Energy and seismic performance of timber buildings in Mediterranean region

A. Polastri
CNR – IVALSA, San Michele all'Adige, Italy

G. H. Poh'siè
CNR – IVALSA, San Michele all'Adige, Italy

I. Paradisi
Fraunhofer Italia Research, Bolzano, Italy

J. Ratajczak
Fraunhofer Italia Research, Bolzano, Italy

ABSTRACT:
The use of timber constructions is not common in the Italian building stock. Timber buildings are characterized by the low thermal inertia, which is one of the main reasons for the worsening of summer thermal behaviour. Hence, it represents a limit during the cooling season in hot climates. The summer thermal performance of timber buildings can be improved by increasing the thermal mass of building components, but at the same time, it implies the worsening of the structure performance, which is crucial in seismic areas in Italy. Italian codes establish restrictive limits for the design of building, particularly in southern regions because of a high seismic activity. The Fraunhofer Italia, the Free University of Bozen-Bolzano with the support of Trees and Timber Institute CNR – IVALSA studied within the TIMBEEST research project how to improve the summer performance of timber buildings without worsening the seismic performance. This study presents solutions for improving summer energy performance of timber buildings by increasing thermal mass of walls in Italian context. The research considered both building physic and structure implications for two timber construction systems - Light Timber Frame and Cross-Laminated Timber.

1 INTRODUCTION

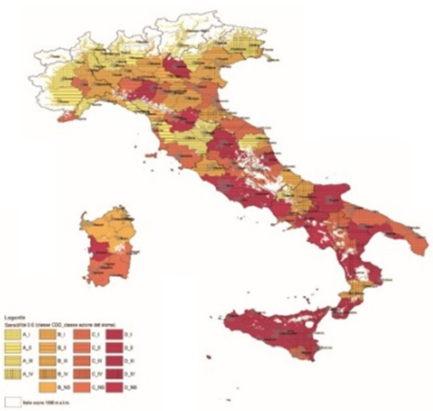
Timber buildings are mostly widespread in cold climates, because of good thermal performance and availability of the row material. Nevertheless, the low thermal inertia of timber buildings affects negatively the summer thermal performance, if compared to buildings built with masonry or concrete materials. Therefore, this can be a limitation for timber technology during the cooling season in hot climates, as in Italy. In order to improve the summer performance of timber buildings without worsening the seismic performances, the Fraunhofer Italia, the Free University of Bozen-Bolzano with the support of the Trees and Timber Institute CNR – IVALSA investigated few technology solutions using thermal mass in walls in Cross-Laminated Timber (CLT) and Light Timber Frame (LTF) systems. Different solutions of walls were proposed for all Italian climatic zones. Within the TIMBEEST project, building physic and structural aspect were considered.

In order to achieve the research goal, the TIMBEEST project analysied the following main fields: 1) environmental restrains on Italian territory; 2) structural analysis of a large number of case studies in seismic zones; 3) energy analysis of a referenced building for all Italian capital cities; 4) monitoring campaign of thermal performance using two outdoor facilities (test cells), which were built in CLT and LTF system. In the first field physical parameters of external restraints such as Climate Indicator (CI) and Seismic Indicator (SI) across the Italian territory were analysed. The CI represents the equivalent Cooling Degree Days (CDD, [K d]) referred to the Test Reference Year (TRY) and is calculated for the period from May to September. The SI represents the horizontal seismic action on buildings (Se (T)). The combination of these indicators allowed to create the Italian Vulnerability Map in terms of seismic activity and climate characteristics given by temperature and solar radiation of the typical year referred to all Italian capital cities. In the second field structural performances of the referenced building models for four cites, which belong to seismic activity classes defined by SI, were evaluated. A structural analysis of a large number of study cases with thermal mass (in walls) in different seismic zones were performed. In particular, two referenced residential buildings (three and five storey) in two different timber construction systems (LTF and CLT) were studied. A linear static analysis were performed according to the Eurocode 8 (CEN 2013) in order to define the seismic load and consequently the proper dimension of the structural elements and the required connection systems. Furthermore, structural limits for thermal mass implementation in terms of building height restriction were defined. In the third field energy performances of the referenced building model for 110 Italian capital cities were evaluated. Firstly, the most common sample of standard buildings components (walls, roofs, slab/floors without mass) in LTF and CLT were identified. Afterwards the energy dynamic simulations of the referenced building composed of standards component were carried out. Secondly, based on the Italian Vulnerability Map as well as inputs from structural analysis regarding the maximum allowable load of thermal mass in timber walls, the improved building walls were designed. According to the multi-criteria analysis made for summer thermal parameters of improved walls, the two most suitable walls in CLT and LTF were choosen for 110 capital cities of Italian Provinces according to climatic zones (CDD). Finally, the energy dynamic simulations were carried out for the same referenced building, but with improved walls and afterwards results were compared to the referenced building with standard walls.Finally, in the fourth field, two outdoor facilities (test cells) were designed and used in a monitoring campaign in order to measure the thermal performance of timber building components in real dynamic conditions. The output data from the monitoring campaign were used to validate a numerical model for thermal dynamic simulation of the referenced timber building with thermal mass in order to provide output data from the energy simulation that are more accurate.

2 ANALYSIS OF ENVIROMENTAL RESTRAINTS

The first part of the research project focused on mapping environmental restraints among the Italian territory that affect the thermal and seismic performance of buildings.

The first restrain was referred to a meteorological parameter significant for cooling energy demand in buildings across the Italian territory. The research team of the Free University of Bolzano-Bozen calculated the equivalent Cooling Degree Days (CDD, [K d]) referred to TRY according to (Gasparella et al. 2011). The equivalent CDD, called also in this paper Climate Indicator (CI), were calculated for the period from May to September considering: a) monthly average sol-air temperature ($\theta_{sol\text{-}air,\ \alpha,}$ [°C]) referred to three different horizontal surfaces with absorption coefficient value (α, [-]) 0,3, 0,6 and 0,9, respectively; b) set point of cooling temperature (θ_{in}, [°C]) equal to 26 °C. The CI provided information regarding the climate characteristic given by temperature and solar radiation of the typical year referred to 110 Italian capital cities.



Class	Cooling Degree Days (CDD), $\alpha = 0.6$	Horizontal seismic action (Se(T))	Class	Cooling Degree Days (CDD), $\alpha = 0.6$	Horizontal seismic action (Se(T))
A_I	< 560 (K·d)	< 0.4 (g)	C_II	670-750 (K·d)	0.4-0.6 (g)
A_II	< 560 (K·d)	0.4-0.6 (g)	C_III	670-750 (K·d)	0.6-0.8 (g)
A_III	< 560 (K·d)	> 0.8 (g)	C_IV	670-750 (K·d)	> 0.8 (g)
A_IV	< 560 (K·d)	Not seismic zone	C_NS	670-50 (K·d)	Not seismic zone
B_I	560-670 (K·d)	< 0.4 (g)	D_I	> 750 (K·d)	< 0.4 (g)
B_II	560-670 (K·d)	0.4-0.6 (g)	D_II	> 750 (K·d)	0.4-0.6 (g)
B_III	560-670 (K·d)	0.6-0.8 (g)	D_III	> 750 (K·d)	0.6-0.8 (g)
B_IV	560-670 (K·d)	> 0.8 (g)	D_IV	> 750 (K·d)	> 0.8 (g)
B_NS	560-670 (K·d)	Not seismic	D_NS	> 750 (K·d)	Not seismic
C_I	670-750 (K·d)	< 0.4 (g)	-	-	-

Figure 1. Synthesis Map for 110 capital cities of Italian Provinces and associated classes - values

The second restraint was referred to the classification of the Italian territory according to seismic activity of the Italian territory based on the horizontal seismic action, (as extensively described at Section 3. The research team from the CNR – IVALSA calculated the Seismic Indicator (SI), which is defined by the elastic horizontal ground acceleration response spectrum (Se(T), [-]). This indicator was calculated for 110 capital cities of Italian Provinces.

The results of this analysis were elaborated by Fraunhofer Italia Research and are represented by the Italian Vulnerability Map, Figure 1. This map shows nineteen classes obtained by combining 4 classes of the CI and 5 classes of the SI, Figure 1. These classes represent critical areas for timber buildings characterized by both summer climate indicator (equivalent CDD) and seismic indicator (Se(T)). Higher value of the CDD indicates higher cooling energy demand in buildings and higher value of the Se(T) indicates higher seismic risks, which means limitations for timber buildings with additional thermal mass loads.

3 ANALYSIS OF STRUCTURAL PERFORMANCE

The second phase of the research project is focused on structural analysis, firstly, preliminary studies in order to define the self-weight of the case study, have been carried out and afterwards a large number of parametric linear elastic analysis have been implemented.

3.1 *Preliminary studies*

Italy is a country characterized by a high seismic activity including areas with low energy earthquakes (e.g. Vesuvius area, Etna area), and areas with seldom earthquakes with higher energy (e.g. Eastern Sicily, Calabria Apennines), as states by the Civil Protection Department. In order to provide a Seismic Indicator (SI), which describes the seismic action on buildings, throughout the Italian territory, the horizontal seismic action on buildings was calculated by the research team from the CNR – IVALSA. To define it, the elastic horizontal ground acceleration response spectrum (Se(T), [-]) was calculated for 110 Italian capital cities according to Italian regulations (MIT 2008) and Eurocode 8 (CEN 2013), assuming the type D of ground classification. Figure 2 represents an example of elastic response spectra: x-axis shows the structural period of the building. It is also possible to affirm that the fundamental period of timber buildings presented in this study is typically between 0,1 [s] and 0,5 [s]. The calculation of Se(T) was carried out using Simqke software developed by the University of Brescia. The SI values were grouped into five classes according to the SI previously defined, as shown in Figure 1.

To improve the summer comfort of timber buildings, in relation also to the cooling energy demand, the strategy, which increase the thermal mass in external wall, was adopted. According to the structural analysis, the limit of the mass integration is up to 1kN per m^2 of wall, namely correspond to 20% of the total weight of the considered building model. Preliminary analysis were performed on a three storey residential building made of two units as shown in Figure 3; structural walls and seismic weight were referred to the same building components evaluated with dynamic simulations. A linear static analysis were performed according to (MIT 2008) and to (CEN 2013), in order to define the seismic load and the total base shear force in particular. It was demonstrated the possibility of designing structural walls with increased weight by using standard connectors as hold downs and angular brackets. According to these consideration, improved building components (walls) with applied additional thermal mass were designed, as shown in Figure 5.

3.2 *Parametric structural analysis*

The aim of the parametric structural analysis is to characterize the behaviour of case studies, represented by a typical residential building (referenced building model) in different seismic zones, from the seismic design perspective based on effects of varying parameters. The following design parameters were considered: a) construction system (CLT or LTF) and relate behavior factor; b) maximum soil acceleration of the different representative Italian cities (Figure

3); c) selected walls (standard or improved) and related mass (light or heavy, Figure 3); number of storey (3-5).
The earthquake action for these case study buildings located in Enna, Caserta, Avellino and Cosenza was calculated according to (CEN 2013) and the associated Italian regulations (MIT 2008) using design response spectra for building foundations resting on ground type D, with a building importance factor of $\lambda = 0.85$. Since Peak Ground Acceleration PGA is variable parameter according to the geographic area, Se(T) was assumed according to the different ranges indicated into Figure 1, for the aforementioned reference cities, Figure 4. The seismic action was calculated starting from the elastic spectra and applying an initial q-reduction factor of 2 for CLT structure (Pozza et al. 2013) and equal to 4 for LTF. Connections were designed using the force pattern obtained applying linear elastic static analysis (CEN 2013) and the seismic action defined by CEN 2013.
Examined case study building superstructures had footprint dimensions of 20 m by 10 m. The Seismic Force Resistant Systems (SFRS) included different internal and external walls as presented in Figure 2. Storey height was 3m in all cases (3 or 5 storey), resulting in total superstructure heights of 9 m and 15 m, respectively. CLT panels walls had a thickness of 140 mm and 100 mm at the upper floors, LTF walls were 160 mm thick and 120 mm at the upper floors. Floor diaphragms were composed of 160 mm CLT panels in all cases.

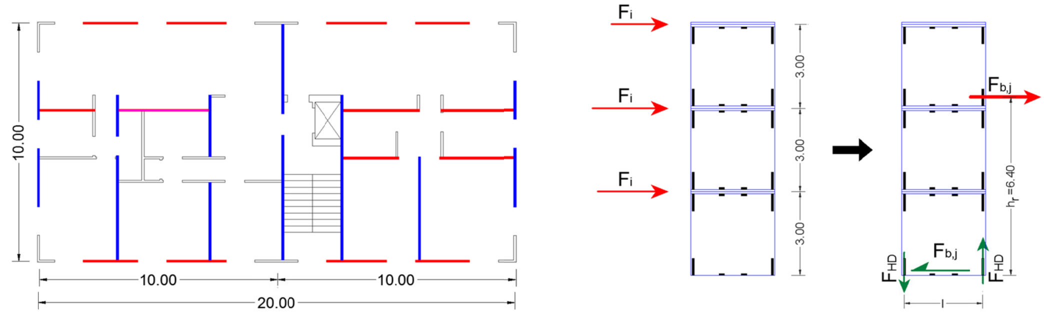


Figure 2. Case study, SFRS walls in x direction -red- and y direction -blu- (left) and adopted calculation schema -3 storey case- (right).

These analyses allowed to characterize the referenced building model in terms of base shear and up-lift forces according to the different design parameters described previously. Furthermore, connection designs were refined using the rotation and translation force equilibrium approach described by Gavric et al. (2011) and Pozza et al. 2015. According to the Eurocode 5 (CEN 2014), the CLT and LTF walls were designed. In order to summarize the results, achieved varying the different design parameters, reference connections configurations were defined, Figure 3 left. For each of the different cases analysed, for each of the structural walls, it was assigned a proper configuration of connections that is function of the force loading the **i**-th wall; Figure 3 shows, by way of example, configurations adopted in the case study.

ID	Description	Type	n. of conn.
AS1	2 brackets - asymmetric	Titan 200	2
	1 hold down - asymmetric	WHT 440	1
S1	2 + 2 angular brackets	Titan 200	4
	1 + 1 hold down	WHT 440	2
S2	4 + 4 angular brackets	Titan 200	8
	2 +2 hold down	WHT 440	4
S3	6 + 6 angular brackets	Titan 200	12
	3 + 3 hold down	WHT 620	6

	n. storey	Elements	Enna		Caserta		Avellino		Cosenza	
			Light	Heavy	Light	Heavy	Light	Heavy	Light	Heavy
CLT	3	Connectors	S1	S2	S2	S2	S2	S3	S3	S3
	5	Connectors	S3	S3	S3	S3	X	X	X	X
LTF	3	Connectors	S1	S1	S1	S2	S2	S2	S2	S2
	3	Panels	OK	OK	OK	OK	OK	OK	OK	NO
	5	Connectors	S2	S2	S3	S3	S3	S3	S3	S3
	5	Panels	OK	OK	X	X	X	X	X	X

Figure 3. Adopted connection configurations (left) and results (right).

According to the aforementioned assumptions, it is possible to affirm that the limit of LTF technology is given by the nails resistance used to connect the OSB panels to the timber elements, as it is lower than the resistance of the connections themselves (hold-down and shear brackets). Regarding the CLT building, on the contrary, the weak element is represented by the connections; therefore the maximum number of storey is dictated by the adopted connections; innovative connections, as for example the new system presented by (Polastri et al. 2014), may in future permit to erect taller timber buildings.

4 ANALYSIS OF ENERGY PERFORMANCE

The third part of the research considered thermal and energy comparisons between standard building components (without thermal mass) and improved building components by the thermal mass. In order to perform thermal assessments and energy simulations for the Italian capital cities, currently six winter climatic zones based on Heating Degree Days (HDD) according to (DPR 1993) are considered. In this classification, the summer climatic considerations are missing. The Fraunhofer Italia Research proposed the following classification of the Italian capital cites combining HDD and CDD and identifying 13 summer climatic zones, Figure 4.

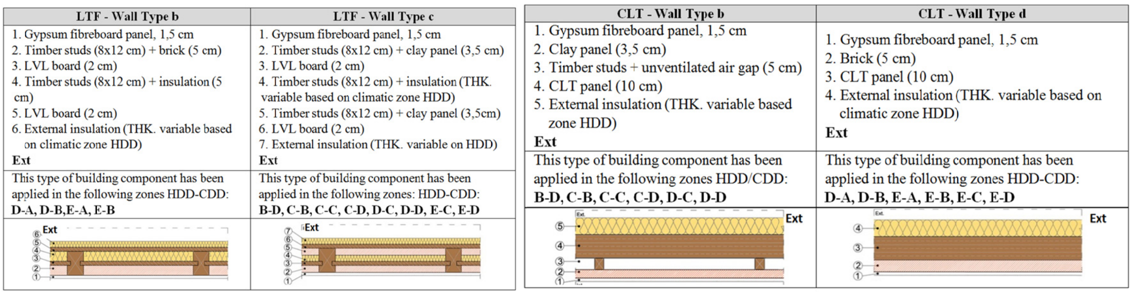
Based on climatic zones HDD and CDD, the Fraunhofer Italia Research made a multi-criteria analysis of thermal parameters for improved building components (walls) in order to find out the best solution of thermal mass integration in the building envelope for each Italian capital city. Thermal analysis methods for both standard walls and improved walls are describe in detail in the research paper of (Ratajczak et al. 2014). The multi-criteria analysis considered four types of improved walls in CLT system and three types of improved walls in LTF system.

		Summer climatic zone based on CDD (α=0,6)			
		A	**B**	**C**	**D**
Winter climatic zones based on HDD (DPR412/93)	A	-	-	-	-
	B	-	-	-	MESSINA, TRAPANI, AGRIGENTO, PALERMO, CROTONE, REGGIO CALABRIA, CATANIA, SIRACUSA
	C	-	BENEVENTO, CATANZARO, SASSARI, OLBIA-TEMPIO	NAPOLI, IMPERIA, RAGUSA, CAGLIARI, BARI, BRINDISI, MEDIO CAMPIDANO, CARBONIA-IGLESIAS, BARLETTA-ANDRIA-TRANI	TARANTO, LATINA, CASERTA, SALERNO, COSENZA, ORISTANO
	D	SAVONA, LA SPEZIA, TRIESTE, MACERATA, MASSA-CARRARA, PISA, SIENA, ISERNIA	GENOVA, LUCCA, VITERBO, CHIETI, NUORO, VIBO VALENTIA, FERMO	PESARO E URBINO, ANCONA, ASCOLI PICENO, PISTOIA, LIVORNO, GROSSETO, TERNI, PESCARA, PRATO, OGLIASTRA	CALTANISSETTA, ROMA, FIRENZE, AVELLINO, FOGGIA, TERAMO, MATERA
	E	NOVARA, TORINO, VARESE, COMO, MILANO, BERGAMO, BOLZANO, TRENTO AOSTA, SONDRIO, VICENZA, UDINE, AREZZO, PORDENONE, VERBANO-CUSIO-OSSOLA, MONZA E DELLA BRIANZA, BIELLA, LECCO	VERCELLI, ALESSANDRIA, BRESCIA, PAVIA, CREMONA, MANTOVA, TREVISO, VENEZIA, PADOVA, LODI, MODENA, BOLOGNA, FORLI'-CESENA, CAMPOBASSO, GORIZIA, RIMINI	REGGIO NELL'EMILIA, PIACENZA, FERRARA, ASTI, RAVENNA, RIETI, POTENZA, L'AQUILA	VERONA, ENNA, PARMA, PERUGIA, FROSINONE
	F	CUNEO, BELLUNO			

Figure 4. Classification of the Italian capital cites based on HDD and CDD.

The analysis considered the following parameters to identify the best solution: a) percentage deviation between the U-value [W m^{-2} K^{-1}] of the improved wall and U-vale of standard wall; b) percentage deviation between the average of the periodic thermal transmittance Y_{ie} [W m^{-2} K^{-1}] and the time shift ϕ [h] of the improved wall and average Y_{ie} and ϕ of standard wall; c) percentage deviation between the total thickness [mm] of the improved wall and total thickness of standard wall; d) percentage deviation between the insulation thickness [mm] of the improved wall and insulation thickness of standard wall.

These parameters were weighted by 1-to-3 scale considering four types of improved walls and climatic zones HDD-CDD. It allowed to select the most suitable type of improved wall to the climatic zone. The results are represented in the Figure 5, which shows the selected improved walls, their layers as well as belonging to climatic zones. In these wall the following materials were used to improve the thermal inertia: 1) brick (d = 5 [cm], ρ = 1800 [kg m^{-3}], λ = 0.8 [W m^{-1} K^{-1}], c = 850 [J kg^{-1} K^{-1}]); 3) clay panels (d = 2.5-3.5 [cm], ρ = 1600 [kg m^{-3}], λ = 0.73 [W m^{-1} K^{-1}], c = 1000 [J kg^{-1} K^{-1}]). Furthermore, the Figure 6 shows, as an example, the percentage of improvement or worsening of the following thermal parameters between selected improved walls and standard walls in Messina city (climatic zone B-D (HDD-CDD)): a) thermal transmittance (U-value, [W m^{-2} K^{-1}]); b), periodic thermal transmittance (Y_{ie}, [W m^{-2} K^{-1}]); c) time shift (ϕ, [h]); d) decrement factor (f, [-]); e) internal areal heat capacity (k_1, [kJ m^{-2} K^{-1}]); f) long term thermal capacitance (d*ρ*c, [kJ m^{-2} K^{-1}])



LTF - Wall Type b	LTF - Wall Type c	CLT - Wall Type b	CLT - Wall Type d
1. Gypsum fibreboard panel, 1,5 cm 2. Timber studs (8x12 cm) + brick (5 cm) 3. LVL board (2 cm) 4. Timber studs (8x12 cm) + insulation (5 cm) 5. LVL board (2 cm) 6. External insulation (THK. variable based on climatic zone HDD) **Ext**	1. Gypsum fibreboard panel, 1,5 cm 2. Timber studs (8x12 cm) + clay panel (3,5 cm) 3. LVL board (2 cm) 4. Timber studs (8x12 cm) + insulation (THK. variable based on climatic zone HDD) 5. Timber studs (8x12 cm) + clay panel (3,5cm) 6. LVL board (2 cm) 7. External insulation (THK. variable on HDD) **Ext**	1. Gypsum fibreboard panel, 1,5 cm 2. Clay panel (3,5 cm) 3. Timber studs + unventilated air gap (5 cm) 4. CLT panel (10 cm) 5. External insulation (THK. variable based zone HDD) **Ext**	1. Gypsum fibreboard panel, 1,5 cm 2. Brick (5 cm) 3. CLT panel (10 cm) 4. External insulation (THK. variable based on climatic zone HDD) **Ext**
This type of building component has been applied in the following zones HDD-CDD: **D-A, D-B,E-A, E-B**	This type of building component has been applied in the following zones: HDD-CDD: **B-D, C-B, C-C, C-D, D-C, D-D, E-C, E-D**	This type of building component has been applied in the following zones HDD/CDD: **B-D, C-B, C-C, C-D, D-C, D-D**	This type of building component has been applied in the following zones HDD-CDD: **D-A, D-B, E-A, E-B, E-C, E-D**

Figure 5. Selected walls with thermal mass.

In order to evaluate the energy performance as well as indoor comfort of the referenced building with both standard walls and selected improved walls, the energy simulations were carried out. The dynamic energy simulations using TRNSYS software were done by the Free University of Bolzano-Bozen for 110 Italian capital cities. The 160 configuration of the referenced building model (size: 10x10x3 m) were considered by combining the following parameters: a) 4 surface area to volume ratio (S/V): S/V_1 = 0,73, S/V_2 = 0,4, S/V_3 =0,63, S/V_4 = 0,3); b) 4 window orientation for S/V_1 and S/V_2, 6 window configuration for S/V_3 and S/V_4; c) 2 window types: U_w = 1,2 [W m^{-2} K^{-1}], SHGC = 0,6 and U_w = 1,2 [W m^{-2} K^{-1}], SHGC = 0,4; d) 2 window dimension: 12.90 m^2 and 25.74 m^2; e) 2 construction timber system: CLT and LTF. For each configuration seven thermal parameters were calculated in the period from May to September: a) power peak [kW]; b) number of hours > 26°C; c) percentage of hours > di 26°C; d) number of hours > 28°C; e) percentage of hours > di 28°C; f) energy demand [MJ m^{-2}]; g) energy demand [MJ]. In total, 1120 data were calculated for each capital city.

Timer System	Building component	Total thickness (mm)		Insulation thickness (mm)		U-value (W m^{-2} K^{-1})		Y_{12} (W m^{-2} K^{-1})		ϕ (h)		f (-)		k_1 (kJ m^{-2} K^{-1})		d*ρ*c (kJ m^{-2} K^{-1})	
			Δ		Δ		Δ		Δ		Δ		Δ		Δ		Δ
LTF	Type c	195	9%	60	60%	0.48	-81%	0.11	0%	-9.54	5%	0.24	45%	55.0	54%	191.7	89%
CLT	Type b	260	-16%	50	0%	0.40	2%	0.09	26%	-11.14	20%	0.21	25%	53.0	59%	204	38%

N.B. Positive value of Δ represents improvement and negative value worsening.

Figure 6. Thermal parameters of walls with thermal mass in Messina city, climatic zone B-D (HDD-CDD)

In order to establish the percentage of improvement or worsening between the referenced building model with standard and with improved walls, data collected from the simulations were compered. Currently, the analysis phase of output data from the energy dynamic simulation are in progress, thus the results of the TIMBEEST research project cannot be included in this publication.

5 TEST CELLS

Within the TIMBEEST project, two full-scale, outdoor test cells were designed and realized by the Fraunhofer Italia Research in order to validate a numerical model of the dynamic energy simulations made by the Free University of Bolzano-Bozen.

The test cells, called also FlexiBox, were installed close to Bolzano city and were used to monitor in real boundary conditions thermal performance of tested building components during the period from May to September 2015.

The concept of the Flexible Box is based on the following paradigms: flexibility, modularity and prefabrication. The test cells can be considered flexible according to two strategies: engineering and envelope solutions. The engineering flexibility is strictly connected to prefabrication and modularity of the construction system. Prefabrication of building components used for testing (walls, roof, etc.) minimizes their assembly and disassembly effort. The dimensions of the test cell allow to transport it by truck, train, enabling to test components in different locations. Furthermore, modularity allows to achieve spatial flexibility. The main structure is a timber frame that enables to create various cells' aggregations by attaching and detaching them both in vertical and horizontal direction. The envelope flexibility allows changing building components multiple times preserving the structural proprieties of the main timber structure. Two test cell are designed as a cube with the dimensions of 2,80 x 2,80 x 2,80 (W x L x H). The test cell's envelop is subdivided in two systems: a) main system made of a timber frame with columns and beams (both size 200 x 120 mm); and b) movable and interchangeable panels that are fastened to the main structure (a) by means of concealed wood connectors. The part (b) is considered as a thermal envelop and it can be changed multiple times based on test requirements and type of building components.

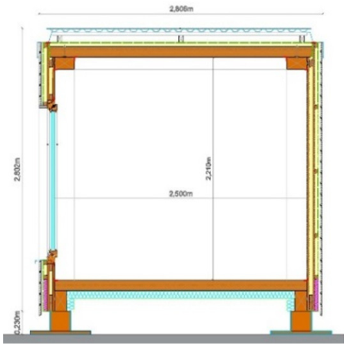
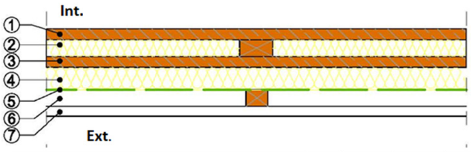
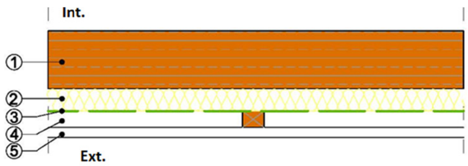
a)  b) 

Figure 7. Section of the test cell with LTF walls (a) and two test cells installed close to Bolzano city

Within this research project, two test cells were constructed because two different walls had to be monitored at the same time. In this specific case study two type of walls have been tested, Figure 8: 1) building components using CLT system with high-density wood fibre insulation; 2) building components in LTF system with low-density wood fibre insulation and high-density wood fibre insulation on the external side. In both cases, the external timber cladding is used. Furthermore, in both test cells the roof and the floor are made using CLT system with high-density wood fibre insulation and XPS insulation, respectively.



n°	Layer	S (mm)	ρ (kg/m³)	λ (W/mK)*	Cs (J/kgK)
1	Laminated veneer lumber (LVL) panel	20	500	0,100	1500
2	Low-density wood fibre insulation + timber studs*	30	98,4	0,0454	2051,6
3	Laminated veneer lumber (LVL) panel	20	500	0,100	1500
4	Low-density wood fibre insulation + timber studs**	40	98,4	0,0454	2051,6
5	Windproof breathable UV-resistant membrane (SD = 0,09 m)	0,3	-	-	-
6	Timber studs + ventilated air gap	30	-	-	-
7	Timber cladding	18	-	-	-



n°	Layer	S (mm)	ρ (kg/m³)	λ (W/mK)*	Cs (J/kgK)
1	CLT panel	105	650	0,130	1500
2	High-density wood fibre insulation	40	190	0,043	2100
3	Windproof breathable UV-resistant membrane (SD = 0,09 m)	0,3	-	-	-
4	Timber studs + ventilated air gap	30	-	-	-
5	Timber cladding	18			

Figure 8. An example of tested building components: LTF wall (left) and CLT wall (right).

The U-vale of these building components was defined according to the test requirements. The thermal bridges of the test cells' envelop were calculated and the heat losses across them were lower than 0,073 [W/mK] for the internal linear thermal transmittance (ψ_{int}) and lower than -0,012 [W/mK] for the external linear thermal transmittance (ψ_{ext}).

6 CONCLUSIONS

It is widely known that structures with higher thermal inertia have better energy performance during the summer period in hot climates. Thus, the TIMBEEST project aimed to study energy performance of standard timber buildings (LTF and CLT systems) and to propose strategies for improvement of the summer performance by integrating an additional thermal mass in walls without worsening the seismic performance of buildings.

The TIMBEEST project demonstrated that summer performance of timber buildings (without additional thermal mass) have a good energy performance in terms of power peak, number of hours > 26°C; number of hours > 28°C and energy demand, especially if we adopt CLT system. Nevertheless, if thermal inertia of walls increases by adopting thermal mass (brick, clay panels) as was proposed in this project, the building can gain relevant benefits in terms of reduction of insulation thickness, which is quite thick in the southern part of Italy, otherwise the summer thermal parameters of wall are not verified. For instance in Messina city the reduction of insulation thickness is up to 60% in LTF building. Furthermore, the improvement of the internal areal heat capacity and the long term thermal capacitance was noticed: 54% and 89% in LTF buildings and 59% and 28% in CLT buildings, respectively. According to the structural analysis, it is possible to increase mass of walls in three storey buildings in both CLT and LTF systems in all Italian seismic zones. In five storey buildings the increase of mass in walls can be done only in zones with low earthquake risk. Currently, the evaluations of output data from the energy dynamic simulation are in progress. As the final results of the TIMBEEST project is expected to provide the cumulative distribution function of each analysed parameters in the dynamic energy simulation for summer climatic zones (based on CDD) as well as for a single capital city.

7 ACKNOWLEDGMENTS

The authors gratefully acknowledge the contributions within this project for the following persons: prof. Gasparella, prof. Marco Baratieri, Ph.D. G. Pernigotto, Ph.D. A. Prada from the Free University of Bolzano-Bozen, Italy, who developed the climatic indicators and performed the energy dynamic simulations. Furthermore, the authors gratefully acknowledge the supportive sponsorship provided by the Autonomous Province of Bolzano-Bozen.

8 REFERENCES

D.P.R. n. 412. 1993. Regolamento recante norme per la progettazione, l'installazione, l'esercizio e la manutenzione degli impianti termici degli edifici ai fini del contenimento dei consumi di energia, in attuazione dell'art. 4, comma 4, della L. 9 gennaio 1991, n. 10.

European Committee for Standardization (CEN). 2013. Eurocode 8 - design of structures for earthquake resistance, part 1: General rules, seismic actions and rules for buildings, CEN, Brussels, Belgium

European Committee for Standardization (CEN). 2014. Eurocode 5 - design of timber structures, Part 1-1, General - Common rules and rules for buildings, CEN, Brussels, Belgium.

Gasparella A., Pernigotto G., Cappelletti F., Romagnoni P., Baggio. P. 2011. Analysis and modelling of window and glazing systems energy performance for a well insulated residential building. *Energy & Building,* 43(4).

Gavric I., Ceccotti A. and Fragiacomo M. 2011. Experimental cyclic tests on cross-laminated timber panels and typical connections. In: *Proceeding of ANIDIS*, Bari, Italy.

Polastri A., Angeli A., Dal Ri G. 2014. A new construction system for clt structures. In: *Proceeding of the World Conference on Timber Engineering.* Quebec City, Canada.

Pozza L., Scotta R., Trutalli D., Polastri A. 2015. Behaviour factor for innovative massive timber shear walls *Bulletin Of Earthquake Engineering,* Vol 13, Issue 11, Pag 3449-3469, DOI 10.1007/s10518-015-9765-7

Pozza L., Trutalli D., Polastri A. and Ceccotti A., 2013. Seismic design of CLT Buildings: Definition of the suitable q-factor by numerical and experimental procedures, *Proceedings 2nd International conference on Structures and architecture, Guimarães*, Portugal: 90 – 97.

Ratajczak, J., Benedetti, C., Polastri, A., Poh'siè, H., Gasparella, A., Baratieri, M., Paradisi. I. 2014. TIMber Buildings with Enhanced Energy and Seismic performance for Mediterranean region: the research project TIMBEEST, *Proceedings of the 30th International PLEA Conference*, 16-18 December 2014, CEPT University, Ahmedabad, India.

TRNSYS software. Web site: http://www.trnsys.com/.

Simqke. University of Brescia. Web site: http://dicata.ing.unibs.it/gelfi/software /simqke/simqke_gr.htm.