STANDARD

ANSI/ASHRAE Standard 152-2014
(Supersedes ANSI/ASHRAE Standard 152-2004)

Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems

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NOTE

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FOREWORD

The objective of this method of test is to provide estimates of the efficiency of thermal distribution systems. This efficiency may be used in energy consumption or system capacity estimates. This method of test provides thermal distribution system efficiencies for both heating and cooling systems. Thermal distribution system efficiency is calculated for seasonal conditions (for energy consumption) or design conditions (for system sizing). This results in a total of four outputs from the method of test. This standard does not address the effectiveness of the tested system to provide comfort in the conditioned space or to deliver the designed or required airflow to individual rooms within the conditioned space.

1. PURPOSE

This standard prescribes a method of test to determine the efficiency of space heating and/or cooling thermal distribution systems under seasonal and design conditions. The objective is to facilitate annual energy calculations and heating and cooling equipment capacity calculations.

2. SCOPE

2.1 This standard applies to single-family detached and attached residences with independent thermal systems.

2.2 This standard applies to air, hydronic, and electric distribution systems.

3. DEFINITIONS

buffer zone: unconditioned part of a building containing some or all of the distribution system.

conditioned space: the portion of a building whose air temperature or operative temperature (combined air and radiant temperatures) is intentionally controlled for human occupancy.

delivery effectiveness: the ratio of the thermal energy transferred to or from the conditioned space to the thermal energy transferred at the equipment-distribution system heat exchanger. Energy delivered to or from the conditioned space includes distribution system losses to the conditioned space.

distribution system efficiency: the ratio between the energy consumption by the equipment if the distribution system had no losses (gains) to the outdoors or effect on the equipment or building loads, and the energy consumed by the same equipment connected to the distribution system under test.

electric distribution system: a thermal distribution system that uses electric wiring as the distribution medium in the building.

equipment: a thermal energy conversion device (furnace, boiler, or water heater) or heat-pumping device (air conditioner or heat pump) that serves all or part of the building.

equipment capacity: the manufacturer's rated capacity at the 35°C (95°F) AHRI rating point for air conditioners and 8°C (47°F) AHRI rating point for heat pumps. Furnace capacity shall be adjusted for altitude effects. For the low-capacity stages of multistaged equipment, consult manufacturers' data.

equipment efficiency: the ratio between the thermal energy transferred at the equipment heat exchanger and the thermal (or its equivalent) energy consumed by the equipment.

equipment factor: the ratio of the equipment efficiency, including the effects of the distribution system to the equipment efficiency without the distribution system.

finned-tube baseboard: a heating-terminal unit that primarily consists of one or more finned tubes and a casing cabinet.

floor area: the conditioned floor area of the building.

forced-air distribution system: forced-air systems are heating and/or cooling systems that use motor-driven blowers to distribute heated, cooled, and otherwise treated air for comfort of individuals in confined spaces.

hydronic distribution system: a thermal distribution system that uses water or a mixture of water and additives as the distribution medium in the building.

infiltration factor: the ratio of the building infiltration load without including distribution effects to the load, including distribution system effects.

radiant barrier: a surface of low emissivity (less than 0.1) placed inside an attic or roof space above (but not touching) the distribution system to reduce radiant heat transfer.

radiant panel: a heating or cooling surface that delivers 50% or more of its heat transfer by radiation that may be either an integral part of the building (e.g., floor or ceiling heating) or detached from the building elements (e.g., suspended ceiling panel).

reduced-absorptivity exterior coating: an exterior finish applied to roof systems in order to reduce the absorption of solar radiation. The solar absorptivity must be 0.4 or less.

thermal regain: the fraction of distribution system losses (gains for cooling) that are returned to the conditioned space.

tile roof: a ventilated barrel tile roofing system.

variable-capacity equipment: some heating and cooling equipment operates in stages of different capacity that depend on building load, e.g., electric furnaces with several separate heater elements.

vented crawlspace: a crawlspace with an open vent area ≥1/150th of its floor area, with vents distributed over all exterior surfaces.

well-vented attic: an attic with an open vent area ≥1/300th of its floor area distributed high and low over attic surfaces.

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4. NOMENCLATURE

a_r = leakage factor for return ducts

a_s = leakage factor for supply ducts

A_{floor} = conditioned floor area of building, m^2 (ft^2)

A_p = surface area of radiant panel, m^2 (ft^2)

$A_{p,wall}$ = surface area of radiant panel against exterior surface, m^2 (ft^2)

A_i = surface area of ducts in unconditioned space *i*, m^2 (ft^2)

A_r = surface area of return duct outside conditioned space, m^2 (ft^2)

A_s = surface area of supply duct outside conditioned space, m^2 (ft^2)

b_r = return duct surface area coefficient

B_r = conduction fraction for return

B_s = conduction fraction for supply

C_s = forced-air duct system flow coefficient, $m^3/(s \cdot Pa^n)$ (cfm/[in. H_2O^n])

C_p = specific heat of air, J/(kg·K) (Btu/[lb·°F])

Cv_{pipe} = volumetric heat capacity of pipe, $J/(m^3 \cdot K)$ (Btu/[ft^3·°F])

Cv_{water} = volumetric heat capacity of water, $J/(m^3 \cdot K)$ (Btu/[ft^3·°F])

Cv_{ins} = volumetric heat capacity of pipe insulation, $J/(m^3 \cdot K)$ (Btu/[ft^3·°F])

d_{pipe} = outside diameter of piping, m (ft)

d_{ins} = outside diameter of insulation around piping, m (ft)

DE = delivery effectiveness

DE_{design} = design delivery effectiveness

$DE_{seasonal}$ = seasonal delivery effectiveness

$DE_{corr,\ design}$ = design delivery effectiveness corrected for regain

$DE_{corr,\ seasonal}$ = seasonal delivery effectiveness corrected for regain

E_{cap} = equipment capacity, W (Btu/h) (negative for cooling equipment)

$F_{cycloss}$ = fraction of energy delivered to conditioned space lost due to equipment cycling

F_{equip} = equipment factor

F_{load} = infiltration factor

F_{recov} = thermal loss recovery factor

F_{regain} = thermal regain factor

$F_{regain,\ s}$ = thermal regain factor for supplies

$F_{regain,\ r}$ = thermal regain factor for returns

F_{out} = fraction of supply duct surface area outside conditioned space

$h_{amb,\ r}$ = enthalpy of ambient air for return, J/kg (Btu/lb)

h_{in} = enthalpy of air inside conditioned space, J/kg (Btu/lb)

h_{out} = enthalpy of outside air, J/kg (Btu/lb)

H_a = heat flow from hydronic loop to outside (W, Btu/h)

$H_{b,\ design}$ = design condition heat flow from hydronic loop to the buffer zone(s), W (Btu/h)

$H_{b,\ seasonal}$ = seasonal condition heat flow from hydronic loop to the buffer zone(s), W (Btu/h)

H_c = heat flow from hydronic loop to conditioned space, W (Btu/h)

$H_{del,\ design}$ = heat delivered by hydronic or electric system under design conditions, W (Btu/h)

$H_{del,\ seasonal}$ = heat delivered by hydronic or electric system under seasonal conditions, W (Btu/h)

H_{design} = design building load, W (Btu/h)

H_{loss} = heat lost by hydronic system, W (Btu/h)

$H_{loss,\ design}$ = heat lost by hydronic or electric system under design conditions, W (Btu/h)

$H_{loss,\ seasonal}$ = heat lost by hydronic or electric system under seasonal conditions, W (Btu/h)

H_{ra} = heat flow from hydronic baseboards or radiant panels to outside, W (Btu/h)

$H_{rb,\ design}$ = design condition heat flow from hydronic baseboards to the buffer zone(s), W (Btu/h)

$H_{rb,\ seasonal}$ = seasonal condition heat flow from hydronic baseboards to the buffer zone(s), W (Btu/h)

$H_{rc,\ design}$ = design condition heat flow from hydronic baseboards to the conditioned space, W (Btu/h)

$H_{rc,\ seasonal}$ = seasonal condition heat flow from hydronic baseboards to the conditioned space, W (Btu/h)

$H_{seasonal}$ = seasonal building load, W (Btu/h)

$H_{u,\ design}$ = design condition heat flow from unfinned piping in the conditioned space, W (Btu/h)

$H_{u,\ seasonal}$ = seasonal condition heat flow from unfinned piping in the conditioned space, W (Btu/h)

$H_{ua,\ design}$ = design condition heat flow from unfinned piping in the conditioned space to outside, W (Btu/h)

$H_{ua,\ seasonal}$ = seasonal condition heat flow from unfinned piping in the conditioned space to outside, W (Btu/h)

$H_{uc,\ design}$ = design condition heat flow from unfinned piping in the conditioned space to the conditioned space, W (Btu/h)

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$H_{uc,\ seasonal}$ = seasonal condition heat flow from unfinned piping in the conditioned space to the conditioned space, W (Btu/h)

K = thermal conductance of hydronic pipe insulation, W/(m·K) (Btu/[h·ft·°F])

$k_{b,\ ins}$ = thermal conductance for insulated hydronic piping, W/(m·K) (Btu/[h·ft·°F])

$k_{b,\ unins}$ = thermal conductance for uninsulated hydronic piping, W/(m·K) (Btu/[h·ft·°F])

k_{rc} = thermal conductance for heat transfer from baseboards to conditioned space, W/(m·K) (Btu/[h·ft·°F])

k_{ra} = thermal conductance to the outside for baseboards or radiant panels, W/(m·K), (Btu/[h·ft·°F])

k_{ua} = thermal conductance between unfinned piping and outside for baseboards or radiant panels, W/(m·K) (Btu/[h·ft·°F])

k_{uc} = thermal conductance between unfinned piping and conditioned space, W/(m·K), (Btu/[h·ft·°F])

K_r = thermal capacitance per unit pipe length of finned terminal units in the conditioned space, J/(K·m) (Btu/[°F·ft])

K_u = thermal capacitance per unit pipe length of unfinned piping in the conditioned space, J/(K·m) (Btu/[°F·ft])

$K_{b,\ unins}$ = thermal capacitance per unit pipe length of unfinned piping in the buffer space that is uninsulated, J/(K·m) (Btu/[°F·ft])

$K_{b,\ ins}$ = thermal capacitance per unit pipe length of unfinned piping in the buffer space that is insulated, J/(K·m) (Btu/[°F·ft])

K_{fins} = heat capacity of fins per unit length of J/(K·m) (Btu/[°F·ft])

$L_{b,\ unins}$ = length of unfinned piping in the buffer space that is not insulated, m (ft)

$L_{b,ins}$ = length of unfinned piping in the buffer space that is insulated, m (ft)

L_r = total length of finned terminal hydronic or electric baseboard units, m (ft)

$L_{r,\ wall}$ = length of finned terminal hydronic or electric baseboard units mounted against exterior wall, m (ft)

L_u = total length of unfinned piping in the conditioned space

$L_{u,\ wall}$ = length of unfinned piping mounted against exterior wall, m (ft)

n_s = pressure exponent for forced-air duct system

NTU = number of heat transfer units in the piping system

Q_{buffer} = ventilation rate of duct location, m^3/s (cfm)

Q_c = flow from duct location to conditioned space, m^3/s (cfm)

Q_e = flow through air-handler fan at operating conditions, m^3/s (cfm)

Q_{eH_2o} = volumetric circulator flow rate for hydronic systems, m^3/s (cfm)

$Q_{e,\ rated}$ = flow through air-handler fan at manufacturer's efficiency rating conditions, m^3/s (cfm)

Q_{imb} = flow imbalance, m^3/s (cfm)

Q_{inf} = natural infiltration rate for building without duct system, m^3/s (cfm)

Q_{max} = maximum flow obtainable through flowmeter when measuring air-handler flow, m^3/h (cfm)

Q_{net} = net infiltration: combined natural and imbalance flow, m^3/h (cfm)

Q_{off} = air-handler fan off infiltration including duct leakage, m^3/h (cfm)

Q_r = return duct leakage to outside, m^3/h (cfm)

Q_s = supply duct leakage to outside, m^3/h (cfm)

Q_{25} = duct leakage flow to outside at 25 Pa, m^3/h (cfm)

$Q_{25,\ s}$ = supply duct leakage flow to outside at 25 Pa, m^3/h (cfm)

$Q_{25,\ r}$ = return duct leakage flow to outside at 25 Pa, m^3/h (cfm)

$Q_{0.1}$ = duct leakage flow to outside at 0.1 in. H_2O, m^3/s (cfm)

$Q_{0.1,\ s}$ = supply duct leakage flow to outside at 0.1 in. H_2O, m^3/s (cfm)

$Q_{0.1,\ r}$ = return duct leakage flow to outside at 0.1 in. H_2O, m^3/s (cfm)

$Q_{25,\ total}$ = total duct leakage flow at 25 Pa, m^3/s (cfm)

$Q_{0.1,\ total}$ = total duct leakage flow at 0.1 in. H_2O, m^3/s (cfm)

R_r = thermal resistance of return duct, m^2·K/W (h·ft^2·°F/Btu)

R_s = thermal resistance of supply duct, m^2·K/W (h·ft^2·°F/Btu)

R_w = thermal resistance of exterior wall of building next to hydronic or electric systems, m^2·K/W (h·ft^2·°F/Btu)

R_{uc} = thermal resistance of unfinned pipe in conditioned space, m^2·K/W (h·ft^2·°F/Btu)

$t_{amb,\ b}$ = temperature of the buffer space with the conditioning system on, supply and return in the same space, °C (°F)

$t_{amb,\ r}$ = ambient temperature for return ducts, °C (°F)

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$t_{amb,\ s}$ = ambient temperature for supply ducts, °C (°F)

t_{attic} = attic air temperature, °C (°F)

$t_{hotwater}$ = nominal or average boiler or water heater water temperature, °C (°F)

$t_{bdesign}$ = design temperature of buffer zone for hydronic system, °C (°F)

$t_{bseasonal}$ = seasonal temperature of buffer zone for hydronic system, °C (°F)

$t_{b,off}$ = temperature of the buffer space with the conditioning system off, °C (°F)

t_{design} = outdoor-air design temperature, °C (°F)

t_{ground} = ground temperature, °C (°F)

t_{in} = temperature of indoor air, °C (°F)

t_{out} = outdoor-air temperature, °C (°F)

t_{rp} = return plenum air temperature, °C (°F)

$t_{seasonal}$ = outdoor-air seasonal temperature, °C (°F)

t_{sp} = supply plenum air temperature, °C (°F)

U = thermal conductance, W/(m^2·K) (Btu/[h·ft^2·°F])

$U_{conv\ +\ rad}$ = convective plus radiative heat transfer coefficient of the outer pipe surface, W/(m^2·K) (Btu/[h·ft^2·°F])

$U_{panel,\ ra}$ = the overall heat transfer between an electric radiant panel and outside unit area of panel, W/(m^2·K) (Btu/[h·ft^2·°F])

$U_{panel,\ rc}$ = the overall heat transfer between an electric radiant panel and the conditioned space per unit area of panel, W/(m^2·K) (Btu/[h·ft^2·°F])

$(UA)_{in}$ = UA value for the interface between the conditioned space and the buffer space, W/K (Btu/h/°F)

$(UA)_{out}$ = UA value for the interface between the outside and the buffer space, W/K (Btu/h/°F)

$(UA)_{infil}$ = effective UA value for the infiltration rate of outdoor air through the buffer space, W/K (Btu/h/°F)

$(UA)_{ground}$ = UA value for the interface between the ground and the buffer space, W/K (Btu/h/°F)

V = building volume, m^3 (ft^3)

w = humidity ratio, kg H_2O/kg dry air (lb H_2O/lb dry air)

w_{design} = design outdoor humidity ratio, kg H_2O/kg dry air (lb H_2O/lb dry air)

$w_{seasonal}$ = seasonal outdoor humidity ratio, kg H_2O/kg dry air (lb H_2O/lb dry air)

$w_{in,\ design}$ = design indoor humidity ratio, kg H_2O/kg dry air (lb H_2O/lb dry air)

$w_{in,\ seasonal}$ = seasonal indoor humidity ratio, kg H_2O/kg dry air (lb H_2O/lb dry air)

y = height of convector enclosure surrounding finned terminal units, m (ft)

Z_{design} = intermediate calculation for $\tau_{ondesign}$

$Z_{seasonal}$ = intermediate calculation for $\tau_{onseasonal}$

ϕ_{man} = manufacturer's rating for heat transfer between baseboards and conditioned space, W/m (Btu/ft)

γ_{man} = manufacturer's rating for heat transfer between an electric radiant panel and the conditioned space per unit area of panel, W/m^2 (Btu/h·ft^2)

ΔP_{fan} = pressure difference across air-handler fan, Pa (in. H_2O)

ΔP_r = average pressure difference between return ducts and outside, Pa (in. H_2O)

ΔP_{rp} = pressure difference between return plenum and conditioned space, Pa (in. H_2O)

ΔP_s = average pressure difference between supply ducts and outside, Pa (in. H_2O)

ΔP_{sp} = pressure difference between supply plenum and conditioned space, Pa (in. H_2O)

Δt_e = temperature rise across heat exchanger, °C (°F)

$\Delta t_{\ln}$ = log-mean temperature difference between the piping and conditioned space, °C (°F)

Δt_{man} = manufacturer's temperature difference rating, °C (°F)

Δt_r = temperature difference between indoors and the ambient for the return, °C (°F)

Δt_s = temperature difference between indoors and the ambient for the supply, °C (°F)

$\eta_{dist,\ design}$ = design distribution system efficiency

$\eta_{dist,\ seasonal}$ = seasonal distribution system efficiency

ρ_{in} = density of indoor air, kg/m^3 (lb/ft^3)

ρ_c = density of buffer zone air, kg/m^3 (lb/ft^3)

$\tau_{cycledesign}$ = circulator cycle time (on + off) under design conditions, h

$\tau_{cycleseasonal}$ = circulator cycle time (on + off) under seasonal average conditions, h

$\tau_{offdesign}$ = design circulator off time, h

$\tau_{offseasonal}$ = seasonal circulator off time, h

$\tau_{ondesign}$ = design circulator on time, h

$\tau_{onseasonal}$ = seasonal circulator on time, h

$\tau_{r,f}$ = relaxation time for a finned-tube baseboard, h

$\tau_{r,u}$ = relaxation time for an unfinned-tube baseboard, h

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$\tau_{b,ins}$ = relaxation time for insulated piping in a buffer space, h

$\tau_{b,unins}$ = relaxation time for uninsulated piping in a buffer space, h

5. CLASSIFICATIONS AND GENERAL REQUIREMENTS

5.1 Thermal Distribution Systems. This standard covers the following distribution systems:

a. Forced air (Section 6)
b. Hydronic finned-tube baseboards (Section 7)
c. Electric finned-tube baseboards and radiant panels (Section 8)

5.2 Distribution System Efficiency. The thermal distribution system efficiency is determined for the following conditions:

a. Heating under seasonal conditions (for energy consumption estimates)
b. Heating under design conditions (for system sizing)
c. Cooling under seasonal conditions (for energy consumption estimates)
d. Cooling under design conditions (for system sizing)

5.3 Input Data Requirements. This standard includes a complete protocol for specifying the input parameters needed for evaluating distribution system performance in existing buildings. For buildings that have been designed but not yet built, predicted distribution efficiencies may be calculated on the basis of projected or specified input values. However, the building shall not be considered to have been evaluated according to this standard unless the measurements and calculations specified in the standard have been carried out following construction.

The user of this standard shall provide a listing of all input data and their sources, clearly indicating how the input parameters were determined.

6. FORCED-AIR DISTRIBUTION SYSTEMS

6.1 Instrument Specifications. The instruments for the diagnostic measurements shall conform to the following specifications. All flow measurements shall be corrected for temperature and barometric pressure effects, according to the manufacturers' instructions.

6.1.1 Pressure Measurement. All pressure measurements shall be made with measurement systems (i.e., sensor plus data-acquisition system) having an accuracy of ±0.2 Pa (0.0008 in. H_2O) or 1% of reading, whichever is greater, and a resolution of 0.1 Pa (0.0004 in. H_2O) or 1% of reading, whichever is greater. All pressure measurements within the duct system shall be made using static pressure probes.

6.1.2 Length Measurement. Measurements of length shall have an accuracy of at least ±5%.

6.2 Apparatus

6.2.1 Air-Handler Fan Flow Using an Air-Handler Flow Plate Device. The apparatus for measuring the air-handler fan flow using an air-handler flow plate device shall consist of the following:

a. An air-handler flow plate device (i.e., sensor plus data-acquisition system) having an accuracy of ±7% of measured flow
b. A static pressure probe
c. A pressure transducer meeting the specifications described in Section 6.1.1

6.3 Procedure. The calculation procedure in the following sections shall be used to determine distribution system efficiencies based on the following principal input parameters:

a. Duct location
b. Geographic climate
c. Duct insulation
d. Duct surface area
e. Air-handler fan flow
f. Duct leakage
g. Equipment capacity

The following additional parameters shall be used where required:

a. Building volume
b. Building floor area
c. Presence of radiant barriers, reduced absorptivity exterior coatings, or a tile roof
d. Venting condition of attics and/or crawl spaces
e. Insulation of the building structure
f. Number of return registers

6.3.1 Indoor Air Conditions

a. For heating, the indoor air temperature shall be 20°C (68°F).
b. For cooling, the indoor dry-bulb temperature shall be 25.5°C (78°F).
c. For cooling, the indoor humidity ratio, w_{in}, and the indoor air enthalpy shall be taken from Table 6.3.1-1 or Table 6.3.1-2.

6.3.2 Unconditioned Duct Locations. Attic, garage, underslab, and exterior wall temperature conditions, and humidity conditions for all duct locations, shall be obtained from Tables 6.3.2-1 (heating) and 6.3.2-2 (cooling). Crawl space and basement temperature conditions shall be determined both with and without the impact of duct losses using Equations 6-1 through 6-4. Default U-factors for use in these equations may be used and are found in Table 6.3.2-3. In Tables 6.3.2-1 and 6.3.2-2, the heating and cooling temperatures for design and seasonal conditions shall be taken from Tables 6.3.1-1 and 6.3.1-2. Design data in Tables 6.3.1-1 and 6.3.1-2 are from the 1997 *ASHRAE Handbook—Fundamentals*[1], and the seasonal data are calculated from temperature-differential-weighted TMY and TMY2 data.[2]

6.3.2.1 Temperature and Humidity with Conditioning System Off. The temperature of the crawl space or basement with the conditioning system off is: