Gas-Fired Rooftop Unit Efficiency Testing

Project #248020

Report for Task 3

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Presented to:

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January 21, 2022

RIGHTS AND OBLIGATIONS

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INFORMATION SHEET

1. Title and subtitle		
Gas-Fired Rooftop Unit Efficiency Testing		
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5. Date of report January 21, 2022	6. Number of pages 62	7. Type of report Report for Task 3
8. Project number 248020	9. Type of project Laboratory testing	10. Period covered September 2020 - December 2021

11. Abstract

This report presents the results of Task 3 of the project, which was an investigation of shell losses (conduction and convection) through the casings and dampers of three tested rooftop units, following AHRI standard 1350 as a guideline.

Damper air leakage losses, casing air leakage losses, and total heat losses were estimated for three tested units at NGTC's laboratory and results are compared to the P.8 calculations to validate the assumptions used in the standard.

12. Client(s)

Natural Resources Canada, 580 Booth Street, Ottawa, ON, K1A 0E4

13. Report distribution

2 copies: 1. Natural Resources Canada (Pierre Gallant), 2. NGTC

14. NGTC's management system has been evaluated and certified compliant with ISO/IEC 17025:2017 for testing and specific requirements for method development. NGTC's scope of accreditation can be found on the Standards Council of Canada website.

SCC Accredited LAB / LAB Accrédité CCN

Laboratory no. 885

15. Explanation of changes

n/a

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SUMMARY

This project is divided into two testing phases:

- Task 2 was to validate the test procedure and methodology of the new CSA P.8 Standard for repeatability, to advise NRCan of any inconsistencies, challenges, or anomalies discovered in the test procedure, and to provide recommendations regarding the repeatability of the test procedure if needed.
- Task 3 was to investigate shell losses (conduction and convection) through the casing and dampers of the three tested units, following AHRI standard 1350 as a guideline.

This report, which is Task 5, concerns the results of Task 3.

Testing was performed following AHRI standard 1350 as much as possible. However, for some air leakage tests, NGTC had to develop a different test procedure because it was not possible to follow the one from AHRI 1350. In addition, AHRI standard 1350 is only for casing performance, and not for damper performance. Therefore, damper air leakage is estimated by subtracting the results of two different tests: the air leakage results of both the casing and damper minus the air leakage results of the casing only (sealed damper). Only an overall thermal transmittance value was obtained (for both the casing and damper), thus results do not provide a separate value for damper thermal transmittance.

Table 1-1 presents the casing air leakage rate and the damper air leakage rate for the three tested units. The main testing results and NGTC's recommendations regarding air leakage considerations in the P.8 standard are the following:

- Damper leakage losses:
  - Because AHRI standard 1350 is not applicable for estimating damper air leakage, NGTC recommends using AMCA 500-D for this purpose (as currently in the P.8 standard).
  - Results show that damper leakage is 41.15 cfm/ft² for the BMU and 1.29 cfm/ft² for the HMU. The MTU values presented in Table 1-1 are not results from testing but estimations according to unit specifications. HMU values results from testing are consistent with the unit specifications. For BMU values, results show that air leakage from dampers can be significant if a damper is not sealed appropriately.
  - For manufacturers that do not test their dampers according to AMCA 500-D, the P.8 test procedure suggests using a default value of 3 cfm/ft², which would be a very well-sealed damper ("Class 1A damper"[1]). NGTC recommends using a higher default value in the P.8 standard. Indeed, currently the default value does not encourage manufacturers to improve the outdoor air damper or test it according to AMCA 500D since a very good default value can be used as a default value.

[1] This class is the best class achievable for dampers following AMCA 500-D. This means that the damper air leakage is lower than 3 cfm/ft² at 1 in w.c. [3].

- Casing leakage losses:
  - According to testing results, casing losses are lower than 1.3 cfm/ft² for all three units tested. However, even if this air leakage seems low, it may be the biggest source of air leakage since the area of the casing is significantly larger than the area of the damper.
  - It would be good to consider casing air leakage in a future version of the P.8 standard. However, as the AHRI 1350 test procedure is relatively complex to follow, it should be first established whether it is commonly used by manufacturers or whether there is another standard that could be used to estimate casing air leakage.

Table 1-1: Air Leakage Rates (testing)

	BMU	MTU (estimated[2])	HMU
Casing leakage rate at 1 in w.c. ($CFM/ft^2_{casing\ (excluding\ damper)}$)	0.67	0.28	1.27
Damper leakage rate at 1 in w.c. (CFM/ft^2_{damper})	41.15	1.50	1.29
Total leakage rate at 1 in w.c. ($CFM/ft^2_{casing\ +\ damper}$)	3.55	0.38	1.27

Table 1-2 presents the heat loss rate for the three tested units. The main testing results and NGTC's recommendations regarding heat loss considerations in the P.8 standard are:

- Total conduction losses (damper + casing):
  - Regarding heat losses through the casing and the damper, results show the theoretical value of heat losses without leakage from the P.8 calculations is relatively well estimated: for the BMU and the MTU, the P.8 value underestimated the heat loss by 11% and 16% respectively. The HMU is underestimated by 44%, however this test was performed with more and bigger fans, so the convection is higher inside the HMU than inside the BMU and MTU. Heat losses with leakage are significantly underestimated in the P.8 calculations due to the underestimation of air leakage.
  - Because the AHRI 1350 test procedure is complex to follow, NGTC does not recommend referring to this standard in the P.8 standard for casing heat loss estimation unless manufacturers commonly use this standard.
  - Because AHRI 1350 is not applicable for damper conduction losses, NGTC recommends keeping the theoretical calculations already used in the P.8 standard, unless there is another standard for estimating damper conduction losses.

Table 1-2: Heat Loss Rate Comparison

	BMU	MTU	HMU
Testing Results (Btu/h.°F)			
Without leakage	30.7	26.2	60.7
With leakage	282.5	805.5	269.1
P.8 Calculations (Btu/h.°F)			
Without leakage	27.3 (-11%)	21.9 (-16%)	33.7 (-44%)
With leakage	39.5 (-86%)	29.2 (-96%)	57.7 (-80%)

[2] For the MTU, it was complex to estimate the casing and damper air leakage. Values presented in this table are estimated using some assumptions, so they cannot be compared with values for the BMU and HMU that come from testing.

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DEFINITIONS AND NOMENCLATURE

BMU: Base model unit
CSA: Canadian Standards Association
DOAS: Dedicated Outdoor Air System
ERV: Energy Recovery Ventilator
$GCOP_{HS}$: Gas Heating Season Coefficient of Performance
HMU: High efficiency model unit
HRV: Heat Recovery Ventilator
MTU: Mid-tier model unit
NRCan: Natural Resources Canada
% OA: Percent of outside air
$TCOP_{HS}$: Total Heating Season Coefficient of Performance

Positive pressure section: Represents the section after the supply fan. Typically, this is where the heat exchanger and supply air duct are.

Negative pressure section: Represents the section before the supply fan and after the outside air damper (for 0-100% OA units and 100% OA units). Typically, this is where the evaporator and return air duct are (except for 100% OA units).

1.0 CONTEXT

The CSA-P.8-09 Standard (R2014) [1] specifies test methods and performance criteria for determining the efficiency of industrial and commercial gas-fired package furnaces. As this standard is published by the Canadian Standards Association (CSA), it is intended to provide performance criteria for package furnaces used in colder climate areas such as Canada and the Northern United States.

Although many changes were made since its first edition published in 1997, the second edition (R2014) does not represent the colder conditions in which rooftop or make-up air units operate in northern climates. The current standard describes a procedure for testing the unit at room temperature only. Therefore, rooftop units with poor performance at lower outdoor temperatures are compared on the same basis as units that would normally be more efficient in those conditions. This means that the measured energy savings do not match the energy model predictions as well as anticipated.

The revised version (Edition 3) of the CSA P.8 is expected to better reflect the seasonal and end-use efficiency of rooftop units.

2.0 OBJECTIVES AND MANDATE

Natural Resources Canada (NRCan) mandated NGTC to validate the test procedure and methodology of the new CSA P.8 Standard for repeatability, to advise NRCan of any inconsistencies, challenges, or anomalies discovered in the test procedure, and to provide recommendations regarding the repeatability of the test procedure if needed (Task 2).

The current objective is to investigate the shell losses through the casings and dampers of three rooftop units, following AHRI standard 1350 (Task 3), to estimate the following losses:

a) Damper leakage losses (seals).
b) Damper conduction losses (insulation levels).
c) Casing leakage losses (seals).
d) Casing conduction losses (insulation levels).

This report, which is Task 5 of the project, only concerns the results of Task 3.[3]

3.0 METHODOLOGY

3.1 TEST OBJECTS

Three units were tested in NGTC's laboratory following AHRI standard 1350 as a guideline [2], using the following four configurations:

1. Base model unit (BMU) with provided damper.

[3] The results of Task 2 were presented in a report sent to NRCan on April 1, 2021.

2. Mid-tier model unit (MTU) with provided damper.
3. High efficiency model unit (HMU) with provided damper.
4. High efficiency model unit (HMU) with insulated damper.[4]

Table 3-1 shows the main characteristics of the three tested units.

Table 3-1: Test Object Characteristics

Sample	BMU	MTU	HMU
Manufacturer	*Confidential*		
Model Number			
Serial Number			
Unit type	RTU (0% OA)	DOAS (0 - 100% OA)	DOAS (100% OA)
Input heating capacity	150,000 Btu/h	160,000 Btu/h	175,000 Btu/h
Number of Stages	2 stages (70% - 100%)	5 stages (20% - 100%)	5 stages (20% - 100%)
Heating efficiency	81%	81%	94%
Airflow	2,000 cfm	2,000 cfm	2,800 cfm
HRV/ERV	No	Yes	Yes
Insulation/Tightness Quality of Casing	Basic (≈ ½″ of insulation)	Good (≈ 1″ of insulation)	High (≈ 2″ of insulation + doors sealed)
Insulation/Tightness Quality of Damper	Basic (no sealing around the economizer damper)	High (Class 1A AMCA 500)[5]	High (Class 1A AMCA 500)[5]

3.2 TEST DETAILS

To calculate the damper leakage and conduction losses of both the dampers and casings, the following tests were performed by NGTC for each unit configuration:

- Test A: Air leakage for the positive pressure section.
- Test B: Air leakage for the negative pressure section with damper closed but not sealed.
- Test C: Air leakage for the negative pressure section with damper closed and sealed.
- Test D: Thermal transmittance for both pressure sections.

Casing air leakage losses are determined with the results of Tests A & C while damper air leakage losses are calculated using the results of Tests B & C. Because damper performance is not included in AHRI standard 1350, this is estimated for each unit by subtracting the air leakage results of just the casing (damper sealed) in Test C from the combined leakage results of the casing and damper in Test B.

[4] This configuration initially planned was not tested because the insulated dampers were not provided to NGTC. But NGTC performed some tests (by adding insulation on dampers) to estimate the impact of better insulated dampers.
[5] Class 1A of the AMCA 500 standard means the damper air leakage is lower than 3 CFM/ft² at 1 in w.c. [3].

The thermal transmittance of the damper and casing is quantified with Test D results. Note that only a global value of conduction losses of the casing and damper is determined with Test D. Indeed, it is not possible to have two distinct values following the AHRI 1350 test procedure used in this project.[6]

As shown in Table 3-2, tests were performed between July and November 2021.

Table 3-2: Test Dates

	BMU	MTU	HMU
Test A	2021-07-05	2021-09-10 (4 tests[7])	2021-07-15
Test B	2021-08-27 & 2021-11-08[8]		2021-11-24
Test C	2021-11-08		2021-11-24
Test D	2021-08-02	2021-08-20 & 2021-08-27[9]	2021-11-12 (2 tests[10])

Details about the test bench and the instrumentation used during the tests are presented in the test protocol in Appendix A and in the next section.

3.3 TEST PROCEDURE - SUMMARY

AHRI standard 1350 includes a total of four tests to estimate the casing performance (damper performance is not included in this standard[11]). For the project objectives, only two of the tests were performed:

- Air leakage testing (section C.6 of AHRI standard 1350).
- Thermal transmittance testing (section C.7 of AHRI standard 1350).

AHRI standard 1350 was followed as a guideline (when possible), which means the test procedure used during the test is not exactly like the AHRI standard 1350 test procedure. The following sections (3.3.1.1 & 3.3.2) present these differences.

In addition, for some air leakage tests, it was not possible to follow the AHRI 1350 test procedure. Therefore, NGTC developed a test procedure to estimate the casing and damper air leakage. Section 3.3.1.2 presents the test procedure developed and used by NGTC for these tests.

[6] This standard is to determine casing losses but not damper losses.
[7] A total of 4 tests were performed using different configurations. See Table 4-2.
[8] This test was performed twice using two different airflow measurement devices (a hot wire anemometer and a turbine anemometer). See Table 4-1.
[9] This test was performed twice using two different configurations: 1 with insulation on the return air damper and 1 without. See Table 4-5.
[10] This test was performed twice using two different configurations: 1 with insulation on the outside air damper and 1 without. Therefore, in 1 test the provided dampers were used and in the other the insulated dampers were used. See Table 4-4.
[11] Damper air leakage is estimated by subtracting Test C results (casing air leakage only) from Test B results (both casing and damper air leakage).

3.3.1 Air Leakage Testing

3.3.1.1 AHRI 1350 Test Procedure

The purpose of this test is to measure the air leakage through the casing at a specific static pressure defined according to the unit characteristics.[12] Then, the air leakage rate is determined at the reference pressure, 1.0 in. w.c.

The test bench for testing is schematized in Figure 3-1. It was composed of a variable flow fan used to pressurize or to depressurize (one test at a time) a pressure measurement device and an airflow measurement device. The test was performed twice – once for both pressure sections of the unit. Block-off plates were installed on the supply and return air duct (labelled outlet and inlet on Figure 3-1)[13] and at a pressure change wall location inside the unit (by the supply fan).

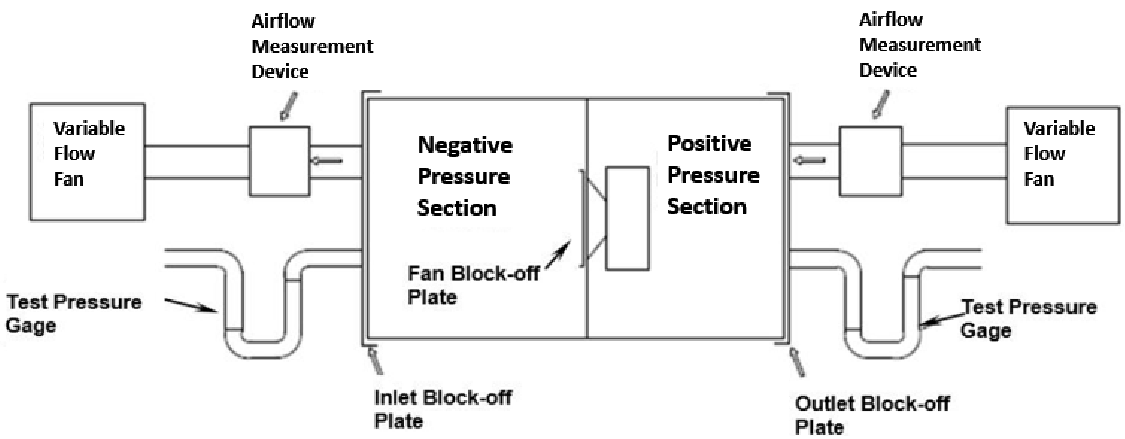

Figure 3-1: Test bench for Air Leakage Testing (AHRI1350)

The AHRI 1350 test procedure was followed for the positive pressure sections of the BMU and the HMU only.

For the MTU, it was not possible to pressurize the positive pressure section following the AHRI 1350 test procedure using NGTC's equipment. One possible explanation is that there is an internal air flow[14] between the positive and the negative pressure sections: the air drawn in the positive pressure section goes to the negative pressure section, making it impossible to achieve the desired positive pressure (more detail about this assumption is provided in Section 5.4).

Compared to the positive pressure section, the negative pressure section is bigger and less airtight due to the outside air inlet (for MTU and HMU) and the economizer (for the BMU). Even when the damper was closed, it was not possible to achieve the negative pressure required for testing using NGTC's equipment and following the AHRI 1350 test procedure.

[12] 1.3 in w.c. for the BMU; 2.0 in w.c. for the MTU, and 0.3 in. w.c. for the HMU.

[13] Other inlets or outlets (for example, outside air inlet) are not blocked off during testing because the objective is to quantify shell losses in a typical operation.

[14] While the internal flow is not "normal", it may not impact the thermal efficiency of the unit because the air is recirculated within the unit.

For both pressure sections of the MTU and the negative pressure sections of the BMU and MTU, NGTC developed a test procedure to estimate the air leakage through the casing. This test procedure was discussed with the project partners and approved.

3.3.1.2 NGTC's Test Procedure

To evaluate the air leakage of the negative pressure section of each unit, the test bench schematized in Figure 3-2 was used. For this test, the return air duct was blocked off, the supply fan of the unit was used to depressurize the negative pressure section at the desired pressure and an airflow measurement device was used to measure the air leakage directly in the supply air duct.

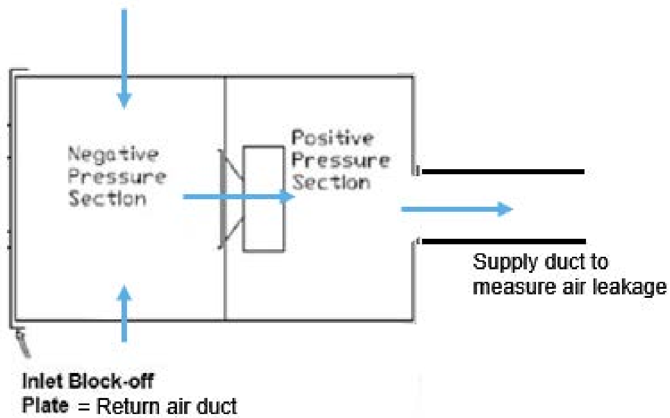

Figure 3-2: Test bench for Air Leakage Testing (NGTC) – Negative Pressure Section

To evaluate the air leakage of the positive pressure section of the MTU, a similar test bench was used. As illustrated in Figure 3-3, the supply air duct was blocked off, the supply fan was used to pressurize the positive pressure section, and air leakage was measured directly in the return air duct. In addition, to be sure that all the air leakage passed into the return air duct where it could be measured, all inlets/outlets in the negative pressure sections were blocked off and sealed.

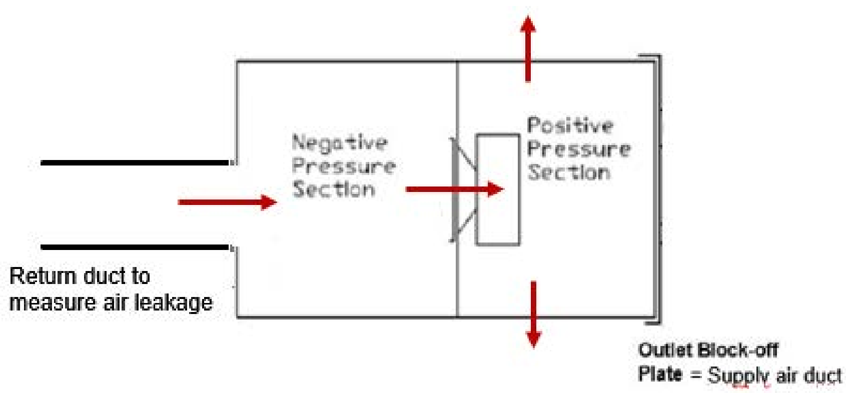

Figure 3-3: Test bench for Air Leakage Testing (NGTC) – Positive Pressure Section

3.3.2 Thermal Transmittance Testing

This test of AHRI standard 1350 aimed to measure the thermal energy transmitted through the casing of the test unit to determine the thermal transmittance. It was performed with internal heaters and circulating fans to provide uniform internal temperatures at least 30 °F (16.6 °C) higher than ambient air temperature.

For this test as well, it was not possible to follow the AHRI 1350 test procedure exactly. The main differences between the performed test and the standard are:

- Fewer thermocouples (TCs) were installed because some sections of the units were not accessible or hard to access. A total of 14 TCs were installed inside the BMU, and 17 TCs inside the MTU and the HMU. AHRI standard 1350 does not specify the number of TCs required; it depends on unit configuration (number of zones, dimensions, etc.) since TCS must be placed at a maximum distance from unit walls and other TCs. Fewer TCs were used in the test, which may have led to a less uniform temperature inside the unit.

- Circulating fans were installed inside the unit to provide adequate air mixing to achieve uniform temperature distribution inside the unit. However, the total airflow delivered by the circulating fans was lower than those specified in AHRI standard 1350 (50 cfm per square foot of the cross-sectional area in each unit section). Indeed, the unit sections were small and big fans could not be installed in them without removing some components of the units (for example, the evaporator, supply fan, heat exchanger, etc.). Since the total airflow was lower than what is called for in the AHRI 1350 test procedure, the convection heat losses may be lower, causing the thermal transmittance to be underestimated.

Table 3-3: Number of TCs, fans, heaters during testing

BMU	MTU	HMU
14 TCs 2 heaters 3 fans	17 TCs 2 heaters 3 fans	17 TCs 2 heaters 5 fans

- The project objective is to estimate the casing and damper conduction losses (two separate values). AHRI standard 1350 is not developed for damper conduction loss estimation, so only overall conduction losses (casing + damper) were determined during Test D. In addition, for the MTU and HMU, the unit volume/section that was heated during testing was smaller than the entire unit volume. Testing only concerns the volume that exists after the outside air damper which is located inside the unit and not in the casing, in order to determine casing and damper conduction losses.

4.0 RESULTS

This section presents the results of the two air leakage and thermal transmittance tests for each of the three tested rooftop units: BMU, MTU, and HMU. Analysis of these results is in Section 5.0.

4.1 AIR LEAKAGE TESTING

Table 4-1, Table 4-2, and Table 4-3 present the test conditions and results of the air leakage tests for the BMU, MTU, and HMU, respectively.

The leakage rate at 1 in w.c., expressed in cfm/100 ft^2, and presented in these tables is calculated according to AHRI standard 1350. It is important to note that the surface area considered in these tables (100 ft^2) represents the total surface under testing (casing + damper). For example, for the BMU:

- Air leakage associated with the damper is equivalent to 331 cfm/100 $ft^2_{under\ test}$:

$$\frac{398\ \text{cfm}}{100\ \text{ft}^2{}_{\text{under test}}} - \frac{67\ \text{cfm}}{100\ \text{ft}^2{}_{\text{under test}}} = \frac{331\ \text{cfm}}{100\ \text{ft}^2{}_{\text{under test}}}$$

- However, damper air leakage is 4,115 cfm/100 ft^2_{damper}:

$$\frac{\frac{398\ \text{cfm}\ \times\ 59.3\ \text{ft}^2{}_{\text{under test}}}{100\ \text{ft}^2{}_{\text{under test}}} - \frac{67\ \text{cfm}\ \times\ 54.5\ \text{ft}^2{}_{\text{under test}}}{100\ \text{ft}^2{}_{\text{under test}}}}{(59.3 - 54.5)\ \text{ft}^2{}_{\text{damper}}} = \frac{4{,}115\ \text{cfm}}{100\ \text{ft}^2{}_{\text{damper}}}$$

Table 5-1 in the Analysis section presents more details about the casing and damper air leakage results.

For the BMU, results show that the casing air leakage is around 65 cfm/100 ft² at 1 in w.c. for both positive and negative pressure sections. The damper air leakage[15] is significantly higher than casing air leakage, at around 331 cfm/100 ft² at 1 in w.c.

Table 4-1: Air Leakage Testing Results for BMU

	BMU			
	Positive pressure section TEST A	Negative pressure section TEST B.1 (2)	Negative pressure section TEST B.2 (1)	Negative pressure section TEST C
Test conditions				
Test procedure followed	AHRI 1350	NGTC		
Return air duct	Blocked off/Sealed	Blocked off/Sealed		
Supply air duct	Blocked off/Sealed	Installed		
Economizer Inlet	N.A.	Not Sealed		
Economizer Damper	N.A.	Closed/Not Sealed		Closed/Sealed
Airflow measurement device	Coriolis flowmeter	Hot wire anemometer	Turbine anemometer	
Pressure (in w.c.)	0.650 ± 0.002	- 0.650 ± 0.002		
Unit Characteristics				
Gross Area (ft²)	10.99 ± 0.07	61.2 ± 0.1		
Net Area (ft²)	8.61 ± 0.07	59.3 ± 0.1		54.5 ± 0.1
Testing results				
Measured Leakage (cfm)	4.1 ± 0.1	178 ± 5	174 ± 5	28 ± 1
Leakage Rate at 1 in w.c. (cfm/100ft²)(3)	64 ± 2	398 ± 12	387 ± 12	67 ± 2

Table notes:

(1) Test B was performed twice: once with a hot wire anemometer (B.1) and once with a turbine anemometer (B.2) to confirm both results. Indeed, during Test C, the airflow was too low to be measured with the hot wire anemometer, so the turbine anemometer was used.

(2) Results of Test B.1 are more accurate than Test B.2. Results of Test B.2 are provided for informational purposes only.

(3) Surface area considered in this table (100 ft²) represents the total surface under testing. This means that the damper air leakage is 331 cfm/100ft$^2_{\text{under test}}$ but is 4,115 cfm/100ft$^2_{\text{damper}}$ = (398 x 59.3 – 67 x 54.5) / (59.3 - 54.5). See Table 5-1 for details about the casing and damper air leakage results.

[15] Test B.1 – Test C = 398 – 67 = 331 CFM/100 ft².

For the MTU, results show that the casing air leakage of the positive pressure section is 27 cfm/100 ft^2. For the negative pressure section, casing air leakage was complex to estimate. However, NGTC performed an exploratory test (with OA inlet and return air outlet sealed) and it confirmed that casing air leakage is low and is perhaps similar to the positive pressure section. Compared to the BMU and HMU, results of Tests B′ and C′ cannot be used to estimate the damper air leakage because this unit has two dampers (OA damper and return air damper) and one of them is open during testing.

Table 4-2: Air Leakage Testing Results for MTU

	MTU			
	Positive pressure section TEST A	Negative pressure section TEST B′ (1)	Negative pressure section TEST C′ (1)	Negative pressure section EXPLORATORY TEST (2)
Test conditions				
Test procedure followed	NGTC	NGTC		
Return air duct	Installed	Blocked off/Sealed		
Supply air duct	Blocked off/Sealed	Installed		
Outside Air Inlet	Sealed	Not sealed		Sealed
Outside Air Damper	Closed/Not Sealed	Closed/Not Sealed		
Return Air Outlet	Sealed	Not sealed		Sealed
Return Damper	Open (100%)/Not sealed	Open (100%)/Not sealed	Open (100%)/Partially sealed	Open (100%)/Not sealed
Airflow measurement device	Turbine anemometer	Hot wire anemometer		
Pressure (in w.c.)	1.000 ± 0.002	- 1.000 ± 0.002		
Unit Characteristics				
Gross Area (ft^2)	60.84 ± 0.09	34.15 ± 0.11		
Net Area (ft^2)	59.11 ± 0.17	32.43 ± 0.11	29.43 ± 0.21	28.30 ± 0.21
Testing results				
Measured Leakage (cfm)	16.0 ± 0.5	732 ± 22	394 ± 12	Not measurable with a hot wire anemometer.
Leakage Rate at 1 in w.c. (cfm/100ft^2)	27 ± 1	2,257 ± 68	1,338 ± 41	

Table notes:

(1) Tests B′ and C′ for the MTU are not similar to Test B and C for the BMU and MTU due to the unit configuration. Indeed, the MTU is a 0 to 100% OA unit, thus it has 2 dampers: an outside air damper and a return air damper (that open and close inversely). During Test B′, the outside air damper is fully closed and the return air damper is fully open (the normal position when the MTU is unplugged or in standby mode). Test B′ overestimated air leakage because the return air damper is open and most of the air leakage comes from the outside air inlet (even if the OA damper is closed) and the return air outlet.

(2) An exploratory test demonstrates that the air leakage of the negative pressure section is low when all inlets/outlets are sealed; thus, casing air leakage is low.

For the HMU, results show that the casing air leakage is between 114 and 164 CFM/100 ft^2 for the casing. The damper air leakage[16] is very low and is estimated at 1 cfm/100 ft^2.

Table 4-3: Air Leakage Testing Results for HMU

	HMU		
	Positive pressure section – TEST A	Negative pressure section - TEST B (1)	Negative pressure section – TEST C
Test conditions			
Test procedure followed	AHRI 1350	NGTC	NGTC
Return air duct	Blocked off/Sealed	Blocked off/Sealed	Blocked off/Sealed
Supply air duct	Blocked off/Sealed	Installed	Installed
Outside Air Inlet	N.A.	Not Sealed	Not Sealed
Outside Air Damper	N.A.	Closed/Not Sealed	Closed/Sealed
Airflow measurement device	Coriolis flowmeter	Turbine anemometer	Turbine anemometer
Pressure (in w.c.)	0.150 ± 0.002	- 0.150 ± 0.002	- 0.150 ± 0.002
Unit Characteristics			
Gross Area (ft^2)	43.5 ± 0.1	116.3 ± 0.2	116.3 ± 0.2
Net Area (ft^2)	39.6 ± 0.2	116.3 ± 0.2	108.3 ± 0.3
Testing results			
Measured Leakage (cfm)	19 ± 1	39 ± 1	36 ± 1
Leakage Rate at 1 in w.c. (cfm/100ft^2) (2)	164 ± 5	115 ± 4	114 ± 4

Table notes:

(1) For Test B, gross and net areas are similar because the return air duct (inlet duct) is located before the outside air damper, so it is not included in the surface area.

(2) Surface area considered in this table (100 ft^2) represents the total surface under testing. This means that the damper air leakage is 1 CFM/100$ft^2_{under\ test}$ but it is 129 CFM/100ft^2_{damper} = (115 x 116.3 – 114 x 108.3) / (116.3 - 108.3). See Table 5-1 for details about casing and damper air leakage results.

16 Test B – Test C = 115 – 114 = 1 CFM/100 ft^2.

4.2 THERMAL TRANSMITTANCE TESTING

Table 4-4 summarizes the thermal transmittance test results for the three tested units. The thermal transmittance values shown in this table are for both casings and dampers.

Overall, results show that BMU has the highest thermal transmittance without leakage (0.451 Btu/h/°F/ft²), and thus the lowest thermal resistance. Surprisingly, the MTU has a lower thermal transmittance than the HMU (0.286 vs. 0.389), which means the MTU seems better insulated than the HMU. This result may come from the fact that: (1) more and bigger fans are used in the HMU (the convection was perhaps higher inside the HMU than inside the MTU during testing); and (2) some sections of the MTU around the heated section were not at ambient temperature but at an unknown temperature because these sections are inaccessible, thus the measured thermal losses are probably lower than in reality.

Table 4-4: Thermal Transmittance Testing Results

	BMU (w/ provided damper)	MTU (w/ provided damper)	HMU (w/ provided damper)	HMU (w/ insulated damper)[17]
Unit Characteristics				
Gross Area (ft²)	72.2 ± 0.1	95.0 ± 0.1	159.8 ± 0.2	
Net Area (ft²)	67.9 ± 0.1	91.5 ± 0.2	153.0 ± 0.2	
Testing conditions				
Mean internal air temperature (°F)	104.5 ± 0.2	108.1 ± 0.2	100.8 ± 0.2	100.8 ± 0.2
Mean external air temperature (°F)	73.0 ± 0.5	72.3 ± 0.5	70.7 ± 0.5	70.7 ± 0.5
Testing results				
Electrical energy (fans + heaters) (kW)	0.283 ± 0.003	0.275 ± 0.003	0.535 ± 0.002	0.535 ± 0.002
Thermal Transmittance w/ leakage (Btu/h/°F/ft²)	4.2 ± 0.1	8.8 ± 0.3	1.7 ± 0.1	1.7 ± 0.1
Thermal transmittance w/o leakage (Btu/h/°F/ft²)	0.451 ± 0.009	0.286 ± 0.005	0.389 ± 0.007	0.389 ± 0.007

- Additional information about the MTU:

The MTU is a 0 to 100% OA unit, thus it has 2 dampers: an outside air damper and a return air damper (that open and close inversely). During the thermal transmittance test, the outside air damper is fully closed, and the return air damper is fully open (which is the normal position when the MTU is unplugged or in standby mode). To evaluate the amount of heat loss by the return air damper (opened during testing), an additional test was performed. For this, a 2" thick expanded polystyrene board was installed on the return air damper to "artificially" close it. Results, presented in Table 4-5, show that with the same amount of heat from fans and heaters, there is a small increase of the air temperature inside the unit and thus a reduction of thermal transmittance. Note that this difference is not significant (less than 6%), so the fact that the return air damper is open only slightly affects thermal transmittance.

[17] The HMU's outside air damper (located inside the unit) was insulated with a 2" expanded polystyrene board.

Table 4-5: Additional Thermal Transmittance Testing Results for MTU

	MTU (w/ provided damper & return air damper artificially closed)
Testing conditions	
Mean internal air temperature (°F)	110.2 ± 0.2
Mean external air temperature (°F)	72.3 ± 0.5
Testing results	
Electrical energy (fans + heaters) (kW)	0.275 ± 0.003
Thermal Transmittance w/ leakage (Btu/h/°F/ft²)	8.8 ± 0.3
Thermal transmittance w/o leakage (Btu/h/°F/ft²)	0.271 ± 0.005

- HMU

In addition to the tests performed on the HMU, some infrared photographs were taken during the test. They show that even if the unit is very well insulated (2" of insulation in the casing and doors are sealed), heat escapes around the doors of the unit.

5.0 ANALYSIS

This section presents the data analysis and a comparison of test results with the P.8 test procedure results to estimate the impact on $TCOP_{HS}$ and $GCOP_{HS}$, two key parameters of the P.8 standard used to evaluate the performance of rooftop units and compare rooftop units.

In addition, this section summarizes NGTC's observations made during the shell loss test.

5.1 AIR LEAKAGE LOSSES

Table 5-1 shows the casing, the damper, and the total air leakage rate for the three tested units. Note that results in this table are expressed using a different surface area reference (i.e., ft^2_{casing}, or ft^2_{damper}, or $ft^2_{casing+damper}$) than the tables in Section 4.1 ($ft^2_{under\ test}$).

The main results are:

- For the BMU, 199 cfm of air leakage comes from the economizer damper, which represents nearly 83% of the total air leakage of the unit. The damper air leakage rate is 4,115 cfm/100 ft^2_{damper} compared to 67 cfm/100 ft^2_{casing} for the casing. This result means that even if the BMU is a 0% OA unit and the economizer damper is closed during the heating season, there is a portion of outside air that comes into the unit when it is running. Improvements of the damper sealing or insulation for this type of unit (0% OA unit) may lead to a better thermal efficiency.

- For the MTU, it was complex to estimate the casing and the damper air leakage. Values presented in Table 5-1 are estimated using the following assumptions, so they cannot be compared with values of the BMU and HMU that come from testing:

- The casing air leakage in the negative pressure section is similar to the casing air leakage in the positive pressure section.
- The damper air leakage rate is lower than 150 cfm/100 ft².[18]

- For the HMU, 10 cfm of air leakage comes from the outside air damper, which represents 5% of the total air leakage of the unit. The damper air leakage rate of 129 cfm/100 ft^2_{damper} is similar to the casing air leakage (127 cfm/100 ft^2_{casing}). This result is consistent with the fact that the HMU damper has a maximum leakage of Class 1A (3 cfm/ft² of damper area at 1 in w.c air pressure differential) when tested in accordance with AMCA Standard No. 500, Test Methods for Louvers, Dampers and Shutters [3][19]. For this unit type (100% OA unit), damper air leakage does not appear to be as important as for 0% OA units; indeed, the outside air damper is only closed when the unit is in standby, and in standby mode, the supply fan is off so the section where the damper is is not depressurized so there is theoretically no air leakage.
- For the three tested units, the casing air leakage rate is lower than 130 cfm/100 ft² of casing, which is less than damper air leakage. However, even if this air leakage is not significant per surface area, it may be the biggest source of air leakage when the casing area is significantly larger than the damper area (as seen in the results with the HMU).

Table 5-1: Air Leakage Comparison and Analysis

	BMU	MTU (estimated)	HMU
Total casing leakage losses at 1 in w.c. (CFM for the casing area – excluding damper area)	42	26 [20]	188
Total damper leakage losses at 1 in w.c. (CFM for the damper area)	199	9 [21]	10
Total leakage losses at 1 in w.c. (CFM for the entire unit area (casing + damper))	241	35	199
Casing leakage rate at 1 in w.c. (CFM/100 $ft^2_{casing\ (excluding\ damper)}$)	67	28	127
Damper leakage rate at 1 in w.c. (CFM/100 ft^2_{damper})	4,115	150	129
Total leakage rate at 1 in w.c. (CFM/100 $ft^2_{casing\ +\ damper}$)	355	38	127

[18] According to the Technical Specifications of the MTU.
[19] According to the Submittal Data of the HMU.
[20] Considering that casing air leakage of the negative pressure section is similar to the casing air leakage of the positive pressure section (NGTC's assumption).
[21] Considering damper air leakage of 1.5 CFM/ft^2_{damper} as indicated in the specifications of the unit.

- <u>Comparison with P.8 calculations</u>

Calculations in the P.8 test procedure assume that the casing air leakage is negligible (so equal to zero) and proposes a damper air leakage default value of 3 cfm/ft² at 1 in w.c.

As shown in Table 5-2 , the default value overestimated damper air leakage for the HMU, which is consistent with the fact that the damper air leakage of this unit is lower than 3 cfm/ft² according to its specification. For the BMU, the P.8 default value significantly underestimated the damper air leakage. For the MTU, it is not possible to conclude since the 150 cfm/100 ft² comes from the specifications of the unit and not from testing.

Table 5-2: Air Leakage Comparison with P.8 calculations (at 1 in w.c.)

Default value used in P.8 test procedure	Testing Results		
	BMU	MTU (estimated)	HMU
3 cfm / ft² = 300 cfm/100 ft²	4,115 cfm/100 ft² *(+1,272%)*	150 cfm/100 ft² *(-50%)*	129 cfm/100 ft² *(-57%)*

Table 5-3 summarizes the overall air leakage of each unit according to the test results and to P.8 calculations. For the 3 units, the air leakage is significantly underestimated in P.8 calculations. For the BMU, this is mainly because damper air leakage is underestimated while for the two other units, this is because casing air leakage is not considered in P.8 calculations.

Table 5-3: Air Leakage Comparison with P.8 calculations (at 1 in w.c.) (2)

	BMU	MTU (estimated)	HMU
Overall air leakage of the unit			
Test results (cfm)	241	35	199
P.8 Calculations (cfm)	14.5 *(-93%)*	18 *(-50%)*	23.3 *(-88%)*

The impact of casing and damper air leakage on $TCOP_{HS}$ and $GCOP_{HS}$ values is discussed in Section 5.3.

5.2 HEAT LOSSES

In the P.8 test procedure, the total enclosure losses (including both damper and casing) are calculated using the thermal resistance and the thickness of each material layer that composed the casing and the damper.

Table 5-4 presents the total heat losses according to test results and the estimated heat losses from P.8 calculations, without and with air leakage, for the three tested units.

Results show that the theoretical value of heat losses without leakage from the P.8 calculations is relatively well estimated: the P.8 value underestimated the heat loss for the BMU and the MTU by 11% and 16% respectively; and it underestimated the heat loss for the HMU by 44%, however, this test was performed with more and bigger fans, so the convection is higher inside the HMU than inside the BMU and MTU. Regarding heat losses with leakage, they are significantly underestimated in the P.8 calculations due to the underestimation of air leakage (see Table 5-3).

Table 5-4: Heat Loss Rate Comparison

	BMU	MTU	HMU
Testing Results (Btu/h.°F)			
Without leakage	30.7	26.2	60.7
With leakage	282.5	805.5	269.1
P.8 Calculations (Btu/h.°F)			
Without leakage	27.3 (-11%)	21.9 (-16%)	33.7 (-44%)
With leakage	39.5 (-86%)	29.2 (-96%)	57.7 (-80%)

5.3 IMPACT ON TCOP AND GCOP

The new P.8 test procedure includes the calculation of two key parameters ($TCOP_{HS}$ and $GCOP_{HS}$) used to evaluate the performance of rooftop units and to compare rooftop units.

Table 5-5 shows $TCOP_{HS}$ and $GCOP_{HS}$ calculated with the P.8 calculator using the default value of damper leakage (3 cfm/ft²) and thermal resistance of casing and damper materials of the three units (P.8 calculation in Table 5-5), and using testing results (P.8 calculations, adjusted with testing results in Table 5-5).

As shown in this table, $TCOP_{HS}$ and $GCOP_{HS}$ calculated following the P.8 standard are different than the $TCOP_{HS}$ and $GCOP_{HS}$ adjusted with the testing results for the BMU only. Indeed, for 100% OA units[22] like the MTU and the HMU, the P.8 calculations consider there is no enclosure heat losses. This assumption comes from the fact that the air temperature inside the unit is supposed to be equal to the outdoor air temperature (because it is a 100% OA unit), which is true only when the unit does not have a heat recovery system (HRV or ERV) (after a heat recovery system, the temperature inside the unit is higher than the outdoor air temperature)[23].

For the BMU, $TCOP_{HS}$ and $GCOP_{HS}$ are significantly lower using testing results.

Table 5-5: Impact of TCOP and GCOP

	BMU	MTU	HMU
P.8 Calculations			
TCOP	0.75	2.78	3.11
GCOP	0.75	2.95	3.22
P.8 Calculations, adjusted with testing results			
TCOP	0.53	2.78	3.11
GCOP	0.54	2.95	3.22

[22] According to the P.8 test procedure, calculations for a 0-100% OA unit (like the MTU) is similar to a 100% OA unit (like the HMU).
[23] The impact on the TCOP and GCOP of considering the air temperature increase after the HRV was discussed during a working group meeting (June 3, 2021), and because the impact is low, it was decided not to change the calculations.

5.4 NGTC'S OBSERVATIONS

This section presents NGTC's observations made during the shell loss tests.

5.4.1 Air Leakage Testing

- Air leakage estimated with the AHRI 1350 test procedure does not consider the internal flow between the positive and the negative pressure sections. This means that if there are some leaks between these two sections, air leakage will be accounted for twice: once during the positive pressure section test and once during the negative pressure section test.
  - For the MTU, it was not possible to achieve the desired pressure in the positive pressure section (unlike for the BMU and the HMU for which it was possible). NGTC's explanation is that there is internal flow between both unit sections. Indeed, during the positive pressure section test, normally the pressure inside the negative pressure section stays at the ambient pressure but during this test it increases.
  - Using the AHRI 1350 test procedure to estimate the air leakage of each section requires the pressure wall change to be entirely sealed and therefore have access to this entire surface.
- The air leakage test requires an airflow measurement device and a fan to pressurize or depressurize the unit. Without knowing the approximative amount of leakage that should be measured before the test, it is complex to determine the equipment that should be used.
  - At the beginning, it was planned to measure the air leakage rate with a meter (typically used in other projects to measure small airflow); however, the measurement range of this equipment is too small for the actual air leakage of the three tested units. Similarly, for some tests, the airflow was measured using the hot wire anemometer, while for others, the air speed was too low to be measurable with it, so a turbine anemometer was used.
  - NGTC's equipment to pressurize or depressurize the unit was appropriate for the three tested units (except for the positive pressure section of the BMU and the HMU). When the air leakage is too high, the supply fan inside the unit can be used (as NGTC did in the tests).
- AHRI standard 1350 is not a standard for damper air leakage estimation. AMCA 500D [3], used as a reference in the P.8 standard, is more appropriate. However, as NGTC did, it is possible to estimate the air leakage from dampers using AHRI 1350.
  - The P.8 test procedure indicates that if the outdoor air damper is not tested, a maximum leakage rate of 3 cfm/ft² can be used. This value is equivalent to a Class 1A damper which is the best class in AMCA 500D. This means that the P.8 standard does not encourage manufacturers to improve the outdoor air damper or test it according to AMCA 500D since a very good default value can be used.
  - The air leakage value used in the P.8 calculations for units able to achieve up to 100% OA units, has no impact on the $TCOP_{HS}$ and $GCOP_{HS}$.
- Air leakage tests provide an idea of the unit air leakage rate; however, they do not represent air leakage of the unit under real operating conditions. Indeed, because the test is done

with some part/components of the unit blocked off or sealed (i.e., return air duct or supply air duct), it probably induces preferred pathways for the air to leak out of the casing or the damper, while typically the air sucked by the supply fan comes from the return air duct and the air blown by the supply fan goes into the supply air duct.

- Testing was complex for the MTU due to the presence of two dampers. For this unit, results are an estimation of the casing and damper air leakage, so they do not represent real air leakage.

- The test procedure used by NGTC was easier than the test procedure mentioned in AHRI standard 1350. Indeed, air ducts already in place and used in the P.8 test procedure can be used to measure the airflow (air leakage), the supply fan can be used to pressurize and depressurize the unit sections rather than removing the supply fan and installing a block off plate.

5.4.2 Thermal Transmittance Testing

- As well as for air leakage, AHRI standard 1350 is not a standard for damper heat loss estimation. The damper surface area is small compared to the total casing of the unit; thus, it is complex to quantify the impact of dampers.

- AHRI 1350 test procedure is complex to follow since some sections of the unit are inaccessible or difficult to access, or for some sections it is complex to set up instrumentation, fans, and heaters. It would probably be easier to estimate the thermal transmittance of the casing without all the components (evaporator, supply fan, HRV, heat heat exchanger, etc.) inside the unit.

- Due to the different results obtained for the HMU compared to the two other units, one assumption is that the CFM delivered by the fan used to uniformize the indoor temperature can impact the result.

- Testing was complex for the MTU due to the presence of two dampers.

- Thermal transmittance according to AHRI 1350 provides an idea of the unit insulation; however, they do not represent heat losses of the unit under real operating conditions. Indeed, tests are done at ambient pressure and not under positive/negative pressure like when it is in operation. For example, for the HMU, the access doors have seals around them, which are squeezed into the casing when the unit is running (negative pressure that sucks the doors on the casing), so thermal resistance may be better in operation mode.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Results of shell loss tests on the three tested units, shown in Table 6-1, are:

- The casing leakage rate is lower than 1.3 cfm/ft² for all of the units. However, even if this air leakage is not significant per surface area, it may be the biggest source of air leakage since the casing area is significantly larger than the damper area.

- The damper air leakage is 41.15 cfm/ft² for the BMU and 1.29 cfm/ft² for the HMU. For the MTU, the value presented in Table 6-1 is an estimation according to the specifications of the unit, so it does not come from testing. The value for the HMU is consistent with the unit specifications. For BMU, results show that air leakage from the damper can be important if the damper is not sealed appropriately.

- The thermal transmittance varies from 0.286 Btu/h/°F/ft² to 0.451 Btu/h/°F/ft². The presence of an insulated damper on the thermal transmittance of the HMU does not impact results.

Table 6-1: Shell losses results

	BMU	MTU (estimated[24])	HMU
Casing leakage rate at 1 in w.c. (CFM/$ft^2_{casing\ (excluding\ damper)}$)	0.67	0.28	1.27
Damper leakage rate at 1 in w.c. (CFM/ft^2_{damper})	41.15	1.50	1.29
Total leakage rate at 1 in w.c. (CFM/$ft^2_{casing\ +\ damper}$)	3.55	0.38	1.27
Thermal transmittance (casing + damper) (Btu/h/°F/ft²)	0.451	0.286	0.389 (same result with provided and insulated dampers)

Finally, results show that:

- Air leakage is underestimated in the P.8 calculations for the three units, mainly because:
  - the damper air leakage default value used in the standard represents a well-sealed damper (Class 1A of AMCA 500-D: the best class), which is not necessarily the case for all the units tested (i.e., the BMU).
  - the casing air leakage is not taken into account in the P.8 calculations.

  However, it is important to note that the test procedure used during this project to estimate air leakage of the casing and damper does not represent the unit under real operating conditions and, likewise, the real air leakage of the unit when it is running. Indeed, because the return and supply air ducts are blocked off and sealed during testing, this induces a preference pathway for the air through the casing or the damper. This preference pathway may lead to overestimating the casing and damper air leakage.

- AHRI standard 1350 is a standard developed to estimate casing performance, including the leakage of air. If this standard is commonly used by manufacturers, a future edition of the P.8 standard could be modified to take casing air leakage into account. Otherwise, NGTC does not recommend adding it in a future version of the P.8 standard since the test procedure is complex to follow and perform, and it does not represent air leakage under real operating conditions.

[24] For the MTU, it was complex to estimate the casing and damper air leakage. Values presented in here are estimated using assumptions, so they cannot be compared with values for the BMU and the HMU that come from testing.

- AHRI standard 1350 is not applicable for estimating damper air leakage. NGTC recommends using AMCA 500-D recommended in the P.8 standard for this purpose. However, for manufacturers that do not test their dampers according to AMCA 500-D, the P.8 test procedure suggests using a default value of 3 cfm/ft², which represents a very well-sealed damper ("Class 1A damper"[25]). NGTC recommends using a higher default value in the P.8 standard because the current default value does not encourage manufacturers to improve the outdoor air damper or test it according to AMCA 500D since a very good default value can be used.

- Thermal transmittance calculated in the P.8 calculations is relatively well estimated. As previously discussed, if AHRI standard 1350 is commonly used by manufacturers, the thermal transmittance value could be added to the P.8 standard. If not, due to the difficulty of using the AHRI 1350 test procedure to quantify thermal transmittance of the casing, NGTC recommends keeping the theoretical estimation of the enclosure losses as they currently are in the P.8 test procedure.

- Both air leakage and thermal transmittance have no impact on the TCOP and GCOP for units able to achieve up to 100% OA (like the MTU and HMU) because enclosure losses are assumed negligeable for these units in the P.8 standard (no heat losses since the air inside the unit is at the same temperature as the outdoor air). The impact is only on 0% OA units (like the BMU) and 30% OA units[26]. If the P.8 calculations remain the same (i.e., accept enclosure losses are zero for units up to 100% OA), it is not required for these units that the damper and casing air leakage is determined according to any standard.

[25] This class is the best class achievable for dampers following AMCA 500-D. This means the damper air leakage is lower than 3 cfm/ft² at 1 in w.c. [3].

[26] Gas-fired package furnace that includes outdoor air dampers and has the capability to heat and cool a range of outside air from 0% up to 90% but does not have the capability to heat and cool 100% outside air.

7.0 REFERENCES

[1] CAN/CSA-P.8-09 (Reaffirmed in 2019): Thermal efficiencies of industrial and commercial gas-fired package furnaces.

[2] ANSI/AHRI Standard 1350 (I-P) with Addendum 1, "2014 Standard for Mechanical Performance Rating of Central Station Air-handling Unit Casings", https://www.ahrinet.org/App_Content/ahri/files/STANDARDS/ANSI/ANSI_AHRI_Standard_1350_I-P_2014_with_Addendum_1.pdf

[3] ANSI/AMCA Standard 500-D-18 : Laboratory Methods of Testing Dampers for Rating, https://www.amca.org/publish/publications-and-standards/amca-standards/amca-standard-500-d-18-laboratory-methods-of-testing-dampers-for-rating.html

APPENDIX

APPENDIX A: TEST PLAN

Gas-Fired Rooftop Unit Efficiency Testing

Project #: 248020

Test Plan - Final

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December 10, 2021

RIGHTS AND OBLIGATIONS

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1.0 OBJECTIVES

The first objective of testing is to validate the test procedure for repeatability of the new edition of CSA P.8 and provide feedback about our experiences during testing and analysis. The second objective is to perform exploratory tests to provide information that could help NRCan to advance their knowledge on shell loss performance. These tests will also help validate the calculations in the standard.

2.0 TEST OBJECTS

Table 1 shows the three rooftop units that will be tested.

Table 1: Test Objects

Sample	Base model unit **(BMU)**	Mid-tier model unit **(MTU)**	High efficient model unit **(HMU)**
Manufacturer	*confidential*		
Model Number			
Serie Number			
Input heating capacity	150 000 Btu/h	160 000 Btu/h	175 000 Btu/h
No Stages	2 stages (70% - 100%)	5 stages (20% - 100%)	5 stages (20% - 100%)
Heating efficiency	81%	81%	94%
Percent Outdoor Air	0%	0 - 100%	100%
Airflow	2,000 cfm	2,000 cfm	2,800 cfm
HRV/ERV	No	Yes	Yes
Insulation/Tightness Quality	Basic	Good	High

3.0 TEST PLAN

3.1 METHODOLOGY

The two following tests will be performed:

- **<u>Test 1: Performance of rooftop units according to CSA P.8-09 (R19 and new)</u>**

This test aims to determine the performance of the three rooftop units according to the old and new CSA P.8-09 procedures using the following configurations:

- BMU
- MTU with the heat recovery in operation
- HMU with the heat recovery in operation

Tests without the heat recovery in operation on the MTU and HMU will be not physically tested but data will be analyzed to estimate the unit efficiency without the heat recovery system.

The reference standards for testing are:

- *CAN/CSA-P.8-09 (Reaffirmed in 2019): Thermal efficiencies of industrial and commercial gas-fired package furnaces.*
- *CAN/CSA-P.8-09 (Edition 3)*: Document sent by NRCan[1].

Note that in P.8 standard, units shall be tested at rated and reduced capacity (see Table 4).

In addition to all measurements required in P.8 standard, the outlet airflow rate will also be measured (as requested by the client). Using the airflow measurement for all three rooftop units, it will be possible to define how close the actual airflow is to the unit's specifications and subsequently establish recommendations regarding the possible adoption of airflow measurement in the standard.

- **Test 2: Shell losses through the casing and dampers according to AHRI 1350 (I-P/2014)**

This test aims to collect data to better understand the impact of the damper and casing leakage and conduction (insulation) on shell losses. The AHRI 1350 (I-P/2014) test procedure will be conducted with the following configurations:

- BMU with provided dampers
- MTU with provided dampers
- HMU with provided dampers
- HMU with insulated[2] dampers

The reference standard for testing is the *ANSI/AHRI 1350 (I-P/2014): Mechanical Performance Rating of Central Station Air-handling Unit Casings*.

3.2 INSTRUMENTATION

The following table presents the measured data and the acquisition system for the two tests.

[1] X:\PROJETS\248020 CSA P.8 RTU Testing\3- Documentation\Official Pilot - CSA P.8 Edition 3_May2020Version_Clean.docx

[2] For this test, a piece of insulation will be added on the provided dampers to simulate an insulated damper. The insulated dampers will finally not be ordered since their thickness dimension does not fit with the tested unit.

Table 1: Measured Data and Acquisition System

Measures	Symbols (when applicable) P.8	Symbols (when applicable) AHRI 1350	Acquisition (manual or automatic)	Frequency	Applicable Tests #1	Applicable Tests #2
Test area temperature (T_r)[3]	T_r	T_{ae}	automatic	10 sec.	X	X
Test area relative humidity ($RH\%_r$)[4]	h	-	manual	instantaneous	X	
Outlet air temperature (T_{out})[5]	-	-	automatic	10 sec.	X	
Outlet air flow rate (Q_{out}) †	-	-	manual	instantaneous	X †	
Outlet air static pressure (P_{out})	-	-	manual	instantaneous	X	
Inlet air temperature (T_{in})	-	-	automatic	10 sec.	X	
Inlet air static pressure (P_{in})	-	-	manual	instantaneous	X	
Flue gas temperature (T_f)[6]	T_f	-	automatic	10 sec.	X	
CO_2 concentration in flue gas (X_{CO2})	C	-	manual	instantaneous	X	
Gas higher heating value (HHV)	HHV	-	manual	instantaneous	X	
Gas temperature (T_{ng})	-	-	automatic	10 sec.	X	
Gas pressure (P_{ng})	-	-	manual	instantaneous	X	
Gas volume (V_{ng})	-	-	manual	instantaneous	X	
Time (t)	-	-	manual	instantaneous	X	
Condensate mass (M_c)	M_C	-	manual	instantaneous	X	
Jacket surface temperature (T_{jacket})[7]	$T_{s,x}$	-	automatic	10 sec.	X	
Total electric consumption (kW_{total})	kW		manual	instantaneous	X	
Power factor (PF)	PF		manual	instantaneous	X	
Pressure (P_m)	-	P_m	automatic	5 min.		X
Air leakage flow ($Q_{leakage}$)	-	Q	manual	instantaneous		X
Inside temperature (T_{ai})[8]	-	T_{ai}	automatic	10 sec.		X
Electric consumption of fans (kW_{fans})	-	$kW_{circulating\ fans}$	automatic	10 sec.		X
Electric consumption of heaters (kW_{heater})	-	kW_{heater}	automatic	10 sec.		X

† Not required in the standard but asked by the client.

[3] Average of 4 thermocouples for P.8 and average of 6 thermocouples for AHRI 1350.
[4] Shall at no time exceed 80%.
[5] 9-point thermocouple grid
[6] 9-point thermocouple grid (if less, report the number of thermocouple)
[7] The exact number of thermocouples will be determined later (once the rooftop units are on the lab).
[8] The exact number of thermocouples will be determined later. It should be between 36 and 72 thermocouples (maximum) depending on the rooftop unit.

3.2.1 Instrument Accuracy

The reference standards used in this project require accurate measurements of parameters. Table 2 lists the most restrictive accuracy required by the reference standards as well as the instruments that will be used on the test objects and their achievable accuracy.

Table 2: List of Instrumentation

Instrumentation	Instrument Identification	Type of Measurement	Units	Achievable accuracy	Required Accuracy
100 x thermocouples (bead type; < 20 AWG)	DAQ 302, DAQ 304 & DAQ 315	Temperatures (T_r, T_{out}, T_{in}, T_f, T_{ng}, T_{jacket}, T_{ai})	°C	±0.5°C	±1°C
1 x Vaisala Humidity and Temperature Transmitter	MIT-000	Relative humidity ($RH\%_r$)	%RH	±1%RH	Not specified
1 x Hot wire anemometer 0-30 m/s	SE-001 + SI-004	Airflow rate (Q_{out})	ft/min	±3% of reading + 19 ft/min	na
1 x manometer	dPT-000	Static air pressure (P_{out}, P_{in})	in w.c.	0.002 in w.c. (±0.5 Pa)	±2 Pa
1 x Ultramat 23 gas analyzer	AI-008	CO_2 concentration in flue gas (X_{CO2})	%	±0.1%	±0.1%
Gas Chromatograph – Varian CP-4900	AI-016	Gas higher heating value (HHV)	Btu/ft^3	±2,1 Btu/ft^3 (<0.5% of reading)	±1% of reading
1 x Dwyer 0-10 in w.c.	dPi-014	Natural gas pressure (P_{ng})	in w.c.	±2% full scale (±0.2 in w.c.)	±0.2 in w.c.
1 x DTM-325 gas meter	QI-005	Natural gas volume (V_{ng})	ft^3/h	±1% of reading	±1% of measured volume
1 x timer	KI-000	Time (t)	s	0,5 s/h	0,5 s/h
1 x balance 0-3100 g	WI-000	Condensate mass (M_c)	g	±0.44 g (< 0.02% of reading)	±1% of reading
1 x Veris Industries with 3 30 Amp. donuts	JT-003 + 3 CTs (JE-007 to JE 009)	Electric consumption (KW_{total}) and Power factor (PF)	kW	0.7% of reading	±1% of reading
1 x measuring tape 25 ft	ZI-004	Dimensions (H, W, L)	mm	0.5 mm	Not specified
1 x manometer	dPi-000	Pressure (P_m)	in w.c.	0.002 in w.c. (±0.5 Pa)	± 0.01 in w.c.
1 x anemometer (hot wire or turbine)	SE-001 + SI-004	Airflow rate ($Q_{leakage}$)	ft/min	±3% of reading + 19 ft/min	±2.0% of reading
1 x Power Analyzer Yokogawa 1 Phase	JI-001	Electric consumption (kW_{fans} + kW_{heater})	kW	+0.4%	±1% of reading
1 x Vaisala Digital Barometer	bP-000	Atmospheric pressure (P_{atm})	mbar	±0.15 mbar	±0.34 mbar

3.2.3 Instrument Calibration and Verification Plan

The instrumentation used for the tests will be verified by NGTC or calibrated by ISO-17025 enterprises to reach the precision required for the measured data. Intern calibration or verification will be made before tests.

Table 3: List of Required Calibration and Verification

Instrument Number	Type		Intern Calibration/Verification Requirement		
	Extern Calibration[9]	Intern Calibration or Verification	Before Tests	During Tests	After Tests
DAQ 302, DAQ 304 & DAQ 315 (Thermocouple)		X	X		
MIT-000	X				
SI-004 + SE-001	X				
dPT-000		X	X		
AI-008		X	X		
Ai-016		na			
dPi-014		X	X		
QI-005	X				
KI-000		X	X		
WI-000	X				
JT-003 + (JE-007 to JE-009)	X				
ZI-004	X				
JI-001	X				
bP-000	X				

3.3 TEST BENCH

3.3.1 Test 1: Performance of rooftop units according to CSA P.8-09(R19)

Rooftop units will be installed in a structure used to elevate and support them. This will allow the installation of the required air ducts under the unit. The steel structure will have a height of approximately 4 feet. The thermally isolated blocks will be placed between the structure and the units to fit with the requirements of the AHRI 1350 tests[10].

The instrumentation will be installed as indicated in P.8 standard. As mentioned in Section 3.1, the airflow in the outlet air duct will also be measured for every rooftop unit as part of the testing.

[9] External calibration must be valid during the entire test period.

[10] For casing and damper conduction tests (section C.7 of AHRI 1350), units must be supported by thermally isolated blocks at 12 to 18 inches above the floor. The blocks will be placed before testing and for all tests Ans as such, the three units won't have to be moved between P.8 and AHRI 1350 tests.

3.3.2 Test 2: Shell losses through the casing and dampers according to AHRI 1350 (I-P/2014)

For casing and damper leakage tests (section C.6 of AHRI 1350) and for casing and damper conduction (section C.7 of AHRI 1350), units will be on the same structure as for the P.8 tests.

The test bench and instrumentation will be as indicated in AHRI 1350 standard.

3.4 PROCESS

3.4.1 Test 1: Performance of rooftop units according to CSA P.8-09(R19)

Table 4 summarizes the three (3) tests required in Test 1. Test order may vary depending on the arrival of the three units.

Table 4: General process for Test 1

Test 1#	Tested unit			Tested capacity (Btu/h)	Specific configuration
	BMU	MTU	HMU		
A	X			150 000 105 000	-
B		X		160 000 32 000	with heat recovery
C			X	175 000 35 000	with heat recovery

1. Install all the instrumentation required in the P.8-09(R19) standard (Table 2).
2. Turn on the data acquisition system.
3. Test the unit by following the P-8 standard testing procedures (units shall be tested at rated and reduced capacities as indicated in the standard).
4. Measure the outlet airflow rate (Table 2 and Section 3.4.1.1).
5. Repeat the previous steps for all subsequent tests (Table 4).

While following the P.8 testing procedures, **any unclear element that would lead to interpretation will be noted** and brought up to NRCan.

3.4.1.1 AirFlow Rate Measurement

As the airflow rate measurement is a request of the client and not a requirement from the P.8 standard, it is important to define the way it will be done in this testing protocol.

The airflow will be measured using the log-Tchebycheff method. According to this method, a defined number of measurements must be done at various locations in the duct. The number of data points to be taken along each side of the duct depends on the width of each side of the duct, as presented in Table 5.

Table 5 : Number of data points required for airflow measurement

Duct Size Length (in)	Number of points
< 30	5
$[30, 36[$	6
> 36	7

For example, as shown in Figure 1 for a 30-36" horizontal dimension (6 points) by 30" vertical dimension (5 points) will require 30 measurements. Once the average air velocity (m/s) has been determined, the airflow (m^3/s) is then calculated by multiplying the former value by the duct's area.

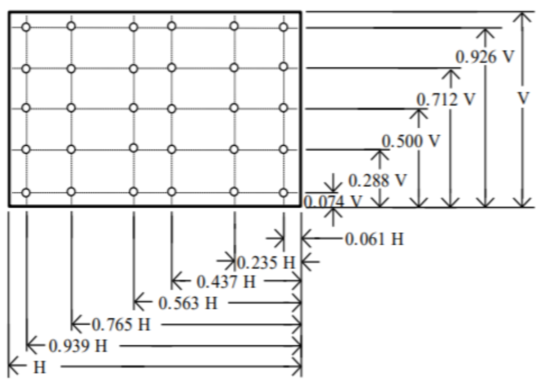

Figure 1 : Location of measuring points for traversing a rectangular duct (log-Tchebycheff method)

3.4.2 Test 2: Shell losses through the casing and dampers according to AHRI 1350 (I-P/2014)

Table 6 summarizes the four (4) tests required in Test 2. Test order may vary depending on the arrival of the three units.

Table 6: General process for Test 2

Test 2#	**Tested unit**			**Specific configuration**
	BMU	MTU	HMU	
A	X			with provided dampers
B		X		with provided dampers
C			X	with provided dampers
D			X	with **insulated** dampers

1. Set the parameters of the unit – i.e. provided or insulated dampers (Table 6).
2. Install all the instrumentation required in AHRI 1350 standard (Table 2).
3. Turn on the data acquisition system.
4. Perform **casing and damper leakage tests**:

   - Test the unit by following Section C6 of the AHRI 1350 standard testing procedure[11] (**casing leakage tests**).
   - Remove the block-off plate on the outside air entrance (dampers).
   - Re-test the unit by following Section C6 of the AHRI 1350 standard testing procedure[12] (**damper leakage tests**).
5. Perform **casing and damper conduction tests**:
   - Test the unit by following Section C7 of the AHRI 1350 standard testing procedure[13] (**casing conduction tests**).
   - Remove the block-off plate on the outside air entrance (dampers).
   - Re-test the unit by following Section C7 of the AHRI 1350 standard testing procedure[14] (**damper conduction tests**).
6. Repeat the previous steps for all subsequent tests (Table 6).

While following the AHRI testing procedures, **any unclear element that would lead to interpretation will be noted** and brought up to NRCan.

4.0 DATA ANALYSIS

Data analysis will be made according to the reference standards:

- For all tests performed under Test 1, data will be analyzed according to CSA P.8-09 (R19) and to the new P.8 (with the calculator provided by NRCan).
- For all tests performed under Test 2, data will be analyzed to calculate the damper leakage losses, the damper conduction losses (insulation levels), the casing leakage losses (seals) and the casing conduction losses (insulation levels) based on AHRI 1350 (I-P/2014).

[11] During this test, block-off plates are installed on all inlets and outlets of the unit (including the outside air inlet).
[12] During this test, block-off plates are installed on inlets and outlets of the units, except the inlet with dampers (outside air inlet).
[13] During this test, block-off plates are installed on all inlets and outlets of the unit (including the outside air inlet).
[14] During this test, block-off plates are installed on inlets and outlets of the units, except the inlet with dampers (outside air inlet).

5.0 UNCERTAINTY ANALYSIS

The experimental uncertainty for each result will be calculated using the Kline-McClintock method (KM method). In brief, the uncertainty for a calculated parameter R can be described as follows:

$$\varepsilon_R = \sqrt{\left(\frac{\partial R}{\partial x_1}\,\varepsilon_1\right)^2 + \left(\frac{\partial R}{\partial x_i}\,\varepsilon_i\right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n}\,\varepsilon_n\right)^2}$$

As such, the KM equation will derive the principal equation for a parameter with respect to each of the independent variables that appear in the equation (such as temperature, flow rate, etc.). This will result in a weighted combination of the uncertainty for each measured property.

Therefore, the uncertainty according to the KM method is presented below for the various parameters calculated in both standards (P.8 and AHRI 1350). As the calculations made per the third edition of the CSA P.8 Standard is to be done by using the calculator sent by NRCan, no uncertainty analysis shall be done for the newest edition of the P.8 (the calculator does not include uncertainties).

5.1 CAN/CSA P.8-09 (EDITION 2, REAFFIRMED IN 2019)

- Latent heat gain (L_G, %)

$$L_G = \frac{100(2449.98)M_C}{Q_C} \qquad \text{Equation a-1}$$

With:

100	Conversion factor to express a decimal as a percentage
$2449{,}98$	Latent heat of vapourization of water (kJ/kg)
M_C	Mass of condensate at steady stage (kg)
Q_C	Condensing gas energy input at steady state (kJ)

$$\varepsilon_{L_G} = \sqrt{\left(\frac{\partial L_G}{\partial M_C}\,\varepsilon_{M_C}\right)^2 + \left(\frac{\partial L_G}{\partial Q_C}\,\varepsilon_{Q_C}\right)^2}$$

$$\varepsilon_{L_G} = 244\,998\sqrt{\frac{{\varepsilon_{M_C}}^2{Q_C}^2 + {\varepsilon_{Q_C}}^2{M_C}^2}{{Q_C}^4}} \qquad \text{Equation b-1}$$

- Heat loss due to hot condensate going down the drain (L_C, %)

$$L_C = \frac{L_G\left[4.187\left(T_f - 21\right) - 1.884\left(T_f - T_{OA}\right)\right]}{2449{,}98} \qquad \text{Equation a-2}$$

With:

T_f	Steady-state flue gas temperature (°C)
21	Combustion air temperature (°C)
$1{,}884$	Specific heat of water vapour (kJ/kg*K)
T_{OA}	U.S. national average outdoor air temperature (5°C)

$$\varepsilon_{L_C} = \sqrt{\left(\frac{\partial L_C}{\partial L_G}\,\varepsilon_{L_G}\right)^2 + \left(\frac{\partial L_C}{\partial T_f}\,\varepsilon_{T_f}\right)^2 + \left(\frac{\partial L_C}{\partial T_{OA}}\,\varepsilon_{T_{OA}}\right)^2}$$

$$\varepsilon_{L_C} = \sqrt{10^{-7}\left(1.666\varepsilon_{L_G}{}^2\left(4.187(T_f - 21) - 1.884(T_f - T_{OA})\right)^2 + 8.836\varepsilon_{T_f}{}^2 L_G{}^2 + 5.913\varepsilon_{T_{OA}}{}^2 L_G{}^2\right)}$$ Equation b-2

- Jacket heat loss (L_J, %)

$$L_J = \frac{h_S}{Q_{IN}} \times 100$$ Equation a-3

With:

h_S Measured jacket heat loss at input rating (kW)
Q_{IN} Heat input rating (kW)

$$\varepsilon_{L_J} = \sqrt{\left(\frac{\partial L_J}{\partial h_S}\,\varepsilon_{h_S}\right)^2 + \left(\frac{\partial L_J}{\partial Q_{IN}}\,\varepsilon_{Q_{IN}}\right)^2}$$

$$\varepsilon_{L_J} = 100\sqrt{\frac{\varepsilon_{h_S}{}^2 Q_{IN}{}^2 + \varepsilon_{Q_{IN}}{}^2 h_S{}^2}{Q_{IN}{}^4}}$$ Equation b-3

- Furnace Thermal Efficiency (E_t)
  - For non-condensing furnaces

$$E_t = 100\,\% - L_F$$ Equation a-4

With:

L_F Percent flue loss at input rating (%)

$$\varepsilon_{E_t} = \sqrt{\left(\frac{\partial E_t}{\partial L_F}\,\varepsilon_{L_F}\right)^2}$$

$$\varepsilon_{E_t} = \varepsilon_{L_F}$$ Equation b-4

  - For condensing furnaces

$$E_t = 100\,\% - L_F + L_L$$ Equation a-5

With:

L_L Net latent heat gain at input rating (%)

$$\varepsilon_{E_t} = \sqrt{\left(\frac{\partial E_t}{\partial L_F}\,\varepsilon_{L_F}\right)^2 + \left(\frac{\partial E_t}{\partial L_L}\,\varepsilon_{L_L}\right)^2}$$

$$\varepsilon_{E_t} = \sqrt{\varepsilon_{L_F}{}^2 + \varepsilon_{L_L}{}^2}$$ Equation b-5

5.2 ANSI/AHRI 1350 (I-P/2014)

Air-handling Unit Case Air Leakage Testing

- Mean Leakage Tester Duct (pre and post test values)

Equation a-6

$$Q_{net} = Q_{gross} - Q_{tare}$$

With:

Q_{net}	Measured average leakage at test pressure (cfm)
Q_{gross}	Average net unit leakage (cfm)
Q_{tare}	Average leakage tester leakage, pre to post – test (cfm)

$$\varepsilon_{Q_{net}} = \sqrt{\left(\frac{\partial Q_{net}}{\partial Q_{gross}}\ \varepsilon_{Q_{gross}}\right)^2 + \left(\frac{\partial Q_{net}}{\partial Q_{tare}}\ \varepsilon_{Q_{tare}}\right)^2}$$

Equation b-6

$$\varepsilon_{Q_{net}} = \sqrt{\varepsilon_{Q_{gross}}{}^2 + \varepsilon_{Q_{tare}}{}^2}$$

- Casing Air Leakage Rate (CL)

Equation a-7

$$CL = CL_m \left(\frac{P_m}{P_r}\right)^{-0.65}$$

With:

CL	Casing air leakage rate (cfm/100 ft^2)
CL_m	Measured leakage (cfm/100 ft^2 at P_m)
P_m	Absolute value of test differential pressure (in. H_2O)
P_r	Reference pressure (1 in. H_2O)

$$\varepsilon_{CL} = \sqrt{\left(\frac{\partial CL}{\partial CL_m}\ \varepsilon_{CL_m}\right)^2 + \left(\frac{\partial CL}{\partial P_m}\ \varepsilon_{P_m}\right)^2}$$

Equation b-7

$$\varepsilon_{CL} = \sqrt{\varepsilon_{CL_m}{}^2 \left(\frac{P_m}{P_r}\right)^{-1.3} + 0.4225\varepsilon_{P_m}{}^2 CL_m{}^2 P_r{}^{-2} \left(\frac{P_m}{P_r}\right)^{-3.3}}$$

Air-handling Unit Case Air Leakage Testing

- Overall electrical energy input (kW_{in})

Equation a-8

$$kW_{in} = kW_{heater(s)} + kW_{circulating\ fan(s)}$$

With:

kW_{in}	Overall electrical energy (kW)
$kW_{heater(s)}$	Electrical energy input of the heaters (kW)
$kW_{circulating\ fan(s)}$	Electrical energy input of the circulating fans (kW)

$$\varepsilon_{kW_{in}} = \sqrt{\left(\frac{\partial kW_{in}}{\partial kW_{heater(s)}}\ \varepsilon_{kW_{heater(s)}}\right)^2 + \left(\frac{\partial kW_{in}}{\partial kW_{circulating\ fan(s)}}\ \varepsilon_{kW_{circulating\ fan(s)}}\right)^2}$$

Equation b-8

$$\varepsilon_{Q_{net}} = \sqrt{\varepsilon_{kW_{heater(s)}}{}^2 + \varepsilon_{kW_{circulating\ fan(s)}}{}^2}$$

- Adjusted net unit leakage (Q_{anet}, cfm)

Equation a-9

$$Q_{anet} = Q_{net}\left(\frac{P_m}{P_r}\right)^{-0.65}$$

With:

Q_{anet}	Adjusted net unit leakage (normalized to 1.0 in H_2O) (cfm)

$$\varepsilon_{CL} = \sqrt{\left(\frac{\partial Q_{anet}}{\partial Q_{net}}\ \varepsilon_{Q_{net}}\right)^2 + \left(\frac{\partial Q_{anet}}{\partial P_m}\ \varepsilon_{P_m}\right)^2}$$

Equation b-9

$$\varepsilon_{Q_{anet}} = \sqrt{\varepsilon_{Q_{net}}{}^2\left(\frac{P_m}{P_r}\right)^{-1.3} + 0.4225\varepsilon_{P_m}{}^2 Q_{net}{}^2 P_r{}^{-2}\left(\frac{P_m}{P_r}\right)^{-3.3}}$$

- Net leakage air energy content (q_l, Btu/h)

Equation a-10

$$q_l = 60 \cdot \rho \cdot C_p \cdot Q_{anet}(T_{ai} - T_{ae})$$

With:

q_l	Energy content of the net leakage air (Btu/h)
ρ	Air density at test conditions (lbm/ft^3)
C_p	Heat capacity of air at test conditions (Btu/lbm/°F)
T_{ai}	Mean external dry bulb Air Temperature (°F)
T_{ae}	Mean internal dry bulb Air Temperature (°F)

$$\varepsilon_{q_l} = \sqrt{\left(\frac{\partial q_l}{\partial Q_{anet}}\ \varepsilon_{Q_{anet}}\right)^2 + \left(\frac{\partial q_l}{\partial T_{ai}}\ \varepsilon_{T_{ai}}\right)^2 + \left(\frac{\partial q_l}{\partial T_{ae}}\ \varepsilon_{T_{ae}}\right)^2}$$

Equation b-10

$$\varepsilon_{E_t} = 60 \cdot \rho \cdot C_p\sqrt{\varepsilon_{Q_{anet}}{}^2(T_{ai} - T_{ae})^2 + Q_{anet}{}^2\left(\varepsilon_{T_{ai}}{}^2 + \varepsilon_{T_{ae}}{}^2\right)}$$

- Thermal transmittance (Btu/h)
  - With leakage (q_{tl})

Equation a-11

$$q_{tl} = q_{in} + q_l$$

Equation a-12

$$U = \frac{q_{tl}}{A_{net}(T_{ai} - T_{ae})}$$

With:

q_{tl}	Total thermal energy with leakage (Btu/h)

U Thermal transmittance (Btu/h/°F/ft²)

$$\varepsilon_{q_{tl}} = \sqrt{\left(\frac{\partial q_{tl}}{\partial q_{in}}\ \varepsilon_{q_{in}}\right)^2 + \left(\frac{\partial q_{tl}}{\partial q_l}\ \varepsilon_{q_l}\right)^2}$$

$$\varepsilon_{q_{tl}} = \sqrt{\varepsilon_{q_{in}}{}^2 + \varepsilon_{q_l}{}^2}$$ Equation b-11

$$\varepsilon_U = \sqrt{\left(\frac{\partial U}{\partial q_{tl}}\ \varepsilon_{q_{tl}}\right)^2 + \left(\frac{\partial U}{\partial T_{ai}}\ \varepsilon_{T_{ai}}\right)^2 + \left(\frac{\partial U}{\partial T_{ae}}\ \varepsilon_{T_{ae}}\right)^2}$$

$$\varepsilon_U = \frac{1}{A_{net}(T_{ai} - T_{ae})}\sqrt{\varepsilon_{q_{tl}}{}^2 + \frac{q_{tl}{}^2}{(T_{ai} - T_{ae})^2}\left(\varepsilon_{T_{ae}}{}^2 + \varepsilon_{T_{ai}}{}^2\right)}$$ Equation b-12

- Without leakage (q_t)

$$q_t = q_{in}$$ Equation a-13

$$U = \frac{q_t}{A_{net}(T_{ai} - T_{ae})}$$ Equation b-13

With:

q_t Total thermal energy without leakage (Btu/h)
U Thermal transmittance (Btu/h/°F/ft²)

$$\varepsilon_{q_{tl}} = \sqrt{\left(\frac{\partial q_{tl}}{\partial q_{in}}\ \varepsilon_{q_{in}}\right)^2}$$

$$\varepsilon_{q_{tl}} = \varepsilon_{q_{in}}$$ Equation a-14

$$\varepsilon_U = \sqrt{\left(\frac{\partial U}{\partial q_t}\ \varepsilon_{q_{tl}}\right)^2 + \left(\frac{\partial U}{\partial T_{ai}}\ \varepsilon_{T_{ai}}\right)^2 + \left(\frac{\partial U}{\partial T_{ae}}\ \varepsilon_{T_{ae}}\right)^2}$$

$$\varepsilon_U = \frac{1}{A_{net}(T_{ai} - T_{ae})}\sqrt{\varepsilon_{q_t}{}^2 + \frac{q_t{}^2}{(T_{ai} - T_{ae})^2}\left(\varepsilon_{T_{ae}}{}^2 + \varepsilon_{T_{ai}}{}^2\right)}$$ Equation b-14

5.3 AIR FLOW

- Air velocity (m/s)

$$v = \sqrt{\frac{2\Delta P}{\rho}}$$ Equation a-15

$$\varepsilon_v = \sqrt{\left(\frac{\partial v}{\partial \Delta P}\ \varepsilon_{\Delta P}\right)^2}$$

$$\varepsilon_v = \varepsilon_{\Delta P} \sqrt{\frac{1}{2\rho * \Delta P}}$$ Equation b-15

- Airflow (m^3/s)

$$Q_{air} = A \cdot \bar{v}$$ Equation a-16

$$\varepsilon_{Q_{air}} = \sqrt{\left(\frac{\partial Q_{air}}{\partial v}\, \varepsilon_v\right)^2}$$

$$\varepsilon_{Q_{air}} = A \cdot \varepsilon_v$$ Equation b-16

5.4 EXAMPLE

This section shows one example of uncertainty calculations for both standards. All uncertainty calculations are in an Excel file[15], and available on demand.

5.4.1 CAN/CSA P.8-09 (Edition 2, Reaffirmed in 2019) – Jacket heat loss (L_J)

Data:

h_S	= 1.1 kW	ε_{hS}	= 0.009 kW
Q_{in}	= 73.3 kW	ε_{Qin}	= 0.7 kW

Parameters:

$$L_J = \frac{1{,}1\ kW}{73{,}3\ kW} \times 100 = 1.5\ \%$$ (Calculation a-3)

Uncertainty:

$$\varepsilon_{L_J} = 0.02\ \%$$ (Calculation b-3)

Summary:

$$L_J = 1{,}5\ \pm 0.02\ \%$$ (Calculations a-3, b-3)

5.4.2 ANSI/AHRI 1350 (I-P/2014) – Casing Air Leakage Rate (CL)

Data:

CL_m	= 5 CFM/100 ft^2	ε_{CLm}	= 1% = 0,05 CFM/100 ft^2
P_m	= 4.0 in. H_2O	ε_{Pm}	= 0,02 in. H_2O
P_r	= 1.0 in. H_2O		

[15] X:\PROJETS\248020 CSA P.8 RTU Testing\4- Feuilles de calcul\Analyse des données

Parameters:

$$\mathrm{CL} = 5\,\frac{CFM}{100\,ft^2}\left(\frac{4.0\,in\,H_2O}{1.0\,in\,H_2O}\right)^{-0.65} = 2{,}03\,\frac{CFM}{100\,ft^2}$$ (Calculation a-7)

Uncertainty:

$$\varepsilon_{\mathrm{CL}} = 0{,}02\,\frac{CFM}{100\,ft^2}$$ (Calculation b-7)

Summary:

$$\mathrm{CL} = 2{,}03\ \pm 0{,}02\,\frac{CFM}{100\,ft^2}\ \text{or}\ \pm 1\,\%$$ (Calculations a-7, b-7)

5.5 ANALYSIS

As the instrumentation NGTC plans to use for the testing is conformed to the required uncertainty of standards, the level of precision is judged enough to adequately quantify the various key parameters of P.8 and AHRI 1350 standards.

6.0 REFERENCES

CAN/CSA-P.8-09 (Reaffirmed in 2019), Thermal efficiencies of industrial and commercial gas-fired package furnaces, Canadian Standard Association, 2019.

CAN/CSA-P.8-09 (Edition 3), Document sent by NRCan. 2020.

ANSI/AHRI 1350 (I-P/2014), Mechanical Performance Rating of Central Station Air-handling Unit Casings, American National Standards Institute, 2014.

7.0 TEST REGISTER

Table 7 and Table 8 present the test register and the calibration and verification register.

The document is available in the project file: X:\PROJETS\248020 CSA P.8 RTU Testing\5-Essais\Protocole de test\248020_Registre_20201021.xlsx

Table 7: Test Register

TEST REGISTER														
Test #	Tested unit			Reference standard		Capacity (Btu/h)	Specific configuration	Technician	Date	Ambiant conditions (lab.)			Raw data file name	Comments
	BMU	MTU	HMU	P.8-09	AHRI 1350					P (psi)	T (°C)	HR (%)		
1.A	X			X		150 000 105 000	-							
1.B		X		X		160000 32000	with heat recovery							
1.C			X	X		175000 35000	with heat recovery							
2.A	X				X	n/a	with provided dampers							
2.B		X			X	n/a	with provided dampers							
2.C			X		X	n/a	with provided dampers							
2.D			X		X	n/a	with insulated dampers							

Table 8: Calibration and Verification Register

Instrument Number	Extern Calibration		Intern Calibration/Verification	
	Completion Date	Due Date	Report Number	Due Date

8.0 REVISIONS

From test plan sent on 2020/10/30 to test plan sent on 2021/03/01:

- Modifications in Section 2.0:
    - Modifications to ensure confidentiality about the tested units.
- Modifications in Section 3.1:
    - Configurations without HRV are not tested in the laboratory. But, as requested in the proposal, the data will be analyzed to compare the results with and without an HRV (for the P.8 Edition 3).
- Modifications in Section 3.2:
    - Minor changes about the instrumentation used during the tests: instrument number, type of acquisition, frequency.

From test plan sent on 2021/03/01 to present test plan:

- Modifications in Section 3.2:
    - Change about the airflow measurement instrumentation used during AHRI 1350 test procedure.

Report last page