CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montreal)
June 12 - 15, 2019

SIMULATION-BASED BUILDING PERFORMANCE COMPARISON BETWEEN CLT-CONCRETE HYBRID, CLT, AND REINFORCED CONCRETE STRUCTURES IN CANADA

Yin, Li[1]
[1] Concordia university, Canada
[1] yin.li.0314@gmail.com

Bruno, Lee[2]
[2] Concordia university, Canada
[2] bruno.lee@concordia.ca

Abstract: Due to climate change and environmental issues, timber attracts more attention as a sustainable construction material compared with steel and concrete. One of the latest achievements in timber construction is the Cross Laminated Timber (CLT). CLT is also often combined with concrete as a hybrid system. Compared with a traditional reinforced concrete building, the hybrid system has less carbon emissions, faster construction period and lighter structural system. Compared with a timber building, the hybrid system has higher fire safety rating and better thermal comfort; however, there is not enough quantitative research discussing the difference of performance between these different structural systems. In this paper, building performance simulation is used to evaluate the energy consumption and peak load of the buildings with different structural systems. A typical residential building is selected as the case study. First, the structural design loop is applied for the different types of constructions according to the National Building Code, and then building performance simulation is applied to evaluate the energy performance in different locations in Canada. The results of different structural systems with different locations in Canada are discussed.

1 INTRODUCTION

In 2015, the National Building Code (NBC) permitted to extend the limit of wood construction from four-storey to six-storey for residential and business/personal services. The government of Quebec released a guideline which outlined the technical principles required to design and construct wooden buildings up to 12 storeys using mass timber (Veilleux, 2015). To achieve this level, mass timber construction material such as Cross Laminated Timber (CLT) must be applied instead of light framing construction. Cross laminated timber is a new type of engineering wood product which has three or more gluing layers of solid sawn lumber. Each layer is oriented perpendicular to adjacent layer and glued on the wide face. CLT can be used for shear wall, roof panel, and floor panel. In the 1970s, CLT was first proposed conceptually, and the first manufacturer of modern CLT panels in the late 1980s was established in Europe. In the 1990s, the first CLT construction was built in Switzerland (Brandner, 2016). Nowadays, CLT has been developing rapidly in Europe and North America, and the concept of CLT have gradually accepted by the market. The high strength of CLT makes it an effective substitute for steel and concrete for new construction projects. Researches also have combined CLT with concrete to explore the potential use.

Concrete can be integrated with CLT in different formats. Skidmore, Owings & Merrill (SOM) conducted a conceptual design study utilizing a timber/concrete hybrid system (Baker, 2014). The proposed system is called “Concrete Jointed Timber Frame”. This system relies primarily on mass-timber for the main structural elements, with supplementary reinforced concrete at the connecting joints.

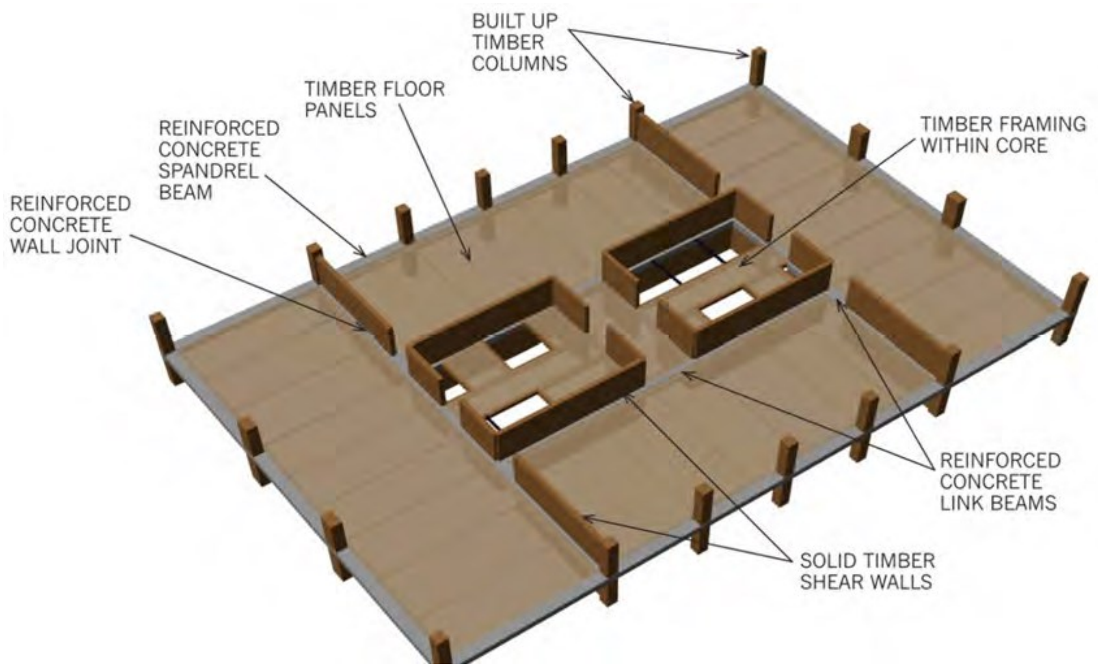

Figure 1. Typical Floor Diagram proposed by SOM (diagram adopted from Baker, 2014)

The University of British Columbia (UBC) successfully built one of the tallest timber-based hybrid buildings in the world. Except the two concrete core and foundation, the rest system is comprised of CLT floors and Glulam columns as shown in figure 2(Tannert, 2017).

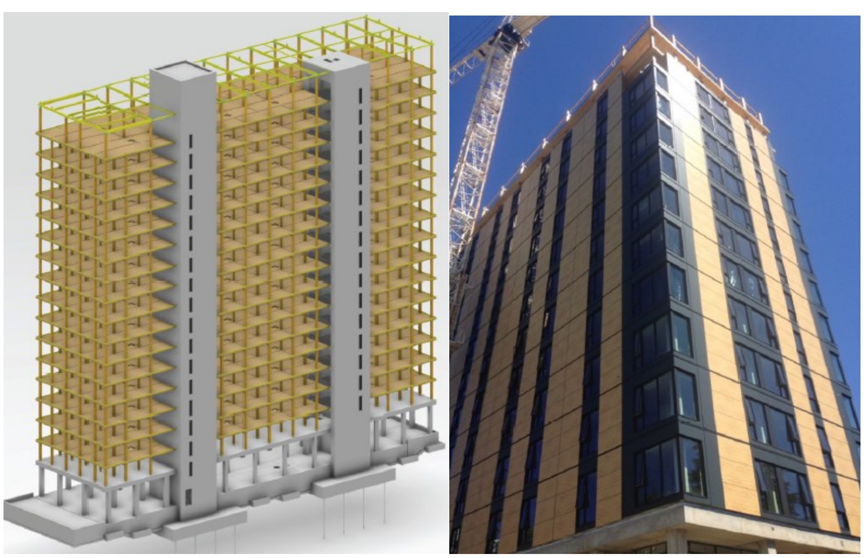

Figure 2. Hybrid structural system of UBC building (diagram adopted from Tannert, 2017)

These projects highlight the benefits of the hybrid system; however, few research has discussed the energy performance of this type of building. In this study, three structural systems are selected for performance comparison including CLT, CLT concrete hybrid, and reinforcement concrete. The CLT system consists of CLT floor and glulam column. The concrete system consists of flat slab and concrete column. The CLT-concrete system consists of CLT floor panel with concrete topping and glulam column. First, the structural design loop is performed to keep the three systems with the same structural capacity. Second, the building performance simulation program Energyplus is applied to evaluate the energy performance of buildings with these three structural systems in different locations in Canada.

2 Methodology

First, the structural design loop is proposed which makes all the three structural systems meet the same level of structural performance, as shown in figure 3. Due to the scope of this study, only the vertical loads are considered. The structural design loads are the same for different structural systems. The criteria is defined as the structural capacity reaching 95% of the load demand which is the combination of different loads. The structural design variables for concrete building is the thickness of concrete slab and column size. These variables are continuous. The structural design variables for CLT and hybrid buildings are discrete due to the fixed thickness of each layer. The deflection and vibration indicator are calculated as loop constrain according to National building code. The concrete structural analysis is conducted using Sap2000 and the CLT and CLT-concrete system structural analysis are conducted using excel following the analysis steps according to the CLT design manual Canadian version. When one structural system meets all the criteria, the parameters like floor slab thickness are transferred to build an energy model in Energyplus. All the other energy model parameters not related to the structural system are kept the same such as insulation and infiltration.

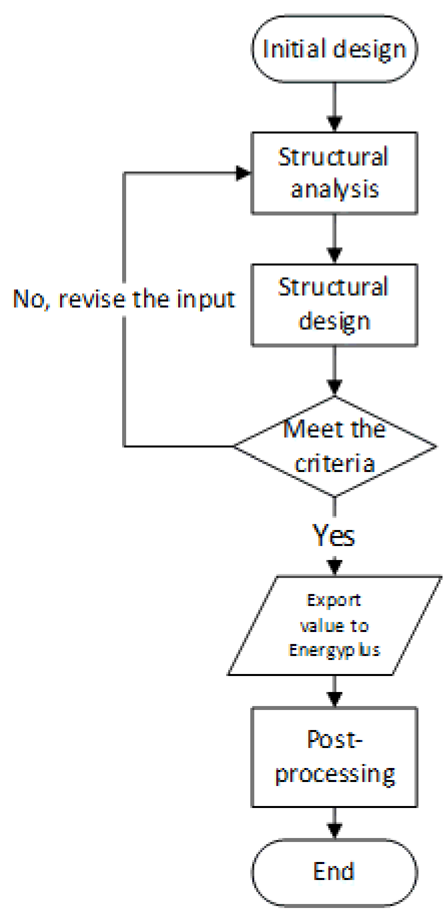

Figure 3. Integrated building performance evaluation workflow

Energyplus is a building energy simulation engine developed by the US Department of Energy (DOE) and the Lawrence Berkeley National Laboratory (LBNL). Energyplus is free, open-source, and can be integrated with different platforms. In this study, the heating/cooling load and annual heating/cooling energy consumption are selected as the performance indicators to evaluate the building energy performance.

3 Case study

3.1 Structural design loop results

In this study, a 10-storey DOE benchmark residential building is selected as shown in figure 4. The floor layout are kept the same for the three structural systems such as the positions of columns which are shown in figure 5. The results of structural design loop are shown in Table 1.

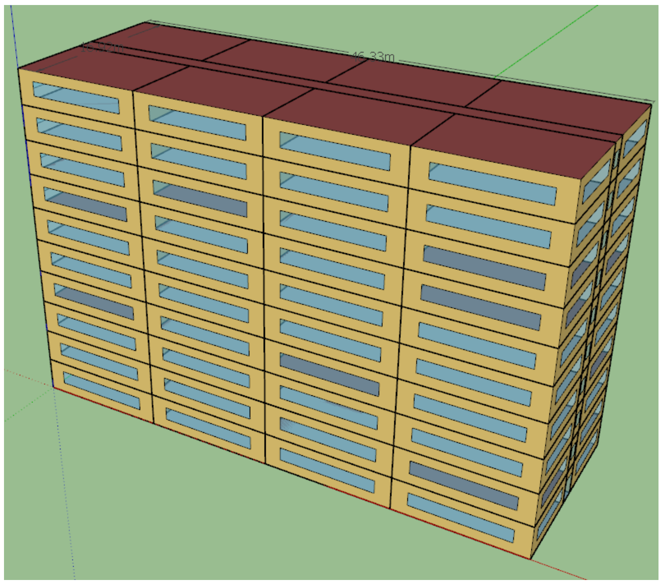

Figure 4. High rise residential building model

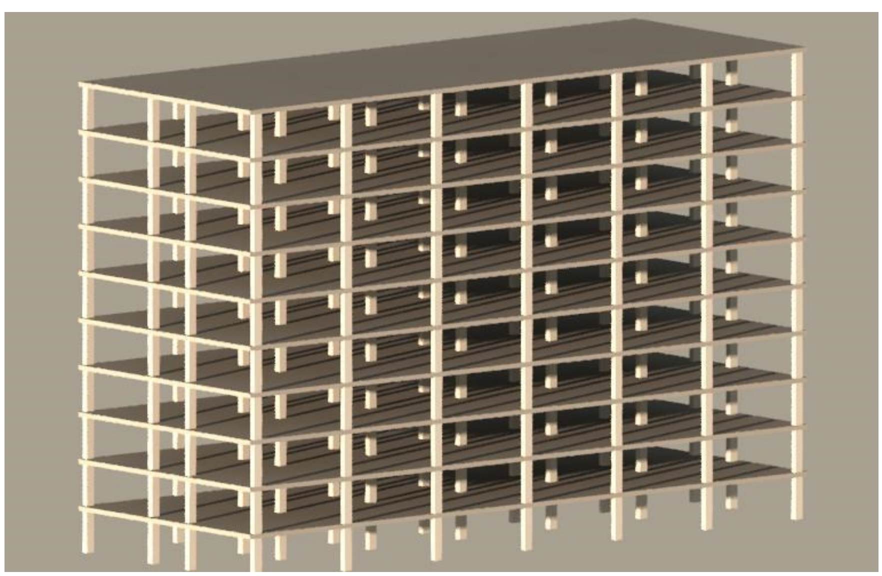

Figure 5. The structural system for the reference building

Table 1. The structural design loop results

System	Floor slab/roof
Concrete	249mm C30 concrete
CLT	244mm 7 lawyer CLT floor panel
CLT-concrete	244mm CLT +10mm concrete

3.2 Energy simulation results

After finishing the structural design loop the structural design variables are used to build energy models are built for Montreal, Toronto and Vancouver using Energyplus. First, the heating and cooling loads of the 6th floor south and north apartments are chosen to evaluate the peak load of the three buildings.

Figure 6. Peak loads of buildings in Montreal

For the cases in Montreal it can be observed from figure 6 that the cooling load of the south apartment in the CLT building is around 19.7% higher than that in concrete building, and the cooling of hybrid building is 11.7% higher than that in concrete building. The cooling load of north apartment in the CLT building is around 3.7% higher than that in concrete building, and the cooling load of hybrid building is 9% higher than it concrete building. For the heating load there is no significant difference between different structural systems for south and north apartment.

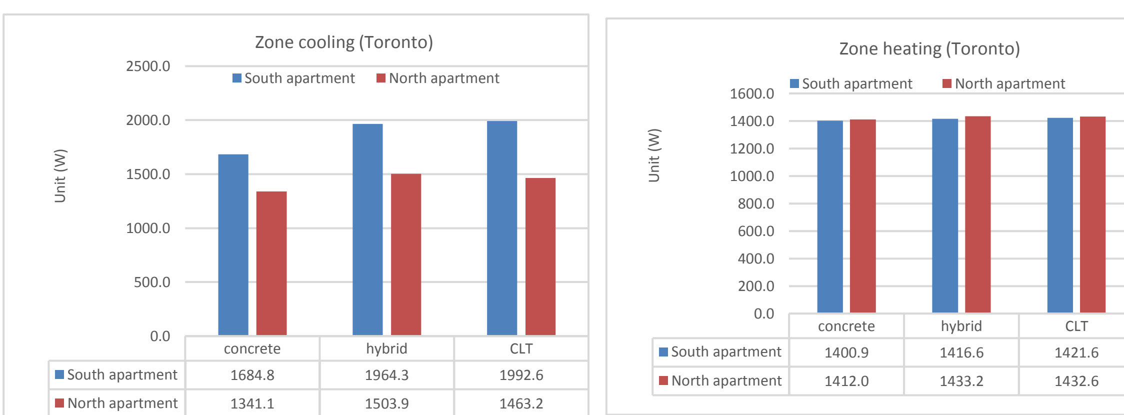

Figure 7. Peak loads of buildings in Toronto

For the cases in Toronto it can be observed from figure 6 that the cooling load of the south apartment in the CLT building is around 18.3% higher than that in concrete building, and the cooling of hybrid building is 16.6% higher than that in concrete building. The cooling load of north apartment in the CLT building is around 9% higher than that in concrete building, and the cooling load of hybrid building is 12% higher than it concrete building. For the heating load there is no significant difference between different structural systems for south and north apartment.

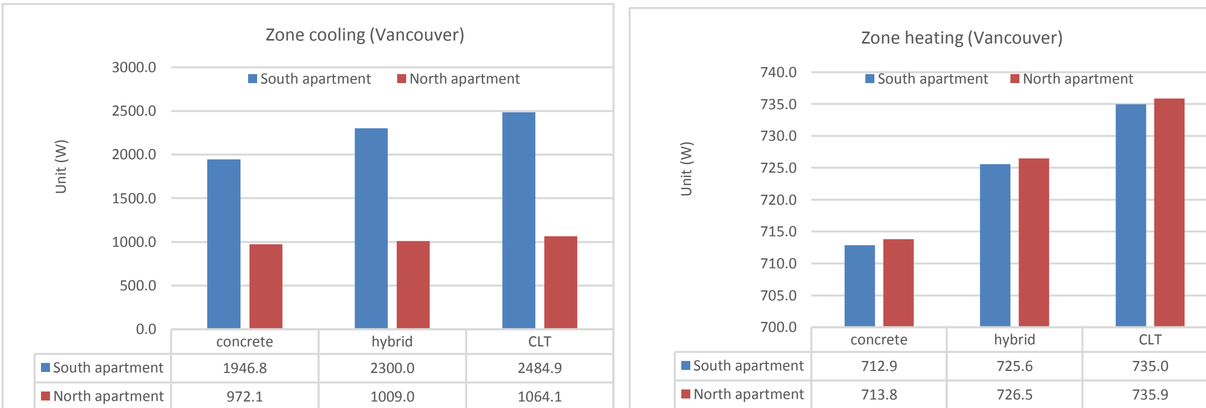

Figure 8. Peak loads of buildings in Vancouver

For the cases in Vancouver it can be observed from figure 6 that the cooling load of the south apartment in the CLT building is around 27.6% higher than that in concrete building, and the cooling of hybrid building is 18.1% higher than that in concrete building. The cooling load of north apartment in the CLT building is around 9.4% higher than that in concrete building, and the cooling load of hybrid building is 3.8% higher than it concrete building. For the heating load there is no significant difference between different structural systems for south and north apartment.

The total heating/cooling energy consumption of the buildings for the three cities are listed in table 2. In Montreal the hybrid and CLT consume 2% and 3.5% energy higher than concrete building. In Toronto the hybrid and CLT consume 3.1% and 3.3% energy higher than concrete building. In Vancouver the hybrid and CLT consume 4.5% and 7% energy higher than concrete building.

Table 2. The annual HVAC energy consumption Units (kWh/m^2)

Structural system	Montreal	Toronto	Vancouver
Concrete	114.84	110.41	80.75
Hybrid	117.29	113.9	84.45
CLT	118.95	114.14	86.43

3.3 Discussion

From the comparison of buildings with different structural systems under the same structural performance, the concrete system has the lowest cooling load, the hybrid system is lower than CLT system which is caused by the thermal mass effect. Thermal mass is a property of the mass of a building which enables it to store heat, providing "inertia" against temperature fluctuations. However, for heating load there is no significant difference between buildings with different structural systems. For the annual heating cooling energy consumption, the concrete system consumes around 2% to 7% lower than CLT and hybrid system and there is no significant difference between CLT and hybrid system.

From the comparison between different cities, the difference of the peak load and annual energy consumption of the buildings with different structural systems in Vancouver is more significant than that in Montreal and Toronto.

Conclusion and future work

This study discussed the energy performance of CLT, CLT-concrete buildings and concrete building. Traditionally the research discussing energy performance considered structural elements as design variables without performing structural analysis. This study proposed a methodology integrated structural design with energy modeling. However, only vertical loads are considered due to the scope of this paper. In the future, the lateral analysis with the shear wall design and the foundation design could be integrated in this methodology.

The energy performance of the buildings with three structural systems are evaluated in this study. Although the difference of annual HVAC energy consumption is less significant than peak load, with the development of renewable energy the building level energy flexibility will become an important performance indicator which make the peak load more important than before. In this paper, only the residential building is discussed, however, the schedules in the residential building are different from the commercial and educational building. Similar comparison could be conducted to explore the interactive impact of schedules and structural systems.

There are more related research should be done in order to investigate the different performance of CLT and CLT concrete hybrid buildings such as carbon emission and life circle cost analysis. Moreover, the CLT design manual Canadian version covers the structural analysis, the acoustic performance, fire rating and floor vibration. For the last three building performance, there is no quantitative evaluation or the comparison with the traditional building systems. This paper casts some insight into the integrated building performance study for CLT and CLT hybrid system.

Reference

Veilleux, L. 2015. *Mass timber buildings of up to 12 storeys.* Gouvernement du Québec.

Chen, Y., 2012. *Comparison of environmental performance of a five-storey building built with cross-laminated timber and concrete*. Sustainable Building Science Program, University of British Columbia-Department of Wood Science, Vancouver, BC, Canada.

Council, C.W., 2017. *Wood design manual*. Ottawa, Canada.

Brandner, R., Flatscher, G., Ringhofer, A., Schickhofer, G. and Thiel, A., 2016. *Cross laminated timber (CLT): overview and development*. European Journal of Wood and Wood Products, 74(3), pp.331-351.

Tannert, T. and Moudgil, M., 2017, April. Structural Design, Approval, and Monitoring of a UBC Tall Wood Building. In *Structures Congress 2017* (pp. 541-547).

Baker, W.F., Horos, D.R., Johnson, B.M. and Schultz, J.A., 2014. *Timber tower research: Concrete jointed timber frame*. In *Structures Congress 2014* (pp. 1255-1266).