

# HVAC System Performance Assessment Calculation Procedures

## Summary

This document provides a standardization of the calculation procedures used to conduct field tests of system-installed efficiency and capacity. Standardization of calculation procedures provides a consistent and comparable set of results across all entities conducting field measurements of system performance.

**Finalized:** December 13th, 2017

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## Use of this document

*This document provides methods for calculating installed system performance from field measurements. Develop formulae and calculations (in conjunction with ASHRAE SPC 221 Committee) required to quantify a system's efficiency sufficiently to allow accurate projection of annual energy usage.*

*It is based on an official [WHPA Work Product](#) of December 13th, 2017 titled "HVAC System Performance Assessment Calculation Procedures". This Work Product was developed by the Field Data Specifications Working Group (CQI-FDS WG) which reports to the WHPA Commercial Quality Installation Committee.*

*This document, and also the WHPA Work Product, may be used in part or whole at no charge. Attribution to the Western HVAC Performance Alliance is requested.*

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## Introduction

In 2015 a WHPA Commercial Installation Field Data Specification Working Group (FDS WG) was formed. This Working Group is associated with the WHPA Commercial Quality Installation (CQI) Committee. The purpose of the Working Group was to write a field specification offering guidance on data collection elements required when measuring the performance of an installed HVAC system in the field.

Previously completed products of this cross-cutting Working Group and the CQI Committee (available on the [WHPA website](#)) that are associated with these System Performance Calculation Procedures include:

- \* [CQI Standardized Field Data Specification for Commercial HVAC Installation](#) detailing the data points required to be collected.
- \* A Commercial Maintenance and a Residential Installation version of this specification have been drafted and are pending approval from other WHPA Committees.

- \* [CQI Definition of an Efficient Commercial HVAC Installation.](#)

The CQI Committee goals for 2017 included an expanded role for the FDS WG including:

- \* Standardized procedures for system performance calculations. This is the document in Industry Insight format. It is also packaged as a [WHPA Work Product.](#)
- \* Best practices for field measurements of quantities required by the performance measurement calculations. This document was adopted by the WHPA Executive Committee at the same time, and is available as an Industry Insight and as a [WHPA Work Product.](#)

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## Work Product

This White Paper provides the methods for calculating installed system performance from field measurements. The calculation methods address the following four system metrics:

- #1 – Equipment Delivered Capacity
- #2 – System Delivered Capacity
- #3 – Equipment Delivered Efficiency
- #4 – System Delivered Efficiency

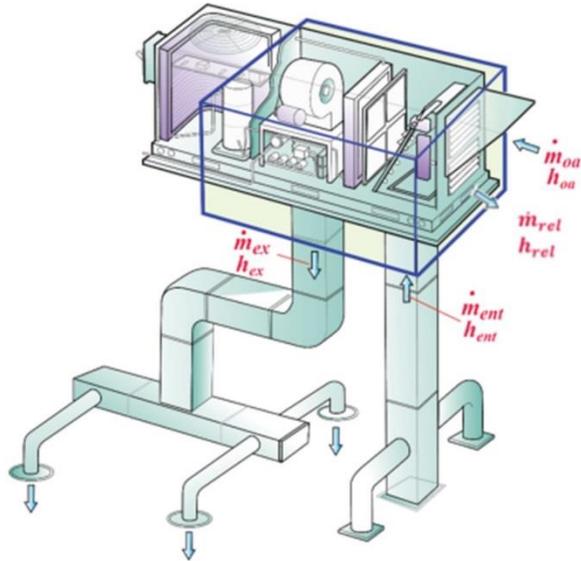
The White Paper was developed from materials presented at the September 13, 2017, CQI FDS WG Meeting on this topic.

The calculation procedures presented in this White Paper are limited to single zone, constant air volume HVAC systems. The calculations address full-load cooling performances only. All equipment is assumed to be operating at full air volume and full cooling output during the test with economizer operating at minimum fresh air setting.

The system performance calculations presented in this White Paper are driven by field measurements that are subject to measurement uncertainty. The [Best Practices White Paper](#) describes instrumentation and measurement techniques designed to minimize the uncertainty in the field measurements and presents expected measurement uncertainties when using the recommended instrumentation and measurement techniques. The uncertainty in the measurements should be propagated through to the final calculated quantities using a propagation of error analysis as described in the Best Practices Work Paper.

## #1 – Equipment Delivered Capacity

A control volume drawn around the HVAC unit is shown below:



An energy balance on the HVAC unit control volume can be expressed as:

$$q_{equip} = \dot{m}_{oa}h_{oa} + \dot{m}_{ent}h_{ent} - \dot{m}_{ex}h_{ex} - \dot{m}_{rel}h_{rel} \dots\dots\dots (1)$$

Where:

- $q_{equip}$  = measured equipment capacity (Btu/hr)
- $\dot{m}_{oa}$  = mass flow rate of outside air entering equipment (lb/hr)
- $\dot{m}_{ent}$  = mass flow rate of return duct air entering equipment (lb/hr)
- $\dot{m}_{ex}$  = mass flow rate of supply air leaving equipment (lb/hr)
- $\dot{m}_{rel}$  = mass flow rate of air exhausted through relief damper or fan (lb/hr)
- $h_{oa}$  = enthalpy of outside air entering equipment (Btu/lb)
- $h_{ent}$  = enthalpy of return air entering equipment (Btu/lb)
- $h_{ex}$  = enthalpy of supply air leaving equipment (Btu/lb)
- $h_{rel}$  = average enthalpy of air exhausted through relief damper or fan (Btu/lb)

Assume:

- $\dot{m}_{ent} - \dot{m}_{rel} = \dot{m}_{ex} - \dot{m}_{oa}$  using conservation of mass
- $h_{rel} = h_{ent}$  relief air that exits the equipment is at conditions equal to air entering equipment

Substituting into equation 1:

$$q_{equip} = \dot{m}_{oa}h_{oa} + (\dot{m}_{ex} - \dot{m}_{oa})h_{ent} - \dot{m}_{ex}h_{ex} \dots\dots\dots (2)$$

Simplifying:

$$q_{equip} = \dot{m}_{oa}h_{oa} + \dot{m}_{ex}h_{ent} - \dot{m}_{oa}h_{ent} - \dot{m}_{ex}h_{ex}$$

$$q_{equip} = \dot{m}_{ex}(h_{ent} - h_{ex}) + \dot{m}_{oa}(h_{oa} - h_{ent}) \dots\dots\dots (3)$$

The mass flow rate is calculated from volumetric flow rates using the following:

$$\dot{m}_{ex} = Q_{ex} \times 4.5 \times ADR \dots\dots\dots (4)$$

$$\dot{m}_{oa} = Q_{oa} \times 4.5 \times ADR \dots\dots\dots (5)$$

Where:

- $Q_{ex}$  = total supply air volumetric flow rate (cfm)
- $Q_{oa}$  = total volumetric flow rate for outdoor ventilation air (cfm)
- 4.5 = constant (lb<sub>m</sub>/cfm at standard conditions)
- ADR = air density ratio (actual air density / standard air density)

The air density should be calculated as a function of temperature and site elevation and corrected to standard conditions (sea level and 20 degrees C).

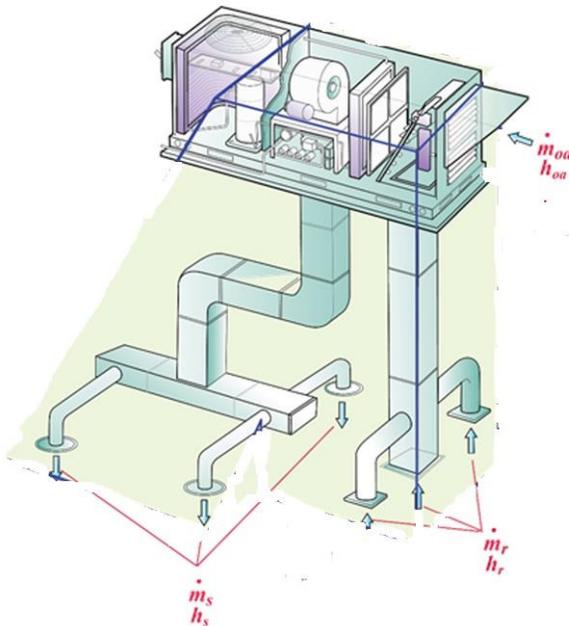
Enthalpies are calculated from dry bulb and wet bulb temperatures (or relative humidity) using standard psychrometric relationships. Note, some combined dry bulb and humidity measurement devices read out directly in enthalpy units.

The equipment delivered capacity is calculated from the following measurements:

- OA entering flow rate (cfm)
- Supply air flow rate (cfm)
- Supply air dry bulb and wet bulb temperature (or RH)
- OA dry bulb and wet bulb temperature (or RH)
- Return air dry bulb and wet bulb temperature (or RH)

## #2 – System Delivered Capacity

A diagram of the full system is shown below:



An energy balance on the airside of the system can be expressed as:

$$q_{coil} = q_{zone} + q_{OA} + q_{loss} \dots\dots\dots (6)$$

Where:

- $q_{coil}$  = the load presented to the evaporator coil of the unit
- $q_{zone}$  = the zone load satisfied by the system
- $q_{oa}$  = the outdoor ventilation air load
- $q_{loss}$  = conduction and leakage losses from the duct system.

Each term in equation (6) can be expanded as follows:

$$q_{coil} = \dot{m}_{ex}(h_{mix} - h_{ex}) \dots\dots\dots (7)$$

$$q_{zone} = \dot{m}_s(h_r - h_s) \dots\dots\dots (8)$$

Where:

- $m_{ex}$  = mass flow rate of the air exiting the HVAC unit
- $h_{mix}$  = enthalpy of the mixed air entering the evaporator coil
- $h_{ex}$  = enthalpy of the air exiting the HVAC unit
- $m_s$  = mass flow rate of the supply air entering the zone
- $h_r$  = enthalpy of the zone air entering the return grill
- $h_s$  = enthalpy of the supply air entering the zone

An energy balance on mixing box can be expressed as:

$$\dot{m}_{ex}h_{mix} = \dot{m}_{oa}h_{oa} + (\dot{m}_{ex} - \dot{m}_{oa})h_{ent} \dots\dots\dots (9)$$

Where:

- $m_{oa}$  = mass flow rate of the outdoor air entering the HVAC unit
- $h_{oa}$  = enthalpy of the outdoor air entering the unit
- $h_{ent}$  = enthalpy of the air entering the HVAC unit

Combining equations (9) and (7) gives:

$$q_{coil} = \dot{m}_{oa}h_{oa} + (\dot{m}_{ex} - \dot{m}_{oa})h_{ent} - \dot{m}_{ex}h_{ex} \dots\dots\dots (10)$$

Combining equations (10) and (6) gives:

$$\begin{aligned} &\dot{m}_{oa}h_{oa} + (\dot{m}_{ex} - \dot{m}_{oa})h_{ent} - \dot{m}_{ex}h_{ex} \\ &= \dot{m}_s(h_r - h_s) + q_{OA} + \dot{m}_{ex}(h_{ent} - h_{ex}) - \dot{m}_s(h_s - h_r) \dots\dots\dots (11) \end{aligned}$$

Simplifying equation (11) gives:

$$q_{oa} = \dot{m}_{oa} \times (h_{oa} - h_{ent}) \dots\dots\dots (12)$$

Solve equation (6) for  $q_{loss}$

$$\begin{aligned} q_{loss} &= q_{coil} - q_{zone} - q_{OA} \\ &= \dot{m}_{oa}h_{oa} + (\dot{m}_{ex} - \dot{m}_{oa})h_{ent} - \dot{m}_{ex}h_{ex} - \dot{m}_s(h_r - h_s) - \dot{m}_{oa}(h_{oa} - h_{ent}) \dots\dots\dots (13) \end{aligned}$$

Simplifying equation (13) gives:

$$q_{loss} = \dot{m}_{ex}(h_{ent} - h_{ex}) - \dot{m}_s(h_r - h_s) \dots\dots\dots (14)$$

The net system delivered capacity can be expressed as:

$$q_{system} = q_{coil} - q_{loss} \dots\dots\dots (15)$$

Substituting equation (15) into equation (6):

$$q_{system} = q_{zone} + q_{oa} \dots\dots\dots (16)$$

$$q_{system} = \dot{m}_s(h_r - h_s) + \dot{m}_{oa} \times (h_{oa} - h_{ent}) \dots\dots\dots (17)$$

The mass flow of the outdoor air, of the return air entering the grills, and of the supply air leaving the registers is calculated from:

$$\dot{m}_r = Q_R \times 4.5 \times ADR \dots\dots\dots (18)$$

$$\dot{m}_s = Q_S \times 4.5 \times ADR \dots\dots\dots (19)$$

Where:

$Q_S = Q_{S1} + Q_{S2} + \dots + Q_{Sn}$  = total volumetric flow rate for all supply registers (cfm)

$Q_R = Q_{R1} + Q_{R2} + \dots + Q_{Rn}$  = total volumetric flow rate for all return grilles (cfm)

$n$  = total number of supply or return registers in the system

4.5 = constant (lb<sub>m</sub>/cfm at standard conditions)

ADR = air density ratio (actual air density / standard air density)

The average enthalpy of the return air entering the grills and of the supply air leaving the registers is calculated from:

$$h_S = \frac{h_{S1} + h_{S2} + \dots + h_{Sn}}{n} \dots\dots\dots (20)$$

$$h_R = \frac{h_{R1} + h_{R2} + \dots + h_{Rn}}{n} \dots\dots\dots (21)$$

The actual air density should be calculated as a function of temperature and site elevation and corrected to standard conditions (sea level and 20 degrees C).

Enthalpies are calculated from dry bulb and wet bulb temperatures (or relative humidity) using standard psychrometric relationships. Note, some combined dry bulb and humidity measurement devices read out directly in enthalpy units.

The equipment delivered capacity is calculated from the following measurements:

- OA entering flow rate (cfm)
- Supply air flow rate delivered to the zone (cfm)
- Supply air dry bulb and wet bulb temperature (or RH) measured at the supply registers
- Return air dry bulb and wet bulb temperature (or RH) measured at the return grilles
- OA dry bulb and wet bulb temperature (or RH) measured at the unit

### #3 – Equipment Measured Efficiency

The equipment field measured efficiency is calculated from:

$$EER_{\text{equip}} = q_{\text{equip}} / W_{\text{equip}} \dots\dots\dots (22)$$

Where:

$EER_{\text{equip}}$  = equipment field measured efficiency (Btu/hr-W)

$Q_{\text{equip}}$  = equipment measured capacity (btu/hr) from equation 3.

$W_{\text{equip}}$  = unit measured input watts

### #4 – System Measured Efficiency

The system field measured efficiency is calculated from:

$$EER_{\text{system}} = q_{\text{system}} / W_{\text{equip}} \dots\dots\dots (23)$$

Where:

$EER_{\text{system}}$  = system field measured efficiency (Btu/hr-W)

$Q_{\text{system}}$  = system measured capacity (btu/hr) from equation 17.

$W_{\text{equip}}$  = unit measured input watts