INTEGRATION OF THICK WALL IN TRNSYS SIMULATION

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Abstract

TRNSYS is a software dedicated to the simulation of dynamic systems. Some obstacles have been encountered in the use of TRNSYS, particularly in the building model: the type 56, whose interface is TRNBuild. Thus, the integration of thick walls not associated with a correct choice of time steps can lead to miscalculations on the responses considered, this being caused by the wall model that considers the Z transform with limited number of terms. We have looked for a trick to resolve artificially a numerical problem. The aim of our study is the analysis of the inclusion of thick walls in TRNSYS. For that several alternatives were considered: divide the thick wall into two thinner walls separated by an empty hole, or play on different time steps used in TRNSYS to successfully calculate the transfer functions of these thick walls without sacrificing quality of results. Some tests have been made with a simplified building and the use of another software (CODYBA) to compare results. We after use the two methods to simulate a real ancient building (Valentino Castle).

1. Introduction

The buildings represent one of the biggest parts of the world energy consumption. However, reducing their energy consumption became a priority only recently. There are two ways to proceed: the first way consists in improving the architecture of the building, in order to reduce the thermal losses and exploit the free gains. The second way consists in producing properly the energy (eg solar energy). These approaches are not contradictive, but complementary, and successive. Integrating renewable energies in a poorly designed building is a complete mistake.

Today, the priority is to reduce the energy consumption of existing buildings (the consumption of new buildings is lower). In order to have a better design for the renovation strategies of ancient buildings, we have to be able to simulate those buildings, generally with high wall thickness. The inertia of these buildings is a good way for the solar energy free gains storage in the structure and the insulation or other solutions have to be studied more precisely. The simulation has to be made, necessarily, in transient conditions, and with a good accuracy to take into account the thermal inertia effects.

2. TRNSYS limits

TRNSYS [1] is a software dedicated to the simulation of dynamic systems, developed by the Solar Energy Laboratory (SEL), University of Madison in the United States. It allows performing dynamic simulations of the thermal behavior of a mono or multi-zone building. It can also follow hourly consumption (heating, air conditioning) or production (solar panels) annual energy facilities of a building.

2.1. Literature review

Some obstacles have been encountered in the utilization of TRNSYS, particularly in the building model (the type 56), whose interface is TRNBuild. Thus, the integration of thick walls not associated with a correct choice of time steps can lead to miscalculations on the responses considered. This being caused by the wall model that considers the Z transform, however the calculation speed of different methods was compared (Berges, 1986, [2]) in the wall case and shows that the method of the Z transform, used in the Type 56, is very efficient compared to the finite difference method.

This wall thickness problem has been met in some research project by the past. In 2005, the Museum of Byzantine Culture in Thessaloniki has decided to convert the White Tower, a six-floor fortress dating back to the 15th century, into a contemporary city museum (Papadopoulos, 2008, [3]), and the designers have pointed out the numerical problem.

In her PhD thesis in 2008 [4], C. Flory-Celini has also encountered difficulties with the simulation of high thermal inertia wall, when this one reaches a certain value of thickness. Some other mathematical problems have been also pointed using the transfer function method in the case of massive walls [5].

2.2. TRNSYS calculation limits

Before talking of the TRNSYS limits, we will make a quick presentation of the software. TRNSYS allows performing dynamic thermal simulation on a year or more with a time step of 1 hour generally. It is mainly composed of two sub-programs:

- TRNSYS Studio which allows to create the simulation model by linking different "types" (each type represents a part of a thermal system, for example, the building is represented by the type 56 which calls the second sub-program TRNBuild, the weather is controlled by another type, ...),
- TRNBuild in which we enter all the geometrical data of a building. TRNBuild generates a INF file which contains every data of the building (geometrical data of each zone, composition of the wall, transfer functions coefficients of the wall, characteristic of windows, ...) and it is this INF file that TRNSYS Studio will read.

In order to understand the limits of TRNSYS, we have created a simple test case: a TRNBuild file with only one wall: WALL001 composed entirely of cellular concrete (conductivity = 0.331W/m^{-1}.K^{-1}, capacity 0.88kJ/kg^{-1}.K^{-1}, density = 800kg/m^3). TRNBuild is able to calculate the transfer functions coefficients of the wall until a thickness of 0.650m. Above this value, the software can no longer calculate these coefficients, however this limit depends of the characteristics of the materials used in the wall.
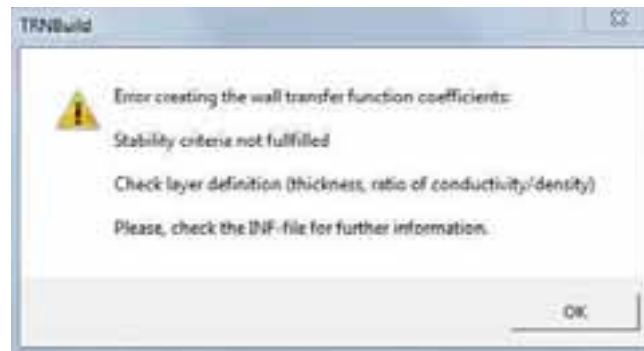

Figure 1: Error message of TRNSYS with thick walls

2.3. Transfer functions (Z transform)

TRNSYS has two different time variable for it simulation:

- the time-step of the simulation which is called **TIME-STEP** (which is the time variable of TRNSYS Studio),
- the time series that characterizes the walls is based upon a time interval equal to the **TIMEBASE** (which is the time variable of TRNBuild).

The transfer function method was developed by G.P. Mitalas ([6] and [7]).

"The method of the transfer function or response factors can be described as the method to tell the "thermal history" of the wall. The wall is considered as a black box. The number of time-steps (k) related to the time-base (defined by the user) shows whether the wall is a heavy wall with a high thermal mass (k ≤ 20) or if only a few time-steps have to be considered to describe the thermal behavior of this wall. If the time-base of the considered wall is higher than the time constant, the calculation of the Transfer-function matrix coefficients is stopped. Therefore such a "thin" wall can be replaced by a resistance definition neglecting the thermal mass." [8].

3. Presentation of techniques

As far as it is not possible to access to the source code of the "type 56" we won't be able to change the calculation of the transfer function coefficient methodology to solve the problem directly.

We have looked for different solutions to resolve artificially the numerical problem concerning the Z transform application in the type 56 of TRNSYS. The aim of our study is the analysis of the inclusion of thick walls in TRNSYS. To achieve that goal several alternatives were considered:

- Manually edit the INF-Files edited by TRNBuild in order to manually enter the transfer coefficients as TRNSYS cannot calculate. *(Method 0)*
- Divide the thick wall into two thinner walls separated by an empty hole. *(Method 1)*
- Play on different time steps used in TRNSYS to successfully calculate the transfer functions of these thick walls without sacrificing quality of results. *(Method 2)*

Unfortunately, the first technique mentioned above (*Method 0*) does not work. Indeed, TRNBuild publishes an INF-Files during its backup, this file contains all data entered (including transfer coefficients calculated or not if the wall thickness is too high). The idea is to manually edit this INF-Files after the TRNBuild backup so that TRNSYS (which itself uses the INF files) has the correct transfer coefficients. However, each time it launches a simulation TRNSYS calls TRNBuild which recompiles it so that publishes a new INF-Files that erases the manually modified one.

4. Case study and hypothesis

To focus on the problem of wall thickness, we have chosen a very simple model. We model a single zone building square shape of 5m, and ceiling height of 2.5m.

For the *Method 1* test, we consider a heating at 21°C from Monday through Friday from 6am to 6pm with a 16°C reduce the remaining time. We also add a cooling from 6am to 6pm from Monday through Friday with a 26°C set temperature. Both have a limit power at 2500W. We use "Lyon Bron" Meteonorm file as meteorological data for these simulations. We use a model without windows on tested walls (the integration of window when we divided the wall in two thinner walls is too complicate because we don't know on which wall put the window and furthermore calculate the solar gain of the indoor is quite complicated in this case). We made two simulations under TRNSYS:

- Simulation 1: walls made of 0,7m of brick (very close of the calculation limit of TRNSYS),
- Simulation 2: two walls of 0,35m of brick separated by a virtual zone.

Table 1: Material characteristics of the simulation for the *Method 1*

		Thickness	Conductivity		C	Density
		m	kJ/(m.K)	W/(m.K)	kJ/(kg.K)	kg/m^3
Outwall	**Brick**	*0,7 or 2*0,35*	3,200	0,889	1,0	1800
Ground	**Floor**	0,005	0,252	0,070	1,0	800
	Stone	0,060	5,000	1,389	1,0	2000
	Silence	0,040	0,180	0,050	1,4	80
	Concrete	0,240	7,560	2,100	0,8	2400
	Insul	0,080	0,144	0,040	0,8	40
Roof	**Concrete**	0,240	7,560	2,100	0,8	2400
	Insul	0,160	0,144	0,040	0,8	40

Particular attention has to be paid in the second model on the convective heat transfer coefficient of the two thinner walls. The main goal here is to reduce the influence of the virtual zone on the calculation results to be equivalent to a thick wall.
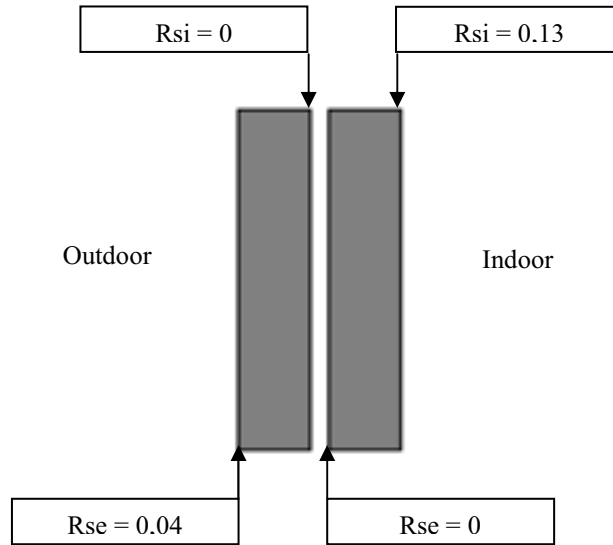

Figure 2: Scheme of the Rsi and Rse to use in *Method 1*

For the simulation for the *Method* 2, we use a different model of building to measure better the influence of our method on the results. The characteristics of the various walls used in the model are all the same, they are given in the following table (table 2). To go further in the analysis of thick walls, we have done three different simulations in which we change the outwall composition:

- Simulation 1: walls not insulated (just 0.7m of concrete),
- Simulation 2: walls with internal insulation (0.7m of concrete and 0.15m of internal insulation),
- Simulation 3: walls with external insulation (0.15m of external insulation and 0.7m of concrete).

Table 2: Material characteristics of the walls for the *Method 2*

		Thickness	Conductivity		C	Density
		m	kJ/(m.K)	W/(m.K)	kJ/(kg.K)	kg/m³
Simulation 1	**Concrete**	0,70	7,560	2,100	0,8	2400
Simulation 2	**Insul**	0,15	0,144	0,040	0,8	40
	Concrete	0,70	7,560	2,100	0,8	2400
Simulation 3	**Concrete**	0,70	7,560	2,100	0,8	2400
	Insul	0,15	0,144	0,040	0,8	40

For each of these simulations, we made two models:
- the first one where the building has neither heating nor cooling,
- the second one for which we have added heating at 20°C (without power limit).

5. Parametric study

5.1. Method 1

For this first method, we compare two TRNSYS simulations: the modeling 1 which nearly reaches the TRNSYS limit explained earlier in this document, and the modeling 2 which is supposed to be equivalent in cutting the wall in two thinner walls. We compare here two outputs given directly by TRNSYS: the temperature of the zone tested, and the heating and cooling needs on one year.

Here are the results of the heating and cooling needs and the indoor temperature on one year for these two simulations:

Table 3: Heating and cooling needs and indoor temperature of the modeling 1 and 2 *(Method 1)*

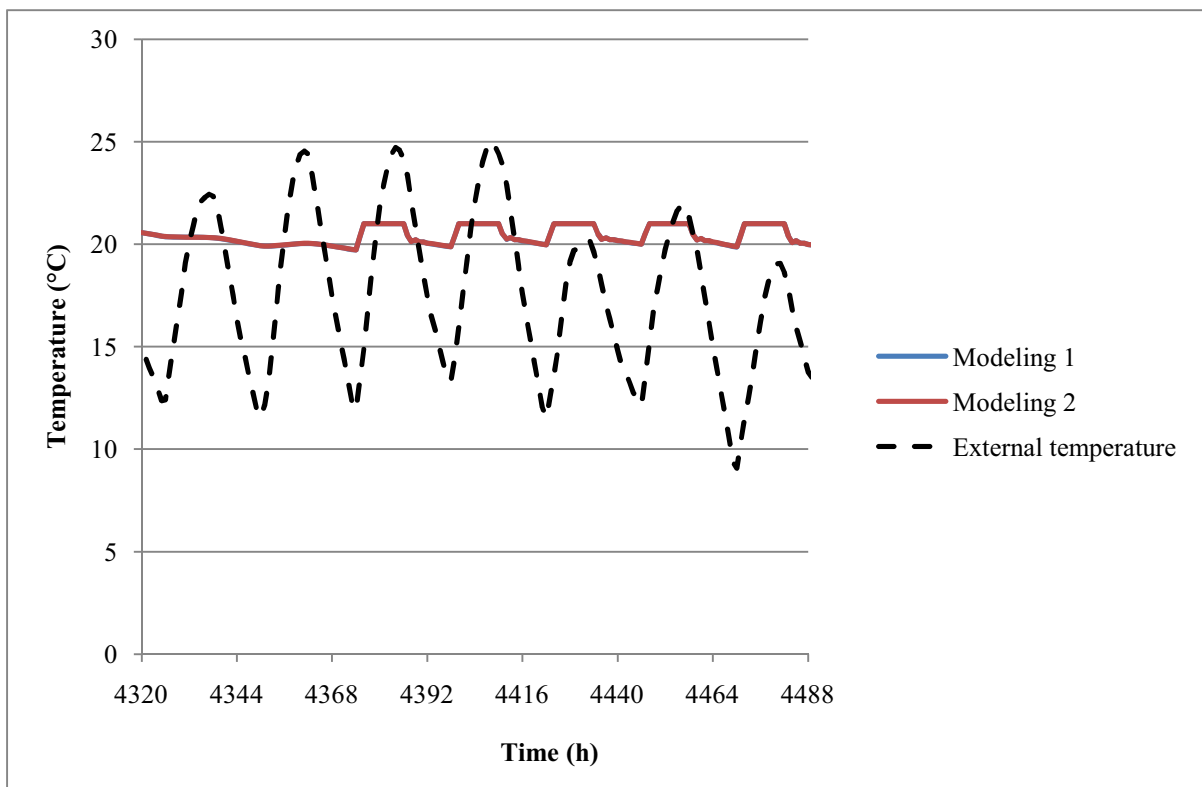|	Modeling 1		Modeling 2	
	Heating	**Cooling**	**Heating**	**Cooling**
P (W)	2306	0	2299	0
B (kWh)	3603	0	3583	0
$T_{average}$ (°C)	18,98		18,98	
T_{max} (°C)	22,96		22,96	
T_{min} (°C)	16,00		16,00	

Figure 3: Internal temperature on a summer week of the modeling 1 and 2 *(Method 1)*

These first results are very encouraging; we can see that the two models are comparable (the two curves are superposed). We observe a difference lower than 0,1% on the heating needs with the second method (which is negligible on a year simulation considering the simplifications made during the creation of the model). But this method isn't compatible with the integration of windows on thick walls (as explain in paragraph 4). In conclusion we can say that this method works on thick wall without windows but it is a complicated way to push further the TRNSYS limits because we need to add new zones.

5.2. Method 2

This second method has already a significant advantage compared to the previous one in the ease of its implementation (especially in the integration of windows).

The thick walls problem actually comes from the TIMEBASE and not the TIME-STEP (this variable are explains in the paragraph 2.3 of this document). The time series that characterizes the walls is based upon a time interval equal to the TIMEBASE, if this time is too low, the software cannot calculate the transfer function coefficient of thick walls. To resolve this problem, we can try to play on this variable that we change on the OUTPUT tab of TRNBuild.

As we cannot simulate the case with a TIMEBASE of 1 hour (in this case we exceed TRNSYS limits so we put a 2h TIMEBASE). We used a reference simulation (with the same characteristics) made with CODYBA [9] to compare the results. CODYBA uses analogical procedures for representing the walls and so has no limitation in the thickness.

Simulations cases with heating:

Table 4 : Heating needs of Simulation 1, 2 and 3 *(Method 2)*

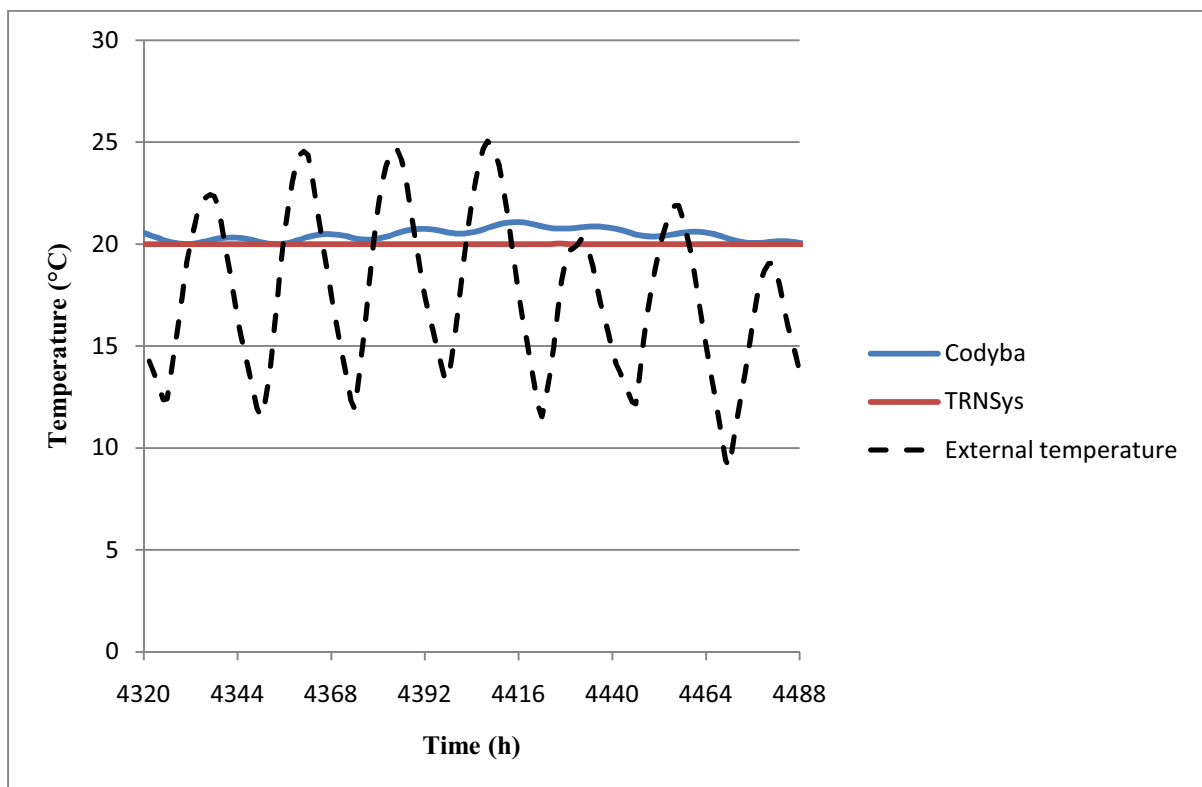|	SIMULATION 1 (0,7m of concrete)		SIMULATION 2 (0.7m of concrete and 0.15m of internal insulation)		SIMULATION 3 (0.15m of external insulation and 0.7m of concrete)	
	CODYBA	TRNSYS	CODYBA	TRNSYS	CODYBA	TRNSYS
P (W)	2899	2848	598	532	527	497
B (kWh)	8407	9158	1676	1719	1626	1676
P (W/m²)	116,0	113,9	23,9	21,3	21,1	19,9
B (kWh/m²)	336,3	366,3	67,1	68,8	65,0	67,0
Comparison	-	+ 8,9%	-	+ 2,5%	-	+ 3,1%

Figure 4: Internal temperature on a summer week of the Simulation 1, thick walls not insulated *(Method 2)*
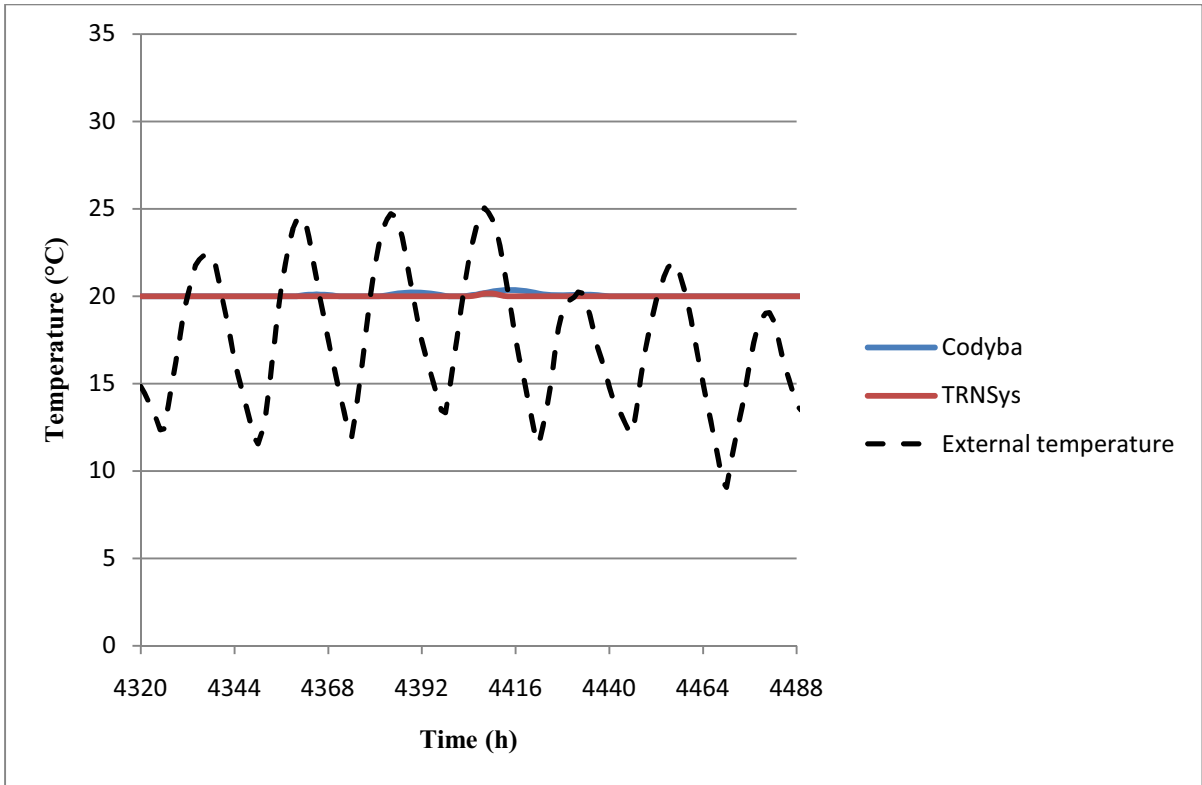
Figure 5: Internal temperature on a summer week of the Simulation 2, thick walls with internal insulation *(Method 2)*
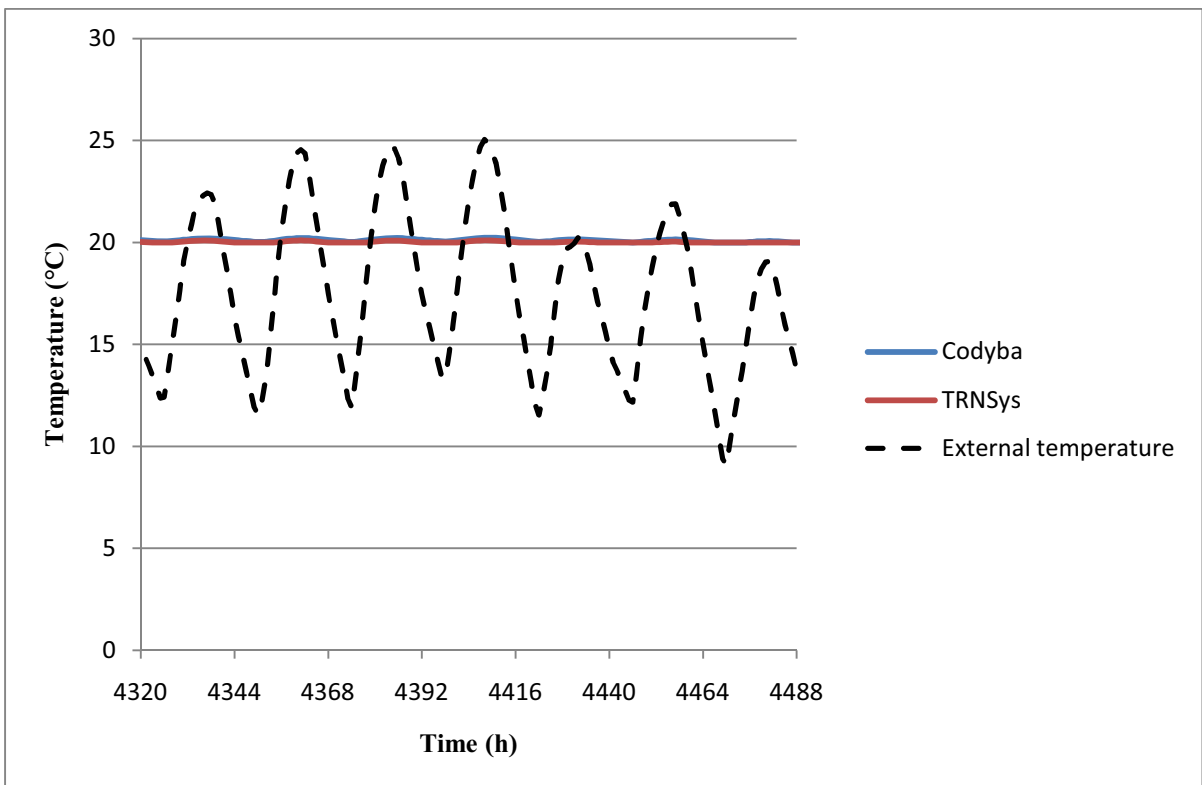

Figure 6: Internal temperature on a summer week of the Simulation 3, thick walls with external insulation *(Method 2)*

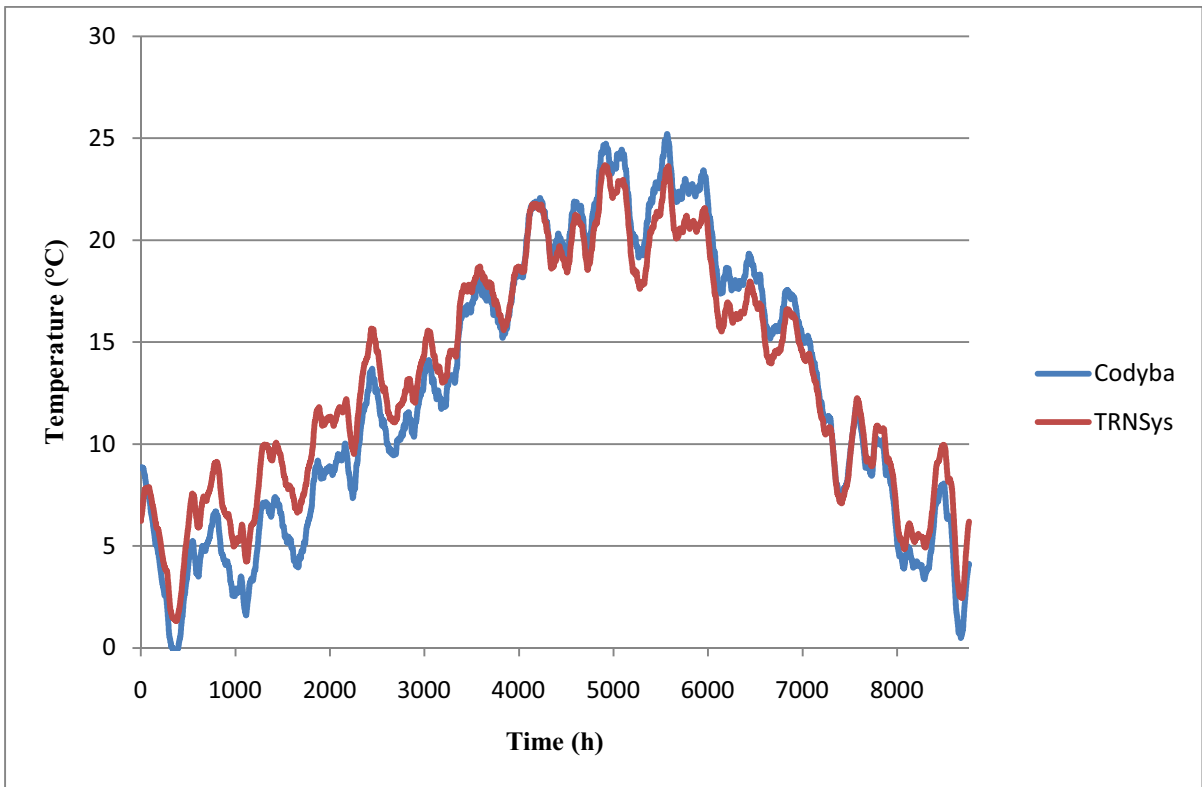**Simulations cases without heating:**

Figure 7: Internal temperature on a year (without heating nor cooling) of the Simulation 1 *(Method 2)*
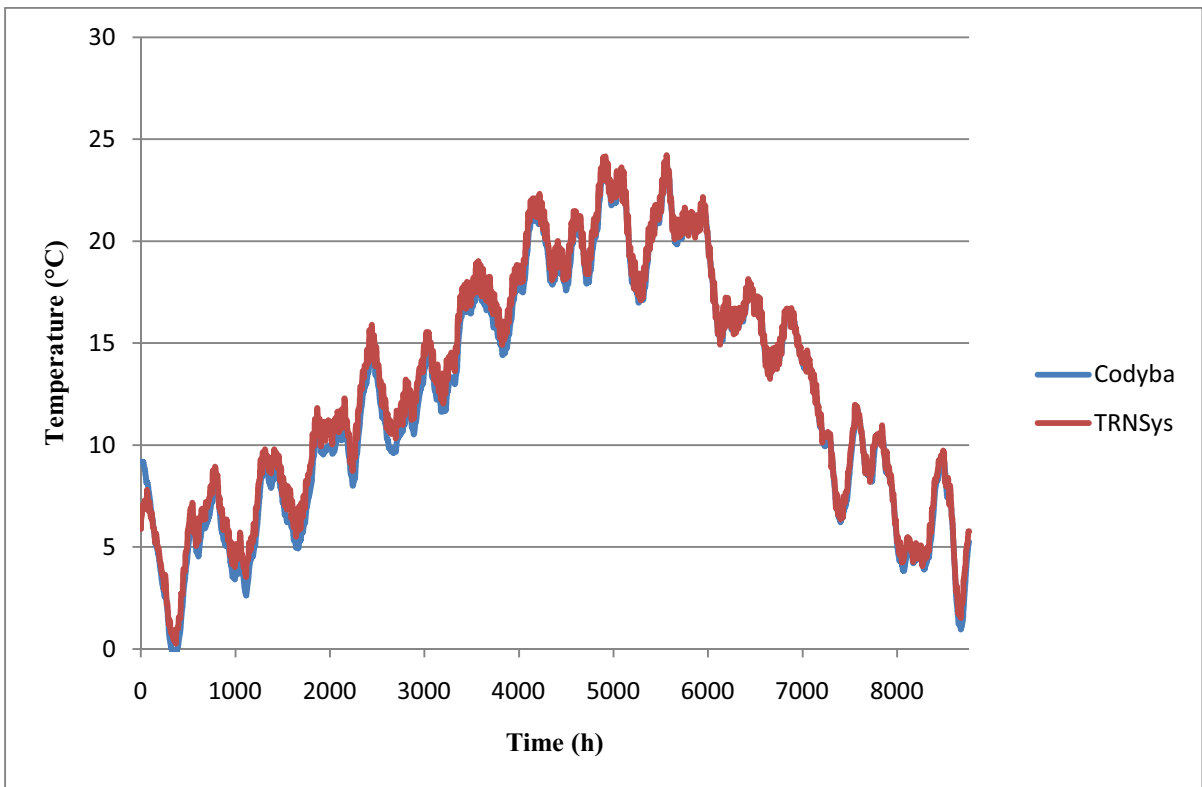

Figure 8: Internal temperature on a year (without heating nor cooling) of the Simulation 2 *(Method 2)*
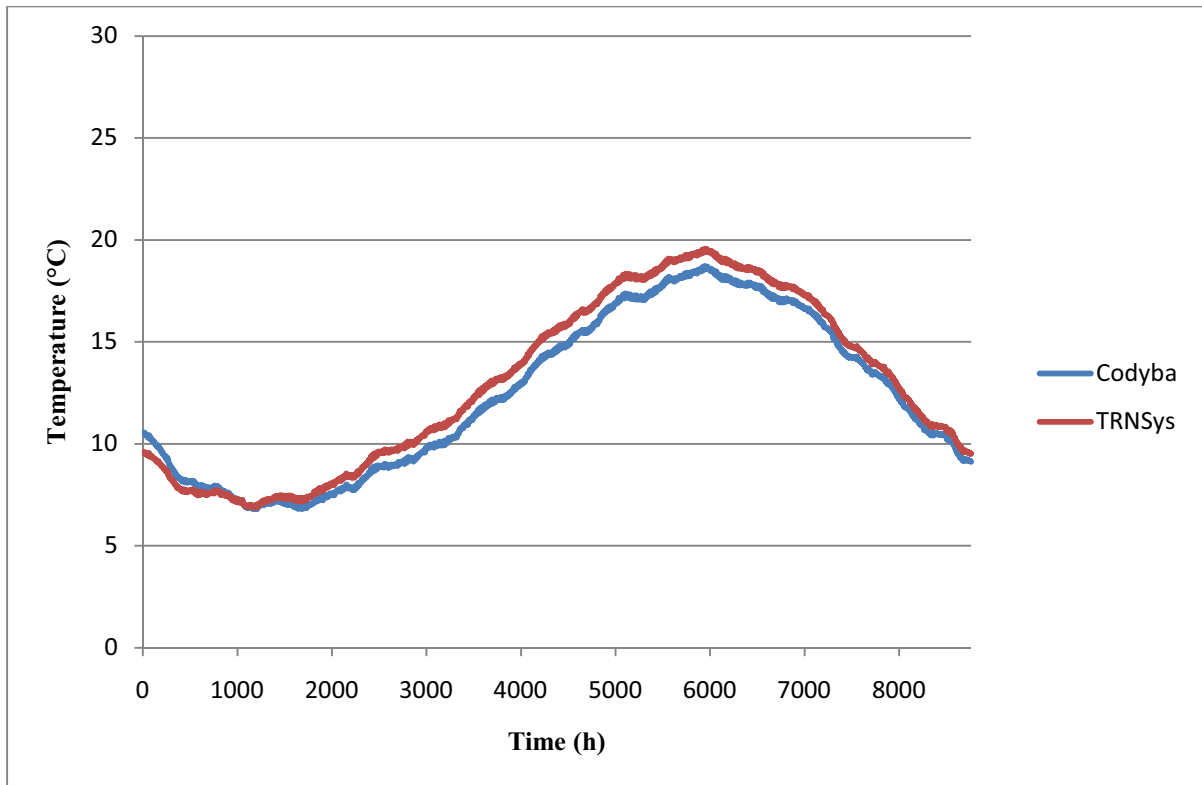
Figure 9: Internal temperature on a year (without heating nor cooling) of the Simulation 3 *(Method 2)*

The differences observed in the case of high inertia structure (wall not insulated or insulated on external side) are somewhat well fitted. We have less than 1C of differences for the temperatures. The bigger difference is for the energy demand (about 9%) for non insulated wall. These discrepancies obviously are due to the difference of the methods of modeling of the walls.

6. Case study in Torino (SEEMPubS Project [10])

We have after used the two methods to simulate a real ancient building (Valentino Castle) of the sixteenth century in Torino (Italy). This case study is one of the buildings tested within the European research project SEEMPubS. In the following we show that we are able to simulate properly such high inertia buildings under TRNSYS software (commercial version), with the *Method 1* and the *Method 2*.

6.1. Presentation of the SEEMPubS project

SEEMPubS specifically addresses reduction in energy usage and CO_2 footprint in existing Public buildings and Spaces without significant construction works, by an intelligent ICT-based service monitoring and managing the energy consumption. Special attention will be paid to historical buildings to avoid damage by extensive retrofitting.

State-of-the-art solutions still lack an effective integrated and holistic approach to the energy efficiency issue and are not able to support the upcoming scenario. The management of buildings' environment is usually performed by different and separate, though possibly energy-efficient, sub-systems focused on heating, cooling and lighting operations.

SEEMPubS' proposed solution provides the capabilities to enable an effective integration at building level (among different sub-systems) but also to support the integration of the resulting smart energy efficient building and surrounding environment into a smart grid scenario.

6.2. Building presentation

In 1859 the building was ceded to the "Regia Scuola di Applicazione per gli Ingegneri" and is now property of the Politecnico. The buildings of the aulic part of the Castle have bearing walls, large window surfaces and high vaulted ceilings. The two wings host classrooms at the ground floor and Department offices at the upper floors; the main central building hosts state rooms for meeting and conferences and student offices. The buildings built in the nineteenth century have similar envelope characteristics and are mainly occupied by Department offices.

6.3. Simulations

We simulated here two similar offices (hatched on the plan (figure 10)): on as a reference and the other one as a test room for further research in the SEEMPubS project (which are not presented in this document). In this document we will only present the simulation for the reference room and the use of the *Method 2* to simulate thick wall on this ancient building.
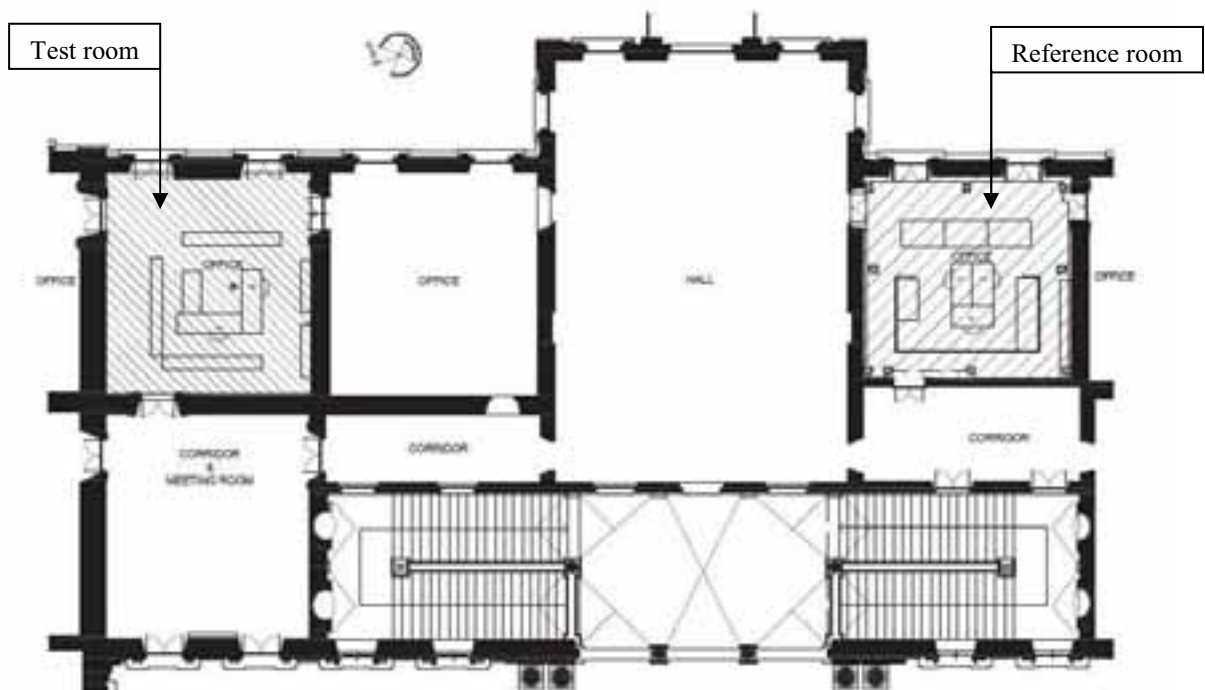

Figure 10: Draw of the simulated parts of the Valentino Castle

We choose to use this example here because of the high thickness of walls and ceiling in this ancient building. For example, the offices ceilings, with a volt shape, reach a thickness of 1,07m and there are composed of three materials:

- 0,05m of wood,
- 0,9m of air,
- 0,12m of bricks.

In this case, TRNBuild can't calculate the transfer function coefficients with a TIMEBASE less or equal than 3 hours. So to perform this simulation we used a TIMEBASE of 4 hours.

6.4. Results

The main goal of this article is to find a way to simulate buildings with high inertia. The principal result of this simulation on the Valentino Castle is that we were able to simulate a room with a ceiling of more than 1m and thick walls and the two methods seem to give available results. The main results of our simulations are presented in the next tables. Figure 11 shows very little differences in the internal temperature between the two methods.

Table 5: Indoor temperature for the two Methods in the Valentino Castle for a yearly simulation

	Method 1		Method 2	
	Reference	**Test**	**Reference**	**Test**
$T_{average}$	19,10 °C	19,19 °C	19,02 °C	19,11 °C
T_{max}	26,57 °C	26,91 °C	26,63 °C	26,93 °C
T_{min}	10,00 °C	10,00 °C	10,00 °C	10,00 °C

Table 6: Heating needs for the two Methods in the Valentino Castle for a yearly simulation

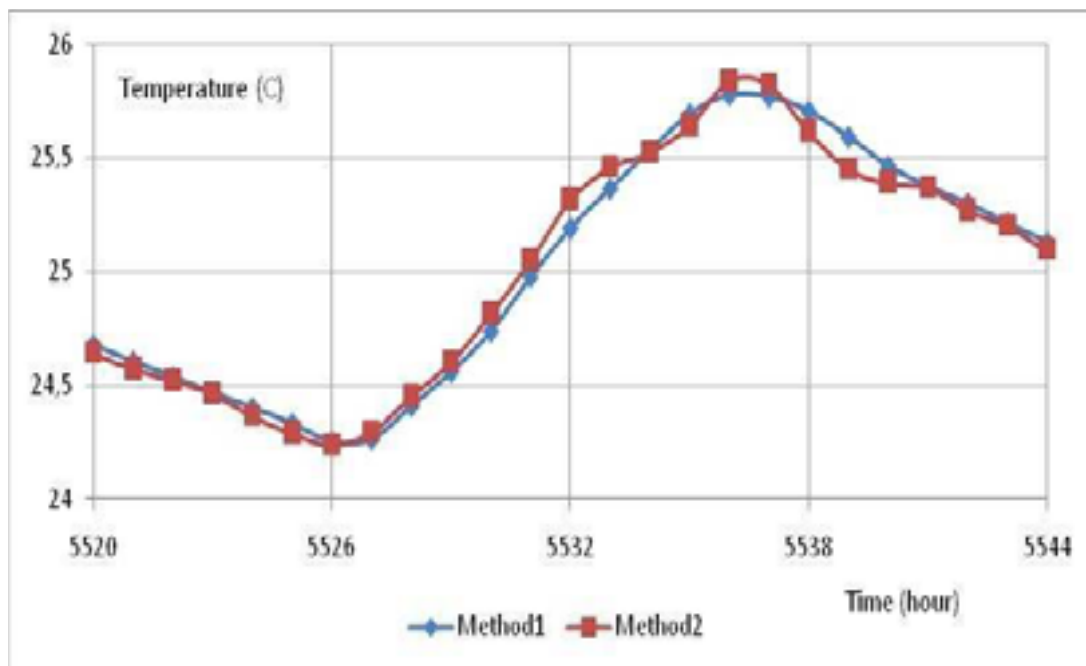|	Method 1		Method 2	
	Reference	**Test**	**Reference**	**Test**
P (W)	10705	10711	9917	9903
B (kWh)	7464	7387	7358	7261
P (W/m²)	180,6	180,7	167,3	167,0
B (kWh/m²)	**125,9**	**124,6**	**124,1**	**122,5**
			-1,42%	*-1,71%*

Figure 11: Internal temperatures simulated in the reference room of the Valentino Castle during a summer day

7. Conclusions

In order to have a better design for the renovation strategies of ancient buildings, we have to be able to simulate those buildings, generally with high wall thickness. The software TRNSYS dedicated to the simulation of dynamic systems presents some obstacles particularly in the building model: the type 56, whose interface is TRNBuild. Thus, the integration of thick walls not associated with a correct choice of time steps can lead to miscalculations on the responses considered. We have looked for a trick to resolve artificially the numerical problem and several alternatives were considered:

- Manually edit the INF-Files edited by TRNBuild in order to manually enter the transfer coefficients as TRNSYS cannot calculate *(Method 0)*.
- Divide the thick wall into two thinner walls separated by an empty hole *(Method 1)*.
- Play on different time steps used in TRNSYS to successfully calculate the transfer functions of these thick walls without sacrificing quality of results *(Method 2)*.

If *Method 0* was not possible to implement, some tests have shown that *Method 1* is very accurate but difficult to use especially in the integration of windows. *Method 2* is very easy to use even if it seems to be less accurate in the case of thick walls. In fact, the differences with CODYBA using a simplified analogical method can be also explained by the non accuracy of this last software.

TRNSYS can be used for all types of buildings: it's necessary in the case of high thermal inertia walls to adopt one of the two methods presented. As an example, we have given simulation results of a real ancient building (Valentino Castle) of the sixteenth century in Torino (Italy): the two methods give very closed results. So, we propose, for the further simulations to use more commonly the second method, more easy to implement.

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[9] CODYBA website: http://www.jnlog.com/codyba1.htm

[10] SEEMPubS Project: http://seempubs.polito.it/