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Integration time step issue in Mediterranean Historic Building energy simulation

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Abstract

The European target towards Zero Energy buildings is focusing on the energy retrofit of existing buildings. Often, in Mediterranean countries, existing buildings have historical relevancies, involving constraints, when dealing with their energy renovation, due to conservation reasons. To analyze possible energy retrofit actions, building energy performance simulation tools (BEPSt) are valuable. However, old buildings are often made of large stone walls whose resolution through conduction transfer function (CTF) used for sub-hourly time step simulation might be critical. This paper analyses how EnergyPlus and TRNSYS address such problem, explaining the differences between them and the reasons for low quality results.

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Keywords: Historic Buildings, Performance simulation, Transient Heat Transfer;

1. INTRODUCTION

Today the European target towards Zero Energy buildings is focusing on the energy retrofit of existing buildings, which represent the majority of the building stock. In Mediterranean countries, like Italy, most of the existing building stock is very ancient and very often those buildings are historic buildings. When dealing with their energy renovation, many constraints have to be taken into consideration due to conservation reasons. To be able to analyze and optimize any potential energy saving option foreseen for a constrained problem like energy saving in ancient or historic

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building, where local specific cultural heritage considerations are dominant, energy performance simulation tools (BEPSt) represent powerful and essential tools.

Old and historic Mediterranean building are often made of large stone walls from 30, 50 cm up to 1.9 m. These thick walls, combined with a small simulation time step, may produce low quality results if conduction transfer functions (CTFs) are used when solving transient heat conduction in such walls. The requirement of using small simulation time step (less than one hour) is often due to the desire of analyzing the impact of complex control systems on the building energy performance, mainly in connection with the exploitation of renewable energy sources. In such case, but also when one-hour time step is used with very large walls, problems could arise that depends on the quality of the method used to calculate the CTF coefficients and on the minimum acceptable CTF time base compared to the imposed simulation time step. The CTF time base is the time step chosen to build its coefficients and represents its time resolution. When a fix or upper bounded number or coefficients are chosen, the CTF time base is lower bounded, i.e. it is possible that a reliable CTF does not exist for such chosen time base and number of coefficients and that a larger time base or an increasing number of coefficients has to be used to find a high quality solution. The simulation time step is instead the time resolution the user has decided to use in solving the overall energy simulation problem.

Today, two of the most diffused BPSts, EnergyPlus (EnergyPlus [1]) and TRNSYS (TRNSYS [2]), make primarily use of conduction transfer functions for heat conduction resolution, even if also finite difference schemes are implemented in EnergyPlus. The CTF coefficients can be calculated following different approaches, and, as a matter of fact, EnergyPlus implements the State-Space method (SS) (Seem [3]), while TRNSYS implements the Direct Root Finding method (DRF) (Mitalas and Arseneault [4]), even if a custom SS method was tested in a TRNSYS 17 development version (Delcroix [5]). To test the quality of those methods, when dealing with heavy, thick walls like that usually found in historic buildings, reference boundary conditions have been chosen that allows comparing CTF solutions with analytical solutions, even if numerically computed. Thus, periodic steady state boundary conditions (BCs) are applied with a period of 24 h and the results in terms of superficial temperatures and fluxes are compared with analytical exact solutions obtained using the harmonic admittance matrix approach (CEN-ISO [6]). The periodic steady state heat conduction is solved for five different walls in 1D domain with different simulation time steps. The effect on the accuracy of the solution of different CTF time bases, compared to the simulation time step, is investigated too.

Nomenclature

x_i	Discrete i-time calculated generic quantity
$\hat{x}_i$	Analytically calculated generic quantity at time t_i
y_i	CTF transfer function calculated setting the Laplace parameter as harmonic at frequency ω_i, i.e. $s = e^{i\omega i\Delta t}$
$\hat{y}_i$	Module or phase of the superficial or cross coefficient of the admittance matrix evaluated at frequency ω_i

2. Test Methodology

The tested transient heat conduction solvers belong to the Conduction Transfer Function (CTF) method and their coefficients are computed using:

- State-Space method (SS), as implemented in EnergyPlus 8.6;
- Direct Root Finding method (DRF), as implemented in TRNSYS 17.

To analyze not only the impact of each method, SS or DRF, on the quality of the solution, but also the impact of any implemented algorithm, which takes care of possible mismatch between the CTF time base and the simulation time step, an entire thermal zone simulation (instead of a single wall test) has been performed. Thus, the scenario taken into consideration is that described in the “Test TC3: Transient Conduction – Sinusoidal Driving Temperature and Multi-layer Wall” of the ASHRAE 1052-RP (Spitler [7]). The ASHRAE report gives the analytically derived solution of such problem for just one wall. To be able to produce those reference analytical results for any kind of wall obtaining the “exact” values of superficial internal and external temperatures, this analytical solution has been implemented inside OpenBPS, a tool developed by our research group, which will be further developed in the PRIN 2015 project (De Santoli [8]). Then, transient conduction through walls, as implemented in EnergyPlus and TRNSYS, has been tested by modelling the before mentioned test case in both tools and by changing the wall type when needed. Heating and cooling system has been ideally modelled, as allowed by each tool, to keep the inside air temperature at the desired constant value of 20 °C. Outside air temperature is imposed with a 24 h sinusoidal variation with average value of 20 °C and amplitude of 15 °C. Internal gains, solar radiation and long wave radiation has been excluded both inside and outside, as required by the test. Conduction is assumed to be one-dimensional. Convection is evaluated through constant superficial heat transfer coefficients: h_{int}= 3,18 W/(m² K); h_{out}= 1,81 W/(m² K), as reported in ASHRAE 1052-RP. Finally, two simulation time steps have been tested, 15 min and 60 min.

Even if the reference solution given by ASHRAE 1052-RP is in terms of instantaneous zone load at specific time stamps, since our focus are the results of the calculation of heat conduction though a wall, fluxes on the inside and outside surfaces of the wall have been taken into consideration and reported.

2.1. Walls definition troubleshooting

An homogeneous wall with thermal conductivity of 0,66 W/(m K), specific thermal capacity of 840 J/(kg K) and mass density of 1500 kg/m³ has been tested with different thicknesses, i.e. 30 cm, 60 cm, 100 cm, 160 cm and 190 cm. TRNSYS does not allow layers with thickness greater than or equal to 1 m, therefore when needed, the homogenous wall has been divided in more layers. Even if EnergyPlus does not have this restriction upon maximum layer thickness, we have seen that for the Wall 160 and 190 it had problems in calculating CTF coefficients, respectively for hourly simulation and for both simulation time steps. After having split also in EnergyPlus these walls, it succeeded in calculating the relative CTF coefficients, but still it didn't allow simulations with time step of 1h for Wall 190. A test on a further splitting of this last wall (Wall 190 split in four layers) has been made, to better understand the implications of different splitting.

The Wall Time Base (WTB), i.e. the time step over which the CTF coefficients are calculated, has been kept in each performed test, as the minimum allowed by each tool. Both tools have implemented some "quality check" routines to allow or not the use of the resulting CTF coefficients, in both cases, the time base must always be an integer multiple of the simulation time step.

In TRNSYS the user must explicitly set the WTB for the DRF coefficients calculation and, even if sometimes in TRNBuild pre-processor, smaller WTBs are allowed by the quality check, the simulation is stopped if it is not an integer multiple of the simulation time step. Therefore, an integer multiple of 15 min and 60 min has been used as WTB in TRNSYS. EnergyPlus calculates the WTB by itself, according to the simulation time step. In general, the time bases calculated by EnergyPlus are smaller than the ones allowed by TRNSYS, as can be seen in **Table 1**.

2.2. Error definition

The errors hereafter reported are calculated with respect to the analytical instantaneous values of walls superficial temperatures and heat fluxes. These analytical values are compared with those produced by the two software without any manipulation, using the time stamp or label associated with the results provided by each tool.

Three kinds of error have been considered:

- a normalized error on the peak value of a variable, using the reference amplitude as a measure of scale:

$$MaxErrPeak = (x_{\max} - \hat{x}_{\max}) / (\hat{x}_{\max} - \hat{x}_{\min})$$

- a normalized error on the amplitude of a variable, using the reference amplitude as a measure of scale:

$$MaxErrAmpl = (x_{\max} - x_{\min}) / (\hat{x}_{\max} - \hat{x}_{\min}) - 1$$

- a normalized root mean square error, using the reference amplitude as a measure of scale:

$$NRMSE = \sqrt{\left(\sum_{i=1}^{N} (x_i - \hat{x}_i)^2 / N\right)} \Big/ (\hat{x}_{\max} - \hat{x}_{\min})$$

- a normalized mean absolute error**,** using the reference amplitude as a measure of scale:

$$NMAE = \frac{1}{N} \sum_{i=1}^{N} \left| x_i - \hat{x}_i \right| \Big/ (\hat{x}_{\max} - \hat{x}_{\min})$$

The first and the second error are directly influenced by the chosen simulation time step (even if conduction could have been solved exactly), because of time discretization: the real maximum value of a variable might be reached in between two time stamps and be missed by numerical "sampling". Smaller time steps allow the numerical calculated maximum to be closer to such analytical maximum value.

Relevant error in peak error and irrelevant in amplitude error would be index of wrong mean value.

Both NRMSE and NMAE can be taken as an indicator of the phase error of the solution when the error on the peak and amplitude are small.

All the simulations have been performed with the selected periodic BC for a whole year and only the results obtained for the last period (24 hours) have been taken into consideration.

Table 1: Time base for CTF coefficients calculation
(Note: * split in two only in TRNSYS)

Wall Type	BPSt	CTF TimeBase [h]	Sim Time Step [h]
WALL 30	TRNSYS	0.25	0.25
		1	1
	Eplus	0.25	0.25
		1	1
WALL60	TRNSYS	0.75	0.25
		1	1
	Eplus	0.5	0.25
		1	1
WALL 100*	TRNSYS	2.25*	0.25
		3*	1
	Eplus	1.5	0.25
		1	1
WALL 160	TRNSYS	Not allowed	Not allowed
		Not allowed	Not allowed
	Eplus	3.75	0.25
		Not allowed	Not allowed
WALL 160split in Half	TRNSYS	5.75	0.25
		6	1
	Eplus	2.5	0.25
		3	1
WALL 190 split in two	TRNSYS	8.25	0.25
		9	1
	Eplus	3.5	0.25
		Not allowed	Not allowed
WALL 190 split in four	TRNSYS	8.25	0.25
		9	1
	Eplus	3	0.25
		Not allowed	Not allowed

2.3. Time synchronization issues

The boundary conditions for heat transfer through envelope walls are imposed, on the outside, by weather variables as outdoor air temperature and solar radiation. It was shown (Mazzarella and Pasini [9]) that the weather data manipulation as implemented in TRNSYS and EnergyPlus may produce some artificial time phase difference in the simulation results. To understand better and to try limiting such effect the following analyses have been performed.

2.3.1. TRNSYS weather data reader

The outside BC has been provided to the wall in TRNSYS directly through an external reader to avoid any automatic weather data manipulation. The settings of this external reader have been chosen to match exactly the BC used in the analytical solution, i.e.:

- with values available each 15 min;
- by setting "no interpolation required" for those values;
- by setting those values as "instantaneous".

In the following, this setting is referred to as "**TRNSYS_ts0.25h_tbMin_tw0.25h**". In this way, the wall BCs are synchronized with simulation time steps and at each time stamp the output results are synchronized with these instantaneous values (i.e. when appropriate, they are instantaneous values at that time too).

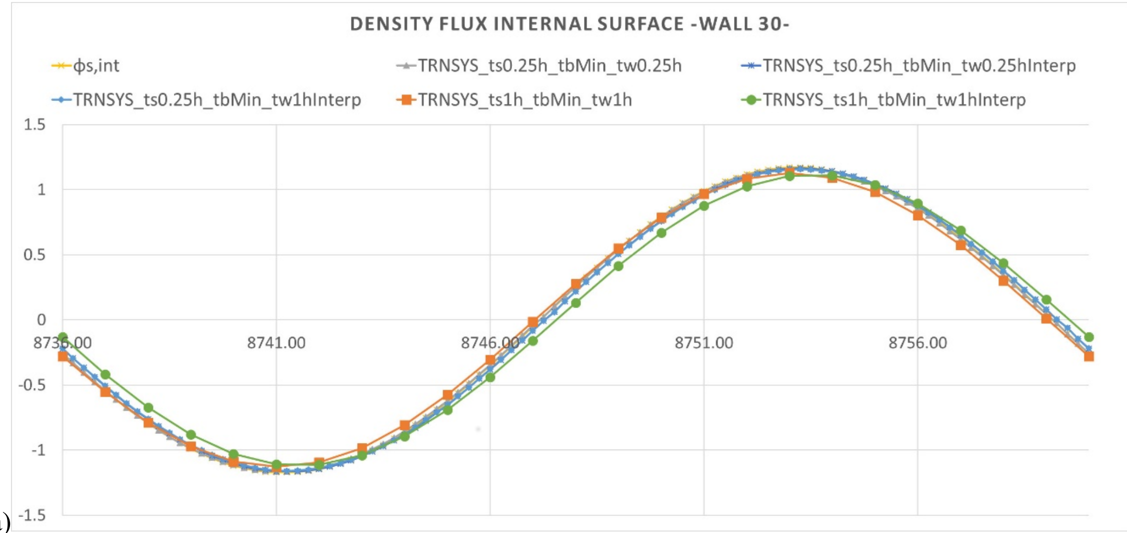
A sensitivity analysis has been performed on these synchronization aspects for assessing their impact on simulation results, considering the following cases:

- 15 min time step simulation with:
  - 15 min data reader file with the "interpolate" instruction set on **ON** (in the following referred to as "TRNSYS_**ts0.25h**_tbMin_**tw0.25hInterp**");
  - 60 min data reader file with the "interpolate" instruction set on **ON** (in the following referred to as "TRNSYS_**ts0.25h**_tbMin_**tw1hInterp**");
- 60 min time step simulation with:
  - 60 min data reader file with the "interpolate" instruction set on **OFF** (in the following referred to as "TRNSYS_**ts1h**_tbMin_**tw1h**");
  - 60 min data reader file with the "interpolate" instruction set on **ON** (in the following referred to as "TRNSYS_**ts1h**_tbMin_**tw1hInterp**").

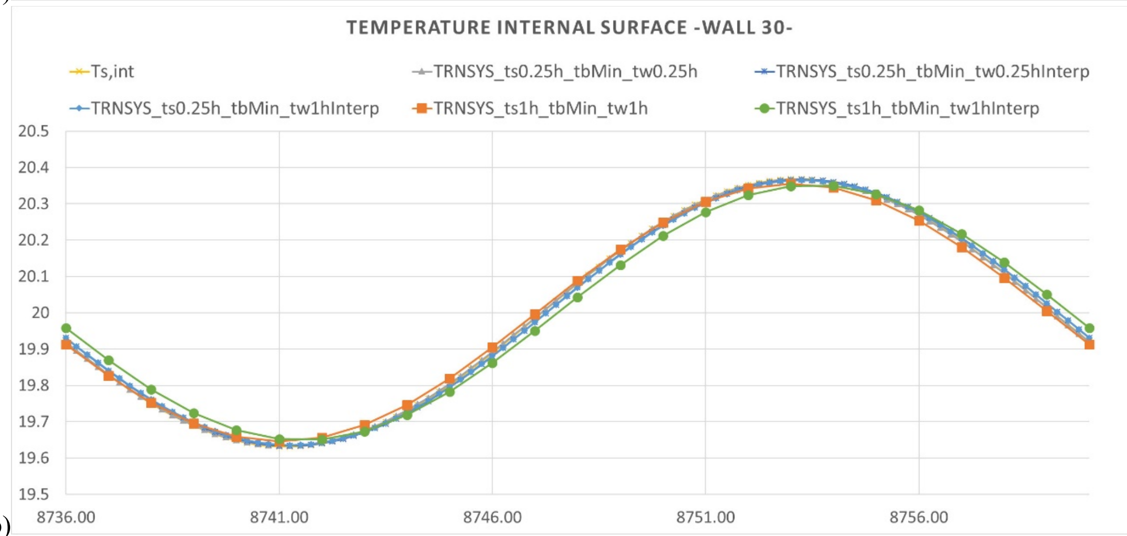
These tests have been carried out for all the considered walls, but only the results for the wall with thickness 30 cm have been here reported, since other wall thickness show same results.

The first case, 15 min data with interpolation, highlights differences due to the use of average values over the previous 15 min instead of providing instantaneous, "exact" values each 15 min. The second case, 60 min data with interpolation, considers differences in using each 15 min a linear interpolation of BC provided only each 60 min. The third case, 60 min data without interpolation, highlights possible differences when using 60 min time base for CTF coefficients calculation and 60 min simulation time step. The last case has been use to underline that even if 60 min data BCs are provided through the data reader to 60 min time step simulation, if interpolation is ON, the tool is shifting the calculation back of half time step linearly interpolating the instantaneous data associated with the time stamp.

Fig. 1, which compares the analytical solutions ($\phi_{s,int}$ or $T_{s,int}$) with the solutions provided by TRNSYS, demonstrates that, looking at the 1h-1h interpolated solutions, the foreseen shift arises, while this effect is reduced with the 15min-15min interpolated solutions and disappears when avoiding interpolation. This is due to the interpolation routine that, regardless of the availability of data at the required time stamp in the data file, performs a backward interpolation at half simulation time step. That means that, when the required data at 10h00' is available, if interpolation is ON the tool will use the linearly interpolated value at 09h30', based on the values at 09h00' and 10h00'.



a)



b)

Fig. 1 – TRNSYS Wall 30: effects of different decisions taken upon BC time alignment

2.3.2. EnergyPlus weather data reader

With EnergyPlus, instead of a data reader, we had used a customized weather data file in its proper format (.epw), by creating two weather data files with the analytically derived instantaneous values of the driving temperature, respectively available each 15 min and each 60 min, and no solar radiation. No other parameter has been set to tell EnergyPlus how to manage these weather data.

In the epw file, the time is reported as comma-separated format respectively by Year, Month, Day, hour and minute values. If an hourly simulation time step is chosen, the minute value is ignored whatever its value is, i.e. the minute value is removed. For instance, if in a hourly weather file, a value of 25,7 °C is associated with a label “1999,1,1,2,60, in EnergyPlus output, with report frequency “TimeStep” or “Detailed”, this value is associated with the “Date/Time” label equal to “01/01 02:00:00”. In 15 min weather file, which can be used only with 15 min or lower simulation time step, the minute value is taken into account; i.e. in the previous example the label in the weather file must be“1999,1,1,2,0” to work correctly. In this case the associated print out is still “01/01 02:00:00”.

The printout from EnergyPlus of the values given as BCs to the walls are reported in *Table 2*, with different simulation time steps and weather data frequencies. As we can see, the output is perfectly aligned with the weather data, i.e. no anomalous automatic back interpolation occurs.

Table 2: EnergyPlus- printout of the BCs

Sim Time Step	WD time step	Date/Time	Environment:Site Outdoor Air Drybulb Temperature [C](TimeStep)
60 min	60 min	**01/01 01:00:00**	**23.88228568**
		01/01 02:00:00	**27.5**
15 min	15 min	01/01 00:15:00	20.98104694
		01/01 00:30:00	21.95789288
		01/01 00:45:00	22.92635483
		01/01 01:00:00	**23.88228568**
		01/01 01:15:00	24.82159198
		01/01 01:30:00	25.74025149
		01/01 01:45:00	26.63433035
		01/01 02:00:00	**27.5**
15 min	60 min	01/01 00:15:00	20.97057142
		01/01 00:30:00	21.94114284
		01/01 00:45:00	22.91171426
		01/01 01:00:00	**23.88228568**
		01/01 01:15:00	24.78671426
		01/01 01:30:00	25.69114284
		01/01 01:45:00	26.59557142
		01/01 02:00:00	**27.5**

The best match between the printout, the provided weather data file and the analytical formula of the BC is obtained with a 15 min simulation time step and a weather data file with values available each 15 min.

Fig. 2, which compares the analytical solutions ($\phi_{s,int}$ or $T_{s,int}$) with the EnergyPlus and TRNSYS provided solutions, shows that EnergyPlus is a little in advance compared to the analytical solution and gives less accurate results than TRNSYS, having always lower amplitude.

3. Simulation results

3.1. Sensitivity analysis to Weather data management

In Table 3, the results of a sensitivity analysis, related to the matching of simulation time steps and BCs time bases, with and without interpolation, are reported. It is worthwhile to note that with a simulation time steps of 15 min, an error of one or two percent is introduced by different choices in setting the BCs. The worst condition is the one with interpolated hourly weather data, because it uses the value calculated half time step before the time label printed out.

3.2. CTF time base and simulation time step mismatch handling

For the first two wall (Wall 30 and Wall 60), which are the less thick, the errors on the interior surface have been evaluated having applied the sinusoidal boundary condition to the outdoor air (Table 3).

Wall 60 is the first wall for which the time base for CTF coefficient calculation is bigger than the minimum simulation time step. In these cases, an algorithm is needed to use the CTF coefficients calculated with a larger time base than the simulation time step. This algorithm has been implemented differently in EnergyPlus and TRNSYS.

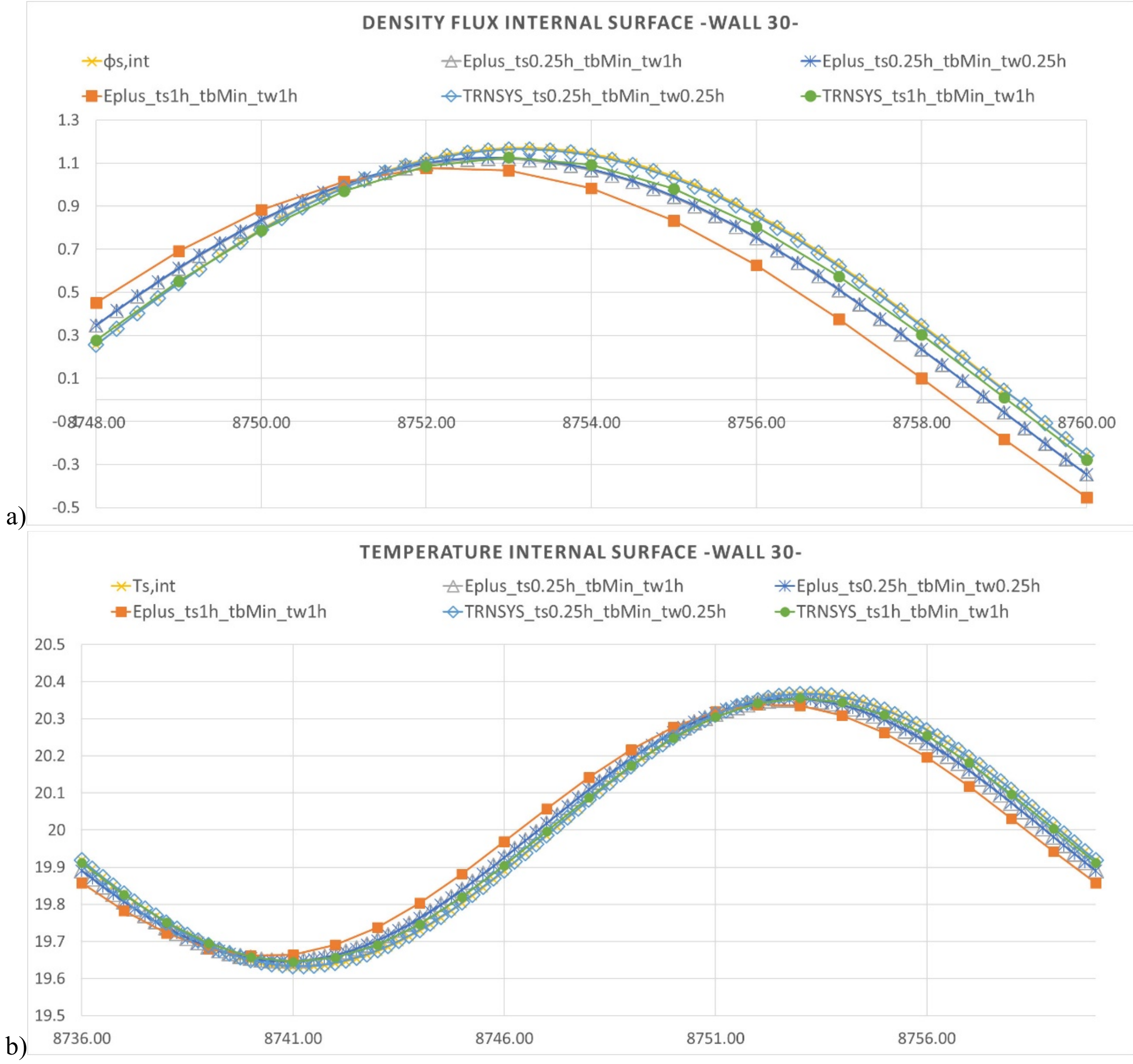


Fig. 2 – EnergyPlus Wall 30: effects of different decisions taken upon BC time alignment

The algorithm implemented in EnergyPlus gives results more smoothed, while the one of TRNSYS produces "discontinuous step-wise" results. Even if the errors are very small in both cases, the results given by TRNSYS, are more synchronized and accurate than those of EnergyPlus (Fig. 3 and Fig. 4).

As shown in Table 3, TRNSYS results have a smaller normalized peak and amplitude error, when simulating Wall 60 with 15 min time step, than with 60 min simulation time step, while cumulative errors (NRMSE and NMAE) show an opposite trend. Thus, the coupling algorithm seems to be the cause of larger error on the cumulative errors. On the contrary, all the results of EnergyPlus for Wall 60 show a worst quality for the simulation with time step of 60 min compared to the simulation with time step 15 min.

For this wall, with both simulation time steps, even if the coupling algorithm of TRNSYS has a worst behavior than to one implemented in EnergyPlus, the results of TRNSYS have better accuracy.

To further distinguish between the error in the results caused by inaccurate CTF coefficients or by an inaccurate coupling algorithm, a frequency based evaluation of the quality of the CTF coefficients (Chen et al. [10]) has been performed. The quality of the coefficients produced with the DRF method, implemented in TRNSYS, and with the SS method, implemented in EnergyPlus is therefore reported for Wall 60 in *Table 4*.

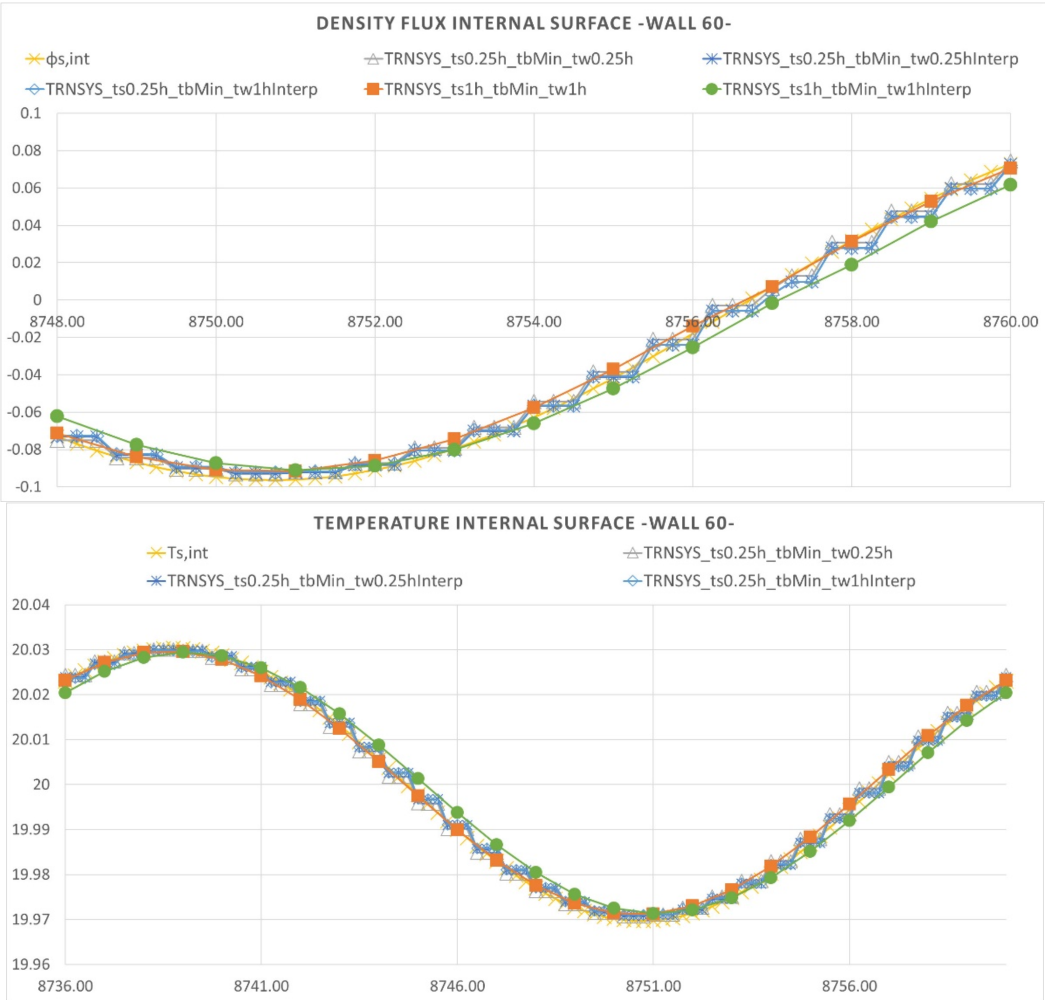
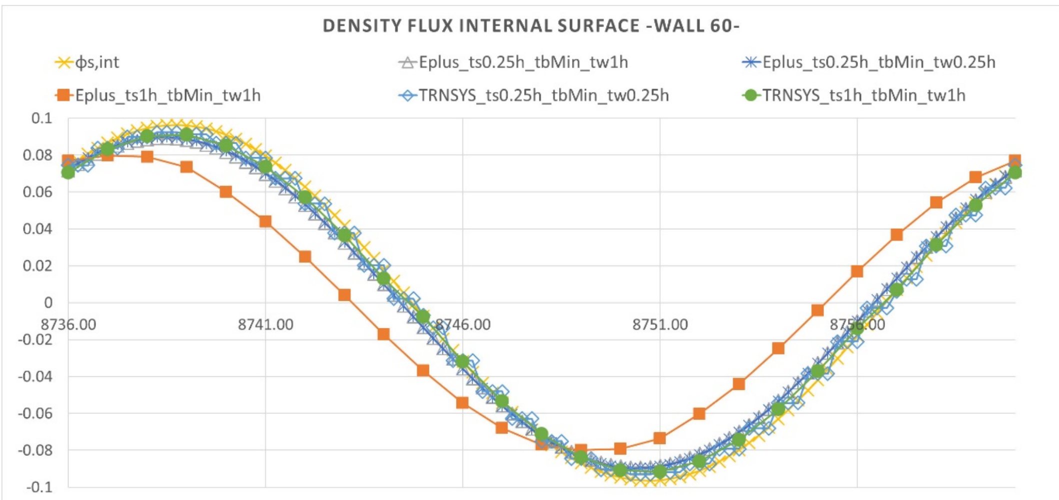


Fig. 3 – Wall 60 TRNSYS effect on the results of its TimeBase-TimeStep coupling algorithm



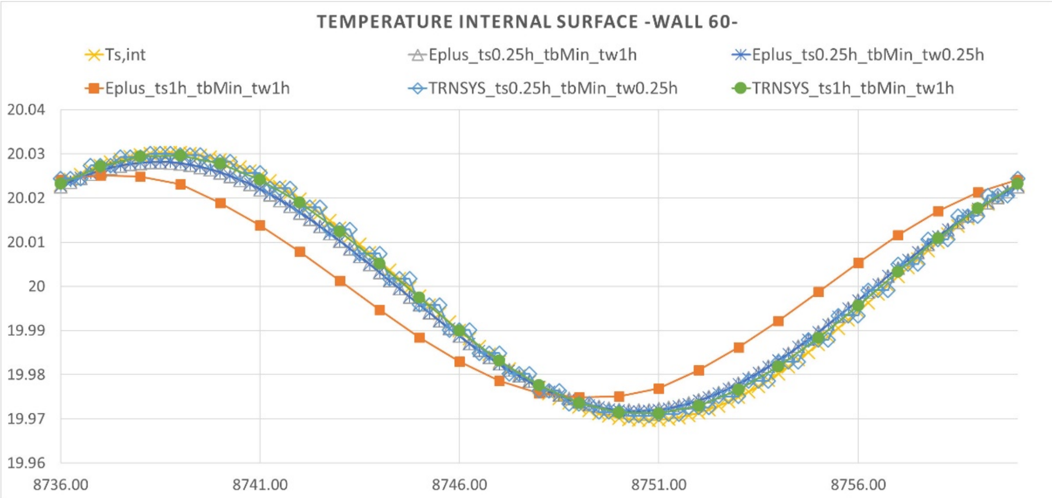


Fig. 4 – Wall 60 EnergyPlus-TRNSYS comparison of the results on the interior side

Table 3: Errors evaluated on opposite side respect to applied time-varying BC (* weather data reader with interpolation; bold values represent the optimal BCs configuration)

					Ts,int				φs,int			
Wall Type	**BPSt**	**CTF Time Base [h]**	**Sim Time Step [h]**	**Wthr Data [h]**	Max err Peak[%]	Mar err Ampl [%]	NRMSE [%]	NMAE [%]	Max err Peak[%]	Mar err Ampl [%]	NRMSE [%]	NMAE [%]
WALL 30	TRNSYS	**0.25**	**0.25**	**0.25**	**-0.39%**	**-0.49%**	**3.56%**	**0.36%**	**-0.66%**	**-0.63%**	**4.41%**	**0.45%**
		0.25	0.25	0.25*	-0.41%	-0.51%	18.74%	1.90%	-0.68%	-0.65%	18.97%	1.93%
		0.25	0.25	1*	-0.94%	-1.04%	19.56%	1.99%	-1.21%	-1.18%	19.93%	2.02%
		1	1	1	-3.51%	-3.62%	14.70%	2.94%	-3.79%	-3.75%	15.11%	3.02%
		1	1	1*	-5.01%	-5.12%	34.87%	6.97%	-5.28%	-5.25%	35.03%	7.01%
	Eplus	**0.25**	**0.25**	**0.25**	**-3.94%**	**-3.94%**	**62.01%**	**6.30%**	**-3.94%**	**-3.94%**	**62.01%**	**6.30%**
		0.25	0.25	1	-4.46%	-4.46%	63.18%	6.41%	-4.46%	-4.46%	63.18%	6.41%
		1	1	1	-8.09%	-8.09%	69.66%	13.93%	-8.09%	-8.09%	69.66%	13.93%
WALL 60	TRNSYS	**0.75**	**0.25**	**0.25**	**-0.84%**	**-2.19%**	**35.36%**	**3.59%**	**-4.14%**	**-3.84%**	**39.86%**	**4.05%**
		1	1	1	-2.35%	-3.71%	13.40%	2.68%	-5.65%	-5.36%	18.01%	3.60%
	Eplus	**0.5**	**0.25**	**0.25**	**-6.89%**	**-6.88%**	**61.89%**	**6.28%**	**-6.89%**	**-6.88%**	**61.89%**	**6.28%**
		1	1	1	-17.15%	-17.14%	122.01%	24.40%	-17.15%	-17.14%	122.01%	24.40%

Instead of comparative graphs, as reported in (Chen et al. [10]), the relative root mean squared error is considered for the CTF *a*, *b*, and *c* coefficients (eq. 1), and shown respectively as R-err YI, R-Err Up and R-err YE.

$$RRMSE = \sqrt{\frac{\sum_{i=1}^{N}\left((y_i - \hat{y}_i)/\hat{y}_i\right)^2}{N}} \tag{1}$$

The results obtained through this analysis (*Table 4*) confirmed a smaller relative root mean squared error on DRF cross response coefficients *b* (**R-Err Up**) with both CTF time bases than those calculated with the SS method. In addition, the relative root mean squared error on both *a* and *c* coefficients are lower for DRF method than for SS. This trend is the same for both the amplitude and phase, with a more pronounced error on phase than amplitude for the SS coefficients in comparison with the DRF ones.

Table 4: CTF quality assessment

Wall Type	tool	time base	R-err YI - a()		R-err YE - c()		R-Err Up - b()	
			Abs	Phase	Abs	Phase	Abs	Phase
Wall 60	TRNSYS	0.75	1.06%	2.28%	1.06%	2.28%	0.64%	0.00%
		1	1.07%	2.28%	1.07%	2.28%	0.64%	0.00%
	EnergyPlus	0.5	2.83%	10.53%	2.83%	10.53%	8.27%	38.93%
		1	7.59%	18.92%	7.59%	18.92%	14.76%	37.05%

3.3. Wall equal or larger than 1 m

TRNSYS does not allow defining any homogeneous layer equal to or larger than one meter. To bypass such limitation, such layer has been split in two or more layers. EnergyPlus, instead, does not exhibit such restriction, but when simulating very large walls the simulation results become inaccurate or are not provided at all.

Table 5: Errors evaluated on the same side respect to applied time-varying BC

Wall Type	BPSt	CTF Time Base [h]	Sim Time Step [h]	Wtr Data [h]	Ts,out				φs,out			
					Max err Peak[%]	Mar err Ampl [%]	NRMSE [%]	NMAE [%]	Max err Peak[%]	Mar err Ampl [%]	NRMSE [%]	NMAE [%]
WALL 100*	TRNSYS	2.25	0.25	0.25	3.96%	2.13%	75.77%	7.69%	2.03%	1.36%	17.64%	1.79%
		3	1	1	-1.81%	-1.81%	51.78%	10.36%	1.28%	1.28%	12.05%	2.41%
	Eplus	1.5	0.25	0.25	4.11%	4.11%	127.97%	12.99%	-3.59%	-3.59%	29.79%	3.02%
		1	1	1	6.85%	6.85%	81.71%	16.34%	-5.36%	-5.36%	19.02%	3.80%
WALL 160	TRNSYS											
	Eplus	3.75	0.25	0.25	15.68%	15.54%	274.25%	27.85%	-8.10%	-8.14%	63.83%	6.48%
		4	1	1								
WALL 160 Split In Half	TRNSYS	5.75	0.25	0.25	-8.29%	-4.22%	215.18%	21.85%	-3.73%	-3.20%	50.08%	5.09%
		6	1	1	8.39%	8.39%	113.53%	22.71%	-1.40%	-1.40%	26.42%	5.28%
	Eplus	2.5	0.25	0.25	0.24%	0.00%	111.12%	11.28%	-2.45%	-2.49%	25.86%	2.63%
		3	1	1	5.01%	5.01%	92.03%	18.41%	-5.26%	-5.26%	21.42%	4.28%
WALL 190 Split In Half	TRNSYS	8.25	0.25	0.25	7.03%	11.18%	311.12%	31.59%	-3.05%	-5.15%	72.41%	7.35%
		9	1	1	0.99%	3.59%	175.00%	35.00%	-5.89%	-4.92%	40.73%	8.15%
	Eplus	3.5	0.25	0.25	-0.13%	0.10%	157.23%	15.96%	-3.69%	-3.56%	36.60%	3.72%
		4	1	1								
WALL 190 Split In Four	TRNSYS	8.25	0.25	0.25	7.03%	11.18%	311.12%	31.59%	-3.05%	-5.15%	72.41%	7.35%
		9	1	1	0.99%	3.59%	175.00%	35.00%	-5.89%	-4.92%	40.73%	8.15%
	Eplus	3	0.25	0.25	-4.50%	-4.54%	102.21%	10.38%	-1.73%	-1.72%	23.79%	2.42%
		4	1	1								

When dealing with such kind of walls, the flux at the inside surface and the interior superficial temperature are respectively almost null and practically constant. Thus, the internal response to sinusoidal internal boundary condition has been considered. Taking advantage of homogeneity, the outdoor response to outdoor periodic boundary condition are used in the following.

The errors on the same side of the exciting BC are summarized in *Table 5*, where only the results of the "optimal configuration of weather data reading" are presented, for the simulation with 15 min and 60 min time step.

EnergyPlus is a bit in advance, compared to the analytical solution, while TRNSYS is more in phase with it. However, TRNSYS results are still influenced by the algorithm implemented for handling the mismatch between the CTF time base and the simulation time step.

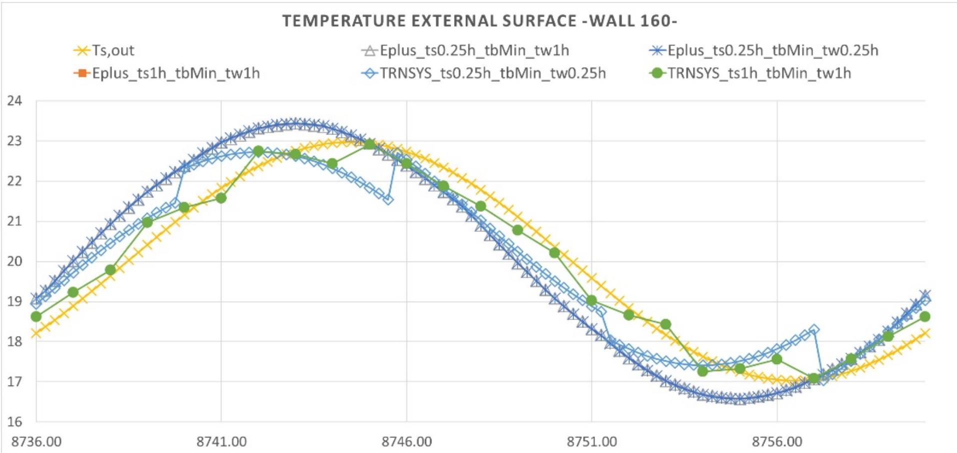


Fig. 5 – Wall 160 EnergyPlus-TRNSYS comparison of the results on the exterior side

Table 6: CTF quality assessment – Wall thickness ≥ 1 m. (Note: * simulation does not converge)

Wall Type	tool	time base	R-err YI - a()		R-err YE - c()		R-Err Up - b()	
			Abs	Phase	Abs	Phase	Abs	Phase
Wall 160 not split	TRNSYS							
	EnergyPlus	3.75	2.78%	10.89%	2.78%	10.89%	8.21%	10.50%
		4*	2.75%	10.97%	2.75%	10.97%	8.26%	10.50%
Wall 160 split in half	TRNSYS	5.75	1.15%	1.15%	1.15%	1.15%	1.15%	1.15%
		6	1.21%	1.21%	1.21%	1.21%	1.21%	1.21%
	EnergyPlus	2.5	0.38%	5.01%	0.38%	5.01%	3.17%	4.02%
		3	1.68%	8.65%	1.68%	8.65%	6.54%	6.96%
Wall 190 split in half	TRNSYS	8.25	0.91%	1.80%	0.91%	1.80%	0.44%	0.00%
		9	1.01%	2.04%	1.01%	2.04%	0.53%	0.00%
	EnergyPlus	3.5	0.43%	5.32%	0.43%	5.32%	3.45%	37.47%
Wall 190 split in four	TRNSYS	8.25	0.91%	1.80%	0.91%	1.80%	0.44%	0.00%
		9	1.01%	2.04%	1.01%	2.04%	0.53%	0.00%
	EnergyPlus	3	0.32%	3.90%	0.34%	3.85%	2.20%	2.63%

Starting with wall 160, EnergyPlus is not able to reach convergence with simulation time step of 60 min, even if it provides the CTF coefficients for one layer wall. Instead, with 15 min simulation time step, the simulation succeed but with poor quality results.

As can be seen in Fig. 5, EnergyPlus overestimates the amplitude of the wall temperature and heat flux. We can see in Table 6, that we have a 10% error on phase shift and 2.5% error on the absolute value for the "*a* coefficients" (**R-err YE**) of the SS coefficients of Wall 160.

Splitting in two layers Wall 160, 1h simulation time step becomes possible in TRNSYS and better results are obtained in EnergyPlus, as can be seen in Fig. 6. Splitting in two layers, the algorithm for the SS coefficients found smaller time bases for both 15 min and 60 min simulation time steps with respect to the one-layer case. In addition, the frequency analysis on the CTF coefficients quality has shown smaller error on the "*a* coefficients" for this case.

With wall 190, EnergyPlus is not able to perform any simulation with both time step, unless a split of the wall in more layers is performed. However, even with the splitting, simulations with time step of 60 min is not possible, while that with 15 min is performed with good results on amplitude and peak but always with some problems on the phase (*Table 5* and Fig. 7), as confirmed by the CTF frequency analysis of Table 6. Splitting this wall in four layers, both 15 min and 60 min time step simulations are allowed for TRNSYS, while only 15 min time step is possible for EneryPlus. The errors in TRNSYS are not sensitive to the splitting, while in EnegyPlus they are.

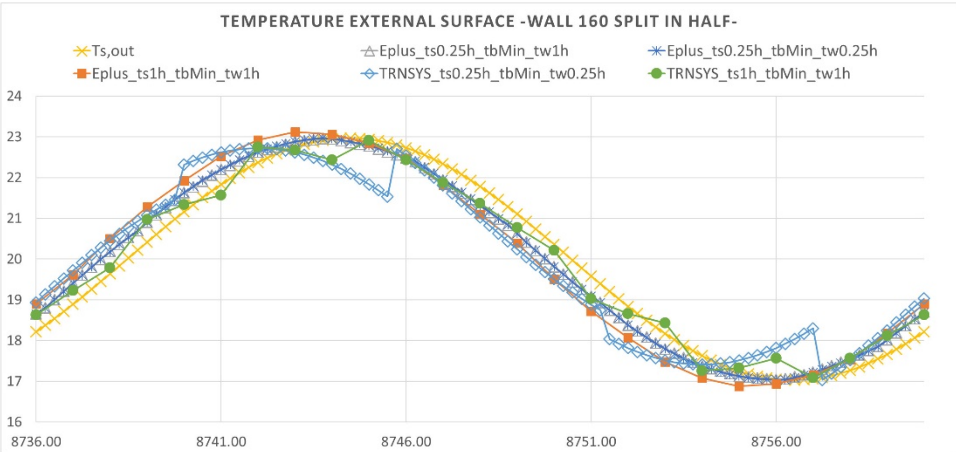


Fig. 6 – Wall 160 split in half EnergyPlus-TRNSYS comparison of the results on the exterior side

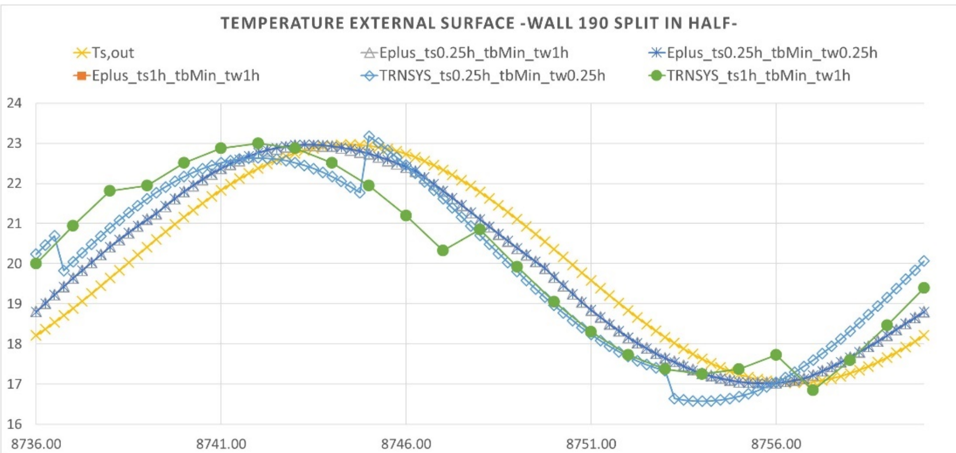


Fig. 7 – Wall 190 split in half EnergyPlus-TRNSYS comparison of the results on the exterior side

The quality analysis of the SS coefficients for different splitting of Wall 190, shows better results both in term of phase and absolute value for the coefficients of the wall split in four (Table 6). Actually, quite all the results shown in *Table 5* and in Fig. 8, have smaller error for the case "split in four". Only the temperature peak and amplitude are better in the case "split in half".

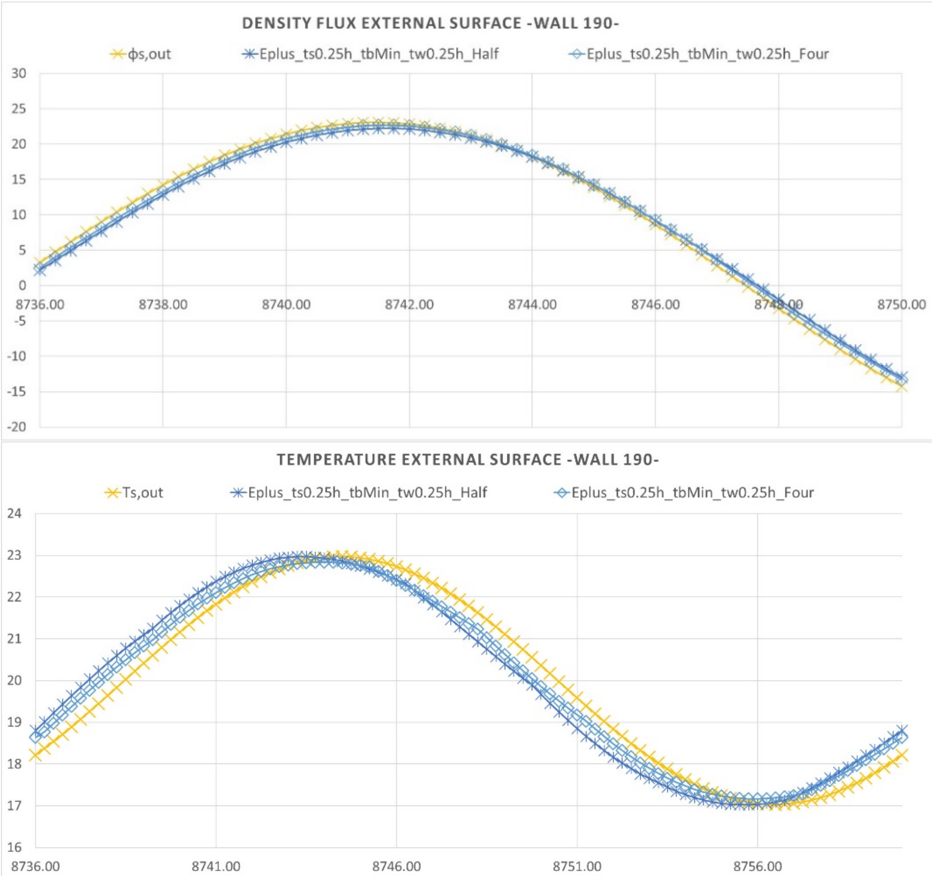


Fig. 8 – Wall 190 EnergyPlus results: sensitivity upon different splittings of the wall

A strange behavior, with periodically "perturbed" results, is gained with TRNSYS when simulating Wall 190 with 60 min time step. In particular, this behavior is influenced by the simulation time step, as can be seen in Fig. 9.

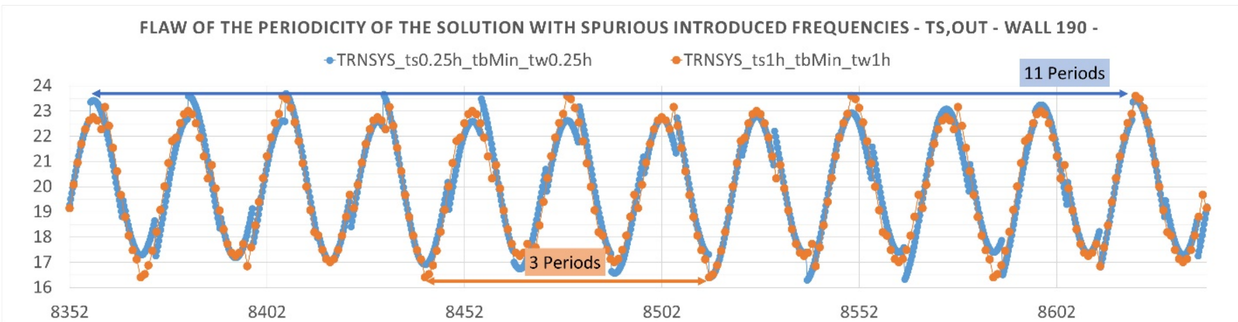


Fig. 9– Modified periodicity of the results with Wall 190 in TRNSYS

The analysis of the DRF coefficients calculated by TRNSYS for Wall 190 gave good results, as can be seen in Table 6, therefore the errors here detected might be caused principally by the coupling algorithm.

4. Conclusions

An analytical periodic solution for one-dimensional heat conduction is used to evaluate errors in calculated superficial temperatures and fluxes, gained by two BPSts, such as TRNSYS 17 and EnergyPlus 8.6, when thick walls and short or hourly time steps simulation are performed.

In TRNSYS it is possible to set the BC on the outside surface of a wall avoiding the weather simulator, by using a data reader. This allows to be sure that the applied boundary conditions are exactly what they are meant to be. In EnergyPlus instead customized weather data files must be used, causing unwished interpolation and BC data distortion to occur.

About time synchronization issue, when the CTF coefficient calculation is not problematic (for instance, Wall 30), from one to maximum four percent error could be introduced by a wrong setting of time synchronization between the imposed BCs and the desired results (instantaneous values at each time stamp).

Respect to the methodology employed to calculate the CTF coefficients, the SS numerical method, implemented in EnergyPlus, finds time bases for the CTF coefficients which always smaller than or equal to the ones allowed by TRNSYS.

Furthermore, the different algorithms implemented to allow simulation with time steps smaller than the CTF coefficients time base have different consequences on the results. The algorithm implemented in EnergyPlus produces smoothed results, while the one of TRNSYS generates discontinuous, step wise and sometimes "spurious/unstable" results, even if the solution does not diverge from the exact solution. Caution should be used therefore, especially when control strategies are tightly coupled with superficial internal temperatures.

When this coupling algorithm is not required, the DRF methods gives more accurate results with respect to the SS method.

A frequency based analysis of the quality of these coefficients has shown than even when the error caused by the coupling algorithm is relevant in TRNSYS, its coefficients are more accurate than those of EnergyPlus.

Finally, TRNSYS does not allow layer thicker or equal to 1m, therefore in all the cases, the walls have been split in two layers; but further splitting did not modify the results. On the contrary, EnergyPlus does not have this limitation, but with thick wall, splitting the wall was the only way to reach a convergent solution, and the obtained results were sensitive to the chosen splitting. Therefore, while this aspect is not relevant in TRNSYS, a sensitivity analysis of the results given by EnergyPlus depending on the splitting might be useful to get more confidence with the obtained simulation results.

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