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ABSTRACT

During testing indoor air handling units, ASHRAE Standard 37 requires installing an inlet duct that might increase the length of the testing setup to exceed the capability of some testing facilities. ASHRAE Research Project 1743 (ASHRAE RP-1743) addresses this issue by evaluating the effect of inlet duct design on fan performance of indoor air handling units. The findings of the study will allow identifying alternative, shorter, inlet duct configurations maintaining the fan performance as of that obtained with ASHRAE Standard 37 inlet duct. The test matrix of the project includes various indoor units differing in motor type, such as Constant Torque Motor (CTM) and Electronically Commutated Motor (ECM), and fan configurations, such as pull-through and push-through configuration. This paper focuses on the findings of testing two pull-through-fan-configuration units, one of which with a CTM fan and the other with an ECM fan. In addition, other effects, such as atmospheric pressure and hysteresis in approaching external static pressure (ESP), were investigated to study their impacts on the repeatability of equipment testing.

The results of the CTM-fan unit showed that the proposed alternative inlet duct configurations can maintain the fan performance within the suggested tolerances, which are 5% in power and 2.5% in air volumetric flowrate relative to the ASHRAE Standard 37 inlet duct. This allows a reduction in the inlet duct stack-length from 38% to 74% compared to ASHRAE Standard 37 inlet duct configuration. Noticeable performance hysteresis was observed at low air flowrate and ESP, while atmospheric pressure had no effect on fan performance.

For the ECM-fan unit, the fan performance was maintained during testing the proposed alternative inlet duct configurations within the suggested tolerance, with a noticeable decrease in power during testing the reduced alternative inlet duct configuration. The reduction in the stack length as compared to the standard inlet duct configuration was 40%, 72%, 74% for the inlet box, 4-inch inlet duct, and reduced alternative configuration, respectively. In contrast to the results of the CTM-fan unit, the hysteresis effect on the ECM-fan unit was found to be insignificant, while atmospheric pressure effect was significant. As the atmospheric pressure increased, air volumetric flowrate and fan's power decreased.

1. INTRODUCTION

ASHRAE Standard 37 provides methods to rate unitary air-conditioning and heat pump equipment (ANSI/ASHRAE, 2009). The methods provided by ASHRAE Standard 37 should enhance the repeatability of rating tests to maintain the rating of equipment consistent regardless of where the equipment is being tested. Among the requirements of ASHRAE Standard 37, a standardized inlet duct should installed during testing equipment. The inlet duct dimensions are determined by the cross-section areas of the inlet of the *Unit Under Test* (UTT; ANSI/ASHRAE, 2009). However, the ASHARE Standard 37 inlet duct can be problematic because the stack-length of equipment testing setups might exceed the height of testing facilities, especially for legacy facilities. Therefore, the main goal of ASHRAE RP-1743 was to identify reduced-length alternative inlet duct configurations that maintain fan performance of the UUT close to that obtained during testing the unit with ASHRAE Standard 37 inlet duct configuration. Also, ASHRAE RP-1743 investigated other effects that could affect test repeatability besides the inlet duct configurations.

In this paper, Section 2 describes the testing facility and instrumentations. Section 3 lists the parameters varied during testing the indoor units for ASHRAE RP-1743. Section 4 shows and discuses the results obtained. Finally, Section 5 concludes the paper by summarizing the findings and suggesting potential future work.

2. EXPERIMENTAL SETUP

2.1 Operational Conditions:

In general, the operational conditions of tests for ASHRAE RP-1743 was in accordance with AHRI Standard 210/240 (AHRI, 2017). To maintain the operational conditions, the project was conducted at the indoor psychrometric chamber of Oklahoma State University (OSU). The chamber has two conditioning bays to maintain the chamber at the testing conditions, which were 80.0°±0.5°F (26.7°±0.3°C) dry-bulb temperature (T_{DB}) and 67.0°±0.3°F (19.4°±0.2°C) wet-bulb temperature (T_{WB}). The chamber's code tester bay was used to measure air coming out of UUT, as well as adjusting the external static pressure (ESP) across the UUT by adjusting the blower of the code tester. For ESP, Table 11 in AHRI Standard 210/240 specifies the minimum ESP for unit groups similar to that tested for ASHRAE RP-1743 to be 0.15 in w.c. (37.3 Pa). The units were tested under seven ESP points ranged from 0.10 in w.c. (24.9 Pa) to 0.55 in w.c. (136.9 Pa) including the 0.15 in w.c. (37.3 Pa) standard point. The units were tested under two nominal air flowrates: 350 cfm/ton (46.97 L/s-kW) and 450 cfm/ton (60.39 L/s-kW). The units were tested vertically, as described by Hossain et al. (2018).

2.2 Instrumentation:

Temperature was measured per ANSI/ASHRAE 41.1 for T_{DB} and ANSI/ASHRAE 41.6 for T_{WB}; in particular, a resistance temperature device (RTD) was used for T_{DB}, and the aspirated wet-bulb psychrometer was used for T_{WB} (ANSI/ASHRAE, 2014, 2013). Air was sampled by a sampling device fulfilling section 5.3.4 in ANSI/ASHRAE Standards 41.1 (ANSI/ASHRAE, 2013).

External Static Pressure (ESP) was measured across the UUT by pressure transducers connected to pressure taps that are fabricated in the inlet and outlet ducts in accordance with the recommended practices in subsections 6.5.1 and 6.5.3 of ASHRAE Standard 37 (ANSI/ASHRAE, 2009). The pressure taps were placed in the standard inlet duct in accordance with subsection 6.4.2.2 in ASHRAE Standard 37, while they were placed for alternative inlet duct configurations either in the horizontal center of a duct or a skirt duct. Also, to enhance the reliability of ESP readings, two pressure transducers were used. Each transducer was connected to two adjacent pressure taps in the inlet duct and the corresponding pressure taps in the outlet duct. One of the transducers was used as a reference to adjust ESP during testing, while the other was used for cross-checking the readings of the first transducer after a test was completed.

Air flowrate coming out of UUT was measured by the nozzle box in the code tester bay of OSU indoor psychrometric chamber. The pressure difference across the nozzle plane was measured and used to determine the air flowrate passing the nozzles in accordance with the steps mentioned in subsection 6.2 of ASHRAE Standard 37 (ANSI/ASHRAE, 2009).

Speed of UUT's fan was measured by a 3^{rd} party rotational speed sensor. The sensor was connected to the *Data Acquisition* system (DAQ) of the OSU psychrometric chamber to sample the readings at the same pace as other parameters. For the UUT's fan power consumption, it was measured by a power meter with an inbuilt data logger. The power data was later integrated into other data obtained by the DAQ of the psychrometric chamber through time-stamps.

Atmospheric Pressure was measured by a barometer placed outside the psychrometric chamber. Then, two transducers were used besides the manometer to measure the atmospheric pressure at the inlet duct. The first pressure transducer measured the pressure difference between the inside and outside of the psychrometric chamber. The second pressure transducer measured the pressure difference between the ambient inside the psychrometric chamber and the inlet duct by connecting one port of the transducers to the pressure taps of the inlet duct, while the other port of the transducers was exposed to the ambient inside the psychrometric chamber.

3. TEST PLAN

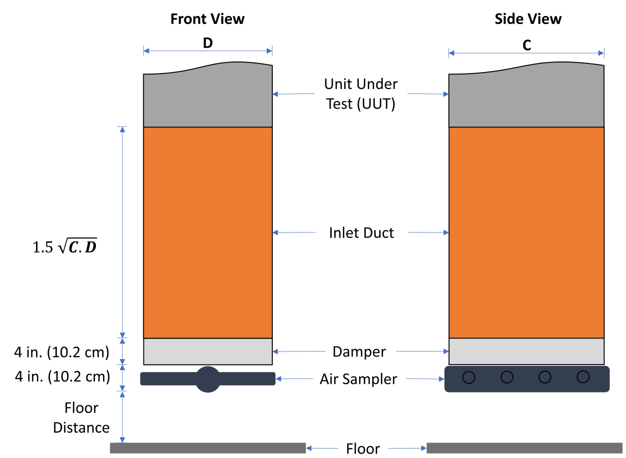
The test plan consisted of testing various units, each of which had a different fan type and configuration, with 3 alternative inlet duct configurations besides the standard inlet duct configuration. For each inlet duct configuration, the UUTs were tested under two nominal air flowrates and seven ESP points, as mentioned in the Section 2.

3.1 Fan Configurations and Types:

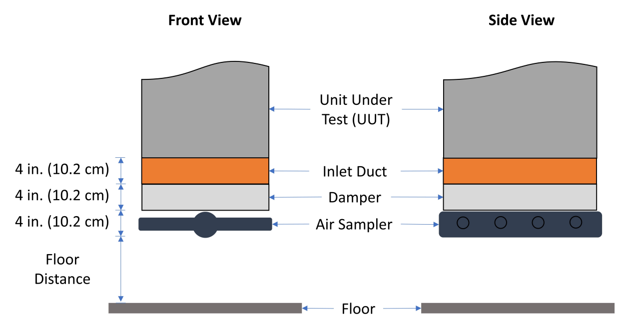
In general, four 3-ton indoor units were tested for ASHRAE RP-1743. In terms of fan types, two of the units had fans with Electronically Commutated Motor (ECM) and the other two had fan with Constant Torque Motor (CTM). The difference among the units having the same fan motor type was the configuration of the fan: pull-through or pull-through fan configurations. In the pull-though fan configuration, the fan was placed downstream the conditioning equipment of the unit, while the equipment was placed upstream in the push-through fan configurations. This paper shows the results obtained for the units with pull-though configuration.

3.2 Inlet Duct Configurations:

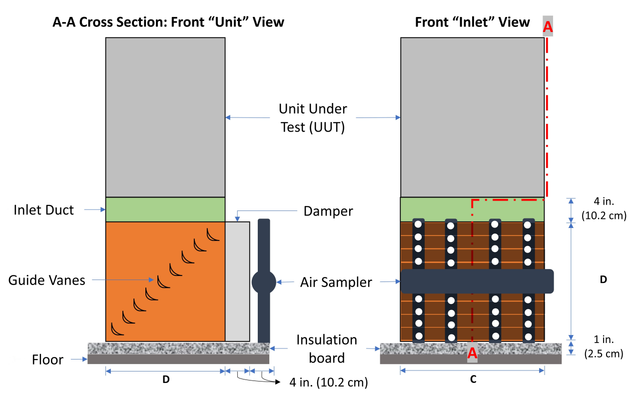
Besides the standard inlet duct, three reduced alternative inlet duct configurations were tested. Figure 1 shows the dimensions of the inlet duct configurations, and Table 1 shows the reduction in the inlet duct configurations as compared to the standard configuration.



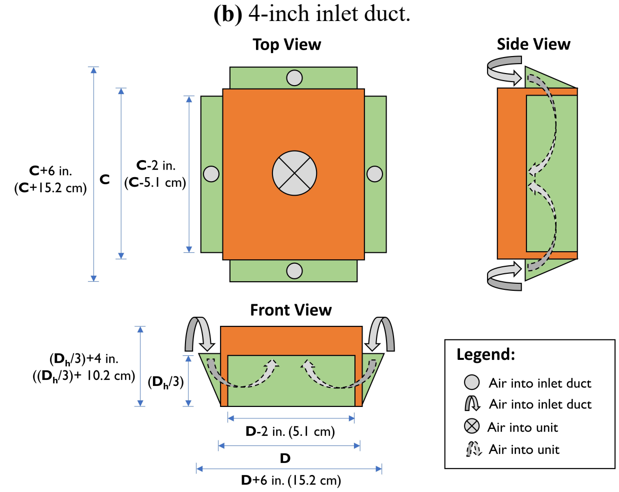
(a) Standard inlet duct.



(b) 4-inch inlet duct.



(c) Box inlet with guide vanes.



(d) Reduced alternative.

Figure 1: Sketches of the inlet duct configurations for ASHRAE RP-1743.

4. RESULTS AND DISCUSSIONS

The units and inlet duct configurations mentioned in Section 3 were tested under the conditions in Section 2. The reported findings in this paper are mostly of 350 cfm/ton (46.97 L/s-kW) and 0.50 in w.c. (124.4 Pa); findings of other conditions are identical unless otherwise mentioned. Also, volumetric air flowrate and fan's power consumption are the variables reported in this paper as they are the variables affecting repeatability UUT's fan performance. To enhance the accuracy of the comparison among the reported cases, data has been interpolated to the nominal ESP point

Table 1: Change in the stack-length of the inlet duct configuration as compared to the standard inlet duct configuration.

Unit	Inlet duct configurations			
	Standard[1] [in]	4-inch[2] [%]	Inlet box [%]	Reduced alt.[3] [%]
CTM-fan	42	-70	-38	-74
ECM-fan	45	-72	-40	-76

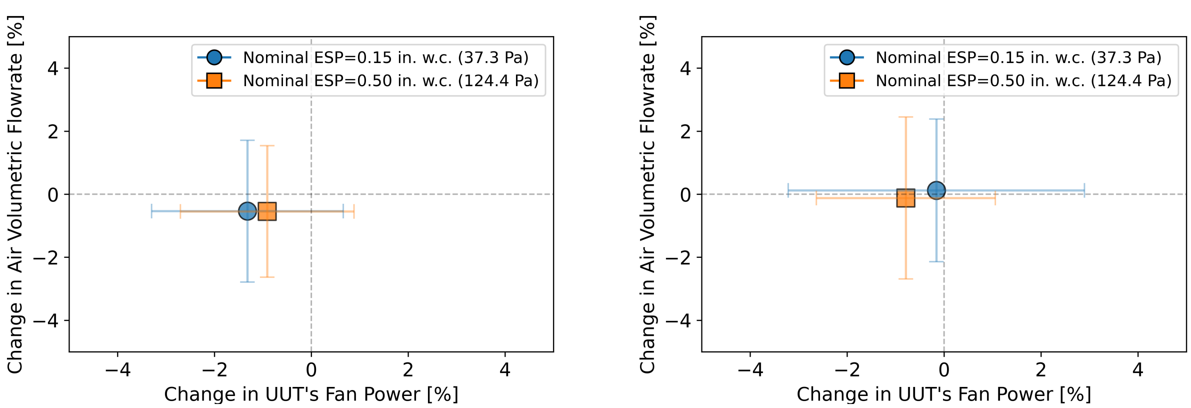
[1] 2 inches were added as a floor distance.
[2] Change vs. Standard excluded floor distance in both inlet ducts.
[3] Air sampler was placed around the inlet duct.

of 0.50 in w.c. (124.4 Pa). In terms of the effects reported in this paper beside the inlet duct configurations, hysteresis effect, which is caused by the direction followed to approach an ESP point, and atmospheric pressure effect are reported in this paper. Those effects was to be found substantial during testing some units for ASHRAE RP-1743.

4.1 Hysteresis Effect:

While testing units for ASHRAE RP-1743, fan performance might have changed significantly as the the direction of approaching an ESP point, from high-to-low or vice versa, was changed. This hysteresis effect can affect the repeatability of testing units, so it was considered vital to be investigated. Observing the fan rotational speed to decide if the effect caused by an instrumentation or the unit, the fan speed would have experienced a change whenever the hysteresis effect was observed. Thus, the hysteresis effect, if occurred, was caused by the unit itself. The direction of high-to-low ESP was considered the basecase that the other direction was compared to after interpolating the the base case to the compared one in order to enhance the accuracy of the comparison.

For the CTM-unit, the hysteresis effect was noticeable at low air flowrate, which was 350 cfm/ton (46.97 L/s-kW), as it is shown in Figure 2a, while the effect was not significant at high flowrate, which was 450 cfm/ton (60.39 L/s-kW), as the change in performance was within the uncertainty of measurements. However, the hysteresis was insignificnt in all tested conditions on the ECM-fan unit, as Figure 2b shows since the change in the performance was within the uncertainty of measurements.



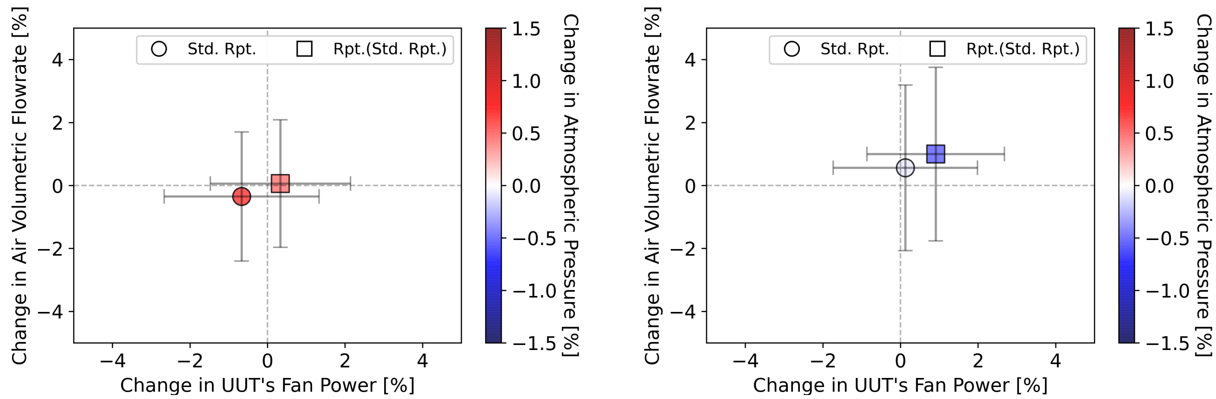
(a) CTM-fan unit.

(b) ECM-fan unit.

Figure 2: Change in the fan performance as the direction of approaching ESP point changed (hysteresis effect) for nominal air flowrate ratio of 350 cfm/ton (46.97 L/s-kW) during testing UUTs with standard inlet duct.

4.2 Atmospheric Pressure Effect:

During repeated tests, it was observed that atmospheric pressure might have affected fan performance. Hence, tests were repeated under different atmospheric pressures without making changes on the setup, such as disassembling the inlet duct. The results show that the atmospheric pressure effect is insignificant for the CTM-fan unit as the fan performance was maintained within the uncertainty in measurements despite the change in atmospheric pressure was relatively high, as shown in Figure 3a. However, the ECM-fan unit experienced a significant effect of atmospheric pressure with a relatively small change in atmospheric pressure: fan's power and air volumetric flowrate increased as the atmospheric pressure decreased, as shown in Figure 3b.



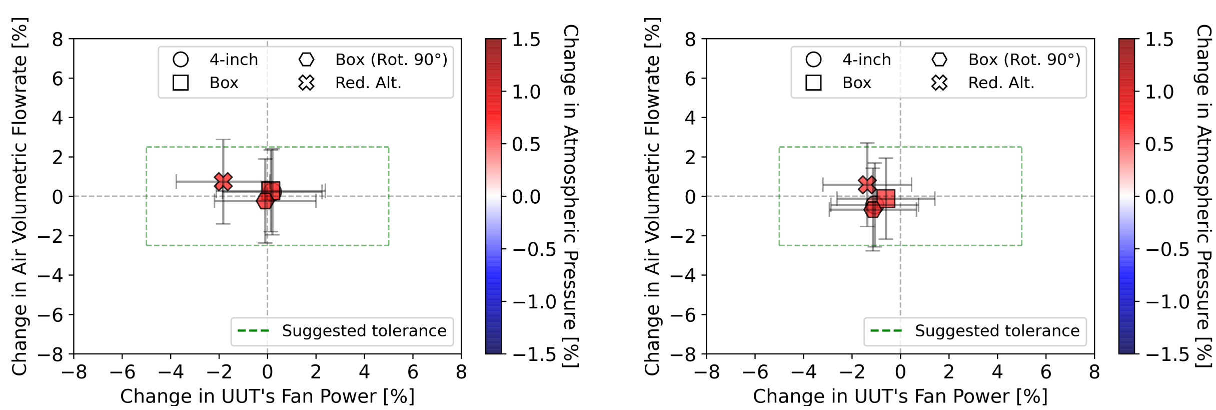
(a) CTM-fan unit. **(b)** ECM-fan unit.

Figure 3: Change in the fan performance as atmospheric pressure changed for nominal air flowrate ratio of 350 cfm/ton (46.97 L/s-kW) and ESP of 0.50 in w.c. during testing units with standard inlet duct.

4.3 Inlet Duct Configuration Effect:

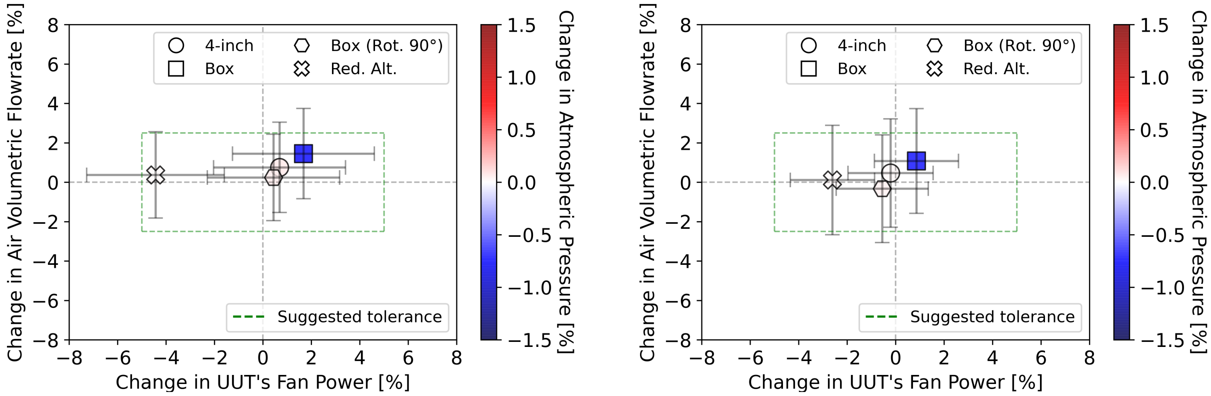
Fan performance during testing the alternative inlet duct configurations were compared to the performance obtained during testing standard inlet duct configuration. A change in fan performance was acceptable if the change was within the suggested tolerance of 5 % in fan's power and 2.5 % in air volumetric flowrate. The results of the CTM-fan unit and the ECM-fan unit are shown in Figure 4 and Figure 5, respectively.

For the 4-inch inlet duct configuration, fan performance was maintained within the suggested tolerance as compared to the standard inlet duct configuration for both units. For the inlet box configuration, the performance was maintained in both units, despite the results on the ECM-fan unit was affected by the change in atmospheric pressure. Also, to determine if the orientation of the inlet side of the inlet box had an effect on the fan performance, the inlet box was rotated by 90°. The rotation of the box did not cause a significant change in fan performance considering the effect of atmospheric pressure when the inlet box was tested first. For the reduced alternative inlet duct configuration, despite fan performance was maintained within the suggested tolerance as compared to the standard inlet duct configuration, fan's power decreased in both units, especially in the ECM-fan unit at low ESP, as shown in Figure 5a. Also, the air volumetric flowrate increased in the CTM-fan unit, while it did not in the ECM-fan unit.



(a) ESP of 0.15 in w.c. **(b)** ESP of 0.50 in w.c.

Figure 4: Change in fan performance of the CTM-fan unit during testing the alternative inlet duct configurations as compared to the standard inlet duct at nominal air flowrate ratio of 350 cfm/ton (46.97 L/s-kW).



(a) ESP of 0.15 in w.c. **(b)** ESP of 0.50 in w.c.

Figure 5: Change in fan performance of the ECM-fan unit during testing the alternative inlet duct configurations as compared to the standard inlet duct at nominal air flowrate ratio of 350 cfm/ton (46.97 L/s-kW).

5. CONCLUSION

The project, ASHRAE RP-1743, aimed to investigate alternative inlet duct configurations that reduced in length as compared to the standard inlet duct specified in ASHRAE Standard 37 (ANSI/ASHRAE, 2009). Along with the main aim of the project, other effects, such as the direction followed to obtain an ESP point and atmospheric pressure, were investigated to eliminate their impacts on the repeatability of tests. The methodology adopted for ASHRAE RP-1743 was to tests four 3-ton units, each of which had a different fan configuration, such as pull-through or push-through, and fan's motor type, such as ECM or CTM. The units were tested under two nominal flowrates and seven ESP points for each of the alternative inlet duct configurations tested. This paper is dedicated to the results of the units with pull-though fan configuration.

The direction followed to obtain an ESP point, which is referred to as the hysteresis effect, was found noticeable in the CTM-fan unit at low air flowrate, while the effect on the ECM-fan unit was insignificant. In general, the hysteresis was not associated with the fan's motor type as the effect was found to be significant in a unit with ECM-unit among the other units considered for ASHRAE RP-1743. Therefore, specifying the direction followed to adjust ESP might be ideal to eliminate a discrepancy source in rating units, as the effect is unpredictable through fan's motor type.

For the atmospheric pressure, it had a significant effect on the ECM-fan unit, while it did not on the CTM-fan unit. In general, the atmospheric pressure affects the density of air, which can be controlled be adjusting the content of moisture in air. Nevertheless, controlling the density by changing the moisture content in the air inside a testing facility will not be practical since an increase in moisture content affects the rating of the unit when the units is operated in cooling mode. This effect of atmospheric pressure was found to be significant on some units despite the change in the atmospheric pressure was within the normal daily fluctuation in one location. The effect would be vital if a unit is rated at different facilities, each of which is located at a different altitude. Therefore, the effect should be addressed to eliminate its impact on the repeatability of tests.

As compared to the standard inlet duct specified in ASHARE 37, the alternative inlet duct configurations considered for ASHRAE RP-1743 generally maintained fan performance for the units within the suggested tolerance of 5 % in fan's power and 2.5 % in air volumetric flowrate. However, the reduced alternative inlet duct configuration caused a noticeable decrease in the fan's power on the units, while an increase was noticed in air volumetric flowrate on the CTM-fan unit only, as compared to the power and flowrate during testing standard inlet duct. Fan's power contribution might be minor in the rating of units because the power consumption constitutes a small portion of the input power as compared to that of the components of the unit, but the change in the air volumetric flowrate might contribute significantly in the rating. For the inlet box configuration, the direction of the inlet side of the inlet box did not affect fan performance. The reduction in the stack-length of the inlet duct is 38% to 74% for the CTM-fan unit, while it is 40% to 76% for the ECM-fan unit.

NOMENCLATURE

ANSI	Air-Conditioning, Heating, & Refrigeration Institute
ASHRAE	American Society of Heating Refrigeration and Air-Conditioning Engineers
CTM	Constant Torque Motor
cfm	Cubic Feet per Minute
DAQ	Data Acquisition system
ECM	Electronically Commutated Motor
ESP	External Static Pressure
in w.c.	inches of water column
L	Liter
Pa	Pascal
OSU	Oklahoma State University
RTD	Resistance Temperature Device
T	Temperature
UTT	Unit Under Test
W	Watt

Subscript

DB	Dry-Bulb
WB	Wet-Bulb

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