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# Improving airflow measurement accuracy in VAV terminal units using flow conditioners

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ABSTRACT

A variable air volume (VAV) terminal unit adjusts its supply airflow rate to meet the heating or cooling load and/or the ventilation requirement of the served space. Consequently, the accuracy of the VAV airflow sensor is highly important to the VAV system operation, and an inaccuracy of the VAV airflow sensor could lead to an energy waste or insufficient ventilation. ASHRAE Research Project (RP) 1353 identified non-ideal inlet conditions, such as an elbow or kinked duct before the VAV terminal unit, as causes of observed inaccuracies of up to 45% in VAV airflow measurements. VAV airflow measurement errors are normally mitigated by on-site balancing; however, it is difficult to achieve accurate reference airflow measurements in the field because of limited straight ductwork before VAV terminal units, as well as ductwork leakage. This study explored the potential solution of using a VAV flow conditioner to regulate the velocity profile upstream of the VAV airflow sensor and increase the VAV airflow measurement accuracy. A variety of flow conditioners were evaluated with computational fluid dynamics (CFD) modeling, and a CFD-optimized prototype of a 60%-porosity K-Lab/Laws plate was fabricated and tested. For all tested inlet conditions, airflow rates, and VAV boxes, the prototype reduced the VAV airflow reading error to ±5% when it was installed immediately before the VAV box inlet, regardless of upstream duct conditions. The prototype flow conditioner had a pressure drop equivalent to that of a 2-row VAV reheat coil.



## 1. Introduction

### 1.1. Problem statement

Heating, ventilating, and air conditioning (HVAC) systems are the largest energy consumers in modern commercial buildings, using about 30% of building energy [1], so reducing the energy used by the HVAC system is an important goal. Because of their ability to provide better energy efficiency, variable air volume (VAV) systems with direct digital controllers (DDC) have been widely adopted in commercial, industrial, and large residential buildings. A VAV terminal unit adjusts its supply air temperature and airflow rate based on the real time heating and cooling loads, as well as the ventilation requirement, of the space that the system is serving.

Fig. 1 shows a typical configuration of a VAV terminal unit. Typically, there is an airflow sensor at the inlet of a VAV terminal unit that measures the airflow rate passing through the VAV box and that rate is sent as a signal to the VAV controller. The VAV controller compares this measured airflow rate to an airflow set point that is determined based on the heating or cooling and/or ventilation demands. If a significant difference exists, the VAV controller commands the actuator to either open or close the VAV damper position and thus change the airflow to some new amount. Obviously, the accuracy of the VAV airflow sensor is crucial. If the VAV airflow measurement is larger than the true airflow rate, the space ventilation requirement would not be satisfied or the reheating equipment could be damaged [2]; if the VAV airflow measurement is lower than the true airflow rate, then energy would be wasted. Based on standard fan laws, the fan power is proportional to the airflow rate to the third order [2], so, for example, a 40% airflow reading error could result in ∼170% fan energy waste. In addition, more heating or cooling energy is consumed to condition the extra airflow.

ASHRAE Research Project (RP) 1353 [3,4] systematically evaluated different VAV terminal units to identify major factors that

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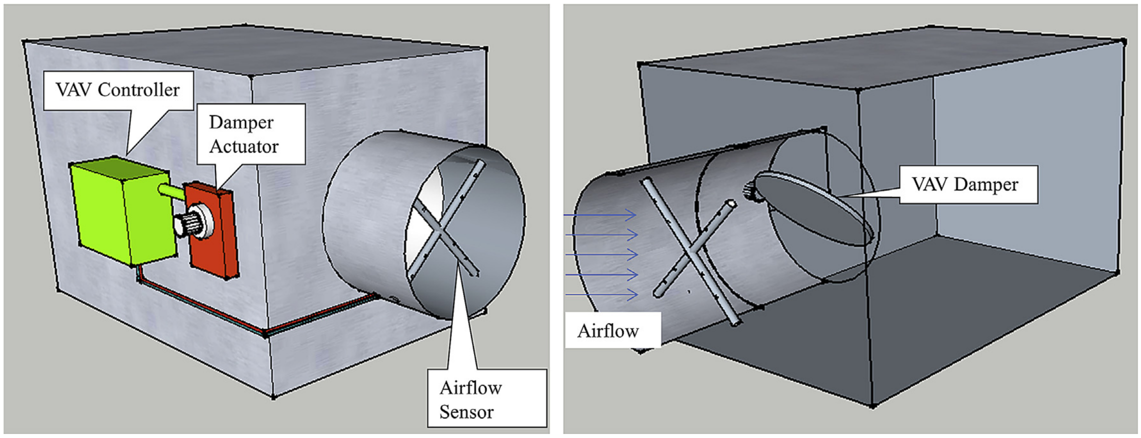


**Fig. 1.** VAV terminal unit configuration.

could cause inaccuracy of VAV airflow measurement. One of the most important factors was the non-ideal inlet condition, such as an elbow and kinked duct, as shown in Fig. 2; a kinked inlet condition could cause VAV airflow reading error up to 45% [3]. On-site balancing is regarded as a solution to correct the VAV airflow measurement error, but it only works when an accurate reference airflow measurement is available, which may be difficult to achieve practically in the field. Two methods are commonly used in the field to measure reference airflow rates: the velocity traverse method (upstream of VAV box) and the flow hood method (downstream of VAV box). For a satisfactory performance of the velocity traverse method, ASHRAE standard [5] recommends that the measuring point be located at least 7.5 duct diameters downstream and 3 diameters upstream from a flow disturbance. In practice, this requirement is rarely met in the field, resulting in non-ideal inlet conditions as the norm [4]. The flow hood method measures the airflow coming out of the diffusers. It is not affected by non-ideal inlet conditions upstream of the VAV box, but it does not account for the leakage of the duct connecting the VAV box to diffusers. This leakage is included in the airflow reading taken by the VAV flow sensor and cannot be ignored. The field test of ASHRAE RP-1353 shows that the leakage between the VAV box and the diffusers can be in excess of 100 cfm, which is often more than 20% of the minimum airflow rate for typical 8 in. VAV boxes. Therefore, it is very difficult to correct the non-ideal inlet condition effect by on-site balancing.

### 1.2. Flow conditioner review

Non-ideal inlet conditions cause large errors in VAV airflow measurements because a non-ideal inlet condition causes irregular air velocity profiles. In typical VAV boxes, flow is inferred from pressure readings, and the limited pressure sensing ports on the VAV airflow sensor may not well represent the airflow profile and thus result in measurement errors. The hypothesis of this work is that if the velocity profile were regulated before going through the VAV airflow sensor, then the measurement accuracy could be improved. Therefore, the impact of a flow conditioner on VAV measurement accuracy is systematically studied here to examine the potential improvement it can afford under non-ideal inlet conditions.

A flow conditioner is a device that regulates the flow profile and removes the swirl, cross-flow, and asymmetry in fluid flow. Thus, with a flow conditioner upstream of a VAV box, flow with a more fully developed velocity profile should encounter the VAV pressure sensors and ensure higher measurement accuracy. The use of flow conditioners is a common approach to improve the accuracy of flow measurements and has been well studied; however, no study was found in the open literature that examined the application of a flow conditioner for an HVAC airflow measurement, particularly on a VAV airflow sensor.

Flow conditioner studies focus often on improving the perturbation-removing effect on a specific flow meter, such as an orifice meter, and reducing the pressure drop across the flow conditioner. For example, Laws [6], Erdal [7], Spearman et al. [8], and Manshoor et al. [9] studied perforated plates (Fig. 3(a)–(c)) and evaluated impacts of the parameters of overall porosity, the grading of porosity along the radius, the wetted perimeter, the perforation distribution, and the number and size of holes in the plate. The graded porosity was very important for developing a velocity profile as fully as possible, and the blocking area on the plate was related to the conditioner pressure drop and turbulent kinetic energy. Laws and Quazzane [10,11] studied the Zanker flow conditioner, which is a combination of a graded perforated plate and a honeycomb section, and the thickness of the plate played an important role and the honeycomb became removable if the plate was thick enough. Ouazzane, Benhadj [12] and Laws [13] designed a Vaned Laws plate flow conditioner consisting of a graded perforated plate with upstream vanes (Fig. 3(d)), and it well removed the swirl and produced a fully developed flow field. Frattolillo and Massarotti [14] compared the performance and pressure drop of different types of flow conditioners, and concluded that the hybrid flow conditioners like Zanker flow conditioner and Vaned Laws plate could generate fully developed velocity profiles in a shorter distance downstream but had higher pressure drops compared to perforated plates only.

A common method to evaluate the performance of a flow conditioner is to examine the velocity profile downstream of it. The velocity profiles at different distances downstream, such as 5D (i.e., 5 × duct diameter, D), 10D, 15D, etc., are compared to those of an ideal duct condition (i.e., long enough straight ducts for flow to fully develop). A high performance flow conditioner should fully develop the velocity profile and remove flow swirl and asymmetry in as short a distance as possible [6–8].

Other than the ability to regulate the velocity flow profile, the pressure drop across the conditioner is also an important factor when evaluating flow conditioner. An increased pressure resistance in the flow consumes more fan energy, so a flow conditioner should have the lowest pressure drop possible [15]. To express the pressure drop independent of velocity, it is common to define the pressure loss coefficient as the pressure drop across the flow conditioner over the velocity pressure, shown in Equation (1):