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Validation of SEAS, a quasi-steady-state tool for building energy audits

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Abstract

SEAS is an energy auditing software that can simulate residential, office, school, and hospital buildings, providing energy requirements for heating, domestic hot water production, ventilation, lighting, and other electrical uses.

In order to validate this quasi-steady-state tool, we simulated in SEAS several reference cases (based on EN 15265 benchmark room) and a residential dwelling. We also used the dynamic simulation software TRNSYS and compared the results of the two software in terms of seasonal energy requirements for space heating and energy fluxes through the elements of the building envelope. Most of SEAS results are in good agreement with EN 15265 and with TRNSYS. Nonetheless, we pointed out that SEAS lacks in accuracy when it simulates high thermal inertia buildings with intermittent heating: for these particular cases, new correlations for dynamic parameters and reduction factors should be developed.

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1. Introduction

Current European Directives [1,2] recognize energy audit as a useful tool, which identifies criticalities in a building system and provides retrofit solutions for the improvement of energy efficiency.

Technical Standard ISO 13790 [3] identifies two methodologies for energy audits: dynamic methods and quasi-steady-state methods. A dynamic method analyses the building thermal-energetic response on hourly-or-less time

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steps through energy balances of all the involved elements of the system: a deep knowledge of the whole system is required, but the provided results are accurate. EnergyPlus (developed by the U.S. Department of Energy) and TRNSYS (University of Wisconsin) are two of the most common software for dynamic simulation of buildings. A quasi-steady-state method simulates the thermal-energetic behavior of the system usually on monthly basis: dynamic effects are considered through correlation factors. A quasi-steady-state simulation is more time-effective and requires less input data than the dynamic method, but its results are generally less accurate.

SEAS (Simplified Energy Auditing Software) is a recent Italian energy simulation software based on a quasi-steady-state method, improved by means of tailored and original methodologies. In this paper, SEAS is briefly presented and two steps for the validation of its accuracy are described, respectively, in Sections 3.1 and 3.2.

2. Description of SEAS

SEAS is an open-access software, developed by DESTEC (Department of Energy, Systems, Territory and Constructions Engineering), University of Pisa, in collaboration with ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development). SEAS performs energy simulations for audits of residential, office, school, and hospital buildings, evaluating energy requirements for space heating, domestic hot water production (DHW), ventilation, lighting, and other electrical uses. It also provides economic indices for the cost-benefit analysis of retrofit actions.

To predict energy use for space heating, SEAS mainly employs the quasi-stationary models presented in [3,4]. Nonetheless, in order to more accurately reproduce the actual use of the building, the energy auditor has to provide bihourly, weekly or monthly schedules of users' presence and behavior (use of electric equipment, windows openings, use of shutters, off-periods of the heating system, etc.). In particular, the bihourly schedules are coupled to the corresponding bihourly climatic conditions. Moreover, the energy auditor can establish the level of accuracy of the input parameters: for instance, it is possible to use climatic data from UNI 10349 [5] or manually insert average monthly temperature and solar radiation for the analyzed location, if more recent or accurate data are available. Further details on all the calculation methodologies can be found in [6].

2.1. Case studies implemented in SEAS

In order to test SEAS, three case studies (an educational building, a historical office building, and a residential dwelling) were conducted. Their characteristics and results (presented in [7]) are summarized here.

The educational building, located in the center of Pisa, is a four-story building of historical value, characterized by high thermal mass and low efficiency windows. No DHW is produced. Space heating is provided by a traditional natural gas boiler and the terminal units are radiators. The uses of electric equipment and the schedules of users' presence (in this case, students) and of windows openings were the most uncertain data.

The office building is also located in the center of Pisa and has historical value. Offices are located in the three central levels (out of five). Differences with respect to the previous case are in users' schedules and internal loads.

The dwelling, recently retrofitted, is located in the province of Lucca. It is heated by means of a LPG condensing boiler. All radiators have thermostatic valves. Two thermal solar collectors and a hot water storage are present.

Table 1 shows the yearly energy requirements obtained by SEAS simulations and the actual consumptions reported on the billings for the three case studies: discrepancies are acceptable for all cases.

Table 1. Yearly energy requirements for the three case-studies

Case study		Billings (MWh)	SEAS (MWh)	Relative deviation (%)
Educational building	Thermal / Electric energy	55.9 / 30.3	54.6 / 30.3	-2.3 / -0.2
Office building	Thermal / Electric energy	101.1 / 24.6	99.2 / 24.9	-1.9 / 1.3
Residential dwelling	Thermal / Electric energy	8.08 / 2.49	6.96 / 2.25	-13.8 / -9.7

3. Validation of SEAS by means of benchmark cases and dynamic code

3.1. Tests based on EN 15265

For the purpose of validation of an original building energy-simulation tool, a simple comparison with energy billings can be misleading (for example, because of counterbalance effects due to underestimation or overestimation of both losses and gains in the energy balance). Hence, it is appropriate to test this new method on standard reference cases, such as the ones reported in Technical Standard EN 15265 [8] or in the International Energy Agency BESTEST procedure described in [9].

In particular, in EN 15265, twelve case studies on a reference room, located in the French town of Trappes, are presented: the differences among the cases concern thermal transmittance of the opaque walls and windows, thermal mass, solar gain coefficient and heating mode (continuous or intermittent mode). Annex A of EN 15265 reports hourly climatic data (external temperature, direct normal solar radiation, diffuse horizontal solar radiation and global solar radiation on a west-wall) for the reference location. A model or software can be validated comparing the energy requirements obtained for the 12 cases with those reported in the technical standard.

We first applied the mentioned methodology to TRNSYS 17, comparing energy requirements for the heating service only. As TRNSYS correctly simulates the 12 cases, with differences of about 5% with respect to the standard results, we used it to create 46 additional benchmark cases, modifying heating modes and thermal characteristics of the envelope elements of the reference room: the obtained heating energy requirements were used as target for SEAS results.

The overall 58 cases were implemented in SEAS, using average monthly climate data. For the original test cases, Table 2 shows the energy requirements for space heating obtained by SEAS and TRNSYS, compared with results from EN 15265. Table 5 in Appendix A reports energy requirements obtained by the two software for the other 46 cases. The building time constants, τ, calculated as in [3], are also reported in Tables 2 and 5 for all the cases.

Table 2: Energy requirements for the 12 test cases of EN 15265 (relative deviations, RD, are calculated as indicated in [8])

Case n.	τ (h)	EN 15265 (kWh)	TRNSYS (kWh)	TRNSYS RD (%)	SEAS (kWh)	SEAS RD (%)
1	36.5	748.0	699.2	-5.0	832.2	8.6
2	100.2	722.7	684.7	-4.1	738.7	1.7
3	36.9	1368.5	1294.4	-5.2	1366.7	-0.1
4	30.2	567.4	655.6	4.2	583.0	0.7
5	36.7	463.1	450.0	-2.0	416.0	-7.1
6	100.3	509.8	513.1	0.5	618.2	15.6
7	36.7	1067.4	1095.6	2.6	1116.0	4.5
8	30.8	313.2	390.6	5.3	208.3	-7.3
9	72.6	747.1	794.2	5.2	1133.5	42.7
10	30.5	574.2	559.0	-2.0	573.5	-0.1
11	72.6	1395.1	1198.0	-14.0	1881.2	34.5
12	60.1	533.5	672.2	9.5	672.9	9.5

Results show that SEAS correctly estimates energy needs for most of the cases, with less than 10% deviations from the technical standard benchmark outputs. However, in a few cases, SEAS outputs differ from benchmark results for more than 30%. These cases are all characterized by a high thermal inertia and a highly intermittent heating mode (heating off on Saturdays, Sundays, and from 6 p.m. to 8 a.m. all working days). Intermittency is modeled in SEAS by means of the procedure described in ISO 13786 [10]: energy requirements are first calculated using continuous heating assumption, then they are scaled with a reduction factor, depending on the time constant of the building zone, the overall gains, and the fraction of weekly hours in which heating is switched on. These results demonstrate that the standard procedure is not suitable for the cases in which high thermal inertia and intermittency are combined. On the other hand, it provides accurate results when intermittent control is performed on low-inertia rooms.

The additional cases reported in Appendix A confirm the above-described trends. In particular, deviations of energy needs between SEAS and TRNSYS are below 15% for two thirds of the 58 tests. The higher deviations are observed for high-inertia rooms with intermittent use. More specifically, for time constants of the buildings below 48 hours, the average deviation is 6%, whereas it is 26% for time constants above 72 hours.

3.2. Residential dwelling

The accuracy of SEAS in predicting seasonal thermal energy needs is not sufficient to conclude that every term of the energy balance and even energy fluxes through the elements of the building envelope are correctly estimated. Hence, as a further validation step, we performed a complete dynamic simulation of an existing building envelope. In particular, we chose the residential dwelling mentioned in Section 2.1. Internal loads are due to the presence of people (a family of 4), traditional domestic electrical equipment and a fireplace. A night setback temperature is scheduled. The time constant of the building is 45 hours. Further details on this case study can be found in [11].

Simulations were run on SEAS and TRNSYS for the months of January and February, central months of the heating season. With respect to [11], use of shutters and presence of external obstructions were considered in both tools. Climate data from CTI (Italian Committee of Thermotechnics) were used in an hourly format for TRNSYS simulation and in an average monthly format for SEAS. TRNSYS simulation differs from SEAS simulation in: thermal characteristics of windows (slightly different thermal transmittance and radiant properties), thermal bridges (absent in TRNSYS simulation, but considered by means of a 5% increase of the thermal transmittance of opaque walls), ground heat exchange (different adopted methodologies in the two simulation tools), and ventilation losses (in TRNSYS, actual windows openings were considered, while, in SEAS, UNI 10339 [12] was used for assessing the ventilation airflow). Results show that SEAS underestimates all the terms of the energy balance, but the discrepancies between the two cases are acceptable, also considering the very different physical models involved in the two software. Besides, the relative weight of each contribution to the building envelope energy balance is nearly the same for the two simulation tools (see Figure 1) and this is particularly important for the selection of the appropriate energy saving actions. Tables 3 and 4 show, respectively, energy fluxes through some external components of the envelope and single terms of energy balance.

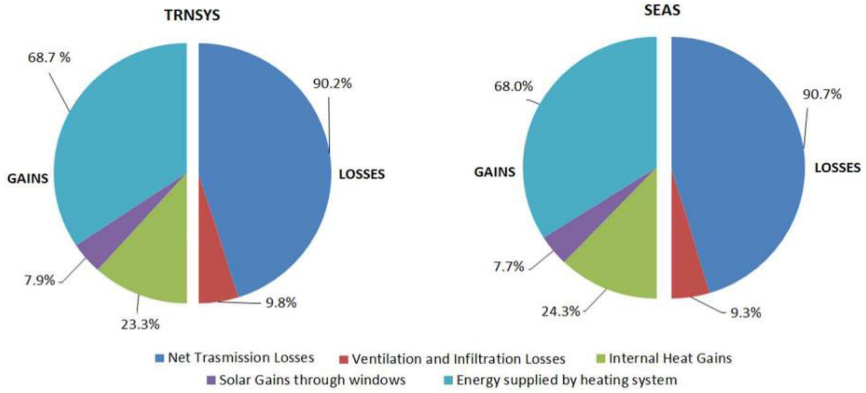

Figure 1: Contribution of losses and gains to the energy balance of the building envelope, according to the two simulation tools.

Table 3: Comparison between SEAS and TRNSYS energy fluxes through some of the building envelope elements

Building envelope element	TRNSYS (kWh)	SEAS (kWh)	Relative deviation (%)
Floor	372	405	8.9
NE-oriented wall	553	506	-8.5
NW-oriented wall	173	181	4.6
Internal wall (toward other unit)	188	171	-9.0
SE-oriented window	357	355	-0.6
SW-oriented window	135	136	0.7

Table 4: Comparison between SEAS and TRNSYS terms of the building envelope energy balance

Terms of building envelope energy balance	TRNSYS (kWh)	SEAS (kWh)	Relative deviation (%)
Overall energy need for space heating	2715	2483	-8.5
Net transmission losses (opaque walls, windows, thermal bridges, ground heat exchange, solar gains on opaque walls)	3564	3312	-7.1
Infiltration and ventilation losses	386	340	-11.9
Internal gains	921	886	-3.8
Solar gains through windows	314	283	-9.9

Conclusion

In this paper, we performed a series of energy simulations with the software SEAS (which uses a quasi-steady-state method) and compared results from this tool and from TRNSYS 17 (based on an accurate dynamic model), in terms of seasonal energy needs for space heating and of energy fluxes of the building envelope components.

A set of benchmark cases based on EN 15265 and a residential dwelling were simulated. Results are encouraging, as SEAS mostly shows low deviations both from EN 15265 validation tests and TRNSYS outputs. Nonetheless, SEAS largely overestimates energy needs of intermittently-heated high thermal inertia buildings. The implemented correlations for dynamic parameters and reduction factors (based on [3]) seem to fail in these particular cases. Hence, for extending the reliable application of SEAS in energy audits, improved correlations for these coefficients should be developed.

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Appendix A. Results of the additional 46 cases based on the benchmark room of EN 15265

Each test case is identified by a case ID: the number indicates the corresponding test in EN 15265, while the letter indicates the set of test cases in which a change (reported in the "Description" column) was applied with respect to the reference cases. For example, in case A-5, the characteristics of the room are the same of case n. 5 in [8], but heating is switched on with a different schedule, as for all the "A" cases.

Table 5: Energy requirements for the additional 46 cases (relative deviations, RD, are calculated as indicated in [8])

Case ID	τ (h)	Description	TRNSYS (kWh)	SEAS (kWh)	SEAS RD (%)
A-5	36.7	Heating on: Mon-Fri: 7 a.m. – 6 p.m. Sat: 7 a.m. – 1 p.m.	446	451	0.6%
A-6	100.3		452	696	31.1%
A-7	36.7		1068	1083	1.3%
A-8	30.8		359	224	-6.8%
A-9	72.6		737	1106	36.5%
A-10	30.5		601	626	2.8%
A-11	72.6		1421	1825	27.3%
A-12	60.1		607	670	3.8%
B-5	36.7	Heating on: Mon-Sat: 5 p.m. – 2 a.m.	428	430	0.2%
B-6	100.7		449	690	30.9%
B-7	36.7		862	969	11.0%
B-8	30.8		354	204	-7.6%
B-9	72.6		730	1092	36.1%
B-10	30.5		593	391	-0.2%
B-11	72.6		1128	1426	25.0%
B-12	63.7		612	650	2.3%

C-5	36.7	Heating on: Mon-Sun: 5 a.m. – 11 p.m.	563	684	12.7%
C-6	100.5		571	693	13.5%
C-7	36.7		1197	1307	8.4%
C-8	30.8		475	550	3.6%
C-9	72.5		1004	1320	24.8%
C-10	30.5		829	1020	16.9%
C-11	72.5		1699	1971	15.5%
C-12	63.7		854	650	-10.7%
D-5	36.7	Heating on: Mon-Sat: 5 a.m. – 11 p.m.	533	598	7.0%
D-6	100.6		544	692	16.8%
D-7	36.7		1166	1182	1.3%
D-8	30.8		446	361	-4.1%
D-9	72.6		943	1319	31.0%
D-10	30.5		774	844	6.5%
D-11	72.6		1638	1970	19.6%
D-12	63.7		798	745	-2.9%
E-5	36.7	Heating on: Mon-Fri: 5 a.m. – 11 p.m.	504	542	4.2%
E-6	100.7		521	691	19.9%
E-7	36.7		1117	1144	2.2%
E-8	30.8		417	303	-5.6%
E-9	72.6		884	1164	24.2%
E-10	30.5		721	760	3.8%
E-11	72.6		1552	1865	19.4%
E-12	63.7		742	714	-1.6%
F-5	44.6	Heating on: Mon-Sun: 5 a.m. – 11 p.m. External wall: thermal transmittance 0.49 W/(m^{2}K) areal heat capacity 73.5 kJ/(m^{2}K) Ceiling 4c: thermal transmittance 0.24 W/(m^{2}K) areal heat capacity 50.5 kJ/(m^{2}K) Roof: thermal transmittance 0.44 W/(m^{2}K) areal heat capacity 38.6 kJ/(m^{2}K)	561	702	15.0%
F-7	53.7		1199	1296	7.5%
F-8	45.1		470	513	2.1%
F-9	34.3		1035	1377	24.9%
F-11	34.3		1724	2001	15.0%
F-12	30.1		917	908	-0.5%

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