of algorithms implemented in Excel sheets to perform the simplified hourly calculation based on an equivalent resistive-capacitive model (R-C) according to the Crank-Nicholson scheme.
A few months after the contract definition, the new calculation engine was implemented on the TERMOLOG Software platform and it was possible to carry out tests.
This report presents the results of a first validation using method according to ANSI/ASHRAE 140-2011 *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs and in the Building Energy Simulation Test (BESTEST) and Diagnostic Method*, an internationally recognized methodology for comparing the results of energetic simulations of buildings in a dynamic calculation.
The ABC Department research team coordinated by Prof. Giuliano Dall'O' is currently testing the reliability of the calculation model (release date 6 December 2017) on a real building that is monitored both in summer and in winter cycle.
The results on summer cycle will be published in a forthcoming paper and have confirmed the validity of the model based on the recent EN ISO 52016 Standard which will become the reference standard for the energy calculations of Buildings in the European Union.

Symbols

Symbol	Name of quantity	Unit
A	area	m^2
C	Heat capacity	J/K
R	thermal resistance	m^2K/W
U	thermal transmittance	$W/(m^2K)$
D	depth	m
c	specific heat capacity	J/(kg K)
λ	conductivity	W/(m K)
ρ	density	kg/m^3
κ	areal heat capacity	$J/m^2K)$

2 Description of the methodology

2.1 BESTEST methodology

"Comparative tests compare a program to itself or to other simulation programs. This type of testing accomplishes results on two different levels, both validation and debugging.
From a validation perspective, comparative tests are very powerful method of assessment, but it is no substitute for determining if the program is correct since it may be just as equally incorrect as the benchmark program or programs. The biggest strength of comparative testing is the ability to compare any cases that two or more programs can model. This is much more flexible than analytical tests when only specific solutions exist for simple models, and much more flexible than empirical tests when only specific data sets have been collected for usually a very narrow band of operation.
The tests described in ANSI/ASHRAE Standard 140-2001, *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs* (ANSI/ASHRAE 2001) were performed. As stated in its Foreword, Standard 140-2001 is a standard method of test that "*can be used for identifying and diagnosing differences in predictions for whole building energy simulation software that may possibly be caused by software errors. The current set of tests included here consists of comparative tests that focus on building envelope loads.*" When necessary, additional information was provided by the IEA 12B/21C sponsored report, Building Energy Simulation Test (BESTEST) and Diagnostic Method (IEA 1995), which served as the basis for the ANSI/ASHRAE standard" [1].
Whole model verification considers the calculation of operative temperatures and sensible energy needs for heating and cooling for a full year for several cases based on BESTEST 600 and 900 described in ANSI/ASHRAE 140 2011 Standard. Table 1 shows the test cases carried out.

Table 1 *Test cases*

Test No.	BESTEST case identifier	Type of construction	Thermostat control strategy
1	600	Lightweight construction	Continuous
2	640	Lightweight construction	Intermittent
3	900	Heavyweight construction	Continuous
4	940	Heavyweight construction	Intermittent
5	600FF	Lightweight construction	Free floating
6	900FF	Heavyweight construction	Free floating

2.2 Geometry and Thermophysical characteristics of the test room

The various test cases refer to a geometry of a single zone with two different types of envelope: lightweight and heavyweight. The geometry of the test room is shown in Figure 1, the geometrical characteristics of the rooms are given in Table 2.

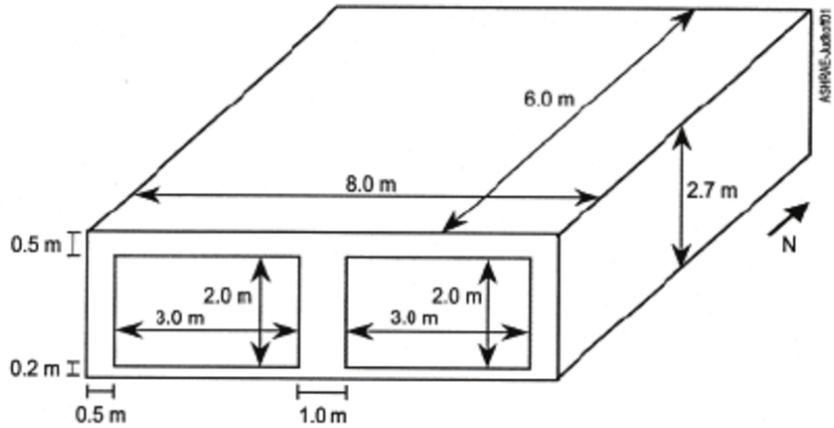


Figure 1 *Geometry of the test room*

Table 2 *Room data*

Component	Area (m^2)
Wall (front)	9.6
Wall (right and left)	16.2
Wall (back)	21.6
Window	12.0
Floor	48.0
Ceiling	48.0
Volume	126.6 m^3

Table 3 *Thermophysical characteristics of the building envelope Test case 600*

Structure	D m	λ W/(mK)	R m^2K/W	κ J/(m^2K)	ρ kg/m^3	c J/(kg K)
External wall (inside to outside)						
Plasterboard	0.012	0.160	0.075	9576	950	840
Fiberglass quilt	0.066	0.040	1.650	665	12	840
Wood siding	0.009	0.140	0.064	4293	530	900
Total surf-surf			1.789			
Floor (inside to outside)						
Timber flooring	0.025	0.140	0.179	19500	650	1200
Insulation	1.003	0.040	25.075	0	0	0
Total surf-surf						
Roof (inside to outside)						
Plasterboard	0.010	0.160	0.063	7980	950	840
Fiberglass quilt	0.1118	0.040	2.794	1127	12	840
Roof deck	0.019	0.140	0.136	9063	530	900
Total surf-surf			2.992			

Table 4 *Thermophysical characteristics of the building envelope Test case 900*

Structure	D m	λ W/(mK)	R m^2K/W	κ $J/(m^2K)$	ρ kg/m^3	c J/(kg K)
External wall (inside to outside)						
Concrete block	0.100	0.510	0.196	140000	1400	1000
Foam insulation	0.0615	0.040	1.537	861	10	1400
Wood siding	0.009	0.140	0.064	4293	530	900
Total surf-surf			1.797			
Floor (inside to outside)						
Concrete slab	0.080	1.130	0.071	112000	1400	1000
Insulation	1.007	0.040	25.175	0	0	0
Total surf-surf						
Roof (inside to outside)						
Plasterboard	0.010	0.160	0.063	7980	950	840
Fiberglass quilt	0.1118	0.040	2.794	1127	12	840
Roof deck	0.019	0.140	0.136	9063	530	900
Total surf-surf			2.992			

Thermophysical characteristics of the opaque elements of the building envelope are described in Table 3 and Table 4. With regard to transparent elements, the window consists of double pane glazing with the following properties:

Transmission coefficient g: 0.710
U value glass: 2.823 $W/(m^2K)$
Mobile solar shield: none

For other details, refer to ANSI/ASHRAE Standard 140-2001 and EN ISO 52016 Standard.

2.6 Climatic Data

The test building is in DENVER (Colorado). The external climatic input data available are temperature, humidity and irradiance values in the global horizontal component, horizontal diffusion and normal direct.

3 Comparison between TERMOLOG Software and Test results from EN ISO 52016

There are currently no calculation programs on the market implementing the EN ISO 52016 Standard model. The first step is to compare the TERMOLOG software output data with those of the reference standard verification test. The comparison data are shown in Table 5, Table 6, Table 7 and Table 8.

Table 5 *Comparison test results sensible energy needs for heating (kWh)*

Month	Case 600		Case 640		Case 900		Case 940	
	TERMOLOG	52016	TERMOLOG	52016	TERMOLOG	52016	TERMOLOG	52016
Jan	1006	1005	762	718	465	84	366	350
Feb	859	849	643	591	434	53	342	333
Mar	674	636	443	358	202	121	135	118
Apr	391	358	232	169	106	147	71	69
May	188	154	90	47	10	175	5	4
Jun	86	63	39	22	13	308	7	8
Jul	9	0	3	0	0	638	0	0
Aug	20	11	8	0	0	656	0	0
Sep	131	95	71	19	2	626	1	0
Oct	421	375	242	151	49	418	32	27
Nov	651	644	441	389	188	84	132	120
Dec	933	938	689	646	379	48	290	272
Annual	5368	5133	3662	3112	1847	3360	1382	1303

Table 6 *Comparison test results sensible energy needs for cooling (kWh)*

Month	Case 600		Case 640		Case 900		Case 940	
	TERMOLOG	52016	TERMOLOG	52016	TERMOLOG	52016	TERMOLOG	52016
Jan	638	640	62	586	83	16	66	63
Feb	521	498	506	451	53	14	37	34
Mar	649	601	624	537	121	13	109	108
Apr	527	464	508	421	149	5	144	141
May	490	404	476	380	186	2	184	173
Jun	549	456	540	446	327	0	325	306
Jul	805	722	803	720	654	0	654	638
Aug	851	778	848	775	664	0	664	656
Sep	928	862	916	835	618	2	617	625
Oct	916	876	893	812	400	6	396	412
Nov	599	589	582	538	84	5	72	68
Dec	610	614	591	557	48	13	38	36
Annual	8084	7503	7349	7057	3387	76	3308	3261

Table 7 *Comparison test results for average operative temperature (°C)*

Month	600		640		900		940		600FF		900FF	
	TERMOLOG	52016	TERMOLOG	52016	TERMOLOG	52016	TERMOLOG	52016	TERMOLOG	52016	TERMOLOG	52016
Jan	22,2	22.0	19,2	19.0	22,2	22.3	21,2	21.2	17,4	17.3	17,4	17.6
Feb	22,1	22.0	19,2	18.9	22,1	22.2	21,0	20.9	17,1	16.7	16,3	16.4
Mar	22,7	22.6	20,0	19.8	23,0	23.1	22,3	22.3	22,4	22.1	21,7	21.9
Apr	22,9	22.9	21,0	20.9	23,9	23.9	23,5	23.5	24,8	24.3	24,7	24.7
May	23,5	23.5	22,4	22.4	24,6	24.5	24,5	24.4	27,5	26.7	26,8	26.6
Jun	24,2	24.4	23,7	24.0	25,7	25.7	25,7	25.7	30,5	29.6	29,6	29.3
Jul	25,3	25.6	25,3	25.6	26,7	26.6	26,7	26.6	35,7	35.0	35,2	34.9
Aug	24,9	25.2	24,8	25.1	26,6	26.6	26,6	26.6	35,8	35.2	35,4	35.2
Sep	24,2	24.2	23,5	23.6	26,1	26.1	26,1	26.1	34,9	34.6	34,5	34.7
Oct	23,3	23.0	21,1	20.9	24,7	24.8	24,6	24.7	29,6	29.7	29,9	30.3
Nov	22,3	22.2	19,7	19.4	22,7	22.8	22,1	22.1	21,6	21.4	21,2	21.3
Dec	22,2	22.1	19,2	19.0	22,1	22.2	21,1	21.1	18,0	17.9	17,9	18.0
Annual	23,3	23.3	21,6	21.5	24,2	24.2	23,8	23.8	26,3	25.9	25,9	25.9

Table 8 *Annual hourly maximum, minimum and average operative temperature (°C)*

Peak internal temperature	600FF		900FF	
	TERMOLOG	52016	TERMOLOG	52016
Maximum (°C)	64,3	63,5	44,7	44,4
Minimum (°C)	-18,4	-16,9	-3	-2,4
Average (°C)	26,3	25,9	25,9	26,0

The data shown in the tables demonstrate a consistency between the outputs of the TERMOLOG program and those reported in EN ISO 52016. The greyed columns (Case 900) highlight non-congruous data contained in the standard: in fact, the values of energy needs for heating in summer are higher than in the winter period.

4 Comparison between TERMOLOG Software and other simulation software

This chapter reports the results of the comparison between the values obtained using TERMOLOG program and those obtained using the most common dynamic simulation software. The software products used as a reference are listed in Table 9 [5]. The comparison bar charts are set out in Appendix A.

Table 9 *Dynamic simulation software used for comparison*

Code name	Computer program	Developer
ESP	ESP-RV8	Strathclyde University, U.K.
BLAST	BLAST-3.0 level 193 v.1	CERL, U.S.
DOE2	DOE2.ID 14	LAN/LBL, U.S.
SRES	SERIRES/SUNCODE 5.7	NREL/Ecotope, U.S.
SERIRES	SERIRES 1.2	NREL, U.S. BRE, U.K.
S3PAS	S3PAS	University of Sevilla, Spain
TRNSYS	TRNSYS 13.1	University of Winsconsin, U.S.
TASE	TASE	Tampere University, Finland
EnergyPlus	Energy Plus ver. 1.2.0.029, May, 2004	U.S. Dept. of Energy

4.1 BESTEST 600

4.1.1 Description of the test

BESTEST 600 is a test based on a building of lightweight construction (see Figure 1).

4.1.2 Energy needs for heating and cooling

Table 10, Table 11, Table 12 and Table 13 compare the values that emerged from the simulation using TERMOLOG software with the minimum, maximum and average values obtained using the reference software.

Table 10 *Energy needs for space heating*

Energy needs for space heating	kWh/year
BESTEST min.	4296
BESTEST max	5709
BESTEST avg	5052
TERMOLOG	5368

Table 11 *Energy needs for space cooling*

Energy needs for space cooling	**kWh/year**
BESTEST min.	6137
BESTEST max	7964
BESTEST avg	6803
TERMOLOG	8084

Table 12 *Peak power needs for space heating*

Peak power for space heating	**W**
BESTEST min.	3437
BESTEST max	4354
BESTEST avg	4021
TERMOLOG	4339

Table 13 *Peak power needs for space cooling*

Peak power for space cooling	**W**
BESTEST min.	5965
BESTEST max	7551
BESTEST avg	6585
TERMOLOG	6762

4.2 BESTEST 640

4.2.1 Description of the test

Case 640 is identical to Base Case building of Case 600 except the following heating and cooling temperature setback schedule as detailed below:

a) from 2300 hours to 0700 hours, heat = on if zone temperature <10°C
b) from 0700 hours to 2300 hours, heat = on if zone temperature <20°C
c) all hours, cool = on if zone temperature >27°C
d) otherwise, mechanical equipment is off.

4.2.2 Energy needs for heating and cooling

Table 14, Table 15,Table 16 and Table 17 compare the values that emerged from the simulation using TERMOLOG software with the minimum, maximum and average values obtained using the reference software.

Table 14 *Energy needs for space heating*

Energy needs for space heating	**kWh/year**
BESTEST min.	2751
BESTEST max	3803
BESTEST avg	3210
TERMOLOG	3662

Table 15 *Energy needs for space cooling*

Energy needs for space cooling	**kWh/year**
BESTEST min.	5952
BESTEST max	7811
BESTEST avg	6564
TERMOLOG	7349

Table 16 *Peak power needs for space heating*

Peak power for space heating	**W**
BESTEST min.	5232
BESTEST max	8078
BESTEST avg	6398
TERMOLOG	8079

Table 17 *Peak power needs for space cooling*

Peak power for space cooling	**W**
BESTEST min.	5892
BESTEST max	7537
BESTEST avg	6550
TERMOLOG	6730

4.3 BESTEST 900

4.3.1 Description of the test

The 900 series of tests adopts the same building model used in the 600 series except that wall and floor materials are heavier. All other building features remain the same.

4.3.2 Energy needs for heating and cooling

Table 18, Table 19, Table 20 and Table 21 compare the values that emerged from the simulation using TERMOLOG software with the minimum, maximum and average values obtained using the reference software.

Table 18 *Energy needs for space heating*

Energy needs for space heating	kWh/year
BESTEST min.	1170
BESTEST max	2041
BESTEST avg	1711
TERMOLOG	1847

Table 19 *Energy needs for space cooling*

Energy needs for space cooling	kWh/year
BESTEST min.	2132
BESTEST max	3415
BESTEST avg	2632
TERMOLOG	3387

Table 20 *Peak power needs for space heating*

Peak power for space heating	W
BESTEST min.	2850
BESTEST max	4081
BESTEST avg	3546
TERMOLOG	3969

Table 21 *Peak power needs for space cooling*

Peak power for space cooling	W
BESTEST min.	2888
BESTEST max	4901
BESTEST avg	3543
TERMOLOG	4013

4.4 BESTEST 940

4.4.1 Description of the test

Case 940 is identical to Base Case building of Case 900 except the following heating and cooling temperature setback schedule as detailed below:

a) from 2300 hours to 0700 hours, heat = on if zone temperature <10°C
b) from 0700 hours to 2300 hours, heat = on if zone temperature <20°C
c) all hours, cool = on if zone temperature >27°C
d) otherwise, mechanical equipment is off.

4.4.2 Energy needs for heating and cooling

Table 22, Table 23, Table 24 and Table 25 compare the values that emerged from the simulation using TERMOLOG software with the minimum, maximum and average values obtained using the reference software.

Table 22 *Energy needs for space heating*

Energy needs for space heating	kWh/year
BESTEST min.	793
BESTEST max	1411
BESTEST avg	1138
TERMOLOG	1382

Table 23 *Energy needs for space cooling*

Energy needs for space cooling	kWh/year
BESTEST min.	2079
BESTEST max	3241
BESTEST avg	2535
TERMOLOG	3308

Table 24 *Peak power needs for space heating*

Peak power for space heating	W
BESTEST min.	3980
BESTEST max	9923
BESTEST avg	6021
TERMOLOG	9029

Table 25 *Peak power needs for space cooling*

Peak power for space cooling	W
BESTEST min.	2888
BESTEST max	4901
BESTEST avg	3543
TERMOLOG	4013

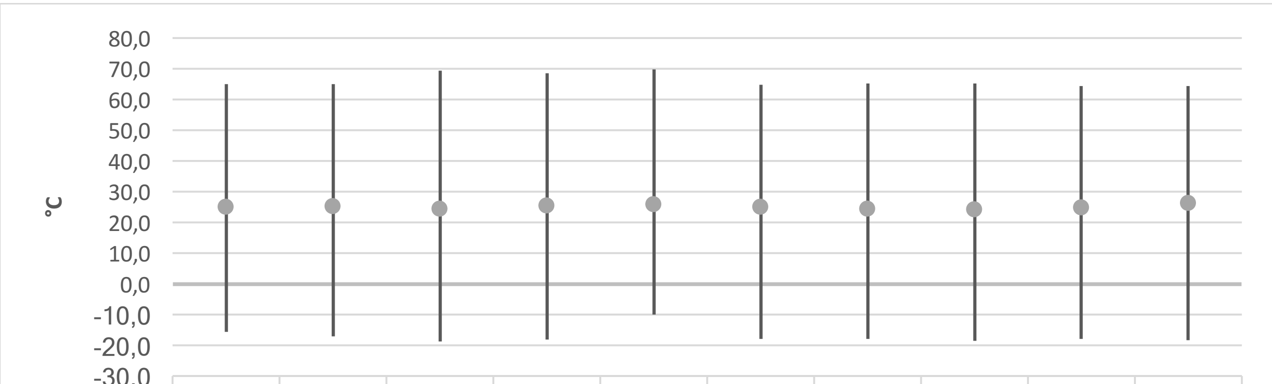
4.5 BESTEST 600FF and 900FF

4.5.1 Description of the test

Case 600 FF is the same as CASE 600 except that there is no mechanical heating and cooling system.
Case 900 FF is the same as CASE 900 except that there is no mechanical heating and cooling system.

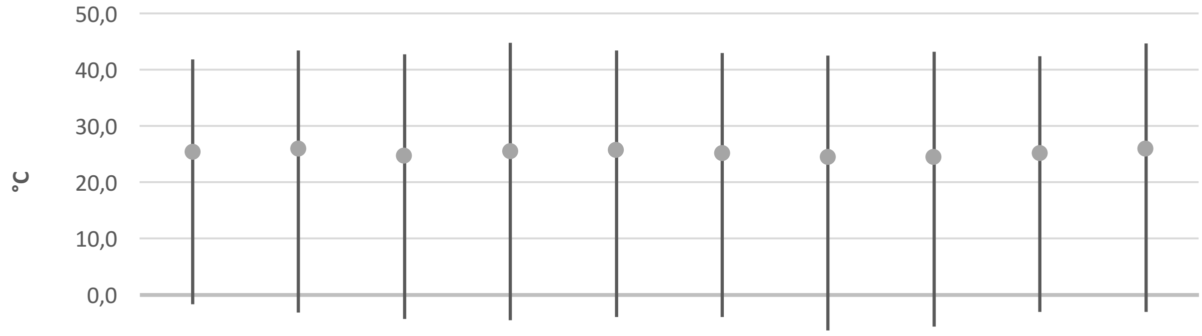
4.5.2 Annual peak temperature

The graphs in Figure 2 and Figure 3 show the comparison between maximum minimum and average temperature for test cases 600FF and 900FF.



	ESP	BLAST	DOE2	SRES	SERIRES	S3PAS	TRNSYS	TASE	EnergyPlus	Termolog
MAX	64,9	65,1	69,5	68,6	69,8	64,9	65,3	65,3	64,4	64,3
min	-15,6	-17,1	-18,8	-18,0	-10,0	-17,8	-17,8	-18,5	-17,9	-18,4
Average	25,1	25,4	24,6	25,5	25,9	25,2	24,5	24,2	25,0	26,3

Figure 2 *BESTEST 600FF peak temperature comparison*



	ESP	BLAST	DOE2	SRES	SERIRES	S3PAS	TRNSYS	TASE	EnergyPlus	Termolog
MAX	41,8	43,4	42,7	44,8	43,4	43,0	42,5	43,2	42,4	44,7
min	-1,6	-3,2	-4,3	-4,5	-3,9	-4,0	-6,4	-5,6	-3,1	-3,0
● Average	25,5	25,9	24,7	25,5	25,7	25,2	24,5	24,5	25,2	25,9

Figure 3 *BESTEST 900FF peak temperature comparison*

5 Conclusions

The set of tests 600, 640, 900, 940, 600FF and 900FF - as specified in ANSI/ASHRAE Standard 140-2001 – has been applied to the program TERMOLOG implementing the hourly dynamic calculation model proposed by EN ISO 52016. The results were compared with tests reported in EN ISO 52016.
Although it was not possible to make a complete comparison because it appears that some values of test case 900 are quoted wrongly in EN ISO 52016, Termolog results are in good agreement.
The results were also compared with other 9 reference programs: only 2 out of 16 tests are slightly outside the range predicted by other software. This could be considered satisfactory, taking into account that EN ISO 52016 method is simplified and not widely tested as other methods implemented in software are.
The tests did not reveal any relevant bugs in the software.

Prof. Giuliano Dall'O'
(Research responsible)

References

1. Robert H. Henninger and Michel J. Witte, 2004, Energy Plus testing with ANSI/ASHRAE Standard 140-2001 (BESTEST), Ernest Orlando Berkeley National Laboratory Berkley, California, USA for U.S. Department of Energy

2. ISO Standard 52016-1:2017 Energy performance of buildings -- Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads -- Part 1: Calculation procedures

3. ANSI/ASHRAE Standard 140-2001, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs. ASHRAE Inc., 1791 Tullie Circle NE Atlanta, GA 30329.

4. ASHRAE Standard 90.1-2001, Addendum p. ASHRAE Inc., 1791 Tullie Circle NE Atlanta, GA 30329.

5. EnergyPlus Testing with ANSI/ASHRAE Standard 140-2001 (BESTEST). EnergyPlus Version 1.1.0.020. May 2003. Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California. Prepared by Robert H. Henniger and Michael J, Witte, GARD Analytics, 1028 Busse Highway, Park Ridge, Illinois 60068, USA.

6. Tests performed on ApacheSim in accordance with ANSI/ASHRAE Standard 140-2001. IES Ltd. 141 St James Road, Glasgow G4 0LT

Appendix A – BESTEST comparison bar charts

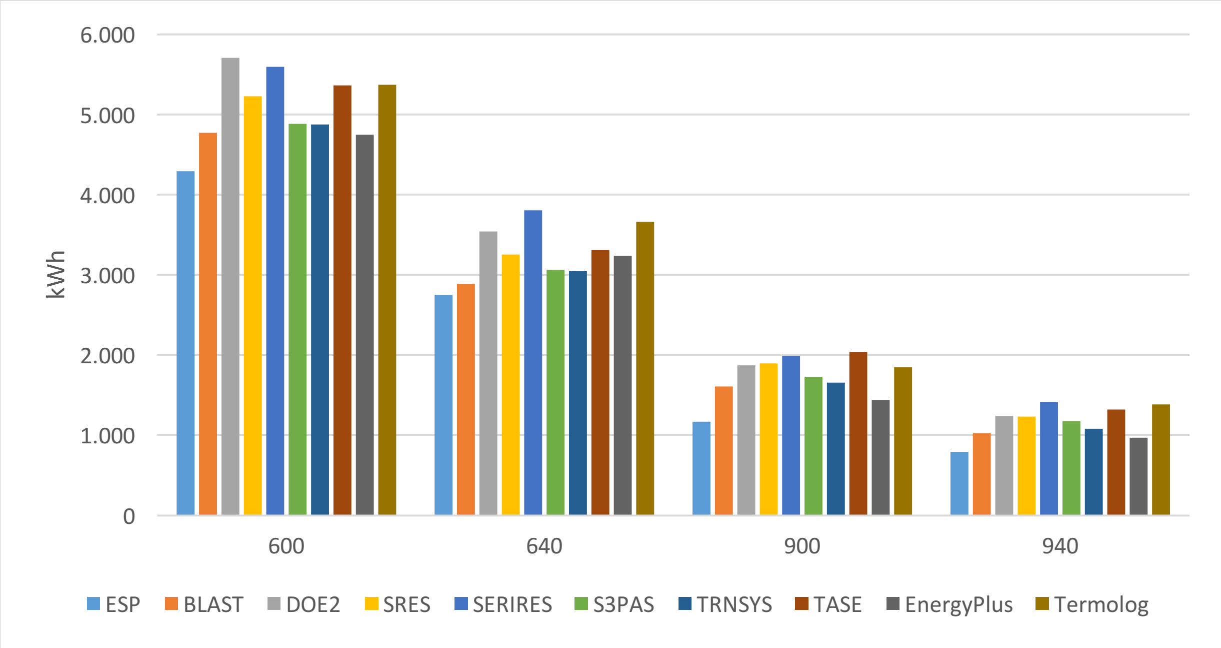


Figure 4 *Annual needs for heating*

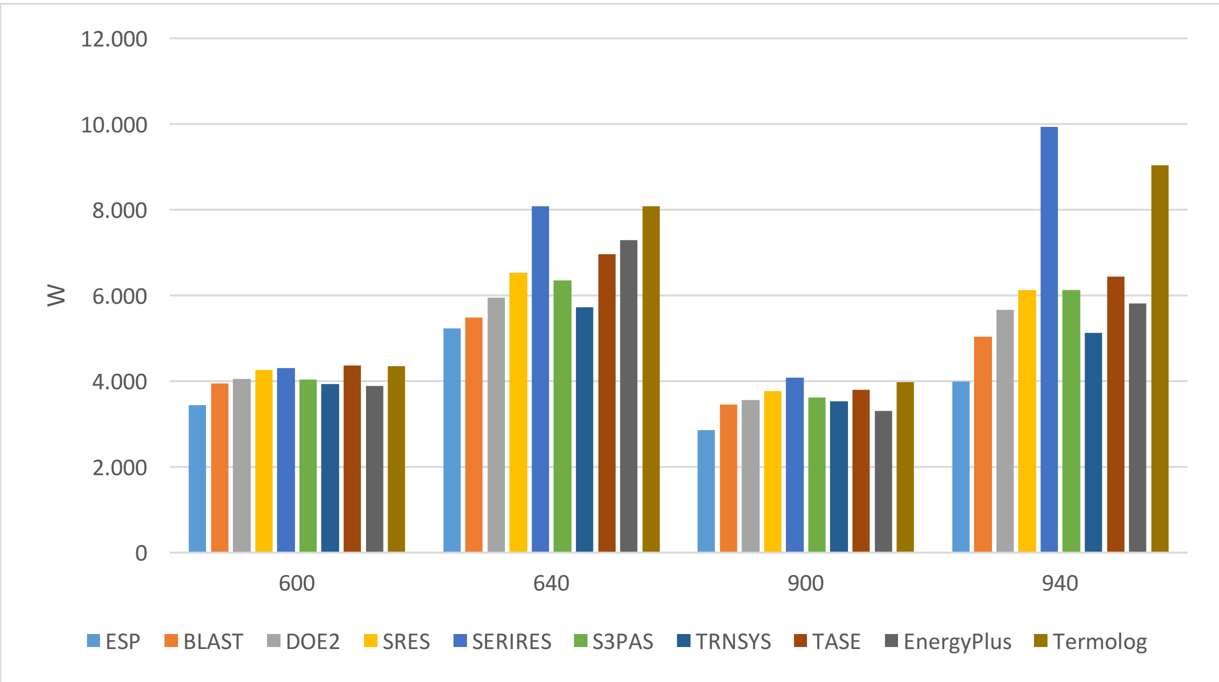


Figure 5 *Annual heating peak power*

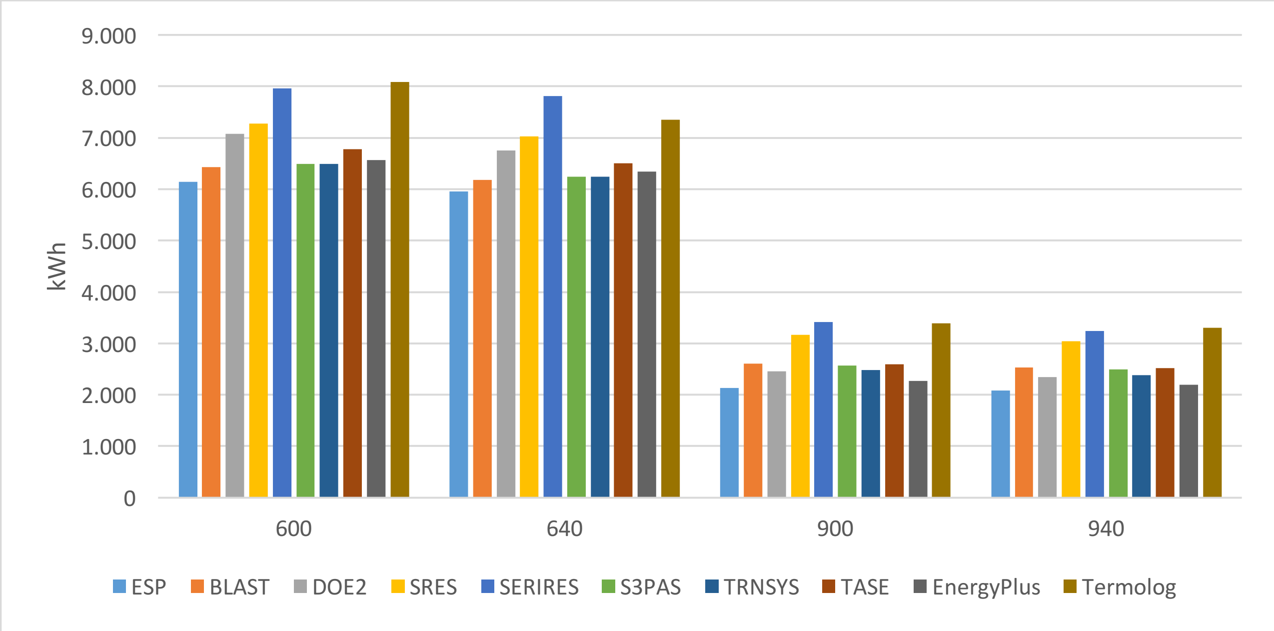


Figure 6 *Annual needs for cooling*

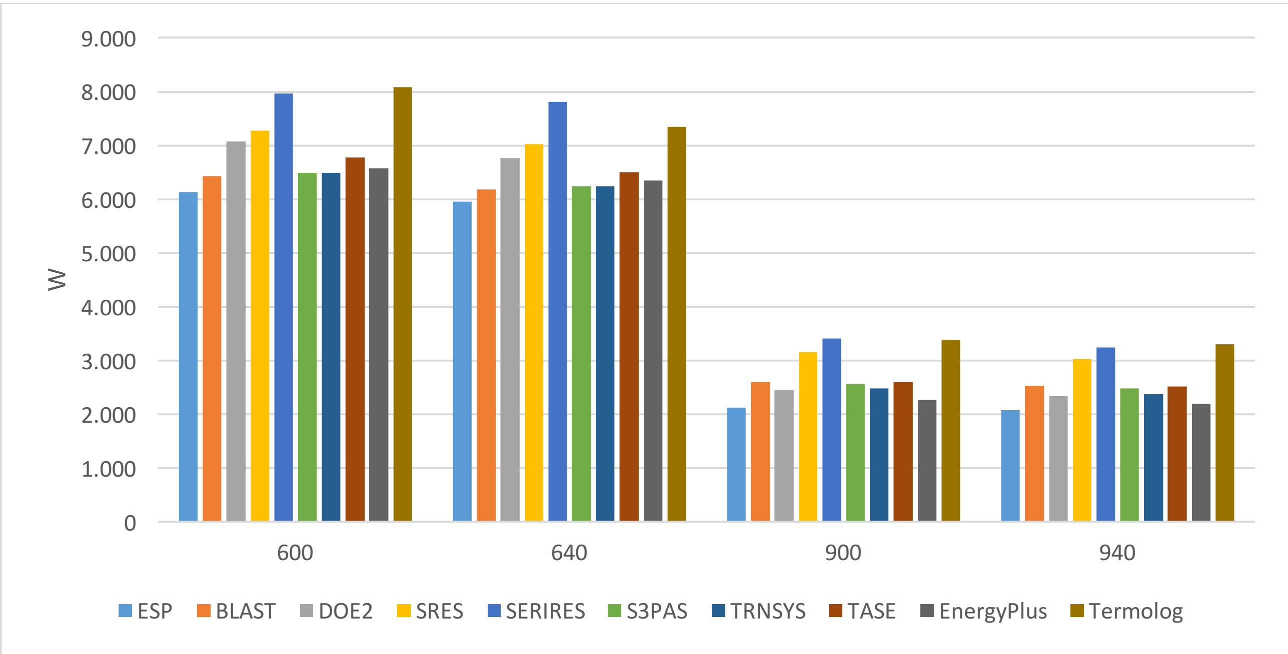


Figure 7 *Annual cooling peak power*