eSim 2018
«BUILDING SIMULATION TO SUPPORT BUILDING SUSTAINABILITY»
IBPSA Canada
The Canadian Chapter of the International Building Performance Simulation Association
Le chapitre canadien de International Building Performance Simulation Association

# Condensing Rooftop Units – A Canadian Cost-Benefit Study

Daniel Knapp
Arborus Consulting, Ottawa, Canada

***Abstract:*** *This market research and simulation study, carried out for the Office of Energy Efficiency at Natural Resources Canada, analyzes the cost-benefit of adding condensing heat exchangers to rooftop units in NECB archetype buildings in Canada's climate zones. This study models and analyzes the addition of condensing furnaces to rooftop units alone and in combination with energy recovery and demand-controlled ventilation to understand the interactions and possible energy and cost savings when controls are optimized for the mix of technologies applied. Energy cost savings due to condensing furnaces are significant. However, payback periods are found to be longer than 10 years and the economics of the current market remain challenging. The primary barrier to the widespread adoption of condensing furnaces in rooftop units is the high cost of purchasing condensing rooftop units from specialized manufacturers who only offer condensing heat exchangers in premium packages.).*

***Keywords:*** *cost-benefit, condensing heat, rooftop units, CAN-QUEST, NECB*

## INTRODUCTION

The Office of Energy Efficiency at Natural Resources Canada commissioned this study of the modelled performance of condensing rooftop units (RTUs) in archetype buildings developed for the National Energy Code of Canada for Buildings (NECB) 2011 (National Research Council Canada, 2011). The goal of this study is to analyze the cost-benefit of adding condensing heat exchangers to rooftop units in a selection of NECB archetype buildings in each of the six Canadian climate zones (4, 5, 6, 7a, 7b, and 8)[1] in order to determine the conditions under which the use of condensing furnaces provides a net cost-benefit.

This study models and analyzes the addition of condensing furnaces to rooftop units alone and in combination with exhaust air energy recovery (ERV) and/or demand controlled ventilation (DCV) to understand the interactions and possible energy and cost savings when controls are optimized for the mix of technologies applied.

Rooftop units are widely used in the commercial building market for heating, ventilating, and air-conditioning. They are used across a wide range of building types and sizes, and are used in over half of the air conditioned commercial floor space in North America (Kosar et al., 2014). Rooftop units provide a factory made assembly in a box that can be dropped onto a roof with minimal installation effort and cost, and can greatly simplify mechanical design.

A rooftop unit will typically sit over a curbed opening in the roof. Different areas of the building which are under different loads or operating schedules can be served by different rooftop units. Rooftop units can serve single or multiple zones and can provide either a constant or variable volume flow rate of supply air. They usually include a supply fan along with a complete cooling package comprised of an evaporator (cooling coil), and a compressor in combination with an air-cooled condenser. In Canada, heating in rooftop units is predominantly provided by natural gas-fired furnaces. Gas-fired furnaces typically operate with a thermal efficiency of 80% with either one or two-stages of heating and a limited ability to modulate the heat capacity. This limitation reduces the part load performance of rooftop units, a problem which is exacerbated in units with oversized heating capacity. In a gas-fired furnace, a single heat exchanger transfers heat between the products of combustion and the supply air stream.

In order to achieve higher heating efficiencies, condensing furnaces, which have become the standard in the residential heating market, have recently been introduced to rooftop units. In a rooftop unit with condensing heat, a second heat exchanger is added. The primary heat exchanger is typically a tube-type heat exchanger while the secondary heat exchanger is typically a finned tube which is designed to maximize the heat exchange area and allow for the transfer of heat at a lower temperature difference.

Exhaust gases from the combustion of heating fuel pass through the primary heat exchanger where they give up most of their heat and then through the secondary heat exchanger where they are further cooled until water vapour condenses out of the exhaust. The condensation of water vapour releases a significant amount of latent heat and improves the peak thermal efficiency from 80% to over 90%. One challenge presented by this condensation is that the condensate needs to be drained away from the rooftop unit. As the water condenses, exhaust gases are dissolved into the water and the resulting condensate is acidic and corrosive. Neutralizers are usually added to the condensate before it is drained to a sanitary drain. The drainage system must be designed to avoid freezing of the condensate, and the neutralizing system requires annual maintenance (mostly to replenish the neutralizer). Frost buildup has also been observed where the cool and moist exhaust gases exit the rooftop unit (Kosar, 2014). Apart from concerns about

[1] NECB climate zones are defined by 18ºC heating degree days. Zone 4: HDD < 3000, Zone 5: 3000 ≤ HDD < 4000, Zone 6: 4000 ≤ HDD < 5000, Zone 7a: 5000 ≤ HDD < 6000, Zone 7b: 6000 ≤ HDD < 7000, Zone 8: HDD ≥ 7000.


ISBN 978-2-921145-88-6

freezing, the maintenance impact is relatively minor and can be incorporated into an existing annual preventative maintenance program. The cost of adding a condensate neutralizer system, such as those used for condensing boilers, is marginal at approximately $72 ($65 USD) (Kosar and Cushman, 2013).

From an energy-saving perspective, the addition of the secondary heat exchanger reduces heating energy but can also increase the energy required to drive the supply fan. With two heat exchangers, the static pressure is increased on the supply fan which means that the supply fan needs more power to provide the same supply air flow rate. The supply of heated air is dictated by a call for heating from the space temperature sensor (space thermostat). However, since supply fans in rooftop units are designed to provide ventilation during operating hours, they will be operating during periods when there is no call for heating. For these non-heating hours, the addition of a secondary heat exchanger will lead to an energy penalty with no net energy benefit. The benefit of natural gas savings from the condensing heat exchanger needs to be weighed against the cost of increased fan energy, especially in those climates with lower heating hours and in rooftop systems with low demand for heating.

### Market Conditions

The authors reached out to a number of North American rooftop manufacturers, and to the emerging technologies group at the Gas Technology Institute to better understand the current state of the market for condensing rooftop units. As noted in the presentation given by Douglas Kosar at the Gas Technology Institute (Kosar, 2014), condensing rooftop units are still considered a specialized product and they are not being manufactured by the major market players. A small number of companies are making condensing rooftop units, but they are largely targeted at specific applications, such as dedicated outdoor air systems, where the demand for energy efficiency is high. The following companies are producing condensing rooftop units: Reznor, Modine, Engineered Air, and ICE (Munters). A fifth manufacturer, Bousquet, is currently testing condensing gas burners. The major manufacturers which produce commodity rooftop units - such as York, Carrier, Daikin McQuay, and Trane - are monitoring the market and developments in building codes, but in conversations with the authors indicated that they have no plans to introduce condensing heat exchangers in the immediate future. The primary concern among manufacturers is that the small packaged RTU market is largely targeted at meeting the minimum standards at the lowest possible price. As such, the large manufacturers do not believe that there will a large enough demand from the market (owners and mechanical designers) to justify investment in the research and development that would be required to add condensing heat exchangers to commodity rooftop units.

As the condensing rooftop market is currently specialized, the cost premium to move from a standard commodity rooftop unit to a rooftop unit with condensing heat is very high. Condensing units tend to be three to four times more expensive than standard units and as much as two times more expensive than a high efficiency unit (which would be packaged with high cooling efficiency, and more efficient fans, and could include variable speed control). For example, in a standard unit with 35 kW (10 tons) of cooling capacity, a base model rooftop unit from a large commodity manufacturer was quoted at $9,900 and condensing-heating rooftop units from two specialty manufacturers were quoted at $44,130 and $35,900 respectively. However, the cost of going from a specialty unit without condensing heat to a specialty unit with condensing heat is only $3000-$5000, depending on the heating capacity. In general, the cost premium in condensing units is due to a number of factors beyond the addition of a secondary condensing heat exchanger: condensing units are constructed with durable, high quality components; the exterior shell is made of a higher quality galvanized steel, which is often double-walled with foam insulation; condensing units use higher quality paints, and the access doors are fully gasketed and hinged for improved air sealing and easy maintenance access; the cooling system operates at much higher peak and part load efficiency with digital compressors, and ECM premium efficiency motors on the condenser fans; the supply fans are of a higher quality with higher efficiency ECM motors and variable speed control; the gas heating systems are fully modulating with a turndown ratio as high as 25:1. In summary, these units will be much more durable, lasting 25-30 years instead of the standard 15 years, and will use less electricity for ventilation and cooling and less gas for heating.

The market for condensing rooftop units is young and appears to be developing slowly. As such, a net cost benefit will likely be confined to high energy-use applications where a premium rooftop unit will be in demand. These applications include dedicated outdoor air systems, ventilating systems with high outdoor air fractions and high operating hours, systems serving perimeter zones with high heating loads (Kosar et al., 2014), and systems in any applications where premium package RTUs are typically specified.

## MODELLING APPROACH

The performance of condensing rooftop technologies is analyzed by considering their placement in five NECB archetype building energy models developed in CANQUEST, which uses the DOE2.2 simulation engine. The five archetype models selected are the Big Box Store, the Medium Office, the Primary and Secondary Schools, and the Warehouse. For each archetype building, the system size and type are used to select rooftop units from a variety of manufacturers. The performance of the rooftop units,


ISBN 978-2-921145-88-6

including the rated thermal efficiency, and the increased pressure drop on the supply fans due to the addition of a secondary heat exchanger were specified for each rooftop system of the archetype buildings. Four different types of rooftop units were specified for each appropriate system: a base model, a higher efficiency model with ERV and DCV, a condensing rooftop unit, and a condensing rooftop unit with ERV. ERVs specified are enthalpy wheels with a sensible effectiveness of 72% and a latent effectivenss of 62%. Heat recovery is modulated and frost buildup is controlled by varying the speed of the energy wheel. Note that ERV and DCV are modelled in the rooftup units only, and not in the whole building which may contain systems which are not rooftop units (i.e. in the primary and secondary school archetypes).

Each building is modelled in six Canadian climate zones. The cities chosen to represent these zones are Victoria (Zone 4), Windsor (Zone 5), Montreal (Zone 6), Edmonton (Zone 7a), Fort McMurray (Zone 7b), andYellowknife (Zone 8). Envelope performance is varied to match the NECB prescriptive requirements in each climate zone, however window-to-wall ratio is left unchanged.

Modelling a condensing heat exchanger in CAN-QUEST is done by specifying the peak thermal efficiency and by using the part load curve for condensing furnaces from the NECB 2011 (National Research Council Canada, 2011). The part load curve for a condensing furnace has a much better part load performance than that for a non-condensing furnace. This difference in part load performance is a reflection of the fact that a higher fraction of the water vapour in the exhaust gases from the natural gas combustion process is condensed at lower part load ratios. We found that it was important to ensure that the rooftop units were not heavily oversized in order to avoid exaggerating the benefits of adding condensing heat exchangers, especially in the Big Box Store Archetype model[2]. For the Big Box Store, the heating capacity was manually sized to a 25% over-sizing factor for each system in each climate zone.

In examining the control issues that may lead to better or worse performance on condensing heat we have found that there is a high degree of overlap with the control issues that maximize the performance of heat recovery on exhaust air. That is to say, many of the control adjustments required to optimize heat recovery savings are the same as those required to optimize energy savings modelling a condensing RTU. For example, it is important to ensure that the system is controlled to allow for high supply air temperatures to maximize the cost benefit of condensing heat exchangers in buildings where perimeter losses may be offset by electric baseboard heat, or where zone reheat coils are electric. The same argument applies to hot water baseboards or to zone reheat coils in buildings where the boiler in use is not a condensing boiler and may operate with a lower seasonal efficiency than the condensing rooftop unit. Higher outdoor air fractions also tend to improve the cost benefit of a condensing rooftop as the heating load for a given supply air temperature increases dramatically with increasing outdoor air fraction.

## Cost Benefit Calculation

The incremental capital cost of adding condensing heat exchangers to the systems modelled was obtained from manufacturers' representatives. The following prices were quoted for each air handling system in each archetype building:

1. a base model rooftop unit matching the supply and outdoor air flow rates used in the archetype model with a thermal efficiency of 80%,
2. a second "high efficiency" air handling system with slightly improved cooling performance along with the addition of heat recovery and demand control ventilation,
3. a condensing rooftop unit with over 90% thermal efficiency (varies from 90.7% to 92.0% depending on the system specified), and
4. a condensing rooftop unit with heat recovery.

The difference in price between each of the systems (2 through 4) specified and the base model rooftop unit (1) is used to determine the increased capital cost of each improved system. Increased first costs are compared to the annual energy cost savings to determine the lifecycle cost savings over the expected lifetime of the equipment (estimated at 15 years for rooftop units) to determine whether the equipment can recover the incremental capital cost within this expected lifetime.

As discussed above, the cost structure for condensing rooftop units is currently very challenging. Only a small number of manufacturers are offering condensing rooftop units, and these manufacturers tend to be secondary manufacturers rather than the dominant market players. As such, condensing rooftop units are currently available in premium packages only, which greatly inflates the cost premium. In going from a base model to a condensing model, one not only adds the cost of a secondary heat exchanger, but also the many costs that go with a premium HVAC product. These premium rooftop units are likely to last longer and to be more durable than a base model. The cost premium in going from a commodity unit to a specialty condensing unit is on the order of $30,000, however, the cost premium for going from a specialty unit without condensing heat to a specialty unit with condensing heat is in the range of only $3000-$5000.

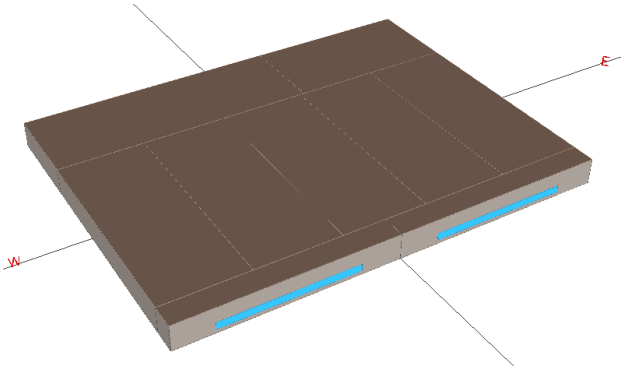
[2] In the Big Box archetype model, CAN-QUEST auto-sizes the heating capacity to over 2.5× higher than the peak heating load. This was corrected by manually sizing the systems.


ISBN 978-2-921145-88-6

Energy costs for electricity and natural gas are based on the 2014 average prices across Canada as published by Quebec Hydro (2014) and by the Canadian Gas Association (2014). Since most of the climate zones studied cross several provincial boundaries, a Canadian population-weighted average utility rate provides a clear basis for comparison from climate zone to climate zone. An average rate of $0.1128/kWh ($31.33/GJ) is used for electricity and a 2014 average commodity supply rate of $0.186/cubic metre is used for natural gas. An additional distribution and transportation charge of $0.1589/cubic metre, which is based on a provincial population weighted average of distribution charges from published commercial rates from eight natural gas distributors across Canada[3] is added to the supply rate for a total rate of $0.3449/cubic metre. As natural gas prices are currently low ($0.3449/cubic metre is roughly equivalent to $0.0328/ekWh or $9.11/GJ) relative to electricity prices, the cost-benefit analysis is skewed toward electricity savings. Use of national average utility rates limits this study to an understanding of national trends. An analysis of the cost-benefit on a province-by-province basis is beyond the scope of this study.

## CONDENSING ROOFTOP UNITS IN NECB ARCHETYPE BUILDINGS

### Big Box Store




The Big Box Store model has 9,290 square meters (100,000 square feet) of floor area and is served by nine single-zone constant-volume packaged systems with natural gas-fired furnaces and direct-expansion cooling. Six of the systems serve thermal zones arranged around the perimeter of the building and the other three systems serve the three core zones. The average outdoor air fraction is 0.268 and the maximum supply air temperature is 48.9ºC (120ºF). The rooftop units supply all of the heat in the Big Box Store model, with no baseboard heat on the perimeter.

A base model with 80% thermal efficiency; a "high efficiency" rooftop unit with improved cooling efficiency, ERV and DCV; a condensing rooftop unit with 91% thermal efficiency; and a condensing rooftop unit with ERV were modelled. The annual energy savings for all of these models are shown in Figure 1.

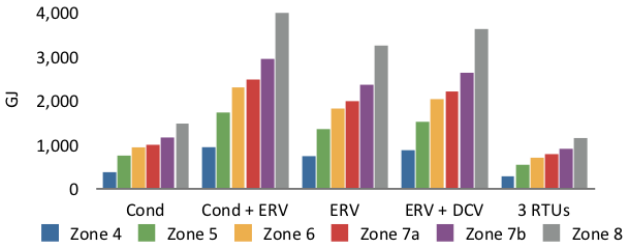



*Figure 1: Annual energy savings in the Big Box Store.*

Condensing rooftop units lead to a space heating savings of approximately 25% in the Big Box Store (see Figure 2 below which shows the space heating savings averaged across all climate zones for each configuration). Adding heat recovery dramatically increases the space heating savings to approximately 73%.

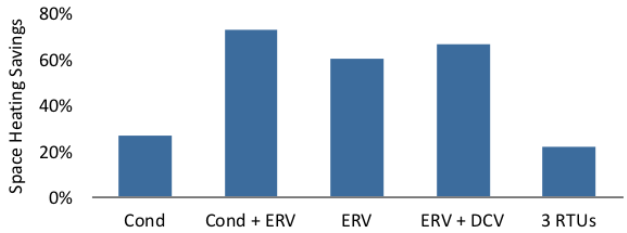



*Figure 2: Space heating savings in the Big Box Store*

However, ERV without condensing heat can achieve approximately 60% energy savings on space heating, which suggests that adding condensing heat to a unit with energy recovery would yield only 13% space heating energy savings, cutting the potential for savings from condensing heat in half. Adding ERV and DCV to the base unit increases the per unit average upfront capital cost of the unit by $13,673, while adding condensing heat along with going to a premium package increases the per unit average upfront capital cost by $32,272. Given that the energy savings from condensing heat are lower than those for ERV + DCV, and given that the cost of adding condensing heat is so much higher, it is not surprising to see that the 15-year lifecycle cost savings for condensing heat, shown in Figure 3 below, are negative in five out of six climate zones. Note that the lifecycle cost savings for the specialty condensing units are calculated assuming an equipment lifecycle of 25 years. These cost savings are then multiplied by 15/25 for

[3] FortisBC (Schedule 3, Large Commercial), ATCO Gas (Mid-Use Delivery Service) in Alberta, SaskEnergy (Large Commercial), Manitoba Hydro (Small General Service Commercial), Engridge Gas (Rate 6) in Ontario, Gaz Metro (Rate D1 General Service) in Quebec, Enbridge Gas New Brunswick (Large General Service), and Heritage Gas (Commercial) in Nova Scotia. Rates were retrieved in February, 2015.


ISBN 978-2-921145-88-6

comparison with the other units which have an expected lifetime of 15 years.

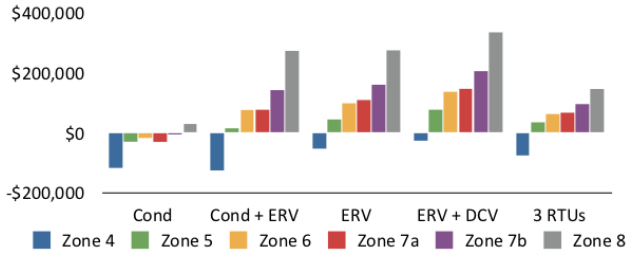
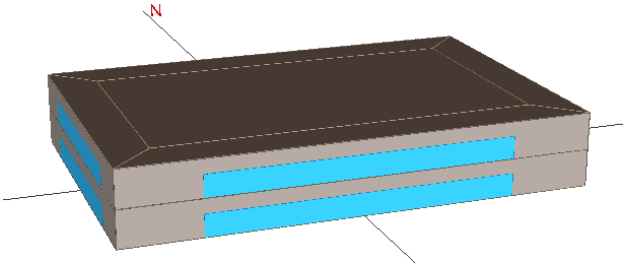



*Figure 3: 15 year lifecycle cost savings in Big Box Store*

In order to maximize the cost benefit we also created a version of the model which uses condensing heat on the three RTUs with the largest annual space heating loads. These three units serve the three largest perimeter zones in the Big Box archetype model and have an average outdoor air fraction of just over 0.31. All other units were modelled with the base model unit at zero incremental cost. These three units are responsible for a large fraction of the Big Box Store's space heating load, and replacing them with condensing heating units leads to 22% space heating savings. This compares favourably to the 27% space heating savings that was obtained by adding condensing heat to all nine rooftop units but at only one-third of the cost (see Figure 2 above, Condensing on 3 RTUs). In this case, positive lifecycle cost savings are seen in climate zones 5 through 8. This suggests that condensing RTUs can have a net cost benefit in the Big Box Store if only applied to those units with the largest heating loads. However, if these three RTUs were to already have ERV installed, the reduction in the heating savings delivered by the condensing heat exchanger would eliminate this net cost benefit in all but the coldest climate region 8.

## Medium Office




The Medium Office model is a two-storey, 3,300 square metre office building with a single packaged VAV air handling system that uses natural gas-fired heat and direct expansion cooling. Electric heating coils are used for zone reheat. VAV systems are controlled to supply air at a relatively low temperature, even in winter, to ensure that the thermal gains from people, lights and office equipment in interior zones are counterbalanced by cool supply air. If the outdoor air fraction is relatively low, and the return air temperature (usually close to the zone temperature setpoint which may be 20ºC) is higher than the supply air temperature setpoint (usually between 13 and 18ºC) it is often advantageous to bring in additional cold outdoor air to provide free cooling. With a low supply temperature, supply air heating is therefore limited to the coldest days of the year, however appropriate control strategies which allow the supply air temperature to be reset to higher temperatures (outdoor air reset, or reset of the supply air temperature to the highest temperature at which it can meet the cooling needs of the warmest zone) can expand the operating range of a condensing furnace. In addition, in peak heating mode when very few of the zones are calling for cooling, the system supplies air at flow rates closer to the minimum outdoor air flow rates. This means that the outdoor air ratio can be much higher than the cooling design outdoor air ratio. Under these conditions, a higher fraction of the heating is done by the rooftop unit as opposed to the zone reheat terminals. The Medium Office is modelled with the supply air flow rate sized to meet the coincident peak cooling load, and the supply air temperature is allowed to rise to 18.3ºC in heating season. A minimum zone air flow setting of 0.2 is used to boost the outdoor air fraction by lowering the supply air flow rate at the minimum flow settings. As it was hard to find condensing rooftop systems that could be sized to meet the full load of the Medium Office, the VAV air handling system was split into two packaged VAV rooftop units, with one unit serving each floor. A thermal efficiency of 91.1% is used for the condensing RTUs. The annual energy savings are shown below in Figure 4 and the lifecycle cost savings are shown in Figure 5.

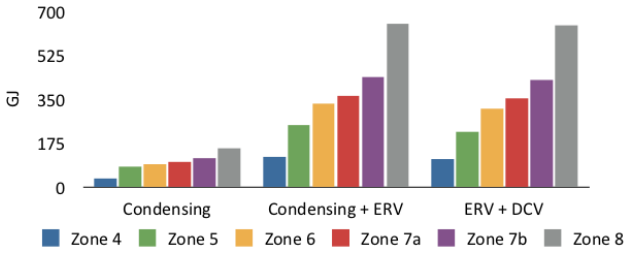



*Figure 4: Annual energy savings in the Medium Office*

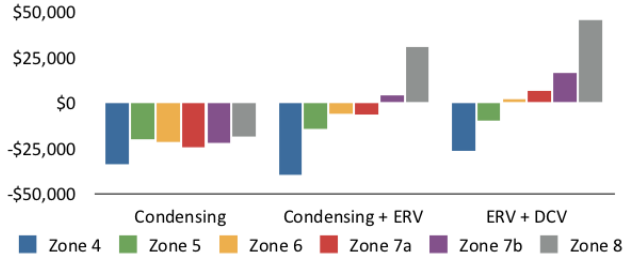



*Figure 5: 15 year lifecycle cost savings in the Medium Office*

The results show that the condensing rooftop unit is outperformed by the combination of ERV and DCV, and the higher upfront costs for condensing heat mean that the lifecycle cost savings are negative.


ISBN 978-2-921145-88-6

In examining the output reports from the ERV+DCV model, it is clear that the annual heating load at the system level is driven to almost zero by the combination of energy recovery and demand control ventilation. For example, with ERV+DCV in the coldest climate zone 8, the annual space heating load on each of the two rooftop units drops from an average of 265 to 17 GJ. This comes about in the Medium Office model because, as noted above, the VAV systems are designed to supply relatively cool air at a maximum supply temperature of 18.3ºC, even in heating mode. Perimeter heating losses are made up at the zone level with baseboard heat and/or zone reheat terminals which can be heated electrically or with a hot water loop. Since the supply air is a combination of incoming cold outdoor air and return air at a warmer temperature of 20ºC, relatively little heat needs to be added to the supply air to maintain the 18.3ºC supply air setpoint, and an enthalpy wheel is able to meet the majority of this demand for heat on its own. As such, the addition of condensing heat to a rooftop packaged VAV system serving multiple zones with perimeter heat and a design outdoor air fraction below 0.20 would offer very little benefit to a system which was already equipped with an enthalpy wheel. Examination of the average space heating savings across all climate regions bears this out. The use of ERV+DCV leads to 53.5% space heating savings and the use of the condensing heat + ERV leads to 53.6% space heating savings (see Figure 6 below).

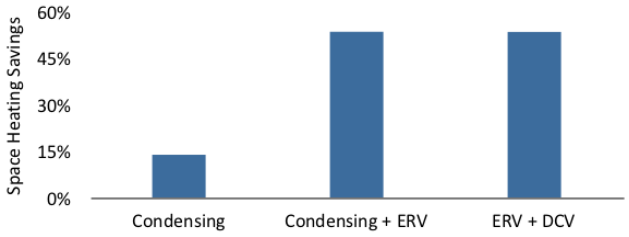
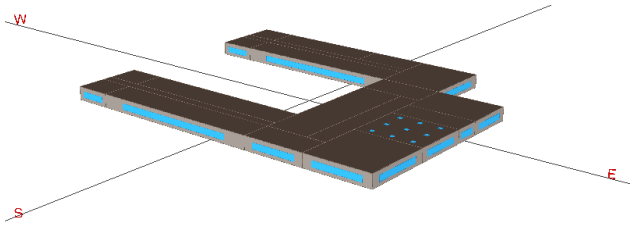



*Figure 6: Space heating savings in the Medium Office*

Note that the VAV system type — which is typically controlled to supply a mix of outdoor air and return air at temperatures below 18.3ºC with additional heat added at the zone level — limits the energy saving opportunities from technologies such as heat recovery on exhaust air and condensing heat. Changing the system type to a dedicated outdoor air system for ventilation with separate zone heating and cooling systems (such as a radiant slab for heating and cooling, or chilled beams) may offer greater opportunities for energy savings, and provide a configuration in which condensing heat would be more cost effective.

## Primary School




Schools tend to have relatively high outdoor air flow rates due to the high occupancy rates of classrooms and auditoriums, and the high activity levels in gymnasiums. The Primary School archetype model is a single storey building served by three air handling systems. One is a large constant-volume air handling system serving the bulk of the building. The other two systems are much smaller single zone systems serving a gymnasium and a cafeteria respectively. The system serving the gymnasium has an outdoor air fraction of 0.50 and the system serving the cafeteria has an outdoor air fraction of 0.31. All three systems have natural gas-fired heating and direct expansion cooling. Additional zone heating is provided by hot water radiators served by a natural gas boiler. Condensing rooftop units with a thermal efficiency of 90.7% are considered for the two single zone systems serving the gymnasium and cafeteria. The maximum supply air temperature was set to 25ºC as this strikes a balance between system and baseboard heating. The annual energy savings from adding condensing heat are shown below in Figure 7.

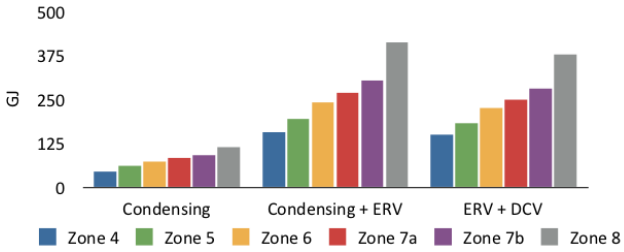



*Figure 7: Annual energy savings in the Primary School*

The lifecycle cost savings (Figure 9) show that condensing heat is not cost effective, whereas ERV+DCV is cost effective in climate zones 7b and 8. In these smaller systems, it appears that the annual heating load is simply too small to provide positive lifecycle cost savings on condensing heat. An important difference between the Primary School model and the Big Box Store is that zone heating loads are met in part by baseboard heating, which reduces the opportunity for condensing heat to provide energy savings at the system level. Space heating savings due to condensing heat are only 3% on average in the Primary School (see Figure 10), whereas the space heating savings in the Big Box Store are approximately 25%. In climate zone 8, the annual space heating load on each unit tops out at 57 GJ, whereas in the Big Box Store, the three largest units have annual space heating loads between 540 and 680 GJ.


ISBN 978-2-921145-88-6

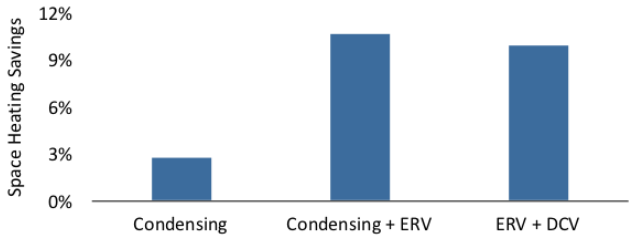



*Figure 8: Average space heating savings in the Primary School*

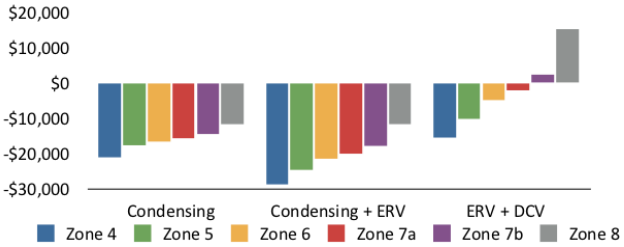
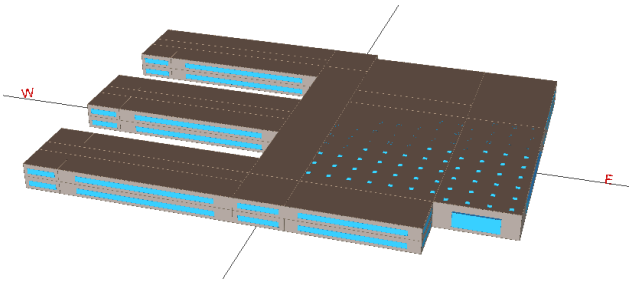



*Figure 9: 15 year lifecycle cost savings for the Primary School*

## Secondary School




The Secondary School archetype model has six constant volume systems with natural gas-fired heating and direct expansion cooling. Two of the systems serve multiple zones and four single zone rooftop systems serve the gymnasium, auxiliary gymnasium, cafeteria, and auditorium. As in the Primary School model, additional zone heating is provided by hot water radiators connected to a natural gas-fired boiler. The outdoor air flow rates are relatively high. As in the Primary School model, the system type was changed to packaged VAV for all of the models, and the maximum supply air setpoint was changed to 25ºC. Condensing heat with a thermal efficiency of 91% was added to the four single zone rooftop systems. The energy savings are shown in Figure 10 and the cost savings are shown in Figure 11. This model, with high outdoor air flow rates, crosses over to positive lifecycle cost savings in climate region 7a where the space heating load per unit reaches an average of 500 GJ. ERV+DCV is cost effective in all six climate zones. Space heating savings are 7.5% for condensing heat, 27.3% for condensing and ERV, and 23.8% for ERV and DCV. With ERV the space heating load is reduced from 800 GJ to 225 GJ in climate zone 8, below the threshold for cost-effectiveness in the Secondary School model.

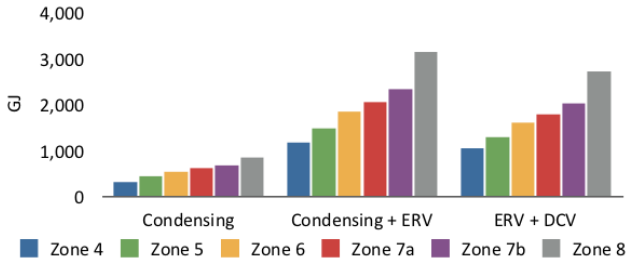



*Figure 10: Annual energy savings for the Secondary School*

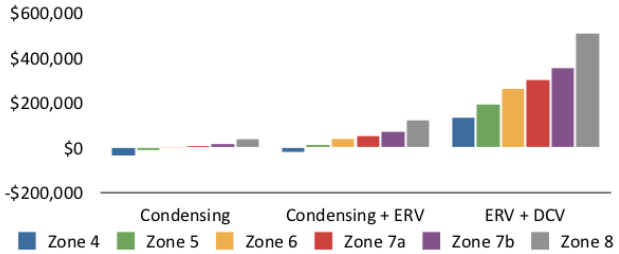



*Figure 11: 15 year lifecycle cost savings in the Secondary School*

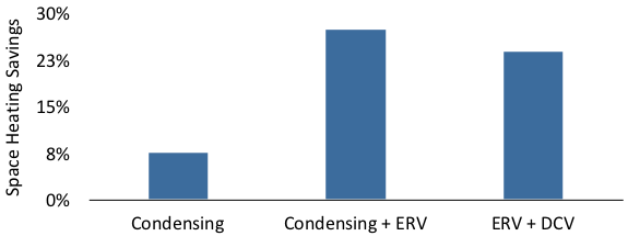
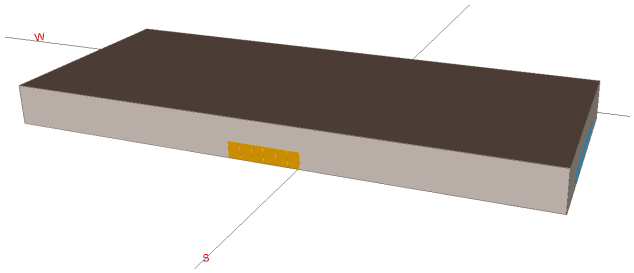



*Figure 12: Space heating savings in the Secondary School*

## Warehouse




Many warehouses are ventilated by infiltration of outdoor air through louvres or dampers coupled to an exhaust system on the other side of the building. Space heating is provided by gas-fired unit heaters to maintain temperature setpoints and space cooling is seldom provided. Packaged rooftop units could be used with energy recovery, but the incremental capital cost may be quite high if it includes the addition of an entire ventilation system. In a warehouse


ISBN 978-2-921145-88-6

without a ventilation system, it may be more cost-effective to consider the use of direct-fired unit heaters.

The Warehouse archetype model provided has a single heating and ventilating system that provides 100% outdoor air at a flow rate of 1,346 litres per second. The maximum supply air temperature is 48.9ºC. Natural gas-fired unit heaters are used to provide additional heat and offset envelope losses. The warehouse shows approximately 10% space heating savings with condensing heat with a thermal efficiency of 91.0%, and 30% space heating savings with condensing heat combined with ERV. The space heating load on the system varies from 750 GJ in climate zone 4 to 1700 GJ in climate zone 8.

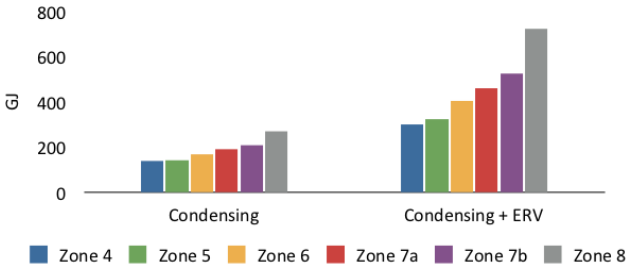



*Figure 13: Annual energy savings in Warehouse*

In this 100% outdoor air application, condensing heat provides lifecycle cost savings in all six climate zones (see Figure 14 below). This is a departure from the results shown in most of the other archetypes. In the Warehouse, there is only one rooftop unit which reduces the capital cost increase of adding condensing heat. In addition, this model uses a dedicated outdoor air system, with additional zone heating provided by gas-fired unit heaters. Concentrating the outdoor air load into one unit with condensing heat proves to be more cost effective than spreading the outdoor air load across several units, such as in the Big Box Store. Nonetheless, the cost structure is still challenging with a simple payback longer than 10 years even in the coldest climate zones.

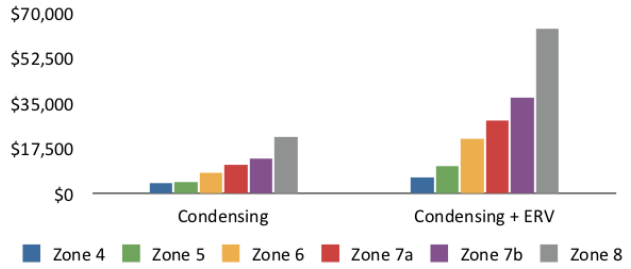



*Figure 14: 15 year lifecycle cost savings in Warehouse*

## DISCUSSION

The addition of condensing heat exchangers to five NECB archetype building energy models was analysed and condensing heat was not found to be cost effective in most cases. The two main exceptions are the Warehouse model (which uses a 100% outdoor air heating and ventilating system) and the Big Box Store (with only the three largest perimeter zone units changed over to condensing heat). A summary of the simple payback periods is shown in Table 1. Apart from the Warehouse and the Big Box Store, the shortest payback periods are seen in the Secondary School model which has high outdoor air fractions of between 40-50%. However, even here, the payback ranges from 17 years in the coldest climate zone 8, to 48 years in the warmest climate zone 4. In the Primary and Secondary School models and in the Medium Office model a significant portion of the space heating load is met by baseboard heat and/or zone terminals which reduces the opportunity for condensing heat to provide space heating energy savings at the system level. In these models, a condensing boiler that serves hot water to zones along with energy recovery at the system level may provide a greater energy-saving benefit. In general, the results indicate that an average annual space heating energy of approximately 500 GJ/year per rooftop unit is required before condensing heat becomes cost effective. Where there is a choice between condensing heat and ERV, the latter will offer greater energy savings per invested dollar, and therefore, shorter paybacks.

*Table 1: Summary of simple payback periods*

| | Zone 4 | Zone 5 | Zone 6 | Zone 7a | Zone 7b | Zone 8 |
|---|---|---|---|---|---|---|
| Big Box | 96.1 | 18.7 | 15.6 | 15.1 | 13.0 | 10.3 |
| Office | 248.8 | 53.8 | 58.8 | 71.8 | 60.7 | 49.6 |
| Pri. School | 87.9 | 62.5 | 57.4 | 53.4 | 49.2 | 41.4 |
| Sec. School | 47.5 | 29.4 | 25.5 | 23.0 | 20.9 | 16.9 |
| Warehouse | 19.7 | 19.3 | 16.3 | 14.4 | 13.2 | 10.3 |

| Legend |
|---|
| 0-10 |
| 10-15 |
| 15-20 |
| 15-20 |
| Over 25 |
| Years |

The biggest challenge to cost effectiveness is the large gap in price between a base model rooftop unit and a premium condensing rooftop unit. If a premium rooftop unit is already specified, the cost increase to add a condensing heat exchanger is relatively small ($3,000 to $5,000). However, the upfront capital costs on premium condensing rooftop units can be as much as three times the cost of a base model rooftop unit with a cost premium ranging from approximately $22,000 to $35,000. At this cost premium, with a natural gas price of $9.11/GJ, each rooftop unit needs to provide annual natural gas savings of over 100 GJ/year to return a net 25 year lifecycle cost benefit. Under the current rooftop unit market, a doubling or tripling of natural gas prices would be required to make condensing heat exchangers more broadly cost effective.

The results presented here are in line with the results of field studies carried out by the Gas Technology Institute in which gas heating run-times were measured in over 100 rooftop units in the Chicago area (Kosar et al. 2014) and in which dedicated outdoor air systems were retrofitted with condensing heat exchangers (Kosar and Cushman 2013, Kosar 2014). The results of a large field study of over 100 conventional rooftop units suggested that condensing


ISBN 978-2-921145-88-6

furnaces in rooftop units are best suited to rooftop units serving perimeter zones and to dedicated outdoor air units with 100% outdoor air. Kosar et al (2014) found that RTUs serving core zones often had as few as zero heating hours, making them poor candidates for condensing heat. In general, they found that RTUs have very diverse heating runtimes, which presents a challenging scenario for a generalized approach to the rooftop market. As part of an emerging market study with Nicor Gas in Illinois (Kosar and Cushman 2013), non-condensing heating modules in two dedicated outdoor air systems on a big box store were retrofitted with condensing heating modules. The gas usage of these two units was then monitored for the 2012/2013 heating season. Based on the results of this monitoring, Kosar and Cushman estimated that adding condensing heating modules provided annual gas savings of 253 GJ (2,395 therms) per unit at $0.30 ($0.27 USD)/cubic metre of natural gas with added fan electricity of 1,290 kWh at $0.082 ($0.075 USD)/kWh for an annual net energy cost savings of $1,874 ($1,704 USD)[4]. With an installed cost premium of $6,676 ($6,069 USD), the simple payback is projected to be 3.7 years. These energy cost savings are in line with the results of our modelling study, however the installed cost premium of $6,676 ($6,069 USD) is far lower than what we have been quoted for adding condensing heat to conventional, or non-premium RTUs. For example, in the Big Box Store, the capital cost increase for adding condensing heat is estimated to be between $23,789 and $35,581 per unit. However, the cost of adding a condensing heat exchanger to a premium unit (which starts at a premium of $20,000 relative to a base model from a commodity manufacturer) was estimated to be only $3,000 to $5,000 per unit. It appears that the cost of adding condensing heat exchangers in a retrofit of existing rooftop units, or to a new rooftop unit as a manufacturer is relatively low. Unfortunately, the market is not providing commodity-priced rooftop units with condensing heat, and the major market players – York, Carrier, Daikin McQuay, and Trane – have indicated that they have no immediate plans to develop rooftop units with condensing heat. As noted by Kosar (2014), condensing rooftop units will need to be competitive with low cost, mass-produced, non-condensing rooftop units before a market transformation can take place.

Were condensing rooftop units to fall in price to a cost premium of $6-7000 per unit, the economics would be much more favourable, and condensing heat exchangers would be able to pay for themselves in all five archetypes modelled in most of Canada's climate regions.

The cost effectiveness of adding condensing heat to a system which is already using heat recovery on exhaust air is even harder to argue for under present market conditions. Energy recovery is observed to reduce the space heating energy required by the condensing heat exchanger in many of the systems in this study by 50% or more. The use of energy recovery will therefore cut the cost savings from adding condensing heat in half, as they will apply to only half of the annual space heating load that exists in the absence of heat recovery. This would require the rooftop unit to serve an annual space heating load of over 1,000 GJ/year to make condensing heat cost effective for a system which already includes energy recovery. In the case of the Medium Office, which uses a packaged VAV system with a relatively low supply air temperature, energy recovery almost completely eliminates the heating load at the system level.

## CONCLUSIONS

Condensing heat is found to lead to net lifecycle cost savings in the following cases:

- for rooftop units serving perimeter zones in the Big Box Store archetype model where the rooftop unit is the primary source of heat in climate zones 5 through 8,
- for rooftop units providing 100% outdoor air in the Warehouse archetype model in all six climate zones,
- for rooftop units providing supply air with a high fraction of outdoor air in the Secondary School archetype model in climate zones 7a, 7b, and 8.

However, even in these cases, the payback periods are longer than 10 years and the economics of the current market remain challenging. The primary barrier to the widespread adoption of condensing furnaces in rooftop units is the current high cost of purchasing rooftop units from a small number of specialized manufacturers which only offer condensing furnaces in premium packages. Four of the major North American manufacturers of rooftop units – York, Carrier, Daikin McQuay, and Trane – have indicated that they have no immediate plans to introduce rooftop units with condensing furnaces. That said, the energy cost savings provided by condensing heat exchangers can be significant. In the Big Box Store, on the three units with the largest heating load, the annual energy cost savings range from $700 per rooftop unit in climate zone 4 to $3,300 per rooftop unit in climate zone 8. Should the installed cost premium fall from $25-35,000 to less than $10,000, or should the price of natural gas triple to $1.00/cubic metre, the simple payback would range from 14 years in climate zone 4 to three years in climate zone 8. Kosar and Cushman (2013) reported an installed cost premium of $6,676 ($6,069 USD) in a retrofit of a

[4] Results reported in USD. Conversion rate of $1.10 $CDN/$USD used per 2013/2014 exchange rates in accordance with the time frame of referenced reports to clarify comparisons with Canadian costing results in this study.


ISBN 978-2-921145-88-6

dedicated outdoor air system in Chicago, and a condensing rooftop unit manufacturer quoted a cost premium of between $3,000 and $5,000 to add condensing heat to their rooftop units which suggests that it should be possible for manufacturers to provide commodity rooftop units with condensing furnaces at a much lower cost premium than is presently observed. It is likely that condensing heat would be an attractive proposition in a mature marketplace in which condensing rooftop units were competitive with low-cost , mass-produced, commodity, non-condensing rooftop units.

In the Big Box Store and the Warehouse, adding condensing heat to rooftop units serving perimeter zones with high heating loads or to dedicated outdoor air systems is shown to be cost effective on a 25-year lifecycle basis in most climate zones with a simple payback of over 10 years. The Secondary School shows a net cost benefit in climate zones 7a, 7b, and 8 with a simple payback of over 15 years. The Medium Office and the Primary School show negative 25-year lifecycle cost savings in all six climate zones. In those cases where there is a net cost benefit, the cost effectiveness is reduced if energy recovery on exhaust air is also used. If energy recovery is already installed, the simple payback period for condensing heat is typically extended by a factor of 2.5-3 times due to the reduction in the annual heating load on the condensing heat exchanger. In the Medium Office, which uses packaged multi-zone VAV rooftop systems with cool supply air and an outdoor air fraction of 0.2, the use of energy recovery is able to meet close to 100% of the heating load at the system level, eliminating the need for a condensing heat exchanger. For this reason, one recommendation of this study is that condensing furnaces are not appropriate for mixed air VAV systems with low supply air temperatures if the use of energy recovery is already mandated. For buildings with large multi-zone systems that provide cool supply air to zones with terminal or baseboard heating, a hot water system served by a condensing boiler that heats both the supply air and the zones would likely provide a greater benefit.

The following conditions reduce the opportunity for energy savings from adding condensing heat exchangers to rooftop units:

- systems controlled to supply low temperature air with envelope heating losses met by zone heating equipment such as baseboards, radiators, VAV terminals, etc.,
- energy recovery on exhaust air is already specified for the rooftop unit, reducing the outdoor air heating load,
- rooftop units serving core zones with smaller heating loads and low outdoor air fractions below 0.2.

Should natural gas prices increase and/or the incremental cost of adding condensing heat exchangers to rooftop units decrease significantly, the following conditions are noted to lead to the greatest benefit:

- rooftop units which serve single zones and act as the primary heating source for the zone with high supply air temperatures,
- outdoor air fractions higher than 0.2,
- rooftop units serving perimeter zones with high space heating loads that are met primarily by the rooftop unit and secondarily by, for example, hot water baseboards or radiators,
- units which are not able to use energy recovery (because of, for example, cross-contamination or fouling concerns).

## ACKNOWLEDGEMENTS

We gratefully acknowledge the support of the Office of Energy Efficiency at Natural Resources Canada who commissioned and funded this study.

## REFERENCES

Canadian Gas Association (2014). Pre-Heating Season Update. Retrieved from http://www.cga.ca/wp-content/uploads/2011/02/CGA_bulletin_Pre-Heating_-EN.pdf.

Kosar, Douglas and Cushman, Gary (2013). Public project report 1001: High efficiency heating rooftop units (RTUs). *energySMART Emerging Technology Program.* Naperville, Illinois: Nicor Gas. Retrieved from http://nicorgasrebates.com/-/media/Files/NGR/PDFs/ETP/1001%20High%20Eff%20Heating%20RTU%20Public%20Project%20Report%20FINAL%2008-04-2014.pdf

Kosar, Douglas et al. (2014). Field Monitoring of Rootop Unit (RTU) Heating Runtimes and Gas Usage for Selected Commercial Buildings (NY-14-C084). *2014 ASHRAE Winter Conference.* Atlanta, Georgia: ASHRAE Inc.

Kosar, Douglas (2014). High-Efficiency Heating Rooftop Units – The Final Frontier for Condensing Gas Furnaces. Retrieved from http://www.gastechnology.org/Expertise/Documents/ETP/ETP-CenterPoint-Energy-Conference-Condensing-RTU-Presentation-05-21-2014.pdf.

Hydro Quebec (2014). Comparison of Electricity Prices in Major North American Cities. Retrieved from http://www.hydroquebec.com/publications/en/docs/comparaison-electricity-prices/comp_2014_en.pdf.

National Research Council Canada (2011). National Energy Code of Canada for Buildings 2011. Ottawa, Ontario: National Research Council Canada.


ISBN 978-2-921145-88-6