Number 6

BUILDER INSIGHT

BC HOUSING
RESEARCH CENTRE

Builder Insight is a series of bulletins and companion videos designed to provide practical information on new technologies, research results, good building practices and emerging technical issues in residential construction to Licensed Residential Builders and others in the industry. This bulletin is produced by BC Housing, and was prepared by RDH Building Engineering Limited (RDH). It is based on the study Performance Monitoring of Rainscreen Wall Assemblies in Vancouver, British Columbia published by RDH.

Contents

Rainscreen Walls: Field Monitoring and Performance in British Columbia

Overview

In the mid 1990s, widespread moisture problems became apparent in the multi-unit residential building stock of coastal British Columbia.

Unlike historical cold-climate moisture problems, caused by vapour diffusion or air leakage from interior moisture, these new failures were attributable primarily to rain water penetration into face-sealed or concealed barrier wall assemblies. Typically, water infiltrated at interface locations and became trapped within the wall assemblies, where it could not drain or dry out. The resulting decay and corrosion required the rehabilitation of many affected buildings.

As part of the response to the widespread moisture problems, rainscreen wall assemblies became a popular construction practice throughout coastal B.C. Most new buildings and many rehabilitated buildings have been clad this way, on the premise that rainscreen wall assemblies are more tolerant of moisture infiltration, because they provide improved drainage with an increased potential for drying. They significantly reduce the accumulation of moisture within sensitive materials.

Rainscreen is a type of wall construction where the cladding (masonry, siding, panel or stucco) is separated from the back-up wall by

Typical four-storey, low-rise with rainscreen walls – ***Building 2 of the Monitoring Study****. Flashing at each floor level directs water from the air cavity to the exterior and allows ventilation.*

an open air cavity. This provides a capillary break, allows drainage of moisture that penetrates past the cladding and allows ventilation through the cavity to further promote drying. The air space effectively increases the durability of both the cladding and the back-up wall assembly. Face-sealed or concealed barrier assemblies rely on the cladding or the concealed membrane behind the cladding to stop all water penetration. They do not have adequate provisions for drainage from the back-up wall assembly or good drying capabilities.

Several Canadian research studies in the 1980s and 1990s supported the concept of rainscreen clad walls; however, the performance of this technology had not been demonstrated for multi-unit residential construction in British Columbia. To provide verification of acceptable performance, an industry-sponsored program was established to monitor the long-term performance of rainscreen walls in five buildings constructed in Vancouver.

The Monitoring Study

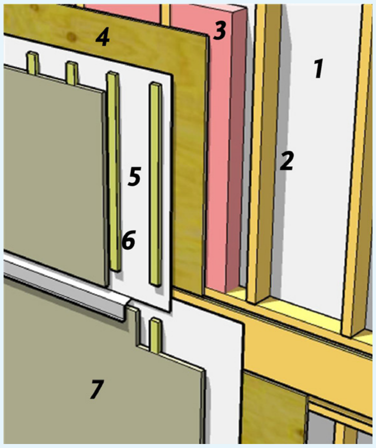
Three new and two rehabilitated multi-unit residential buildings were selected for the monitoring study, which was initiated in 2000. For each of the buildings, at least five different rainscreen wall locations were instrumented with sensors to measure temperature, relative humidity (RH), moisture content, relative wetness and pressure differential within the wall assemblies. Temperature and RH levels were also monitored for sample interior suites and weather stations were installed on each rooftop to measure wind, rain, temperature and RH. Finally, driving rain gauges were installed at two locations on each building façade to understand local driving rain loads.

For each building, the majority of the monitoring locations were chosen to represent areas most likely to be wetted during severe weather (for example, on the east and south elevations at key details such as vents, windows, balcony transitions, and saddle flashings where historically, high moisture levels have been observed). Finally, locations were also selected away from details, to act as controls.

Rainscreen Wall Performance

Data from six years of field monitoring across the five different buildings show that rainscreen walls are generally working well in Vancouver's coastal climate. Seasonal moisture levels in wood and gypsum materials, most sensitive to moisture damage, remain below safe thresholds. However, it was also found that rainscreen walls, like all wall assemblies, are susceptible to damage if exposed to excessive moisture at vulnerable construction details. Also, insulation placement, ventilation behind the

*Eight monitored wall locations and weather sensors – **Building 3 of the Monitoring Study**.*



Generic wood-frame stucco rainscreen wall assembly.

1. *Interior gypsum board and polyethylene vapour barrier*
2. *Wood framing*
3. *Fiberglass insulation*
4. *Plywood sheathing*
5. *Sheathing membrane*
6. *Wood strapping/air space*
7. *Stucco cladding on backer board*

cladding, exterior and interior environments and detailing all have a large influence on rainscreen wall performance.

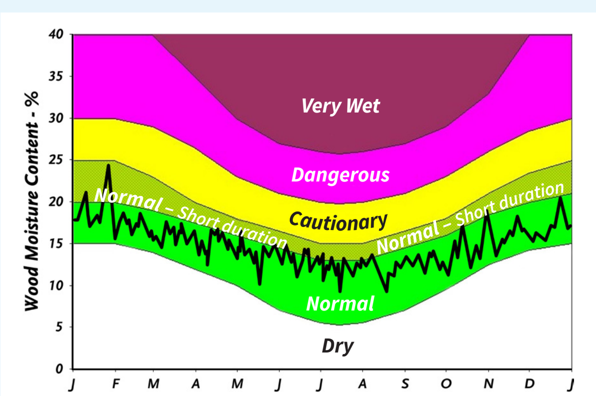
Moisture Content Varies Seasonally

Like the climate we live in, the microclimate within a wall is variable, and this impacts the performance of wall assemblies. During mild and rainy winter months, the sheathing behind rainscreen claddings will be exposed to RH levels of 80-100% for prolonged periods, which results in a moisture content of up to 20% (based on equilibrium conditions with the average RH). During prolonged rainy periods, it is normal for the sheathing moisture content to rise up to 25% for a few days when the cavity RH is sustained at 95-100% RH.

In the strapping or sheathing, a sustained (>1 month) moisture content of 20 to 30% indicates long-term exposure to high RH levels (>90%) within the rainscreen cavity. This could result from a rainwater leak into the cavity, condensation or poor cladding ventilation. A moisture content above approximately 28% (fibre saturation point of wood) is most likely the result of a rainwater leak directly contacting the affected sheathing or strapping and should be further investigated.

Conversely, during summer months, moisture content readings above even 20% could indicate abnormal performance. These are important factors to take into consideration when performing building condition assessments at different times of year.

Figure 1



Seasonal moisture content ranges expected within woodframe rainscreen wall assemblies.

Figure 1 compares typical seasonal moisture content ranges for sheathing within a wood-frame rainscreen wall in coastal B.C. (similar to that in the generic assembly shown). The black line plots typical measured values from the monitoring study. Normal, cautionary and dangerous ranges were developed from field measurements and computer modeling based on commonly accepted thresholds for wood products.

Understanding seasonal variations in wood moisture contents as well as the specific properties of wood products, is important when assessing the condition of the building enclosure components.

As moisture content measurements vary with temperature, wood species and engineered board product, readings must be interpreted accordingly. The wood should be physically examined for staining or damage to verify the conditions indicated by moisture readings.

Detailing is Critical

Even with more moisture tolerant rainscreen wall assemblies, proper detailing of all penetrations through the wall assembly (pipes, ducts, hose-bibs, etc.), and transitions between walls and adjacent elements (windows, balconies, roofs, etc.) are very important. The extent of damage observed in past decades within face-sealed or concealed barrier approaches will not likely result with rainscreen wall assemblies. However, localized moisture damage and microbial growth may still result from water penetration or an excessive moisture loading. Therefore, details must ensure that water can drain out, dry out and not be trapped within the wall assembly.

During the study period, two detectable rainwater leaks past the cladding were identified within the conventional, strapped-cavity rainscreen walls. The first leak occurred at a poorly constructed flashing termination (an exhaust vent through vinyl siding). Small amounts of water infiltrating over time raised the sheathing moisture content up to 30% for several weeks during the first winter of monitoring. Drying did not occur until spring, and only after the detail was disassembled and the deficiency was corrected. Left uncorrected, localized damage to the plywood sheathing would have been likely.

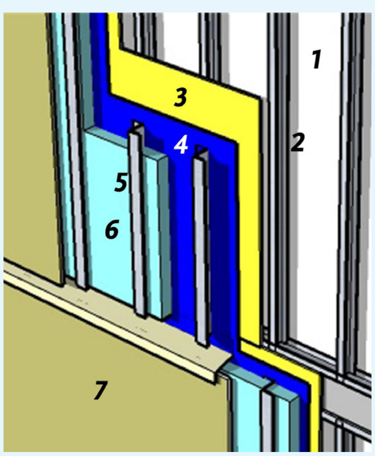
The second leak past the cladding occurred below a window corner subject to high rainwater runoff. During a severe winter storm, water penetrated the stucco cladding and wetted the wood strapping, but not the sheathing. For the remainder of the winter, the strapping sustained elevated moisture levels, drying out in the spring. Wood strapping will likely be exposed to occasional wetting during severe storms in most walls, particulary where exposed to runoff. Treated wood is therefore generally recommended for highly exposed walls, or where the cladding and water shedding surface may allow for water penetration into the cavity (for example, open rainscreen designs types).

The type of cladding is less critical to the performance of a drained and ventilated rainscreen wall than traditional wall assemblies. Stucco, fiber cement board and vinyl siding all had similar performance at the five monitored buildings.

Exterior Insulated Rainscreen Walls Work Best

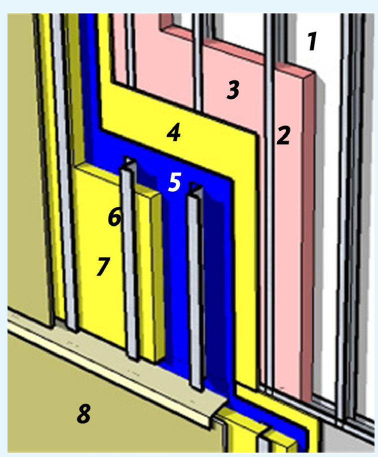
The highly exposed, 30-storey high-rise building monitored was constructed with an exterior insulated wall assembly. This wall assembly consists of stucco cladding on backerboard over a ventilated and drained air space, extruded polystyrene and a self-adhered air/vapour/water barrier membrane applied directly to fiberglass-faced gypsum sheathing. With the insulation outside the sheathing, moisture sensitive materials are kept warm and dry, close to interior conditions. This rainscreen wall assembly proved most resistant to moisture from driving rain and exterior and interior humidity. All sensors in this building returned dry readings for the entire year. No evidence of exterior moisture penetration or condensation was observed at any of the monitored wall locations. Inward or outward vapour drive was not found to be an issue with the assembly.

Hygrothermal modeling also shows that, in the case of small infrequent leaks past the impermeable air/vapour/water barrier, drying can occur towards the interior when vapour permeable interior finishes are used.



*Exterior Insulated Rainscreen Wall Assembly of **Building 5** of the Monitoring Study.*

1. *Painted gypsum drywall*
2. *Steel stud framing (no insulation)*
3. *Exterior grade fibreglass faced gypsum*
4. *Self-adhered bituminous membrane*
5. *Steel Z-girts/air space*
6. *Rigid polystyrene insulation*
7. *Stucco cladding on backer board*



*Split Insulated Rainscreen Wall Assembly of **Building 3** of the Monitoring Study.*

1. *Painted gypsum drywall*
2. *Steel stud framing*
3. *R-8 fibreglass batt insulation*
4. *Exterior grade fibreglass faced gypsum*
5. *Self-adhered bituminous membrane*
6. *Steel Z-girts/air space*
7. *Semi-rigid mineral wool insulation*
8. *Stucco cladding on backer board*

Extra Insulation Requires Careful Design

Rainscreen walls can use insulation placed both inside the stud space and outside the sheathing. These wall assemblies are referred to as dual or split insulated. This is sometimes done to attain required thermal R-values while minimizing the overall wall thickness.

Building 3 of the monitoring study was rehabilitated with a dual insulation wall assembly. The original assembly consisted of face-sealed stucco over an insulated steel stud wall back-up. During rehabilitation the polyethylene sheet was removed, but the existing fibreglass batt insulation in the steel stud cavity was retained. New gypsum sheathing, a self-adhered air/ vapour/water barrier membrane, 2″ of mineral wool insulation and new stucco cladding were added to the exterior side of the walls.

Following the enclosure rehabilitation, the average winter-time interior RH was sustained in excess of 60%. This level was high compared to typical wintertime levels of 35-50% measured within the other monitored buildings in the study.

Over several years, monitoring of this building showed seasonal elevated moisture conditions at all eight monitored locations. RH levels of greater than 90% (with peaks up to 100%) within the stud space, and gypsum sheathing moisture contents greater than 1.5% (dangerous level) were recorded from October to March every year. Field exploration confirmed the high readings and wet conditions within the wall.

Analysis of the wall assembly and boundary conditions determined that warm moist interior air leaking into the stud cavity and vapour diffusing through the painted interior gypsum resulted in the constant wetting observed. The distribution of insulation and location of vapour retarding layer (self-adhered membrane on gypsum sheathing) resulted in a wall assembly that was too sensitive to the interior conditions. Since reducing the permeability of the interior finishes did not adequately address the problem and could potentially introduce other problems, the building underwent a mechanical system retrofit to improve suite ventilation and to lower the RH in wintertime.

In dual or split insulated wall assemblies, interior and exterior climate considerations dictate how insulation, vapour and air barrier elements must be used. Airflow, vapour diffusion and rainwater penetration control are critical for these assemblies. Due to the large variability of occupant and HVAC driven interior conditions, these assemblies may be more risky. When properly designed and considerations are made for vapour permeability of the materials and insulation ratios, split insulated wall assemblies can perform better than stud space insulated walls.

Rainscreen Walls Benefit from Cladding Ventilation

The function of the air space between the cladding and the backup construction of a rainscreen assembly is to provide drainage, ventilation, and a capillary break. Drainage removes any bulk water that penetrates past the cladding. However, drainage alone cannot remove small droplets of bound water or water absorbed into the sheathing, strapping or cladding. Ventilation is shown to have a significant impact on this aspect of performance in rainscreen walls. A 10mm to 19mm continuous open gap behind the cladding, which is common for most residential construction, is generally sufficient.

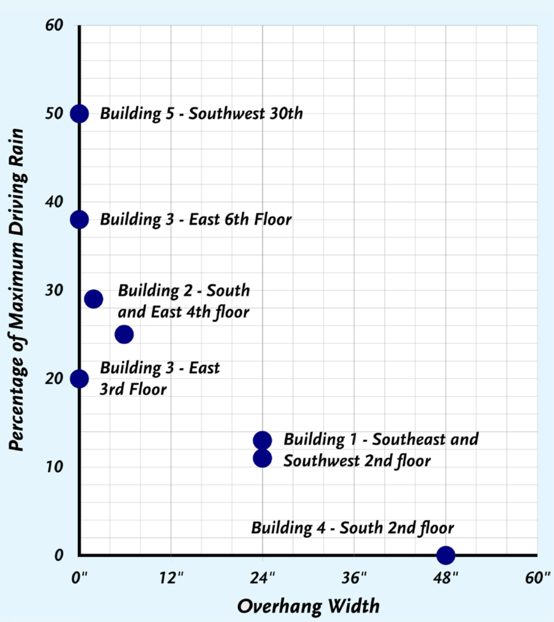
This air space is typically created using vertical strips of treated wood strapping/ furring or metal girts. Proprietary products are also available to create this gap. Some proprietary drain mat products are impermeable to vapour, therefore ventilation is critical and extra care must be taken not to block any of the vent openings with these systems.

Cladding ventilation reduces relative humidity within the rainscreen cavity and serves to help dissipate the small amount of water that may get past the cladding and through penetration details from time to time. Absorptive claddings such as brick, stucco, or fiber-cement can also introduce vapour into the cladding cavity. Ventilation can remove this moisture as well. Where ventilation rates are insufficient, an inward vapour drive can result in increasing moisture within the wall structure to the interior. To ensure adequate ventilation, large and unrestricted vent openings should be provided through the cladding. Continuous cross-cavity strip vent openings are ideal. Discrete vent openings (such as the ones used in brick veneer) are also effective but they can reduce the ventilation flow, and result in moisture ingress if designed or constructed incorrectly.

Venting of the wall cavity at both the top and bottom is the most effective and allows for continuous ventilation. Top vent openings must be protected by flashing or baffles. The termination of a wall at a soffit should not allow direct continuation of the rainscreen cladding ventilation into the attic.

Finally, consideration for building shrinkage or sustained deflection must be made to prevent cladding ventilation gaps from closing up. Cross cavity vent openings should be designed to account for normal floor to floor height wood shrinkage or concrete slab deflection.

Figure 2



Roof overhang width versus measured percentage of driving rain potential.

Benefits of Overhangs

Roof overhangs and other projections from the building façade such as balconies or eyebrows, reduce the amount of driving rain against sensitive cladding interfaces and details. Restricting the wetting of a wall naturally reduces the risk of moisture damage.

The five buildings in the study have varying roof overhang widths. Driving rain gauges placed on the vertical façade of the building enclosures provided some insight regarding the magnitude of the reduction of driving rain with overhang width.

While the annual rainfall amounts recorded were similar across all five buildings, wind speed differences, particularly at the four-storey buildings, account for the large differences in actual driving rainfall. Figure 2 compares the effect of roof overhang width versus driving rain accumulation at varying locations for all five monitored buildings. The measured driving rain is compared to the cumulative potential driving rain, based on horizontal rainfall, wind speed and wind direction measured at the roof. As shown, buildings with large overhangs (24-48") received significantly less driving rain than buildings with no overhang or overhangs less than 12". A 48" overhang on a relatively sheltered four-storey building can reduce driving rain on its façade to negligible levels. As anticipated, when overhangs are not present, upper floors received more driving rain than lower floors; however increased wetting from water cascading down over the lower wall areas is not shown by this figure. Taller buildings have greater wind-driven rain potential due to these wind spatial differences.

Moisture from the Inside Requires Consideration

The impact of the interior environment on wall assemblies is a critical design factor. This is especially true for rehabilitation projects when modifications include increasing the building airtightness and using alternate vapour retarding layers and insulation strategies. The measured interior conditions varied across all five buildings and none could be considered average for design standards (for example, controlled to 21°C year-round). The temperatures varied largely as a result of occupant behaviour and the interior dewpoint. Relative humidity varied considerably as a function of moisture generation and suite ventilation rates. As none of these buildings have air conditioning systems, average interior suite temperatures of 25-27°C were normal during July and August. Interior temperatures of up to 34°C were recorded during the hottest summer days at all buildings, and even more often at the penthouse suites of the high-rise building. Some low interior wintertime RH levels (<40% average) were measured. Suites that had low wintertime RH levels (between 30 and 40%) had sufficient – and in one case excessive – ventilation rates. High wintertime RH levels (between 50 and 70%) were only observed in Building 3 and were found to be primarily due to insufficient suite ventilation and partially from occupant behaviour.

Air Leakage within Multi-Unit Residential Buildings is an Issue

As part of the study, air leakage testing was performed to understand and quantify air leakage within multi-family buildings. Three buildings from the monitoring study and a fourth building also affected by interior humidity problems were tested. A test method was developed using multiple fan doors and pressure neutralizing to isolate and quantify air leakage between adjacent suites, floors, common spaces and through the exterior enclosure. Results gathered demonstrate the impact that inter-suite air leakage and enclosure airtightness has on the ventilation rates and interior RH levels and on the overall wall performance recorded. These findings are summarized on page 8.

- Modern exterior walls, with a peel-and stick air/ vapour/ moisture barrier, were significantly more airtight than traditional walls constructed with polyethylene or housewrap/building paper.
- Significant air leakage occurs between adjacent suites and between suites and common areas within multi-unit residential buildings. These interfaces should be airtight for noise, odour and fire/smoke control reasons.
- Up to 2/3 of the hourly air exchange came from adjacent suites and corridors (not exterior) in some of the suites tested.
- The more airtight the exterior enclosure (as in new construction or rehabilitation work), the greater inter-suite air leakage becomes an apparent and significant issue.
- Common residential mechanical systems using pressurized corridors and in-suite mechanical exhaust perform poorly in airtight buildings unless controlled in-suite exhaust (with sufficient make-up air) is provided. Many occupants apply weather stripping or block off door-undercuts to reduce noise and odours. This exacerbates the problem, as air from adjacent suites is drawn in instead. Ideally, fresh air should be ducted into each suite directly, by-passing the corridor spaces.
- Rehabilitated buildings will likely require mechanical system revisions to account for tighter building enclosures. If not, then interior humidity and condensation problems may develop.
- Low noise bathroom and kitchen exhaust fans that are automated or running continuously may be necessary to provide adequate ventilation within suites at certain times of the year. In addition, make-up air flow needs to be provided by passive vents or unblocked entry door undercuts. With continuous ventilation, heat recovery ventilators (HRV's) may be warranted in order to reduce energy costs.

HVAC Design and Rehabilitation Considerations

While an airtight building enclosure is necessary for energy efficiency and thermal comfort, it requires more effective mechanical ventilation systems.

Airtight buildings place higher demands on the mechanical ventilation systems. Deficient systems can have serious ramifications for building performance and occupant comfort.

This is especially important when rehabilitating to increase the airtightness of a building enclosure. In older buildings, relatively high levels of air leakage have typically been allowed both through and around window and wall assemblies.

As a result, mechanical designers may assume that a significant portion of a building's overall ventilation requirements take care of themselves. When this type of building needs rehabilitation to reduce water infiltration and repair damage to underlying wall components, the conventional sheathing paper is typically replaced with continuous, sealed air and watertight membranes. The existing windows are often replaced with higher performance air and watertight windows, and sealant is used around all penetrations and joints.

Air leakage testing of rehabilitated buildings confirms that the renewed building enclosure is much more water and airtight than the original construction, so any previous assumption of exterior air leakage is no longer valid. The percentage of inter-suite stale air leakage was found to increase after rehabilitation, when the air exchange to the exterior was reduced. After rehabilitation, the interior relative humidity increases unless ventilation capacity is adjusted accordingly, or occupants keep their windows open. Condensation and mould growth on windows and exterior walls is an issue following some building enclosure rehabilitations because of insufficient interior ventilation.

As part of a building enclosure rehabilitation program, check the HVAC system to confirm it will function adequately once the new cladding and glazing assemblies are installed. If adequate performance cannot be achieved, include adjusting the building's HVAC system into a rehabilitation program. This may require the installation of adequate and tamper-proof exhaust vents and dedicated fresh air-returns into and within suites to improve the ventilation. Other measures may be required.

Key Points

The following recommendations are supported by the results of the study:

- ❑ Rainscreen wall assemblies are generally effective in managing exterior moisture loads from wind-driven rain in coastal British Columbia.
- ❑ Appropriate detailing and construction of interfaces and penetrations are important for the success of rainscreen wall assemblies.
- ❑ For greater durability, wood strapping/ furring used to create the rainscreen cavity should be treated for exposure to occasional rainwater wetting and a high humidity environment. Plywood or OSB sheathing will be exposed to high relative humidity and borderline safe moisture content levels for several months of the year (~20%).
- ❑ Consider treated plywood as an additional safety factor for exposed buildings.

- ❑ Split or dual insulated wall assemblies require design by a building professional. The distribution of insulation and location of vapour and airflow control layers is a critical factor in performance, as is control of interior relative humidity.
- ❑ Consider an entirely exterior insulated wall assembly for improved performance and increased moisture tolerance.
- ❑ Cladding ventilation reduces inward driven moisture from absorptive claddings – but if insufficient, elevated moisture levels from inward driven vapour may result.
- ❑ Roof overhangs significantly reduce the amount of driving rain on a building façade.
- ❑ High RH levels within suites may develop as the result of insufficient ventilation systems within modern airtight buildings.
- ❑ Care must be taken to avoid air leakage between interior suites and provide a balanced mechanical system.
- ❑ Mechanical system revisions should be considered when rehabilitating the building enclosure.

More Information

- Building Enclosure Design Guide – Wood-Frame Multi-Unit Residential Buildings
- BC Energy Step Code Builder Guide
- Building Envelope Guide for Houses Part 9 Residential Construction
- Performance Monitoring of Rainscreen Wall Assemblies in Vancouver, British Columbia

All bulletins are available at www.bchousing.org

- Subscribe to receive Builder Insight bulletins, available at www.bchousing.org
- The Performance of Rainscreen Walls in Coastal British Columbia. Graham Finch, MASc Thesis. Department of Civil Engineering, University of Waterloo, 2007

About BC Housing's Research Centre

BC Housing's Research Centre works in collaboration with housing sector partners to foster excellence in residential construction and find innovative solutions for affordable housing in British Columbia. Sharing leading-edge research, advances in building science, and new technologies encourages best practice. The Research Centre identifies and bridges research gaps to address homelessness, housing affordability, social housing challenges and the needs of distinct populations. Mobilizing knowledge and research expertise helps improve the quality of housing and leads to innovation and adoption of new construction techniques, Building Code changes, and enhanced education and training programs. Sign up to receive the latest news and updates from BC Housing's Research Centre at www.bchousing.org/subscribe.

BC HOUSING RESEARCH CENTRE

1701-4555 Kingsway, Burnaby, BC V5H 4V8

Phone: 778-452-6482
Toll-free: 1-866-465-6873

Email: research@bchousing.org
www.bchousing.org