Vertical Movement Monitoring in Six-Storey Wood-Frame Building in British Columbia

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By:

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SUMMARY

Vertical movement and wood moisture content (MC) were measured from construction to service in a six-storey wood-frame residential building in the Lower Mainland of British Columbia. The major objective of the project was to assess the impact of various factors on the building movement and to improve the prediction of vertical movement in future designs.

The factors considered included construction materials and methods, wood MC, and load. Wood MC was measured on dimensional lumber including wall plates and studs using a hand-held capacitance-based meter during on-site visits at the framing stage. After the roof sheathing was installed, displacement sensors were installed from the first floor to the top floor in a party wall, a corridor wall, and an interior partition wall, plus the bottom two floors of an exterior wall, to measure vertical movement, with one sensor measuring each floor. Electrical resistance-based moisture pin sensors were installed in the exterior wall and the interior partition wall on the first floor to measure wood MC, together with RH/T sensors to measure the relative humidity and temperature in the environment.

The monitoring generated information consistent or complementary to the results from previous monitoring studies on a four-storey and a five-storey building. Since the majority of the framing was completed in the relatively dry summertime, the wood stayed dry, with an average MC of about 15% throughout the framing stage based on measurements using the portable moisture meter. The moisture sensors installed in the exterior and interior walls of the first floor, covering locations with the highest moisture risk such as sill plates, showed that the dimensional lumber dried slowly, from a MC range of 15 to 20% when the roof sheathing was installed, to a range of 9 to 15% half a year into service. The *in-situ* monitoring for operational service environments showed that it was colder and damper in the exterior wall in the winter season, particularly close to the exterior sheathing, compared to the warmer and drier indoor conditions.

The vertical movement measured in this building was generally small due to the use of engineered wood floor joists and the dry weather conditions during framing, relative to the four-storey building of the previous study. The measured movement over the entire height (from top of foundation to underside of roof trusses) reached 35 mm at the party wall, 39 mm at the corridor wall, and 39 mm at the interior partition wall after 15 months of monitoring. The movement of the exterior wall appeared to be smaller based on the measured values from the bottom two floors. The measured shrinkage amounts were overall larger than the calculated values by the author. The shrinkage calculations included only wall plates and studs based on the measured MC change and did not take into account the effect of load or shrinkage of the engineered wood floor members. Due to the variations and difficulty of accurately predicting building movement, it is suggested that a good margin of safety should be added in design to avoid potential adverse consequences. The effect of load, as well as contribution of engineered wood members, should be taken into account through applying a factor to the calculated shrinkage, although it is not required by the related codes and standards in North America.

It is recommended to continue the field monitoring of this building to generate a more complete picture of vertical movement and wood MC changes. In future, more field monitoring should be carried out to specifically investigate the effects of different climates or building systems. Engineered wood products should be tested for moisture-related behaviour to improve the prediction of building movement in mid-rise and taller buildings.

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1 OBJECTIVES

The objective of the project is to:

- Collect data on vertical movement in a six-storey wood-frame building through field monitoring using displacement sensors; and,
- Monitor changes in wood moisture content (MC) from construction to service

In order to validate the estimation of movement to improve structural integrity, serviceability and building envelope design.

2 INTRODUCTION

Platform frame wood construction is the dominant construction type for residential buildings in North America. Movement is intrinsic to many building materials and is not a new issue for building design and construction. However, differential movement over the height of wood-frame buildings has become a very important consideration with the increase in building height. Six-storey wood-frame buildings have been allowed in the provinces of British Columbia, Quebec and Alberta, and the new 2015 National Building Code of Canada (NRC 2015).

To help assist in the design and construction of mid-rise wood-frame construction, FPInnovations started a project in 2010 to assemble existing knowledge and experience in addressing differential movement and to measure vertical movement in buildings (Wang and Ni 2010; 2012). With strong support and help from the design and construction community in the Lower Mainland of British Columbia, vertical movement and wood MC changes in a four-storey and a five-storey building were monitored (Wang *et al.* 2013; Wang and Ni 2014). A laboratory test was conducted to assess the impact of MC change and load by using two simulated platform frame structures built with dimensional lumber, under controlled environmental and loading conditions (Wang and King 2015). Wood shrinkage was confirmed to be the major cause of vertical movement; the effect of load was relatively small. Information from the mentioned studies was covered in Chapter 5: Design for Vertical Differential Movement in the Mid-rise Wood-Frame Construction Handbook (Ni and Popovski 2015). Load-induced deformation (e.g., elastic compression, creep) is calculated in design in Europe (CEN 2004); however, it is not yet required in North America. Moreover, very little information is available to predict dimensional changes of engineered wood products. Recently, a six-storey wood-frame building in the Lower Mainland of British Columbia was monitored to measure vertical movements in its walls. This report summarizes this most recent monitoring activity in FPInnovations' continuing study into vertical differential movement.

3 STAFF

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4 MATERIALS AND METHODS

4.1 Construction Information

The six-storey building, located in Richmond, British Columbia, was framed from May to November, 2014. Different from conventional stick-built construction method typically used for low-rise wood-frame buildings, this project utilized a high level of prefabrication including prefabricated wall panels and roof trusses, and engineered wood products. The building used “S-Dry” Douglas-fir dimensional lumber for bottom and top wall plates and “S-Dry” Spruce-Pine-Fir (SPF) wall studs. It also used engineered wood products including laminated strand lumber (LSL) rim joists and I-joists (with OSB as the web and laminated veneer lumber as the flange with an actual depth of 9.25 in.), with plywood subflooring (Table 1).

Table 1 Major horizontal members in the vertical load path (from top of foundation to underside of roof trusses)

Building element	Material type and quantity	Size over the building height (mm)
Sill plates	Dimensional lumber, 2 in. nominal thickness, 1 layer	38
Bottom/top plates	Dimensional lumber, 2 in. nominal thickness, double layers at each location*, 22 pieces in total	836
Floor joists	LSL rim joists and I-joists, 9.25 in. deep	1175
Subflooring	Plywood, 5/8 in. thick, 5 pieces	80

*There were localized variations in the number of dimensional lumber installed between the roof truss and the studs below on the top floor. An average of two top plates was assumed for the sixth floor.

4.2 Field Measurements

4.2.1 Vertical Movement Monitoring

Instruments were installed based on the established monitoring systems and protocols used in the previous studies (Wang *et al.* 2013; Wang and Ni 2014), after the roof was sheathed and before the walls were closed in. The locations of monitoring were determined based on input from the project structural engineer. A central suite in the building was chosen for instrumentation. A wire displacement sensor (Model WPS-50-MK30-P50, with a range of 25 mm) was used to measure vertical movement. One sensor was used to measure each floor, installed on the sill or bottom plate, extending upwards in a stud cavity, and then through the top plates, floor and bottom plates above (Figure 1). Three lines of displacement sensors were installed to measure the vertical movement at a party wall, a corridor wall, and an interior partition wall from the first floor to the sixth floor (Appendix I, Figure 10). The sill plates were not measured. The party wall, being a shear wall, was a double-stud wall built with nominal 2 in. by 4 in. (actual 38 mm by 89 mm) dimensional lumber and had plywood sheathing pre-installed on one side. The displacement sensors were installed in a stud cavity of the wall without plywood sheathing. The corridor wall, also a shear wall, was built with staggered studs using nominal 2 in. by 4 in. dimensional lumber and with plywood sheathing pre-installed. The sensors were installed close to the sheathing side. The interior partition wall was built with nominal 2 in. by 4 in. dimensional lumber without plywood sheathing. Displacement sensors were also installed on the bottom two floors of the exterior wall, built with nominal 2 in. by 6 in. (actual 38 mm by 140 mm) dimensional lumber and had plywood sheathing pre-installed.

Only two floors were chosen since the exterior wall did not have many clear stud cavities available for instrumentation due to the large windows in the wall. Monitoring the exterior wall became a lower priority since the previous monitoring had shown that exterior walls had considerably smaller amounts of vertical movement compared to interior walls resulting from differences in wood MC and load (Wang *et al.* 2013; Wang and Ni 2014). Spacing between studs at the measurement locations varied. The linear design loads for these four locations are provided in Appendix II, Table 3. For each displacement sensor, the stainless wire used to extend the draw wire of each sensor to measure the movement over each floor was protected with a 1/2 in. (13 mm) metal conduit. Effort was made during the installation to ensure that each conduit was vertically aligned. Each displacement sensor was wired individually to a data logger located in the electrical closet on the fourth floor. A computer was installed nearby to transmit data hourly.

Figure 1 Displacement sensor boxes sitting on the bottom plate of an interior partition wall

4.2.2 Wood MC Measurement

The MC of dimensional lumber during framing was measured on site visits using a hand-held capacitance-based moisture meter (Wagner Digital Recording Moisture Meter, Model L 610). This device measures average MC close to the wood surface and was used to show the general trends of wood MC changes during the construction. Limited numbers of measurements were conducted in this building compared to the previous monitoring studies since plenty of information was already generated (Wang *et al.* 2013; Wang and Ni 2014). The measurements were randomly conducted on the wall plates and studs close to the displacement sensors, with over 10 measurements for each category (e.g., studs on 1st floor). The species of “lodgepole” in the MC meter was selected for measurements on the wall studs (“SPF”) and “Douglas-fir” was selected for the wall plates.

Resistance-based moisture pin sensors and RH/T sensors (for measuring ambient relative humidity (RH) and temperature) were installed in the suite on the first floor to measure wood MC as well as the environmental conditions in service, including locations with the highest moisture risk. Four moisture sensors were installed to measure the MC at specific locations in the exterior wall. Two of them were placed on the studs at chest height, being in mid-depth of the 2 × 6 in. dimensional lumber (Figure 2); two others on the sill plate, with one sensor being deeper in the plate (i.e., adjacent to the concrete curb) and the other being central in the sill plate. Within the same stud cavity, two RH/T sensors were installed at chest height to measure the service environment close to the exterior plywood sheathing and the interior drywall, respectively (Figure 2). In a similar way, four moisture sensors were installed in the interior partition wall to measure MC of the sill plate and two studs above, together with two RH/T sensors at chest height to measure the environmental conditions in the stud cavity, i.e., the indoor environmental conditions.

For measuring wood MC, the effects of wood species and temperature were compensated by a formula built in the data logging system, mostly based on the calibration work done by FPInnovations (then operating as Forintek Canada Corp.) for kiln drying of dimensional lumber (Garrahan 1988). Similar to the measurements during the construction based on the portable moisture meter, species “lodgepole” was selected for measuring the wall studs (“SPF”) and “Douglas-fir” for the wall plates. All these sensors were connected to data loggers located in the electrical closet on the first floor. Note that MC measurement of wood-based composite products (e.g., LSL rim boards) would require different calibration coefficients and was not conducted in this study. Such measurements may be possible in the future since a calibration study has started in the FPInnovations laboratory for a range of solid wood and composite products using a range of MC measurement tools.

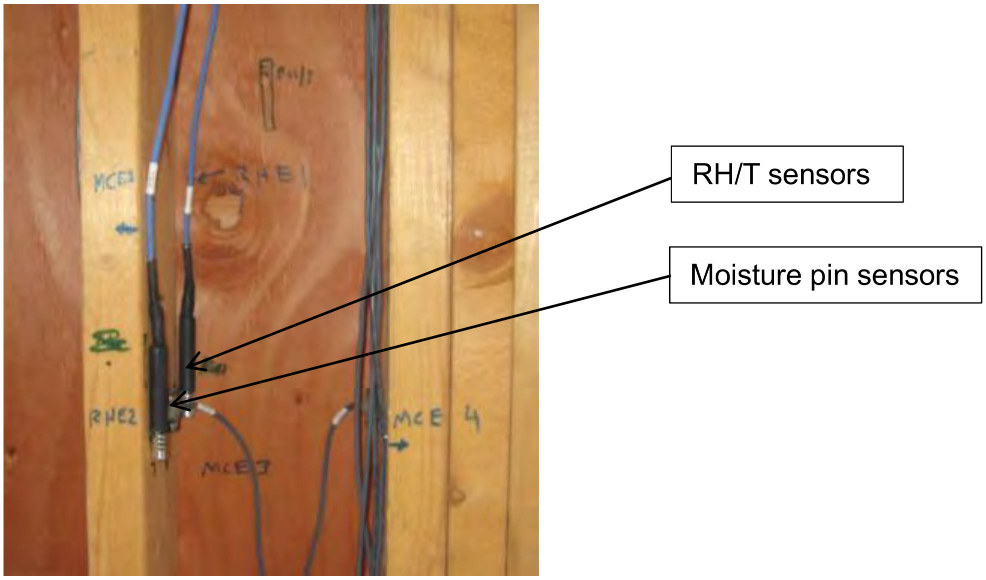

Figure 2 Moisture pin sensors and RH/T sensors installed at chest height on the interior side of an exterior wall

5 RESULTS

5.1 Wood MC Changes during Framing

The MC measurements on site visits during framing indicated that the differences in MC between wall plates and studs, or among the different floors of the building, were very small. Climate data showed that the early summer (May, June) of 2015 was much drier, with dramatically reduced precipitation, than normal weather conditions (the average temperature and precipitation data for May, June, and July from 2011 to 2015 are provided in Appendix III, Figure 11). The average MCs of studs measured during four site visits are shown in Figure 3. The results were consistent with those from the similar summertime measurements in a previous study (Wang and Ni 2014), with an average MC of about 15% throughout the framing stage. The weather became relatively wet when the walls were being enclosed (October-December, 2014) but the MC of wood did not appear to have increased significantly and there was no need for space heating. The weather conditions during framing are the most important factor for on-site moisture management. The wood is well protected against rain-induced wetting once the roof and exterior walls are covered with water-proofing membranes.

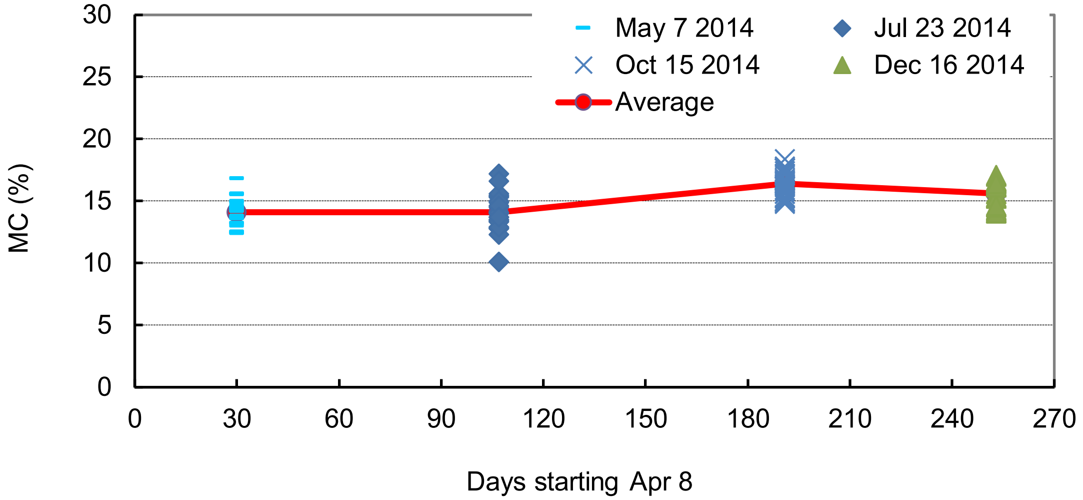

Figure 3 **Average moisture content of dimensional lumber based on measurements using a hand-held capacitance meter during framing**

5.2 MC from Construction to Service based on *In-situ* Monitoring

MC changes from construction to service for the different locations in the exterior wall and the interior wall on the first floor are shown in Figure 4 based on the installed resistance-based moisture pin sensors. In general, the MC reduced from a range between 15% and 20% when the roof sheathing was installed, to a range from 9% to 15% half a year into building service. The wood dried very slowly. Different from the capacitance-based meter used at the framing stage, each moisture sensor measures MC at the specific location. It was found that the MC readings from the exterior wall were overall higher than those measured from the interior wall, and those measured from the sill plates were higher than those from the studs at chest height.

Closely relevant to wood MC changes, the measurements of RH and temperature showed service environmental conditions for those wood elements (Figure 5). It was found that the ambient service environments were similar between the exterior wall and the interior wall in the summertime (June-August) when occupancy just started (and air conditioners were not used). The indoor RH measured from the interior partition wall had dropped greatly since September, with the start of the heating season. Compared to the warmer and drier conditions in the interior walls, it generally became colder and damper (i.e., higher RH) in the exterior wall. The RH on the drywall side of exterior walls reduced much more slowly with considerably higher readings compared to the interior wall conditions. On the exterior sheathing side, the measurements had actually showed a trend of increase in RH from September, with the readings occasionally approaching 80%. This environment appeared to be mostly influenced by the exterior weather conditions. These measurement results confirm the higher durability risk that exterior sheathing typically experiences in a heating climate (especially when there is no insulation installed to the exterior of the sheathing). The monitoring study also implies that the riskier locations, which tend to trap moisture and to dry slowly (e.g., sill plates) or are in a damper service environment (e.g., exterior sheathing), deserve more attention in design and during construction to reduce wetting and to promote drying to ensure long-term durability of the wood elements.

Note that the readings from the moisture pin sensors discussed above had not been specifically calibrated for the wood species (Douglas-fir or lodgepole pine) based on the measurement tool and they might slightly be reduced once calibrated. Taking the relatively stable RH of around 60% at a temperature of about 20°C in the summer (May-August) as an example, wood on average should theoretically achieve an equilibrium moisture content of approximately 11% under such an ambient condition (FPL 2010). But the readings from the pin sensors ranged from 12 to 18% depending on locations and wood species. Although it is understood that the wood may not have reached equilibrium, it appeared there could be a discrepancy between measurements and actual values. The ongoing calibration study is expected to shed light on this when it is completed.

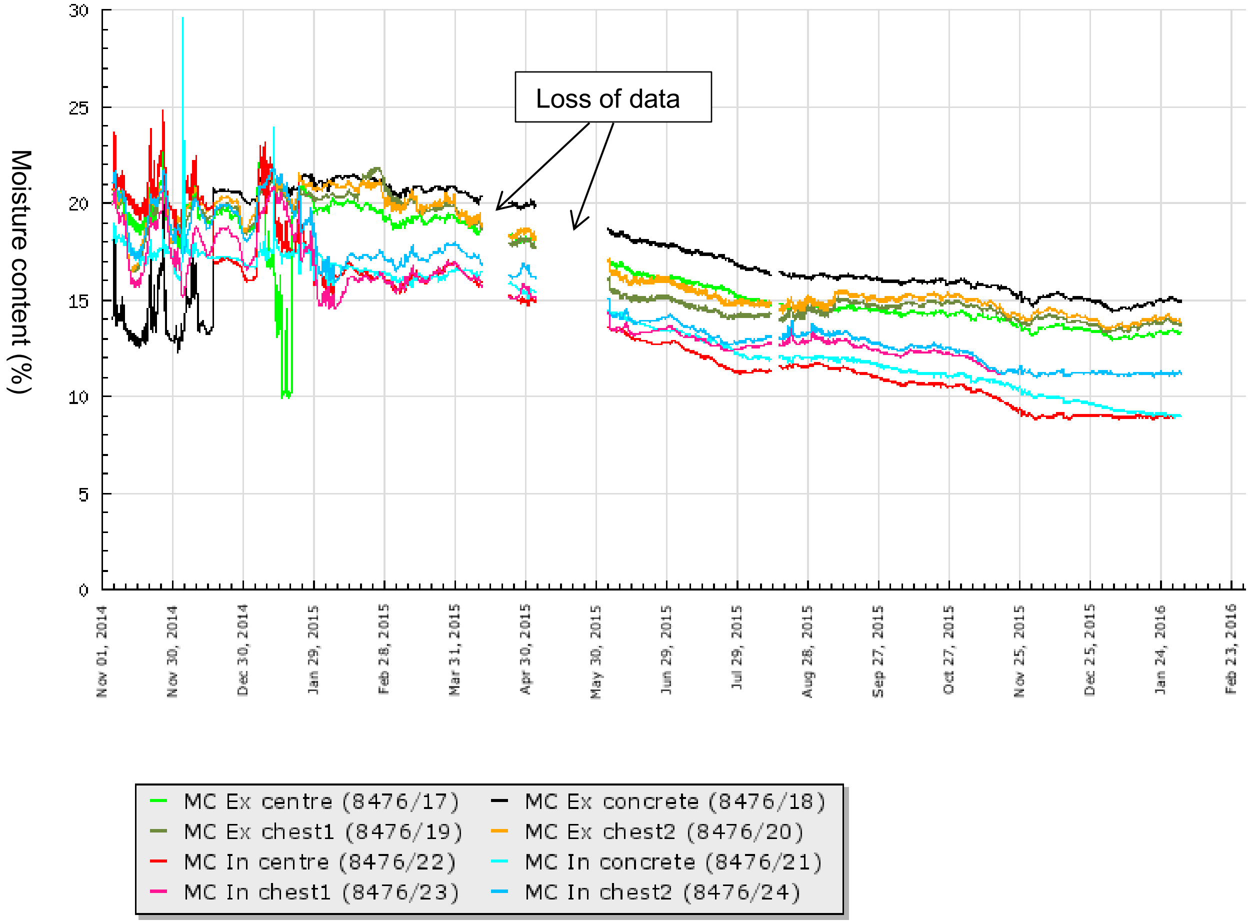

Figure 4 Moisture content measurements in the exterior wall and the interior partition wall on the first floor based on electrical resistance-based sensors

(Chart legends: "MC" means "moisture content", "Ex" means "exterior wall", "In" means "interior partition wall", "concrete" means "being adjacent to the concrete curb", "centre" means "in central sill plate", and "chest" means "at chest height".)

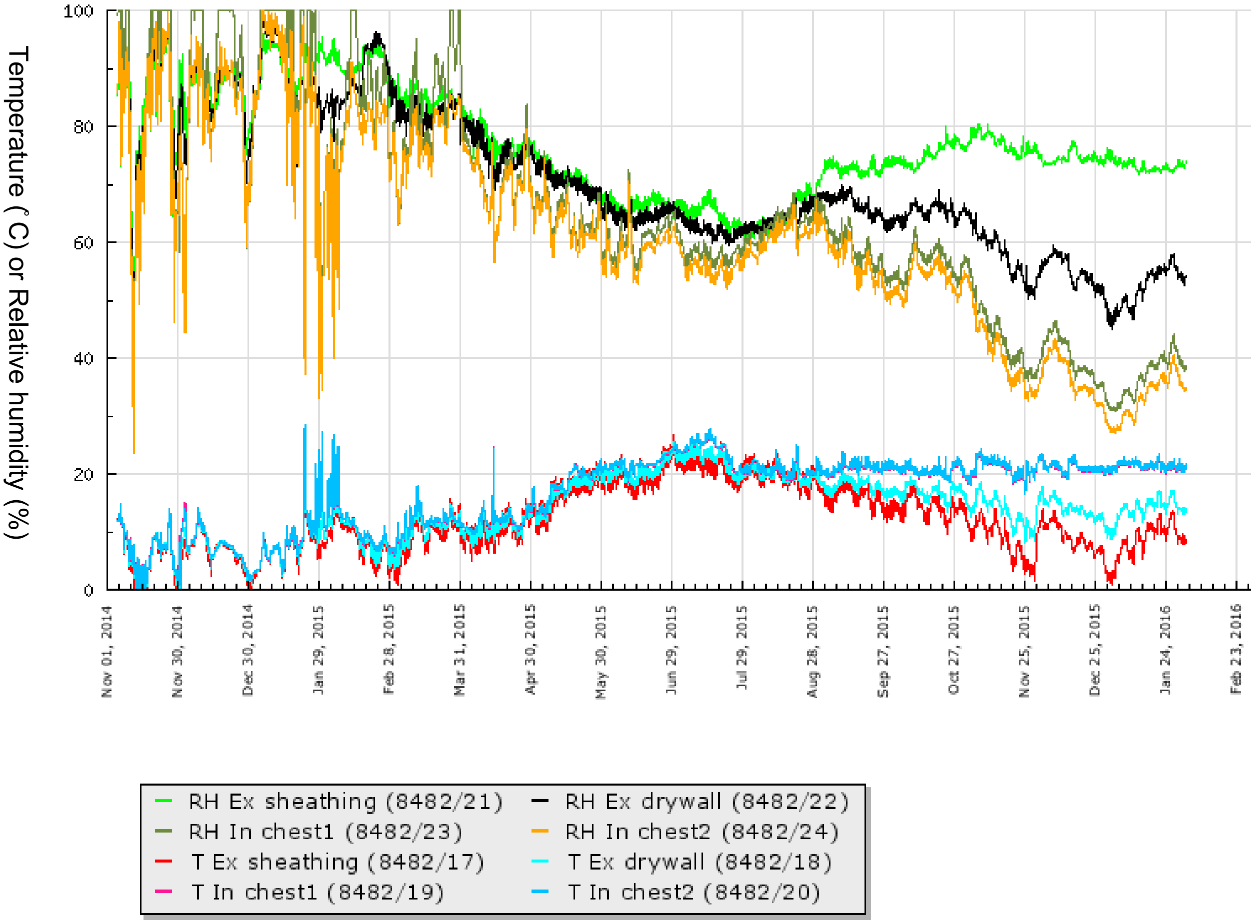

Figure 5 Changes in relative humidity and temperature in the exterior wall and the interior partition wall on the first floor

(Chart legends: “RH” means “relative humidity”, “T” means “temperature”, “In” means “interior partition wall”, “concrete” means “being adjacent to the concrete curb”, “centre” means “in central sill plate”, and “chest” means “at chest height”.)

5.3 Vertical Movement

A displacement sensor records any movement (i.e., vibration, wood shrinkage, load-induced movement, etc.) for the direction measured. The readings from displacement sensors show the trends of downward movement resulting from wood shrinkage and load-induced movement (primarily creep) in a monitoring study. The sensors in this building overall produced more consistent readings compared to those from the previous five-storey building (Wang and Ni 2014) probably resulting from improved quality of sensor installation. Relative to the four-storey building, overall the downward movement amounts were found to be small in this building, due to the use of engineered wood floor joints and the relatively dry framing season, similar to Phase B of the five-storey building (Wang and Ni 2014). By comparison, the previous four-storey building showed the highest movement amounts per floor due to a wet framing season and use of dimensional lumber floor joists (Wang *et al.* 2013). Being consistent with the results from the two previous monitoring studies (Wang *et al.* 2013; Wang and Ni 2014), this study showed that the vertical movement amounts were generally higher in the interior walls than in the exterior wall, and higher on bottom floors than on upper floors (Figure 6 – Figure 9). Such differences are believed to be mostly caused by differences in wood MC and load.

The curves in Figure 6 – Figure 9 showed high fluctuations and considerable amounts of downward movement during the construction between November 2014 and January 2015. Drywall and other interior and exterior finishing were installed, greatly increasing dead loads, together with large live loads and localized vibrations due to construction activities. But the wood was not drying significantly based on readings from the moisture pins installed (Figure 4). Afterwards the downward movement at each location greatly increased from May to July, when the construction was being completed and the building gradually occupied. Aside from a small effect of load, those dramatic increases in vertical movement must have been primarily caused by wood drying resulting from the drier service environment. This was partially confirmed by the measurements of wood MC and ambient humidity conditions on the first floor (Figure 4, Figure 5). The dry weather in 2015 (Appendix III, Figure 11) appeared to have led to relatively rapid wood drying and consequently greatly increased downward movement.

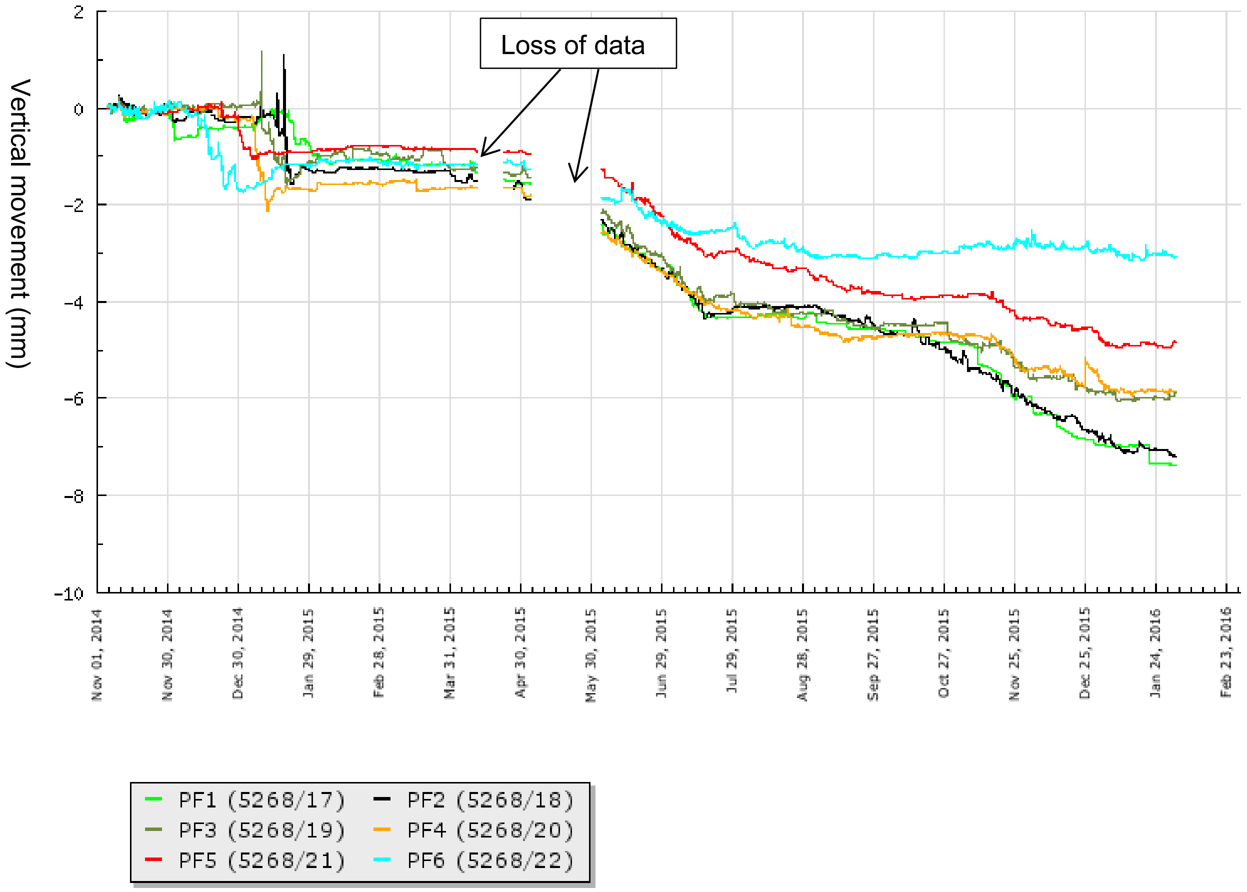

Figure 6 Movement measurements from sensors installed in the party wall

(Chart legends: "PF" means "party wall", the number in each label means the floor level. Negative readings indicate downward movement.)

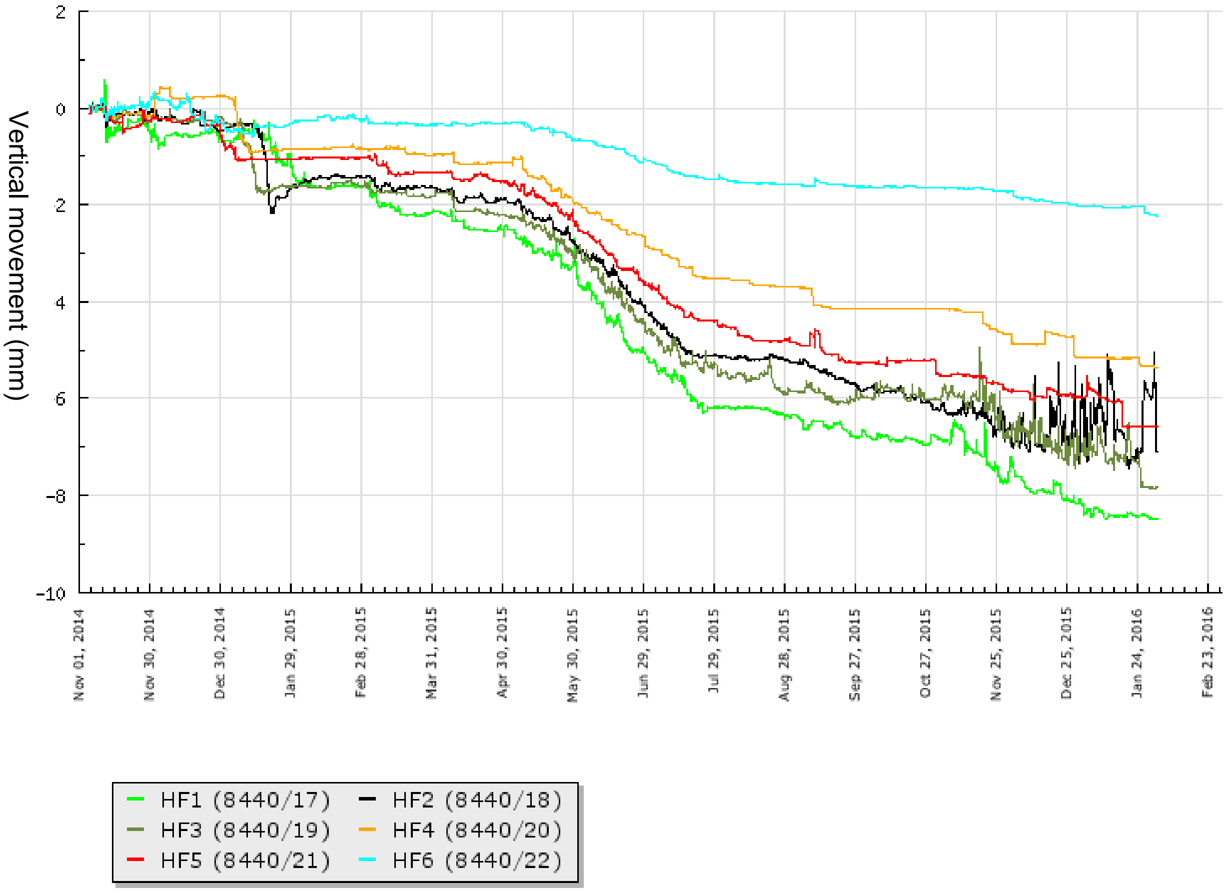

Figure 7 Movement measurements from sensors installed in the corridor wall

(Chart legends: “HF” means “corridor wall”, the number in each label means the floor level. Negative readings indicate downward movement.)

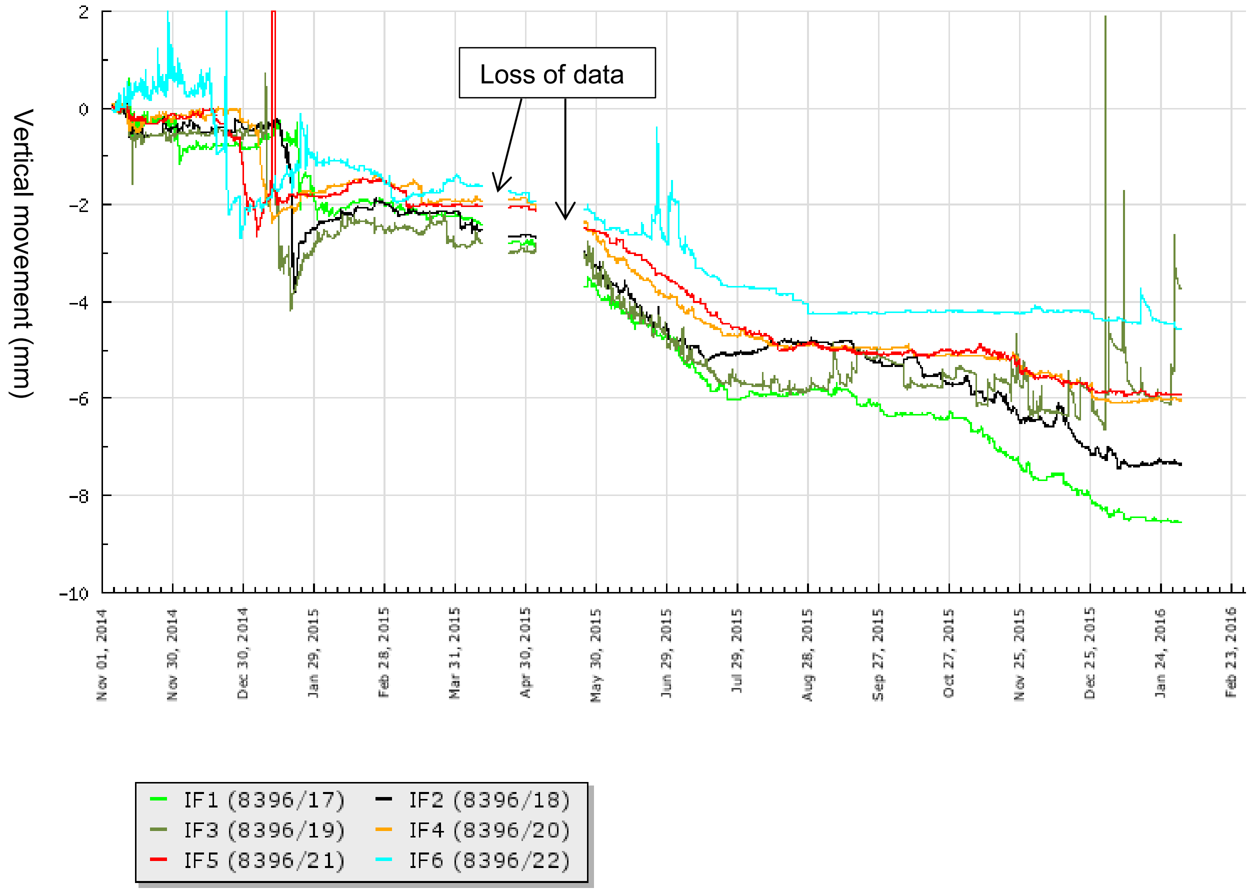

Figure 8 Movement measurements from sensors installed in the interior partition wall

(Chart legends: “IF” means “interior partition wall”, the number in each label means the floor level. Negative readings indicate downward movement.)

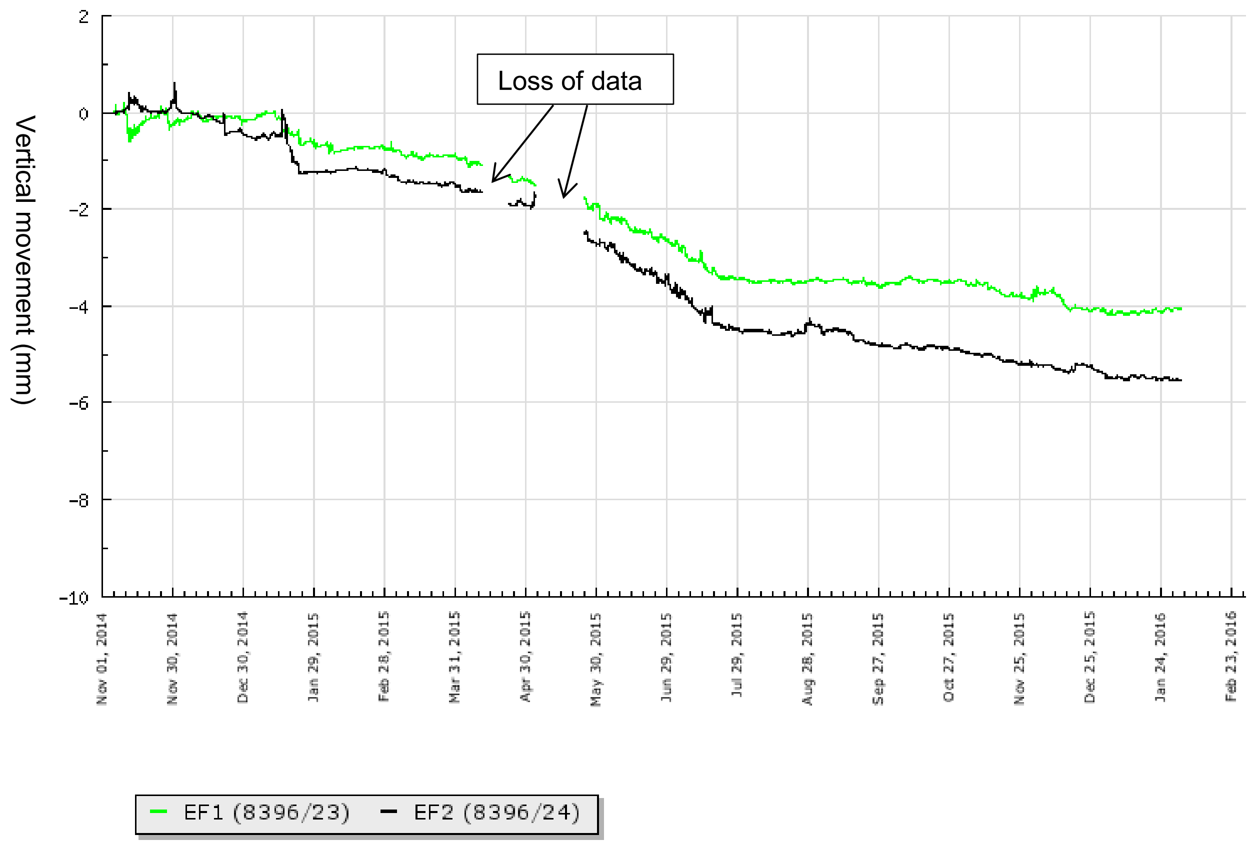

Figure 9 Movement measurements from sensors installed in the exterior wall

(Chart legends: “EF” means “exterior wall”, the number in each label means the floor level. Negative readings indicate downward movement.)

5.4 Comparison between Measured Movement and Calculated Shrinkage

The measured vertical movements are shown in Table 2. The interior partition wall, the corridor wall, and the party wall showed very similar amounts of vertical movement, with the former two having slightly higher downward movement than the party wall. These three walls were all interior walls and should have the same level of wood MC. Differences in local load, framing patterns, and with or without structural sheathing could have a small effect. The party wall had the lowest design loads (Appendix II, Table 3). The exterior wall had the smallest movement amount compared to the three interior walls, based on measurements on the bottom two floors. The main reason for its reduced downward movement would be the higher service MC in this wall as a result of being affected by the exterior weather conditions. The downward movement at leach location may further increase slightly, although most curves appeared to have levelled off. The measured movement over the entire height (from top of foundation to underside of roof trusses) reached 35 mm at the party wall, 39 mm at the corridor wall, and 39 mm at the interior partition wall after 15 months of monitoring. Note an estimated movement amount of 1 mm based on shrinkage prediction was assumed for the sill plate in order to calculate the entire building movement.

The effect of load on vertical movement is included in the Mid-Rise Wood-Frame Construction Handbook based on the research conducted by FPInnovations (Ni and Popovski 2015). However, the contribution of load to vertical movement is not required by the relevant standards, such as the CSA O86 (CSA 2014), nor is it covered in other design books (Breyer *et al.* 2006; CWC 2011) in North America. Therefore, a comparison between measured vertical movement and calculated shrinkage is made in this report without factoring in loading effects.

The shrinkage was calculated by the author for the dimensional lumber members over the height, without taking into account contribution of load or movement of the engineered wood members (Appendix IV, Table 4). The calculation used an average initial MC of 16% based on the measurements conducted during framing (as described above), a service MC of 8%, a shrinkage coefficient of 0.25% per 1% change in MC for the horizontal dimensional lumber members, and a shrinkage coefficient of 0.005% per 1% change in MC for the studs (based on the previous studies (Wang and Ni 2012; Wang *et al.* 2013; Wang and Ni 2014; Wang and King 2015) and design recommendations (CWC 2011)). In terms of the floor joists made of engineered wood products, the same MC, 8%, was assumed to be both the initial and the service MC, due to the lack of data for both shrinkage behaviour and moisture changes of such products during construction. By doing this, the movement of the engineered wood floor joists was ignored in this report. The contribution of plywood subflooring was also ignored because of its small dimension in the load path and the expected overall small contribution to vertical movement. There was also a lack of information for accurately predicting the shrinkage and compression of a subflooring material.

Table 2 compares the measured vertical movements with the calculated shrinkage. It can be seen that the measured vertical movement from most displacement sensors exceeded the calculated wood shrinkage, as shown by the numbers in red in the table. The exceeded amount for the entire building height ranged from about 12 mm at the party wall to 17 mm at the interior partition wall. The differences may be explained by the fact that the calculated shrinkage did not include the effect of the overall building load or the movement of the engineered wood members. In building design, estimating vertical movements should therefore include the effects of both shrinkage and vertical load[1]. Since estimating vertical movements caused by load is not straightforward, one possible approach would be to apply a factor to the calculated shrinkage to provide a better estimate for the overall vertical movement.

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[1] The project engineer estimated wood shrinkage to be about 5.8mm (0.23 in.) per floor and specified an allowance of 9.5 mm (3/8 in.) per floor for this building to account for effects of load and other variations.

Table 2 Differences in measured vertical movement and calculated shrinkage

Location		Floor	Measured movement on Feb. 2, 2016 (mm)	Calculated shrinkage (mm)	Difference (mm)*
Interior wall	Party wall	1st	7.4	4	3.4
		2nd	7.2	4	3.2
		3rd	5.9	4	1.9
		4th	5.9	4	1.9
		5th	4.8	4	0.8
		6th	3.1	2.5	0.6
		Sill plate***	1.0	1	0
		In total	35.3	22.6	**12.7**
	Corridor wall	1st	8.5	4	4.5
		2nd	7.1	4	3.1
		3rd	7.8	4	3.8
		4th	5.4	4	1.4
		5th	6.6	4	2.6
		6th	2.2	2.5	-0.3
		Sill plate***	1.0	1	0
		In total	38.6	22.6	**16.0**
	Partition wall	1st	8.5	4	4.5
		2nd	7.4	4	3.4
		3rd	6.0**	4	2.0
		4th	6.0	4	2.0
		5th	5.9	4	1.9
		6th	4.6	2.5	2.1
		Sill plate***	1.0	1	0
		In total	39.4	22.6	**16.8**
Exterior wall		1st	4.1	4	0.1
		2nd	5.5	4	1.5

* The shrinkage was estimated by the author for the wall plates and studs based on the MC measurements and other information available (see Appendix IV). A red value indicates that the measured downward movement exceeds the calculated shrinkage.

** A reading on Jan. 29 was used instead since large fluctuations occurred afterwards.

*** The sill plate was not measured so its calculated shrinkage was used in this table for calculating the entire building movement.

6 CONCLUSIONS

The MC and movement monitoring in this six-storey wood-frame building generated much useful information:

- The wood stayed dry with an average MC of about 15% based on measurements on the dimensional lumber (i.e., wall plates and studs) during the framing stage. The majority of the framing was completed in the relatively dry summer weather in the Lower Mainland of British Columbia.
- The moisture sensors installed to measure the MC on the first floor of an exterior and an interior wall, covering locations with the highest moisture risk such as sill plates, showed that the MC of the dimensional lumber slowly decreased from a range of 15 to 20% when the roof sheathing was installed, to a range of 9 to 15% half a year into service.
- As expected, the *in-situ* monitoring showed that it was colder and damper in the exterior wall in the winter season, particularly at locations close to the exterior sheathing, compared to the warmer and drier service conditions of the interior walls.
- The measured movement over the entire height (from top of foundation to underside of roof trusses) reached 35 mm at the party wall, 39 mm at the corridor wall, and 39 mm at the interior partition wall after 15 months of monitoring (i.e., after the roof sheathing was installed). The movement of the exterior wall appeared to be smaller, based on measurements on the bottom two floors.
- The measured vertical movement exceeded the calculated shrinkage, when the shrinkage calculation included only dimensional lumber wall plates and studs based on the measured MC change and did not take into account the effect of load or shrinkage of the engineered wood floor members.

7 RECOMMENDATIONS

- Estimating vertical movements should include the effects of both shrinkage and load. Due to the variations and difficulty of accurately predicting building movement, it is suggested that a good margin of safety should be added in design to avoid potential adverse consequences.
- Continue the field monitoring in this building to obtain a full understanding of vertical movement and wood MC changes over a longer period of time.
- Further investigate different service environments (humidity, temperature, and wood MC) of exterior walls and interior walls and their impact on vertical movement, especially in different climates, or when different wall assemblies (e.g., with exterior insulation) are used.
- Test engineered wood products to improve prediction of wood shrinkage and load-induced deformation of those materials.

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APPENDIX I: ILLUSTRATION OF DISPLACEMENT SENSORS ON EACH FLOOR

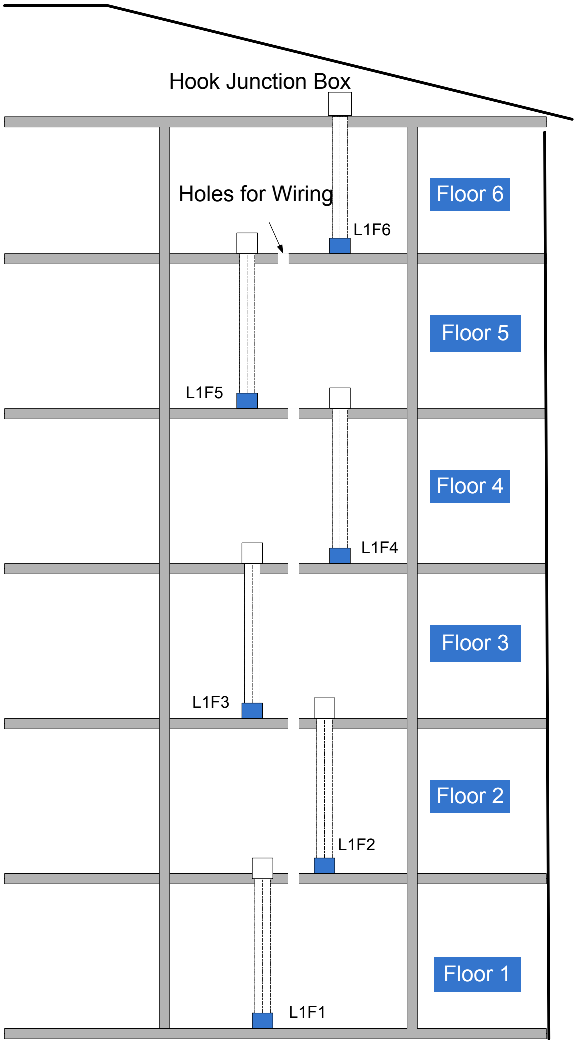

Figure 10 An elevation to illustrate displacement sensors installed on each floor

APPENDIX II: DESIGN LOADS

Table 3 Design dead loads and live loads at each floor of the four measurement lines

Wall location		Dead load (plf)	Live load (plf)	Snow load (plf)
Party wall	6th	115	0	28
	5th	222	26.7	28
	4th	328	53.3	28
	3rd	435	80	28
	2nd	542	107	28
	1st	648	133	28
Corridor wall	6th	559	0	525
	5th	858	478	525
	4th	1158	955	525
	3rd	1457	1433	525
	2nd	1756	1910	525
	1st	2056	2388	525
Interior partition wall	6th	90	0	0
	5th	378	317	0
	4th	666	633	0
	3rd	954	950	0
	2nd	1242	1267	0
	1st	1530	1583	0
Exterior wall	2nd	1731	1340	497
	1st	2031	1675	497

Design loads were provided by the project engineer. All data are expressed as linear loads, in plf (pounds per linear foot).

APPENDIX III: CLIMATE DATA OF MAY, JUNE AND JULY FROM 2011 TO 2015

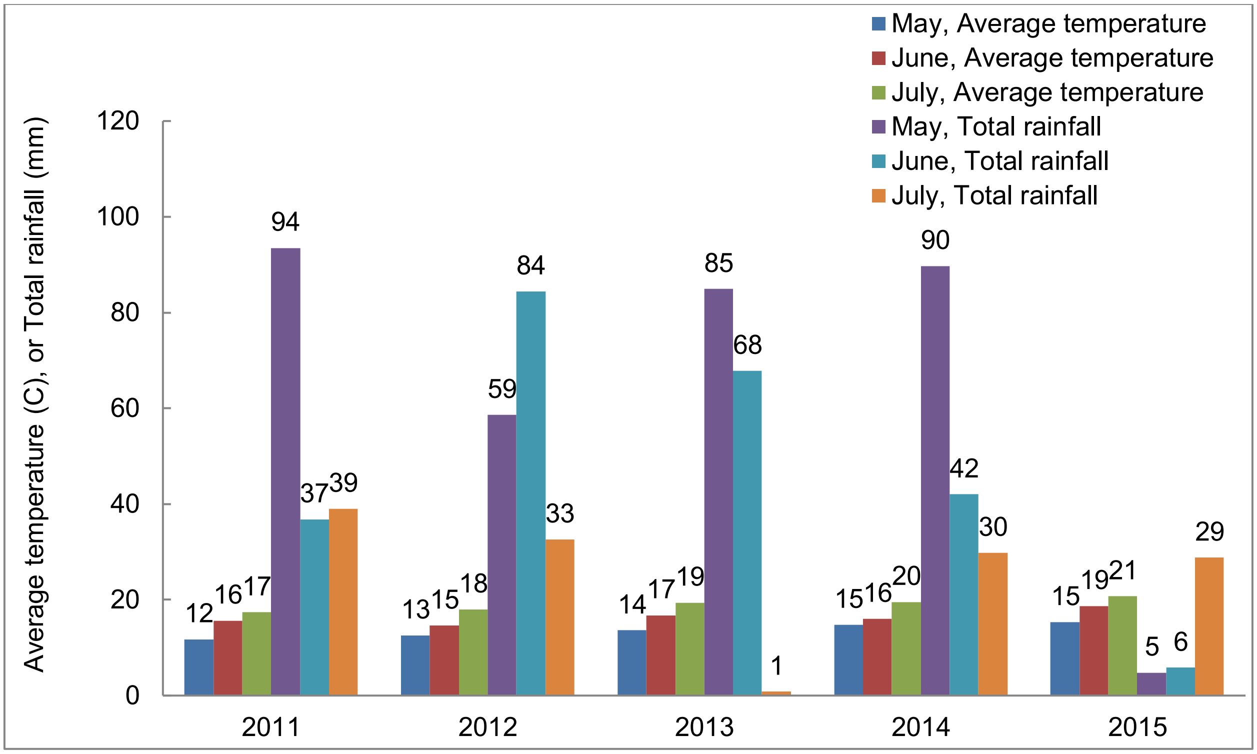

Figure 11 Average monthly temperatures and total rainfall amounts in May, June and July from 2011 to 2015[2]

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[2] 2 Daily climate data was downloaded from http://climate.weather.gc.ca/.

APPENDIX IV: CALCULATED SHRINKAGE

Table 4 Calculated shrinkage

Floor instrumented	Member	Dimension in load path (mm)	Shrinkage coefficient	Initial MC (%)	Service MC (%)	Calculated shrinkage (mm)	Calculated shrinkage for each floor (mm)
6th*	Top plates	76	0.0025	16	8	1.5	2.5
	studs	2440	0.00005	16	8	1.0	
5th	I-Joist	235	0.0025	8	8	0.0	4.0
	T&B plates	152	0.0025	16	8	3.0	
	studs	2440	0.00005	16	8	1.0	
4th	I-Joist	235	0.0025	8	8	0.0	4.0
	T&B plates	152	0.0025	16	8	3.0	
	studs	2440	0.00005	16	8	1.0	
3rd	I-Joist	235	0.0025	8	8	0.0	4.0
	T&B plates	152	0.0025	16	8	3.0	
	studs	2440	0.00005	16	8	1.0	
2nd	I-Joist	235	0.0025	8	8	0.0	4.0
	T&B plates	152	0.0025	16	8	3.0	
	studs	2440	0.00005	16	8	1.0	
1st	I-Joist	235	0.0025	8	8	0.0	4.0
	T&B plates	152	0.0025	16	8	3.0	
	studs	2440	0.00005	16	8	1.0	
Sill plates		38	0.0025	19	8	1.0	1.0
Total shrinkage						23.6	23.6

There were localized variations in the number of dimensional lumber installed between the roof truss and the studs below on the top floor. An average of two top plates was assumed.

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