Harley-Davidson Museum

Milwaukee, WI

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Mechanical Option

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[TECHNICAL REPORT ONE]

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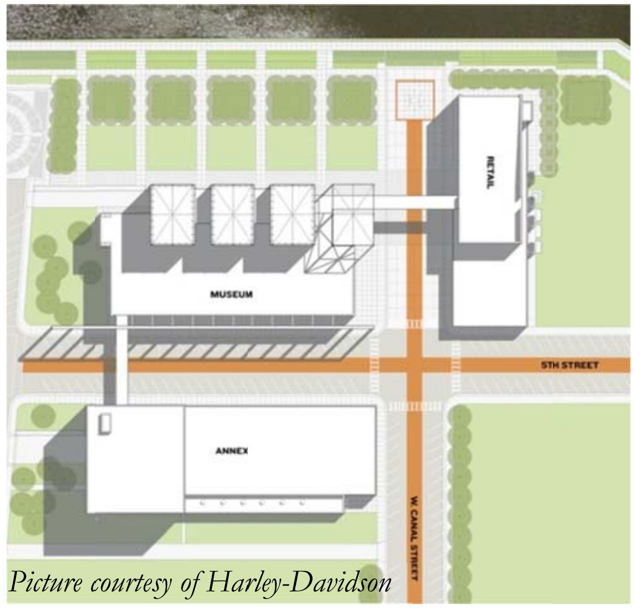
EXECUTIVE SUMMARY



Picture courtesy of Harley-Davidson

This thesis technical report was conducted on the Harley-Davidson Museum in Milwaukee, Wisconsin which was completed in 2008. Separated into three distinct parts, the complex consist of a 60,000 SF Museum which houses the permanent exhibits; a 45,000 SF Annex Building which will accommodate temporary exhibits and Harley Davidson's extensive archives; and a 25,000 SF building which houses a 150-seat restaurant, a grab and go cafe, a retail space, and a special event space. The museum has an exposed structure inside and outside, but many of the areas did not permit ductwork to be visible which created a challenge for the engineers at HGA.

The purpose of this report is to evaluate the Harley-Davidson Museum's mechanical, lighting, and electrical systems, as well as the overall construction, on the standards established by the American Society of Heating, Refrigerating, and Air Conditioning Engineers. Specifically sections 5 and 6 of ASHRAE Standard 62.1- Ventilation for Acceptable Indoor Air Quality and Section 5 through 10 of ASHRAE Standard 90.1 – Energy Standard for Buildings.

The first standard evaluated was ASHRAE Standard 62.1. The purpose of this standard is to specify minimum ventilation rates and other measures intended to provide indoor air quality that is acceptable to human occupants and that minimizes adverse health effects. A comprehensive study of the buildings compliance with the standards in sections 5 and 6 concluded that the mechanical components that control indoor air quality are in complete compliance with section 5; however, not all of the ventilation rates are in compliance with section 6 and may lead to poor indoor air quality. ASHRAE 62.1 section 6 was not used by the engineers at HGA due to the unusual occupancy of the building. Assumptions were made and are discussed later in this report.

The second standard evaluated was ASHRAE Standard 90.1. The purpose of this standard is to provide minimum equipment efficiencies and provide standards to create an energy efficient design. Overall, the Harley-Davidson Museum complied with the majority of the standards in this section; however, some standards such as wall R-value and fan efficiencies were found to be non-compliant with the standard. For a building where energy efficiency was not the main focus in the design, the Harley-Davidson Museum was still able to exceed many of the standards set forth by ASHRAE. A further investigation of the buildings energy use will be investigated in the 2nd technical report.

PROJECT BACKGROUND

HGA worked with Pentagram Architecture to transform an underutilized site with environmental and geotechnical challenges into an award winning Museum for Harley-Davidson. This attracts 350,000 visitors annually and serves as a catalyst for redevelopment of the old historical warehouse neighborhood. Suitably located in Milwaukee, a city built around manufacturing, the design of the museum was inspired by factories. The style of architecture is industrial, yet refined, particularly appropriate to which it reflects the character of Harley-Davidson. An honest architectural palette of steel, brick, and glass, creates a straightforward understanding of the building's form and reveals the reality behind its unique aesthetic.

Careful consideration went into the design to properly reflect the industrial character of Harley-Davidson. The layout of the museum was designed to follow a chronological path. The use of motorcycles, posters, film clips, and interactive displays, form a narrative of the history of Harley-Davison from its founding to the present. Encompassing a 20 acre site, this project creates an additional amenity on the riverfront for the public by creating five acres of terrace and park space on the 20 acre site.

The Harley-Davidson Museum's façade is comprised of brick metal and glass. Ebony black matte Field Brick covers the majority of the façade on all three buildings in the museum complex. Larger areas not covered by brick utilize a pre-fabricated, field assembled, curtain wall. The curtain wall is a high-rise aluminum thermally broken curtain wall framing system with windows and entrance framing systems designed to accept 1 inch of glazing material. Harley-Davidson's colors of gray, orange, and black, were applied in the design and application of the curtain wall system. Extruded bars give the curtain wall texture. Exterior aluminum decorative louvers are used to conceal rooftop mechanical systems.

All three buildings making up the Harley-Davidson have a roofing system comprised of fully adhered thermoplastic single ply membrane over tapered insulation and vapor retarder on metal decking. Roof deck is 3" 20 gage galvanized steel.

Careful consideration went into making the Harley-Davidson Museum sustainable without compromising the architectural integrity. A study was conducted on solar angles to minimize the amount of solar radiation entering the museum. Automatic louvers open and close according to the amount of sun entering the building. Extended overhangs over the windows block the sun during the hottest times of the day and year. It was important for the architects to preserve as much of the site as possible. Two water towers from the existing site were preserved and serve as architectural focal points instead of filling up a landfill. Local vegetation was planted to minimize excess watering. The river walk was preserved creating a sense of community next to the river. The river walk also serves as an alternate carbon free way to travel to and from the museum.

Mechanical Summary

The Museum Building has two central 42,000 CFM variable air volume air handling units with two central return air points. The Retail Building has 5 constant volume air handling units serving the five separate zones: retail, kitchen, café, restaurant, and special event space. The Annex Building has 4 air handling units. The exhibit space is served by 1 custom built 21,500 CFM constant air volume air handling unit. The workshop, exhibit prep and storage are served by the 1 modular 8,000 CFM constant air volume air handling unit. General offices are served by 1 modular 5,000 CFM variable air volume air handling unit. The loading dock, security, employee bream room and remaining areas of the annex are served by 1 modular 5,000 CFM variable air volume air handling unit.

The heating water system consists of four 1500MBH sealed combustion condensing boilers with gas fired burners. The heating water system distribution is a variable-primary pumping system. Primary pumps are 386 GPM, 25 HP, variable speed, end suction base mounted type. One pump is used for stand-by. Variable speed pumps have dedicated variable speed drive controller. This heating system provides hot water heat to air handling unit hot water coils, variable air volume box reheat coils, hot water finned tube radiation, unit heaters and similar devices throughout the building.

The cooling plant consists of 2 roof mounted 250 ton air cooled rotary screw chillers and utilize R134A refrigerant. The chillers have variable speed drive control. A variable-primary pumping system with 747 GPM, 75 HP, and variable speed end suction base mounted type is utilized. The chilled water system uses a 35 percent glycol for freeze protection.

Hydronic piping distribution systems throughout the building are schedule 40 steel pipe through 10 inches and standard weight for pipe sizes 12 inches and larger. Welded joints for 3 inch and larger pipe sizes and threaded joints for 2-1/2 inch and smaller pipe sizes were preferred. Hard drawn copper pipe was acceptable for pipe sizes 1 inch and smaller.

Some energy efficiency features in the mechanical design include; operating pumps using variable speed drive controllers, multiple boilers operating at part load capacity, multiple chiller with variable speed capacity adjustment, use of outdoor air for making chilled water during winter, operating air handling units using variable speed drive controllers, use of air flow measuring stations in outdoor air intake, and use of outdoor air for cooling during cooler days.

ASHRAE STANDARD 62.12007
Section 5: Systems & Equipment

Section 5.1 – Natural Ventilation

This section is not applicable; natural ventilation is not incorporated into the design of this building.

Section 5.2 – Ventilation Air Distribution

The Harley-Davidson Museum is able to meet the ventilation air distribution requirement. Mechanical ventilation systems have means of adjustment such that the minimum ventilation airflow specified in section 6 can be maintained under any load. Section 6 is discussed later in this report. Manual dampers are located to adjust supply and return airflow to each ventilation zone. Airflow rates are clearly labeled in the design documents for balancing.

Section 5.3 – Exhaust Duct Location

Rooftop electrical fans maintain a constant negative pressure throughout the exhaust duct to prevent exhaust air leaking into occupied spaces. All exhaust ducts are held at negative 2 inch wg. Generator exhaust is insulated and sealed in accordance with SMACNA Seal Class A.

Section 5.4 – Ventilation System Controls

AHU's supplying ventilation to zones have supply and return fans each having dedicated variable speed drives. The BAS has access to all VSD control points. The supply fan starts when indexed to occupied mode by the BAS. Flow measuring stations are used to monitor the outdoor air damper minimum position to maintain the programmed minimum outside air intake set point. VAV boxes have a minimum position that meets minimum ventilation requirements for each zone given in section 6 of standard 62.1. The Harley-Davidson Museum complies with section 5.4.

Section 5.5 – Airstream Surfaces

Products that come in contact with stainless steel have a leachable chloride content of less than 50 ppm when tested according to ASTM C 871. Flexible elastomeric duct liner is made of unicellular polyethylene thermal plastic complying with ASTM C 534. Specification state that all Non-metal ductwork is listed and labeled as complying with UL 181. All other ductwork is G90 galvanized steel and falls under the general exception for sheet metal surfaces and metal fasteners.

Section 5.6 – Outdoor Air Intake

The ventilation system outdoor intakes are designed in accordance with table 5-1 from section 5.6 of ASHRA standard 62.1. All outdoor air intakes are located such that the shortest distance from intake to any specific potential outdoor contaminant source is equal or greater than the distances listed in table 5-1.

TABLE 5-1 Air Intake Minimum Separation Distance

Object	Minimum Distance, ft (m)
Significantly contaminated exhaust (Note 1)	15 (5)
Noxious or dangerous exhaust (Notes 2 and 3)	30 (10)
Vents, chimneys, and flues from combustion appliances and equipment (Note 4)	15 (5)
Garage entry, automobile loading area, or drive-in queue (Note 5)	15 (5)
Truck loading area or dock, bus parking/idling area (Note 5)	25 (7.5)
Driveway, street, or parking place (Note 5)	5 (1.5)
Thoroughfare with high traffic volume	25 (7.5)
Roof, landscaped grade, or other surface directly below intake (Notes 6 and 7)	1 (0.30)
Garbage storage/pick-up area, dumpsters	15 (5)
Cooling tower intake or basin	15 (5)
Cooling tower exhaust	25 (7.5)

Note 1: Significantly contaminated exhaust is exhaust air with significant contaminant concentration, significant sensory-irritation intensity, or offensive odor.
Note 2: Laboratory fume hood exhaust air outlets shall be in compliance with NFPA 45-1991[3] and ANSI/AIHA Z9.5-1992.[4]
Note 3: Noxious or dangerous exhaust is exhaust air with highly objectionable fumes or gases and/or exhaust air with potentially dangerous particles, bioaerosols, or gases at concentrations high enough to be considered harmful. Information on separation criteria for industrial environments can be found in the ACGIH Industrial Ventilation Manual[5] and in the *ASHRAE Handbook—HVAC Applications*.[6]
Note 4: Shorter separation distances are permitted when determined in accordance with (a) Chapter 7 of ANSI Z223.1/NFPA 54-2002[7] for fuel gas burning appliances and equipment, (b) Chapter 6 of NFPA 31-2001[8] for oil burning appliances and equipment, or (c) Chapter 7 of NFPA 211-2003[9] for other combustion appliances and equipment.
Note 5: Distance measured to closest place that vehicle exhaust is likely to be located.
Note 6: No minimum separation distance applies to surfaces that are sloped more than 45 degrees from horizontal or that are less than 1 in. (3 cm) wide.
Note 7: Where snow accumulation is expected, distance listed shall be increased by the expected average snow depth.

Outdoor air intakes that are part of the mechanical ventilation system meet the rain entrainment requirements of section 5.6.2. Louvers restrict wind-drive rain penetration and enlarged O.A.I plenums reduce flow velocity and the chance of rain being brought into the building.

Section 5.7 – Local Capture of Contaminants

The discharge from non-combustion equipment that captures the contaminants generated by the equipment is ducted directly to the outdoors or the equipment is specifically designed for discharge indoors; therefore, the Harley-Davidson Museum meets this requirement.

Section 5.8 – Combustion Air

The emergency generator located in the Annex building of the Harley-Davidson Museum has adequate outside air regulated by a motorized damper to ensure a full combustion process. Its exhaust is directly vented out of the building through the roof.

Section 5.9 – Particulate Matter Removal

The filters used have a minimum efficiency that meets ASHRAE standard 52.2-1999. Every AHU uses a 30% pleated pre filter followed by a 95% cartridge filter. See Air Filter Schedule for filter details in figure 1 below. These filters reduce the rate of accumulation of particulate matter and reduce the level or airborne particles that may be harmful to humans, such as microorganisms and respirable particles to a level that complies with this section.

AIR FILTER SCHEDULE (AF)

TAG	LOCATION	TOTAL CFM	FILTER TYPE	EFF (%)	FILTER DATA DEPTH (IN)	FILTER DATA AREA (SQ FT)	FILTER DATA APD (IN WG)	SERVICE ACCESS	MANUFACTURER	MODEL	NOTES
AF-A1A	AHU-A1	9,500	PLEATED	30	2	18.9	0.75	SIDE	PURAFIL		1,2
AF-A1B	AHU-A1	9,500	CARTRIGE	95	12	18.9	1.5	SIDE	PURAFIL		1,2
AF-A2A	AHU-A2	25,200	PLEATED	30	2	54.3	0.75	SIDE	PURAFIL		1,2
AF-A2B	AHU-A2	25,200	CARTRIGE	95	12	54.3	1.5	SIDE	PURAFIL		1,2
AF-A3A	AHU-A3	16,500	PLEATED	30	2	34.1	0.75	SIDE	PURAFIL		1,2
AF-A3B	AHU-A3	16,500	CARTRIGE	95	12	34.1	1.5	SIDE	PURAFIL		1,2
AF-A4A	AHU-A4	3,000	PLEATED	30	2	5.6	0.75	SIDE	PURAFIL		1,2
AF-A4B	AHU-A4	3,000	CARTRIGE	95	12	5.6	1.5	SIDE	PURAFIL		1,2
AF-A4C	AHU-A4	3,000	GAS PHASE	-	12	12	0.5	SIDE	PURAFIL		2,3,4
AF-AG1	GEN. RM.	16,500	PLEATED	30	2	34.1	0.75	BOTTOM	PURAFIL		2,5
AF-M1A	AHU-M1	45,000	PLEATED	30	2	104	0.75	FRONT	PURAFIL		1,2
AF-M1B	AHU-M1	45,000	CARTRIGE	95	12	104	1.5	FRONT	PURAFIL		1,2
AF-M2A	AHU-M2	45,000	PLEATED	30	2	104	0.75	FRONT	PURAFIL		1,2
AF-M2B	AHU-M2	45,000	CARTRIGE	95	12	104	1.5	FRONT	PURAFIL		1,2
AF-R1A	AHU-R1	10,400	PLEATED	30	2	21.5	0.8	SIDE	PURAFIL		1,2
AF-R1B	AHU-R1	10,400	CARTRIGE	95	12	21.5	1.5	SIDE	PURAFIL		1,2
AF-R2A	AHU-R2	3,200	PLEATED	30	2	6.9	0.75	SIDE	PURAFIL		1,2
AF-R2B	AHU-R2	3,200	CARTRIGE	95	12	6.9	1.5	SIDE	PURAFIL		1,2
AF-R3A	AHU-R3	15,000	PLEATED	30	2	30.3	0.75	SIDE	PURAFIL		1,2
AF-R3B	AHU-R3	15,000	CARTRIGE	95	12	30.3	1.5	SIDE	PURAFIL		1,2
AF-R4A	AHU-R4	11,000	PLEATED	30	2	21.9	0.75	SIDE	PURAFIL		1,2
AF-R4B	AHU-R4	11,000	CARTRIGE	95	12	21.9	1.5	SIDE	PURAFIL		1,2
AF-R5A	AHU-R5	14,200	PLEATED	30	2	28.3	0.75	SIDE	PURAFIL		1,2
AF-R5B	AHU-R5	14,200	CARTRIGE	95	12	28.3	1.5	SIDE	PURAFIL		1,2

NOTES:
1. FILTER PART OF RESPECTIVE AIR HANDLING UNIT SCHEDULED IN AIR HANDLING UNIT SCHEDULE.
2. APD BASED ON DIRTY FILTER.
3. GAS PHASE WITH ACTIVATED CARBON FILTER MEDIA.
4. PROVIDE DEDICATED SIDE ACCESS FILTER HOUSING OUTSIDE AHU.
5. FILTER BANK TO CONSIST OF NINE (9) 24 x 24 FILTERS IN A 18ft. X 2ft. BANK.

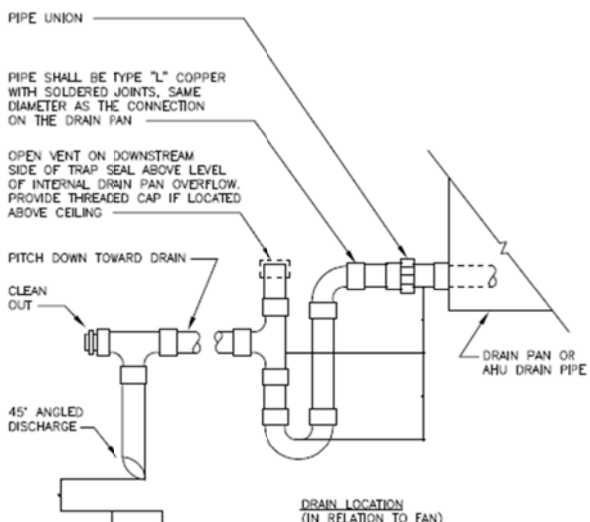
Figure 1

Section 5.10 – Dehumidification Systems

The maximum relative humidity in the Harley-Davidson Museum is 50%. This complies with the limited 65% set by ASHRAE. Because of the exhibits sensitivity to humidity, the museum is held at a constant 50% RH by a tight control system. Recent tests have shown that the annex building is not able to maintain a maximum of 50% RH. This is due to an over estimate in occupancy and a reduced amount of chilled/dehumidified air to the space. There is no reheat so there is no option to over cool to dehumidify.

Section 5.11 – Drain Pans

All drain pans are designed to prevent standing water and limit water droplet carryover. Drain configurations that result in negative static pressure at the drain pan relative to the drain outlet includes a trap, shown in figure 2, to maintain a seal against the entry of ambient air while allowing complete drainage of the drain pan under any normally expected operating conditions. Specifications state -"Install drain traps for each condensate drain pan for cooling coils in air handling units and fan-coil units. Provide vented water seal and terminate with a turned-down elbow at a clear water waste hub drain." Drain pans extend downstream from the leaving face or edge to a distance that complies with section 5.11.4 and can be seen in figure 3.



	A DIM.	B DIM.
DRAW THRU	1" + X	.5" • X
BLOW THRU	.5" • X	1" + X

Figure 2: detail of the cooling coil drain piping and trap

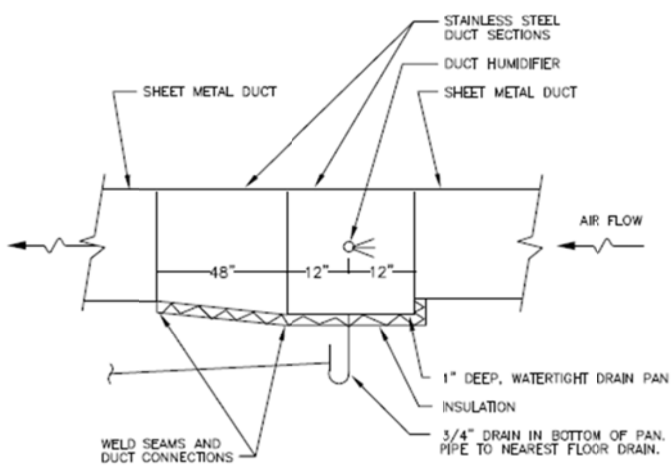


Figure 3: detail of the duct humidifier and drain

Section 5.12 – Finned-tube Coils and Heat Exchangers

All drain pans are in accordance with section 5.11; therefore, they comply with section 5.12. Finned-tube coils have adequate access space for cleaning. All fin tubes used are 1 row and 40 fins per foot, having a lower pressure drop then maximum 0.75 in. specified in this section; therefore, it complies.

Section 5.13 – Humidifiers and Water-Spray Systems

Water used for humidification originates directly from a potable source. There are no obstructions downstream of the humidifier in a short enough distance that would cause condensation or collection of water; therefore, the design complies with this section. Drip pans are located under the humidifier and comply with this section and section 5.11.

Section 5.14 – Access for Inspection, Cleaning, and Maintenance

Air handling units M1 and M2 are tightly placed in individual mechanical rooms. Entry doors to these two mechanical rooms are placed strategically to allow access and removal of filters for maintenance. All other mechanical rooms have adequate space for routine maintenance specified by the National Electric Code. All ventilation systems have access doors for unobstructed access for inspection, maintenance, and calibration of ventilation system components. Mechanical chases have access panels that coordinate with architectural access.

Section 5.15 – Building Envelope

Appropriate weather barriers are provided to prevent water penetration into the envelope. An exterior vapor retarder is provided to limit water vapor diffusion to prevent condensation on cold surfaces within the envelope. Water is able to drain behind brick. All interior surfaces that may be colder than the dewpoint temperature of the surrounding air are insulated and comply with this section.

Section 5.16 – Buildings with Attached Parking Garages

The Harley-Davidson Museum does not have a parking garage; therefore, this section does not apply.

Section 5.17 – Air Classification Recirculation

Commercial kitchen hoods classified as air class 4 and 3 in table 5-2 from ASHRAE are 100% exhausted to the outside. All restrooms are also exhausted 100% to the outside. The retail, restaurant, kitchen, special events, museum, and offices each have separate air circulation with no cross contamination.

TABLE 5-2 Airstreams

Description	Air Class
Diazo printing equipment discharge	4
Commercial kitchen grease hoods	4
Commercial kitchen hoods other than grease	3
Laboratory hoods	4
Residential kitchen vented hoods	3

Section 5.18 – Requirements for Buildings Containing ETS Areas and ETS-Free Areas

The Harley-Davidson Museum is a smoke free facility; therefore, this section does not apply.

Section 6: Ventilation Rate Procedure Analysis

ASHRAE Standard 62.1, section 6 outlines the Ventilation Rate Procedure used to design each ventilation system used in the building. A prescriptive approach is used to calculate the minimum outdoor air to individual zones in the buildings based on space category, occupancy, and floor area. Ventilation is intended to dilute contaminants in indoor spaced generated by primarily two types of sources: Occupants (bio-effluents) and off-gassing from building materials. This study is a comparison of calculated minimum ventilation to the designed ventilation of the Harley-Davidson Museum.

In this study of the mechanical ventilation of the Harley-Davidson Museum, 9 of 10 air handling units were analyzed. AHU-4A serves the paper archives in the Annex building and was not included in the study because of its limited need for ventilation and controlling requirement for humidity and temperature control.

The following calculations were used in the study and come from ASHRAE Standard 62.1 section 6.

- The ventilation rate required to control both people related sources (V_p) and building related sources (Va) is the sum of ventilation required to control each of them alone at the breathing zone (Vbz).
  - Vbz = Vp+ Va
  - Vbz = Rp · Pz + Ra · Az (Equation: 6-1)
    - Az = zone floor area (ft^2)
    - Pz = zone population: largest number of people expected to occupy the zone during typical usage. When Pz could not be predicted default occupant density listed in Table 6-1 ASHRAE 62.1 were used.

- Rp = outdoor airflow rate per person (CFM/person) (Values from Table 6-1)
- Ra = outdoor airflow rate per unit area (CFM/ft^2) (Values from Table 6-1)

- The outdoor airflow that must be provided to the zone by the supply air distribution is determined by equation 6-2
  - Voz = Vbz/Ez (Equation: 6-2)
    - Ez = zone air distribution effectiveness. In this study Ez was assumed to be 1.
  - When one air handler supplies a mixture of outdoor air and recirculating air to only one zone the outdoor air intake flow (Vot) = Voz (Equation: 6-3)
- For multiple-zone recirculating systems (Vot) is determined by the following equations:
  - Vot = Vou / Ev (Equation: 6-8)
  - Ev is found in ASHRAE Table 6-3 based on maximum Zp value or in ASHRAE appendix A.
  - Zp = Voz/Vpz (Equation: 6-5)
    - Zp = zone primary outdoor air fraction
    - Vpz = minimum expected primary airflow for design purposes
  - Vou = D · (Vbz) (Equation: 6-6)
    - D = diversity factor (assumed to be 100% in this study)

Appendix A contains spreadsheets comparing the design conditions to the minimum ventilation requirements calculated in this study to illustrate its compliance with ASHRAE Standard 62.1 section 6. Detailed calculations that follow the procedure listed above are located in Appendix B. A summary of results can be found below.

Results

AHU	Minimum OA supplyed by AHU	Minimum OA required	Complies With ASHRAE 62.1
A3	2640	6056	No
A2	7500	1620	Yes
M1	8300	13795	No
M2	8300	10633	No
R1	1120	884	Yes
R2	750	609	Yes
R3	1500	438	Yes
R4	2400	1470	Yes
R5	4500	870	Yes

Figure 2: Summary of Compliance

ASHRAE Standard 62.1 Summary

The Harley-Davidson Museum is in 100% compliance with Section 5 of ASHRAE Standard 62.1.

The Harley-Davidson Museum was not designed to comply with ASHRAE section 6. Because of the high people count the Museum owner wanted the buildings to be designed for and the low frequency of when maximum occupancy would actually be seen, the engineers at HGA used ventilation rates to only meet the ventilation code of 7.5 CFM/person. Critical zones where high occupancy is common (restaurant and retail) or zones where indoor air quality is vital (kitchen) far exceed the requirements specified by ASHRAE. The excess ventilation provides a high quality of indoor air; however, without heat recovery these systems use more energy than required to meet space loads. Museum gallery spaces utilize a VAV system and do not comply with the ASHRAE standard. The indoor air quality and occupant comfort levels of the areas that do not comply with the ASHRAE standard should still be adequate. The Museum will rarely meet the occupancy load used in the ASHRAE calculations and when the occupancy load is maximum it will be for a short duration.

ASHRAE Standard 90.12007
Section 5: building Envelope

Section 5.1.4 - Climate

The Harley-Davidson Museum is classified as nonresidential conditioned space located in Milwaukee, WI, corresponding to the cold-humid 6a climate zone determined by Figure/Table B-1 located in ASHRAE 90.1.

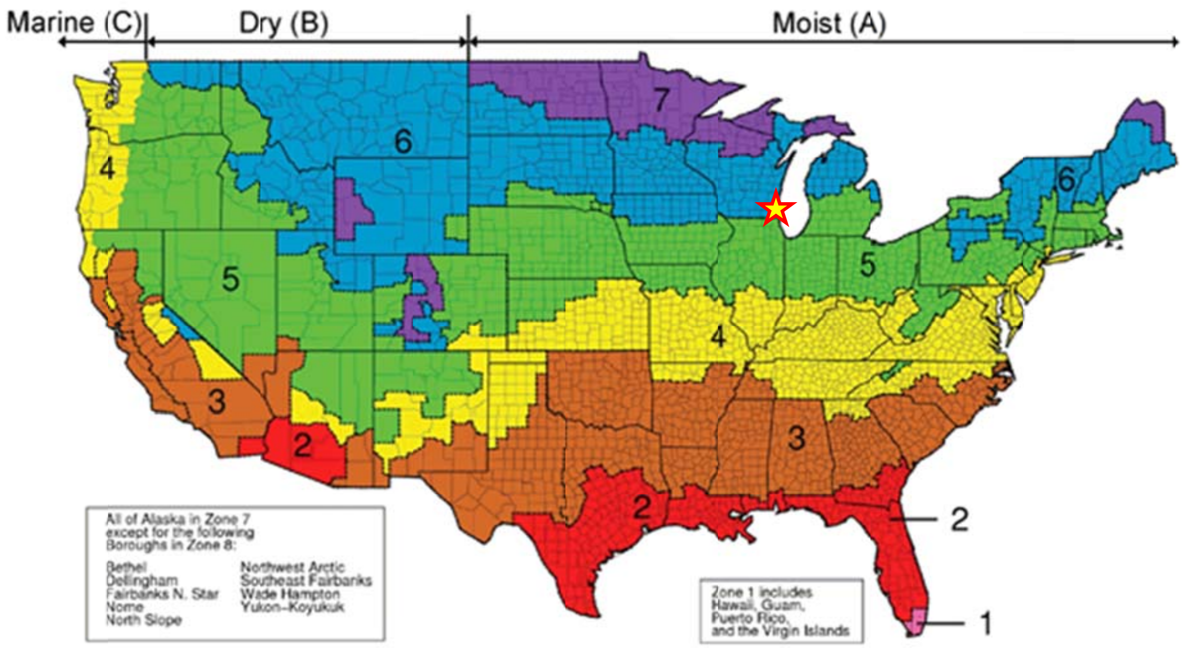


Figure B-1: Climate zones for the United States (ASHRAE)

Section 5.4 – Mandatory Provisions

The building envelope of the Harley-Davidson Museum is sealed, caulked, gasketed, or weather-stripped to minimize air leakage in all areas complying with ASHRAE 5.4.3.1. Building entrances that separate conditioned space from the exterior are protected with an enclosed vestibule equipped with self-closing doors separated no less than 7 feet.

Section 5.5 – Prescriptive Building Envelope

A building envelope comparison was conducted to examine if the design of the Harley-Davidson Museum complies with section 5.5 of ASHRAE 90.1. Worst case design values were compared to values specified in ASHRAE table 5.5-6. This study concluded that the walls of the Harley-Davidson Museum are not designed to comply with ASHRAE and allow more heat transfer than generally desired. Table-2 illustrates the results of this study.

A second comparison was conducted to examine the vertical fenestration area of the Harley-Davidson Museum to the standard set forth by ASHRAE. The study concludes that the Harley-Davidson Museum has a total vertical fenestration area of 33.5% and complies with the maximum of 40% set forth by ASHRAE. The low percent of vertical fenestration is due to the sensitivity of light in many of the gallery zones. The main gallery zone has automatic louvers that close with increase amount of sunlight. It is reported that the museum leaves the louvers closed at all times of the day; however, in this study worse case scenarios were assumed and the louvers were not analyzed in this section. Table-3 illustrates the results of this study.

Building Envelope Requirements For Climate Zone 6a							
Table 5.5-6 ASHRAE		Nonresidential ASHRAE		Nonresidential Design		ASHRAE Complient	
		Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value		
Opaque Elements	Construction	U-value C-value F-value	R-Value	U-value C-value F-value	R-Value	U-value C-value F-value	R-Value
Roof	Metal Building	0.065	19	0.0446	22.42152466	Yes	Yes
Walls, Above-Grade	Steel Fram	0.064	13	0.096	10.41666667	No	No
Walls, Below-Grade	Below-Grade	0.119	7.5	NA	NA	NA	NA
Floors	Mass	0.064	12.5	NA	NA	NA	NA
Slab-On-Grade Floor	Unheated	0.54	10	0.49	10.2	Yes	Yes
Opaque Doors	Swinging	0.7					
Fenestration		U-Value	SHGC	U-Value	SHGC	U-value	SHGC
Verticle Glazing	Metal Framing	0.45	0.3915	0.29	0.2697	Yes	Yes

Table 2: Building Envelope

Vertical Fenestration Area				
Total Building Window Area (sf)	Total Building Wall Area (sf)	Building Total Window %	ASHRAE Standard	ASHRAE Compliant
30602	91234	33.50%	40%	Yes

Table 3: Vertical Fenestration

Section 6: Heating, Ventilating, and Air Conditioning

Section 6.2 – Compliance Path(s)

ASHRAE 90.1 Section 6.2 defines two methods to evaluate the efficiency of the overall building mechanical system. The Simplified Approach method cannot be used for the Harley-Davidson Museum Building because it does not comply with section 6.3. The Mandatory Provision method is described in section 6.4

Section 6.4 – Mandatory Provisions

The Harley-Davidson Museum meets all minimum equipment efficiencies set forth in ASHRAE tables 6.8.1A through 6.8.1G. Condensing boilers and air cooled chiller compliances are illustrated in Table 4.

Compliance with Section 6.4.1.1 - ASHRAE Table 6.8.1						
Condensing Boilers						
Tag	Equipment type	Subcategory	Size Category (Btu/h)	Minimum Efficiency	Design Efficiency	ASHRAE Compliant
B-M1	Hot water	Gas-Fired	>300,000	75%	86%	Yes
B-M2	Hot water	Gas-Fired	>300,000	75%	86%	Yes
B-M3	Hot water	Gas-Fired	>300,000	75%	86%	Yes
B-M4	Hot water	Gas-Fired	>300,000	75%	86%	Yes
Air Cooled Chiller						
CH-M1	Condeser, electrically operated	All Capacities		2.80 COP	2.80 COP	Yes
CH-M2	Condeser, electrically operated	All Capacities		2.80 COP	2.80 COP	Yes

Table 4: Compliance with Section 6.4.1.1

The Control system consists of sensors, indicators, actuators, interface equipment, accessories, and software connected to controllers operating on a network and programmed to control mechanical systems. An operator workstation permits interface with the network via dynamic color graphics with each mechanical system, building floor plan, and control device depicted by point-and-click graphics. The operator workstation serves the following functions: Real-time graphical viewing and control of environment, scheduling and override of building operations, collection and analysis of historical data, alarm reporting, routing, messaging and acknowledgment, and program editing. The BAS Provides a calendar type format for simplification of time-of-day scheduling and overrides of building operations. Schedules reside in operator's PC workstation, DDC Controller, and HVAC Mechanical Equipment Controller to ensure time equipment scheduling when PC is off-line; PC is not required to execute time scheduling, complying with section 6.4.3.3.1 of ASHRAE 90.1.

Zones are individually controlled by thermostatic controls responding to temperature within the zone. Thermostatic controls have a dead band of 5 degrees complying with section 6.4.3.1.2. A DDC controller and room temperature sensor modulates vav box dampers and hot water reheat coil control valves in sequence to provide heating and cooling to satisfy space temperature set points.

All supply and return ducts and plenums installed as part of the HVAC air distribution system are stated in the specs to have duct liner of sufficient thickness to comply with energy code and ASHRAE/IESNA 90.1.

Section 6.5 – Prescriptive Path

All air handling units have an occupied mode and a non-occupied mode. The two air handling units serving the gallery spaces in the museum have an additional chilled water system economizer mode meeting the requirements set forth in sections 6.5.1.1 through 6.5.1.4.

Based on the Motor Nameplate Horsepower method of calculating fan system power limitations, there are 5 fan systems that exceed the allowable fan system motor nameplate hp set forth in Table 6.5.3.1.1A and illustrated in Table 5. Many of the fan powers are significantly lower than the established limit; therefore. the fans that exceed the limit by a minimal fraction will not put a noteworthy burden on the energy load of the building.

Fan Power Limitations - ASHRAE Table 6.5.3.1.1A				
Fan Tag	hp	CFM	Limit	ASHRAE Compliant
RF-A#	10.00	13860	20.79	Yes
RF-M1	20.00	36700	55.05	Yes
RF-M2	20.00	36700	55.05	Yes
SF-A1	15.00	9500	14.25	No
SF-A2	30.00	25200	37.8	yes
SF-A3	30.00	16500	24.75	No
SF-A7	7.50	3000	4.5	No
SF-M1	60.00	45000	67.5	Yes
SF-M2	60.00	45000	67.5	Yes
SF-R1	15.00	10400	15.6	Yes
SF-R2	7.50	3200	4.8	No
SF-R3	25.00	15000	22.5	No
SF-R4	15.00	11000	16.5	Yes
SF-R6	20.00	14200	21.3	Yes
RF-A1	7.50	34000	37.4	Yes
RF-R1	1.50	10400	11.44	Yes
RF-R2	2.00	14200	15.62	Yes
RF-R5	2.00	14200	15.62	Yes
EF-A1	1.00	1200	1.32	yes
EF-A2	0.17	300	0.33	Yes
EF-A3	0.75	5000	5.5	Yes
EF-M1	0.20	300	0.33	Yes
EF-M2	0.25	1700	1.87	Yes
EF-M3	1.50	7000	7.7	Yes
EF-R1	0.33	2200	2.42	Yes
EF-R2	0.75	1350	1.485	Yes
EF-R3	3.00	4800	5.28	Yes
EF-R4	3.00	5400	5.94	Yes
EF-R5	3.00	5400	5.94	Yes
EF-R6	1.50	3500	3.85	Yes

The Limit for Constant Volume Fans is CFM x 0.0011 and Variable Volume fans is CFM x 0.0015

Table 5: Fan Power

Section 6.7 – Submittals

The Harley-Davidson Museum building operation personnel received full construction documents and ample training for start-up, testing and operating the control systems and equipment. Operator instructions were provided with training and included the overall operational program, equipment functions, commands, system generation, advisories, and maintenance. Construction documents and manuals provide the building owner the location and performance data on each piece of equipment, general configurations of duct and pipe distribution system.

Section 7: Service Water Heating

Section 7.4 – Mandatory Provisions

All water heating equipment, hot-water supply boiler used solely for heating potable water, and hot-water storage tanks meet the criteria listed in ASHRAE Table 7.8 and are illustrated in Table 6 below. The Museum building and the Annex building each have dedicated domestic hot water systems. Each system consists of one high efficiency sealed combustion condensing natural gas fired domestic water heater with integral 50 gal. storage tanks. Hot water is maintained at 115 deg. F. and is recirculated. The retail building has a dedicated domestic hot water system consisting of two high efficiency sealed combustion condensing natural gas fired domestic water heated with integral 75 gal. storage tanks. Hot water is maintained at 140 deg. F and is blended with cold water to provide 115 deg. F. hot water where required. 180 deg. F. hot water for kitchen use is generated locally near the point of use.

Compliance with Section 7 - ASHRAE Table 7.8					
Gas Water Heater					
Tag	Equipment Type	Subcategory	Performance Required	Design Performance	ASHRAE Compliant
GWH-A1	Gas Storage	>75,000 BTU/h	80%	94%	Yes
GWH-M1	Gas Storage	>75,000 BTU/h	80%	94%	Yes
GWH-R1	Gas Storage	>75,000 BTU/h	80%	94%	Yes
GWH-R2	Gas Storage	>75,000 BTU/h	80%	94%	Yes

Table 6: Equipment Efficiency

Section 7.5 – Prescriptive Path

Service heating systems are exclusively used for potable water and are not used for additional functions such as space heating; therefore, this section does not apply.

Section 8: Power

The Harley-Davidson Museum wiring specification states - A voltage drop of 6% or higher is not acceptable. This does not comply with the maximum voltage drop of 2% for feeders and 3% for branch circuits set forth in ASHRAE standard 8.4.1.

Section 9: Lighting

Section 9.4 – Mandatory Provisions

Lighting in the Harley-Davidson Museum is controlled with automatic controlling devices to shut of building lighting in all space. Lights are on an "eight day" program – uniquely programed for each weekday and for holidays. Outdoor lights are connected to outdoor photoelectric switches with a monitoring range of 1.5 – 10 foot-candles. A direction lens is in front of the photocell to prevent fixed light sources from causing turn off and a time delay of 15 seconds is used to prevent false operation. Indoor spaces are equipped with occupancy sensors, which unless otherwise indicated turn lights on when its covered area is occupied and off when unoccupied. There is a time delay for turning lights off with adjusted range of 1 – 30 minutes. This design complies with ASHRAE 90.1 Section 9.4.1.1.

Section 9.5 – Building Area Method Compliance Path.

ASHRAE Table 9.5.1 specifies that museums should have a maximum of 1.1 LPD (W/ft^2). A study was completed and the results concluded that the Harley-Davidson Museum has a LPD of 1.06 complying with the ASHRAE Standard. A detailed breakdown is in Appendix C.

Section 10: Other Equipment

Section 10.4 – Mandatory Provisions

Minimum efficiencies for motors are defined by ASHRAE based on rated horsepower and motor speed. The Specifications for the Harley-Davidson Museum state that all motor efficiencies comply with NEMA MG1, thus the motors also comply with ASHRAE Table 10.8 since the values used in ASHRAE are in accordance with NEMA Standard MG1.

ASHRAE Standard 90.1 Summary

Standard 90.1 provides minimum requirements for the energy-efficient design of building and building system. The Standard specifies sensible design practices and technologies that minimize energy consumption without forgoing either the comfort or productivity of the occupants. By conducting a comprehensive comparison of the Harley-Davidson Museum to ASHRAE Standard 90.1 a detailed profile of energy efficiency can be examined.

The prescriptive performance evaluation method was used to determine compliance of ASHRAE Standard 90.1. As a whole the Harley-Davidson Museum did not comply with the standard 100%, but significantly exceeded the standard in some areas. There were several areas in the design that could lead to poor overall comfort for occupants, and excess usage of energy. The Harley-Davidson Museum was designed with great weight on the overall architectural aesthetic. Sacrifices in the HVAC system and building envelope were made in order to provide the building owner with an overall exceptional and attractive building.

The building envelope has a smaller R-value than desired by ASHRAE. A slight increase in wall thickness would allow for more insulation that could easily meet the ASRHAE Standard, although the significantly lower percent in fenestration area may compensate for the loss in R-value.

All of the equipment in the Harley-Davidson Museum is compliant with ASHRAE except for 5 fans that exceed the limit by a small fraction. This could be due the architectural limitations on ductwork size in some location in the building. A small adjustment in duct size could decrease pressure loss to a level that complies with ASHRAE.

Although the Museum has a copious amount of luminaires the LPD is below the limit set forth by ASHRAE. The lower LPD reflects the use of high efficiency advanced lighting such as LEDs and T5HO linear fluorescents.

A further evaluation of system performances will be conducted in Technical Report 2 and 3.

References:

ANSI/ASHRAE. (2007). Standard 62.1 – 2007, Ventilation for Acceptable Indoor Air Quality. Atlanta, GA: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.

ANSI/ASHRAE. (2007). Standard 90.1 – 2007, Energy Standard for Buildings Except Low-Rise Residential Buildings. Atlanta, GA: American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.

HGA, Inc. Construction Documents. HGA, Milwaukee, WI.

Project Team

- Owner: Harley-Davidson Motor Company, www.harley-davidson.com
- Construction Manager: M.A. Mortenson Company, www.mortenson.com
- Design Architect: Pentagram Architecture
- Architect of Record: Hammel, Green & Abrahamson, Inc.
- Structural and MEP Engineers: Hammel, Green & Abrahamson
- Environmental Services: The Sigma Group
- Landscape Architect: Oslund And Associates
- Civil Engineer: Graef Anhalt

APPENDIX A

Appendix A includes Ventilation Compliance tables for each air handler analyzed in this report. More detailed calculations are in Appendix B.

Harley-Davidson Museum Ventilation Compliance
AHU-3 General Areas

VAV	Room #	Room Name	Building	Area (sf)	Design Ventilation (CFM)	Minimum Ventilation OA (CFM) Vbz	% Outside Air to Ventilation.	Design - Min OA
VAVA106	A130a	Offices	Annex	1200	600	102	17.0	
VAVA107	A130b	Offices	Annex	1200	600	102	17.0	
VAVA104	A160	break Room	Annex	400	175	44	25.1	
VAVA103	A170	Security	Annex	150	90	12	13.3	
VAVA101	A175	Loading Dock	Annex	630	500	75	15.0	
VAVA207	A255	Reading Room	Annex	280	126	48	38.1	
VAVA208	A256	Conference	Annex	280	150	89	59.3	
VAVA201	A306	Visitors gallery	Annex	250	100	45	45.0	
VAVA205	A310	Restoration	Annex	2600	675	498	73.8	
VAVA203	A320 A322 A305	Photo Studio	Annex	1000	450	70	15.6	
VAVA202	A200	Visitors Gallery	Annex	500	70	67	95.7	
VAVA200	A215	Processing	Annex	1250	255	150	58.8	
VAVA204	A220 A205	Flec Space	Annex	1600	280	60	21.4	
VAVA206	A250	Offices	Annex	900	300	76	25.3	
VAVA209	A300	Bike Storage	Annex	5700	1300	684	52.6	
VAVA105	A180	Shop	Annex	960	300	225	75.0	
VAVA102	A181	Exhibit Prep	Annex	440	320	52	16.3	
VAVA100	A182	Storage	Annex	2200	300	264	88.0	
	Total			21540	6591	2663	40.4	3928
	System				2640	2663	100.9	-23
	System				2640	6056	229.4	-3416
The sum of all Ventilation to occupide zones			The Sum of all minimum outside are calculated			Minimum outside aire provided by AHU, including zones not on list (bathrooms / corridors)		Adjusted outdoor air intake required for system

ASHRAE 62.1 Appendix A

Vps: System Primary Airflow	Vou: Zone Outdoor Airflow	Xs: Average Outdoor Air Fraction	Evz:	Vot: Outdoor Air Intake
6591	2663	0.404035806	0.44	6056

Appendix A is used in the detailed spreadsheets and matches with this calculation. All other AHU's will use the Vot off of the detailed spreadsheets

Harley-Davidson Museum Ventilation Compliance
AHU-2 Tempprary Exhibit

VAV	Room #	Room Name	Building	Area	Design Ventilation (cfm)	Minimum Ventilation OA (cfm) Vbz	% Outside Air to Ventilation.	Design - Min OA
NA	A105c	Temp Exhibit	Annex	4500	7500	1620	21.6	
	Total			4500	7500	1620	21.6	5880
	System				7500	1620	21.6	5880
	System				7500	1620	21.6	5880
The sum of all ventilation to occupide zones			The Sum of all minimum outside air calculated			Minimum outside aire provided by AHU, including zones not on list (bathrooms / corridors)		Adjusted outdoor air intake

Harley-Davidson Museum Ventilation Compliance

AHU-M1 Museum

VAVM Tag	Room #	Room Name	Building	Area (sf)	Design Ventilation (CFM)	Minimum Ventilation OA (CFM) Vbz	% Outside Air to Ventilation.	Design - Min OA
111,113,114, 116, 117, 115, 112, 110, 104, 105	M170	First Floor Exhibit	Museum	9810	7540	3532	46.8	
109, 118, 108	M201	Theme Gallery	Museum	3000	1080	1080	100.0	
103	M145	Corridor	Museum	100	300	6	2.0	
107	M203	Gallery	Museum	1000	360	360	100.0	
100	M131	Corridor	Museum	410	85	24	28.2	
105	M005	Stair	Museum	410	780	24	3.1	
119, 202, 203, 201	M200	Exhibit	Museum	5040	2000	1814	90.7	
301	M335	Rent Space	Museum	470	480	103	21.5	
302	M345	Rent Space	Museum	300	330	93	28.2	
304	M325	Rent Space	Museum	1100	840	216	25.7	
								0
	Total			21640	13795	7252	52.6	6543
	System				8300	7252	87.4	1048
	System				8300	13795	166.2	-5495
The sum of all ventilation air to occupide zones			The Sum of all minimum outside are calculated			Minimum outside aire provided by AHU, including zones not on list (bathrooms / corridors)		Adjusted outdoor air intake required for system

Harley-Davidson Museum Ventilation Compliance

AHU-M2 Museum

VAVM Tag	Room #	Room Name	Building	Area (sf)	Design Ventilation (CFM)	Minimum Ventilation OA (CFM) Vbz	% Outside Air to Ventilation.	Design - Min OA
124, 125	M180	Lobby	Museum	3000	540	430	79.6	
121	M160	Office	Museum	100	30	11	36.7	
122	M165	Security	Museum	100	200	11	5.5	
120	M155	Ticketing	Museum	480	120	43	35.8	
123	M150	Coat Check	Museum	450	60	54	90.0	
127, 128, 129, 130, 133, 134, 135, 136,	M170	South Exhibit	Museum	8620	7590	3100	40.8	
204, 206, 207,208	M200	Exhibits	Museum	3240	1606	1166	72.6	
131, 132	M202	Exhibits	Museum	2500	960	900	93.8	
306	M315	Rent Space	Museum	460	390	103	26.4	
305	M320	Rent Space	Museum	470	480	103	21.5	
								0
	Total			19420	11976	5921	49.4	6055
	System				8300	5921	71.3	2379
	System				8300	10633	128.1	-2333
The sum of all ventilation air to occupide zones			The Sum of all minimum outside are calculated			Minimum outside aire provided by AHU, including zones not on list (bathrooms / corridors)		Adjusted outdoor air intake required for system

Harley-Davidson Museum Ventilation Compliance								
AHU-R1 Retail								
VAV	Room #	Room Name	Building	Area (sf)	Design Ventilation (CFM)	Minimum Ventilation OA (CFM) Vbz	% Outside Air to Ventilation.	Design - Min OA
NA	R165	Retail	Retail	3800	1120	884	78.9	236
	Total			3800	1120	884	78.9	236
	System				1120	884	78.9	236
	System				1120	884	78.9	236
The sum of all ventilation air to occupide zones				The Sum of all minimum outside are calculated		Minimum outside aire provided by AHU, including zones not on list (bathrooms / corridors)		Ajusted outdoor air intake required for system

Harley-Davidson Museum Ventilation Compliance								
AHU-R2 Café								
VAV	Room #	Room Name	Building	Area (sf)	Design Ventilation (CFM)	Minimum Ventilation OA (CFM) Vbz	% Outside Air to Ventilation.	Designed OA to Min OA
NA	R115	Café	Retail	1300	750	609	81.2	
	Total			1300	750	609	81.2	141
	System				750	609	81.2	141
	System				750	609	81.2	141
The sum of all ventilation air to occupide zones			The Sum of all minimum outside are calculated			Minimum outside aire provided by AHU, including zones not on list (bathrooms / corridors)		Adjusted outdoor air intake required for system

Harley-Davidson Museum Ventilation Compliance								
AHU-R3 Kitchen								
VAV	Room #	Room Name	Building	Area (sf)	Design Ventilation (CFM)	Minimum Ventilation OA (CFM) Vbz	% Outside Air to Ventilation.	Designed OA to Min OA
NA	R140	Kitchen	Retail	1700	1500	438	29.2	
	Total				1500	438	29.2	1062
	System				1500	438	29.2	1062
	System				1500	438	29.2	1062
The sum of all ventilation air to occupide zones			The Sum of all minimum outside are calculated			Minimum outside aire provided by AHU, including zones not on list (bathrooms / corridors)		Adjusted outdoor air intake required for system

Harley-Davidson Museum Ventilation Compliance								
AHU-R4 Restaurant								
VAV	Room #	Room Name	Building	Area (sf)	Design Ventilation (CFM)	Minimum Ventilation OA (CFM) Vbz	% Outside Air to Ventilation.	Design - Min OA
NA	R120	Restaurant	Retail	4000	2400	1470	61.25	
	Total			4000	2400	1470	61.25	930
	System				2400	1470	61.25	930
	System				2400	1470	61.25	930
The sum of all ventilation air to occupide zones			The Sum of all minimum outside are calculated			Minimum outside aire provided by AHU, including zones not on list (bathrooms / corridors)		Adjusted outdoor air intake required for system

	Harley-Davidson Museum Ventilation Compliance							
	AHU-R5 Special Event							
VAV	Room #	Room Name	Building	Area (sf)	Design Ventilation (CFM)	Minimum Ventilation OA (CFM) Vbz	% Outside Air to Ventilation.	Designed OA to Min OA
NA	R215	Special Event	Retail	6160	4500	870	19.3	
	Total			6160	4500	870		3630
	System				4500	870		3630
	System				4500	870		3630
The sum of all ventilation to occupide zones			The Sum of all minimum outside are calculated			Minimum outside aire provided by AHU, including zones not on list (bathrooms / corridors)		Adjusted outdoor air intake required for system

Appendix B

This appendix includes detailed calculations for AHU ventilation.

Building:	**Harley-Davidson Museum**
System Tag/Name:	**AHU-A2 Temp Exhibit**
Operating Condition Description:	
Units (select from pull-down list)	**IP**

	Name	Units		System	Potentially Critical Zones	
Inputs for System	**Name**	**Units**		**System**		
Floor area served by system	As	sf		4500		
Population of area served by system (including diversity)	Ps	P	100% diversity	180		
Design primary supply fan airflow rate	Vpsd	cfm		25,200		
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf		0.06		
OA req'd per person for system area (Weighted average)	Rps	cfm/p		7.5		
Inputs for Potentially Critical zones					**Potentially Critical Zones**	
Zone Name			*Zone title turns purple italic for critical zone(s)*		***Temp Echibit***	**new zone**
Zone Tag					**A105c**	**New zone ID**
Space type		Select from pull-down list			**Museums/galleries**	**Office space**
Floor Area of zone	Az	sf			4,500	0
Design population of zone	Pz	P	(default value listed; may be overridden)		180	0
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm			25,200	0
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?		Select from pull-down list or leave blank if N/A				
Local recirc. air % representative of ave system return air	Er					75%
Inputs for Operating Condition Analyzed						
Percent of total design airflow rate at conditioned analyzed	Ds	%		100%	100%	100%
Air distribution type at conditioned analyzed		Select from pull-down list			CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez				1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep				100%	
Results						
Ventilation System Efficiency	Ev			**1.00**		
Outdoor air intake required for system	Vot	cfm		**1620**		
Outdoor air per unit floor area	Vot/As	cfm/sf		**0.36**		
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p		**9.0**		
Outdoor air as a % of design primary supply air	Ypd	cfm		**6%**		

	Name	Units		Formula		System	Temp Echibit	new zone
Detailed Calculations								
Initial Calculations for the System as a whole								
Primary supply air flow to system at conditioned analyzed	Vps	cfm	=	VpdDs	=	25200		
UncorrectedOA requirement for system	Vou	cfm	=	Rps Ps + Ras As	=	1620		
Uncorrected OA req'd as a fraction of primary SA	Xs		=	Vou / Vps	=	0.06		
Initial Calculations for individual zones								
OA rate per unit area for zone	Raz	cfm/sf					0.06	0.06
OA rate per person	Rpz	cfm/p					7.50	5.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm					25200	0
Unused OA req'd to breathing zone	Vbz	cfm	=	Rpz Pz + Raz Az	=		1620.0	0.0
Unused OA requirement for zone	Voz	cfm	=	Vbz/Ez	=		1620	0
Fraction of zone supply not directly recirc. from zone	Fa		=	Ep + (1-Ep)Er	=		1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		=	Ep	=		1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		=	1-(1-Ez)(1-Ep)(1-Er)	=		1.00	1.00
Unused OA fraction required in supply air to zone	Zd		=	Voz / Vdz	=		0.06	0.00
Unused OA fraction required in primary air to zone	Zp		=	Voz / Vpz	=		0.06	0.00
System Ventilation Efficiency								
Zone Ventilation Efficiency (App A Method)	Evz		=	(Fa + FbXs - FcZ) / Fa	=		1.00	1.06
System Ventilation Efficiency (App A Method)	Ev		=	min (Evz)	=	**1.00**		
Ventilation System Efficiency (Table 6.3 Method)	Ev		=	Value from Table 6.3	=	1.09		
Minimum outdoor air intake airflow								
Outdoor Air Intake Flow required to System	Vot	cfm	=	Vou / Ev	=	**1620**		
OA intake req'd as a fraction of primary SA	Y		=	Vot / Vps	=	**0.06**		
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	=	Vou / Ev	=	1492	**127.89**	
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		=	Vot / Vps	=	0.06	**0.08**	
OA Temp at which Min OA provides all cooling								
OAT below which OA Intake flow is @ minimum		Deg F	=	{(Tp-dTsf)-(1-Y)*(Tr+dTrf	=	-192		

Building:	Harley-Davidson Museum
System Tag/Name:	AHU-A2 General Office
Operating Condition Description:	
Units (select from pull-down list)	IP

	Name	Units		System																		
Inputs for System	**Name**	**Units**		**System**																		
Floor area served by system	As	sf		20448																		
Population of area served by system (including diversity)	Ps	P	100% diversity	58																		
Design primary supply fan airflow rate	Vpsd	cfm		6,591																		
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf		0.11																		
OA req'd per person for system area (Weighted average)	Rps	cfm/p		6.0																		
Inputs for Potentially Critical zones					**Potentially Critical Zones**																	
Zone Name			*Zone title turns purple italic for critical zone(s)*		**Office**	**Office**	**Break Room**	**Security**	**Loading Dock**	**Reading Room**	**Conf Room**	**Visitors Gallery**	**Restoration**	**Photo**	**Storage**	**Processing**	***Gallery***	**Office**	**Bike Storage**	**Shop**	**Exhibit Prep**	**Staging**
Zone Tag					**VAVA106**	**VAVA107**	**VAVA104**	**VAVA103**	**VAVA101**	**VAVA207**	**VAVA208**	**VAVA201**	**VAVA205**	**VAVA203**	**VAVA204**	**VAVA200**	**VAVA202**	**VAVA206**	**VAVA209**	**VAVA105**	**VAVA102**	**VAVA100**
Space type			Select from pull-down list		**Office space**	**Office space**	**Break rooms**	**Office space**	**Shipping/receiving**	**Libraries**	**Conference/meeting**	**Lobbies**	**Wood/metal shop**	**Stages, studios**	**Storage rooms**	**Storage rooms**	**Museums/galleries**	**Office space**	**Storage rooms**	**Wood/metal shop**	**Storage rooms**	**Storage rooms**
Floor Area of zone	Az	sf			1,200	1200	400	150	630	280	288	250	2600	1000	500	1250	500	900	5700	960	440	2200
Design population of zone	Pz	P	(default value listed; may be overridden)		6	6	4	0.75	0	2.8	14.4	6	3	1	0	0	5	4.5	0	5	0	0
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm			600	600	175	90	500	126	150	100	675	450	280	255	70	300	1300	300	320	300
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?			Select from pull-down list or leave blank if N/A																			
Local recirc. air % representative of ave system return air	Er					75%	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%
Inputs for Operating Condition Analyzed																						
Percent of total design airflow rate at conditioned analyzed	Ds	%		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Air distribution type at conditioned analyzed			Select from pull-down list		CS	CS	CS	CS	CS	CS	CS	CS	CS	CS	CS	CS	CS	CS	CS	CS	CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez				1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep				100%																	
Results																						
Ventilation System Efficiency	Ev			**0.44**																		
Outdoor air intake required for system	Vot	cfm		**6056**																		
Outdoor air per unit floor area	Vot/As	cfm/sf		**0.30**																		
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p		**103.6**																		
Outdoor air as a % of design primary supply air	Ypd	cfm		**92%**																		
Detailed Calculations																						
Initial Calculations for the System as a whole																						
Primary supply air flow to system at conditioned analyzed	Vps	cfm	= VpdDs =	6591																		
UncorrectedOA requirement for system	Vou	cfm	= Rps Ps + Ras As =	2664																		
Uncorrected OA req'd as a fraction of primary SA	Xs		= Vou / Vps =	0.40																		
Initial Calculations for individual zones																						
OA rate per unit area for zone	Raz	cfm/sf			0.06	0.06	0.06	0.06	0.12	0.12	0.06	0.06	0.18	0.06	0.12	0.12	0.06	0.06	0.12	0.18	0.12	0.12
OA rate per person	Rpz	cfm/p			5.00	5.00	5.00	5.00	0.00	5.00	5.00	5.00	10.00	10.00	0.00	0.00	7.50	5.00	0.00	10.00	0.00	0.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm			600	600	175	90	500	126	150	100	675	450	280	255	70	300	1300	300	320	300
Unused OA req'd to breathing zone	Vbz	cfm	= Rpz Pz + Raz Az =		102.0	102.0	44.0	12.8	75.6	47.6	89.3	45.0	498.0	70.0	60.0	150.0	67.5	76.5	684.0	222.8	52.8	264.0
Unused OA requirement for zone	Voz	cfm	= Vbz/Ez =		102	102	44	13	76	48	89	45	498	70	60	150	68	77	684	223	53	264
Fraction of zone supply not directly recirc. from zone	Fa		= Ep + (1-Ep)Er =		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		= Ep =		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		= 1-(1-Ez)(1-Ep)(1-Er) =		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Unused OA fraction required in supply air to zone	Zd		= Voz / Vdz =		0.17	0.17	0.25	0.14	0.15	0.38	0.60	0.45	0.74	0.16	0.21	0.59	0.96	0.26	0.53	0.74	0.17	0.88
Unused OA fraction required in primary air to zone	Zp		= Voz / Vpz =		0.17	0.17	0.25	0.14	0.15	0.38	0.60	0.45	0.74	0.16	0.21	0.59	0.96	0.26	0.53	0.74	0.17	0.88
System Ventilation Efficiency																						
Zone Ventilation Efficiency (App A Method)	Evz		= (Fa + FbXs - FcZ) / Fa =		1.23	1.23	1.15	1.26	1.25	1.03	0.81	0.95	0.67	1.25	1.19	0.82	0.44	1.15	0.88	0.66	1.24	0.52
System Ventilation Efficiency (App A Method)	Ev		= min (Evz) =	**0.44**																		
Ventilation System Efficiency (Table 6.3 Method)	Ev		= Value from Table 6.3 =	n/a																		
Minimum outdoor air intake airflow																						
Outdoor Air Intake Flow required to System	Vot	cfm	= Vou / Ev =	**6056**																		
OA intake req'd as a fraction of primary SA	Y		= Vot / Vps =	**0.92**																		
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	= Vou / Ev =	n/a																		
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		= Vot / Vps =	n/a																		
OA Temp at which Min OA provides all cooling																						
OAT below which OA Intake flow is @ minimum		Deg F	= {(Tp-dTsf)-(1-Y)*(Tr+dTrf) =	53																		

Building:	Harley-Davidson Museum
System Tag/Name:	AHU-M1 Museum North
Operating Condition Description:	
Units (select from pull-down list)	IP

	Name	Units	Formula / Note	System	Exhibits	*Theme Gallery*	Corridor	*Gallery*	Corridor	Stair	Exhibits	Rent Space	Rent Space	Rent Space
Inputs for System	**Name**	**Units**		**System**										
Floor area served by system	As	sf		21640										
Population of area served by system (including diversity)	Ps	P	100% diversity	794										
Design primary supply fan airflow rate	Vpsd	cfm		13,795										
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf		0.06										
OA req'd per person for system area (Weighted average)	Rps	cfm/p		7.5										
Inputs for Potentially Critical zones					**Potentially Critical Zones**									
Zone Name			*Zone title turns purple italic for critical zone(s)*		Exhibits	*Theme Gallery*	Corridor	*Gallery*	Corridor	Stair	Exhibits	Rent Space	Rent Space	Rent Space
Zone Tag					M170	M201	M145	M203	M131	M005	M200	M335	M345	M325
Space type			Select from pull-down list		Museums/galleries	Museums/galleries	Corridors	Museums/galleries	Corridors	Corridors	Museums/galleries	Multi-use assembly	Multi-use assembly	Multi-use assembly
Floor Area of zone	Az	sf			9,810	3000	100	1000	410	410	5040	470	300	1100
Design population of zone	Pz	P	(default value listed; may be overridden)		392.4	120	0	40	0	0	201.6	10	10	20
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm			7,540	1080	300	360	85	780	2000	480	330	840
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?			Select from pull-down list or leave blank if N/A											
Local recirc. air % representative of ave system return air	Er					75%	75%	75%	75%	75%	75%	75%	75%	75%
Inputs for Operating Condition Analyzed														
Percent of total design airflow rate at conditioned analyzed	Ds	%		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Air distribution type at conditioned analyzed			Select from pull-down list		CS	CS	CS	CS	CS	CS	CS	CS	CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez				1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep				100%									
Results														
Ventilation System Efficiency	Ev			**0.53**										
Outdoor air intake required for system	Vot	cfm		**13795**										
Outdoor air per unit floor area	Vot/As	cfm/sf		**0.64**										
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p		**17.4**										
Outdoor air as a % of design primary supply air	Ypd	cfm		**100%**										
Detailed Calculations														
Initial Calculations for the System as a whole														
Primary supply air flow to system at conditioned analyzed	Vps	cfm	= VpdDs =	13795										
UncorrectedOA requirement for system	Vou	cfm	= Rps Ps + Ras As =	7253										
Uncorrected OA req'd as a fraction of primary SA	Xs		= Vou / Vps =	0.53										
Initial Calculations for individual zones														
OA rate per unit area for zone	Raz	cfm/sf			0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
OA rate per person	Rpz	cfm/p			7.50	7.50	0.00	7.50	0.00	0.00	7.50	7.50	7.50	7.50
Total supply air to zone (at condition being analyzed)	Vdz	cfm			7540	1080	300	360	85	780	2000	480	330	840
Unused OA req'd to breathing zone	Vbz	cfm	= Rpz Pz + Raz Az =		3531.6	1080.0	6.0	360.0	24.6	24.6	1814.4	103.2	93.0	216.0
Unused OA requirement for zone	Voz	cfm	= Vbz/Ez =		3532	1080	6	360	25	25	1814	103	93	216
Fraction of zone supply not directly recirc. from zone	Fa		= Ep + (1-Ep)Er =		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		= Ep =		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		= 1-(1-Ez)(1-Ep)(1-Er) =		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Unused OA fraction required in supply air to zone	Zd		= Voz / Vdz =		0.47	1.00	0.02	1.00	0.29	0.03	0.91	0.22	0.28	0.26
Unused OA fraction required in primary air to zone	Zp		= Voz / Vpz =		0.47	1.00	0.02	1.00	0.29	0.03	0.91	0.22	0.28	0.26
System Ventilation Efficiency														
Zone Ventilation Efficiency (App A Method)	Evz		= (Fa + FbXs - FcZ) / Fa =		1.06	0.53	1.51	0.53	1.24	1.49	0.62	1.31	1.24	1.27
System Ventilation Efficiency (App A Method)	Ev		= min (Evz) =	**0.53**										
Ventilation System Efficiency (Table 6.3 Method)	Ev		= Value from Table 6.3 =	n/a										
Minimum outdoor air intake airflow														
Outdoor Air Intake Flow required to System	Vot	cfm	= Vou / Ev =	**13795**										
OA intake req'd as a fraction of primary SA	Y		= Vot / Vps =	**1.00**										
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	= Vou / Ev =	n/a										
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		= Vot / Vps =	n/a										
OA Temp at which Min OA provides all cooling														
OAT below which OA Intake flow is @ minimum		Deg F	= {(Tp-dTsf)-(1-Y)*(Tr+dTrf =	55										

Building:	**Harley-Davidson Museum**														
System Tag/Name:	**AHU-M1 Museum**														
Operating Condition Description:															
Units (select from pull-down list)	**IP**														
Inputs for System	**Name**	**Units**			**System**										
Floor area served by system	As	sf			19420										
Population of area served by system (including diversity)	Ps	P	100% diversity		649										
Design primary supply fan airflow rate	Vpsd	cfm			11,976										
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf			0.06										
OA req'd per person for system area (Weighted average)	Rps	cfm/p			7.3										
Inputs for Potentially Critical zones						**Potentially Critical Zones**									
Zone Name		*Zone title turns purple italic for critical zone(s)*				**Lobby**	**Office**	**Security**	**Ticketing**	**Coat Check**	**Exhibits**	**Exhibits**	***Exhibits***	**Rent Space**	**Resnt Space**
Zone Tag						**M180**	**M160**	**M165**	**M155**	**M150**	**M170**	**M200**	**M202**	**M315**	**M320**
Space type		Select from pull-down list				**Lobbies**	**Office space**	**Office space**	**Office space**	**Storage rooms**	**Museums/galleries**	**Museums/galleries**	**Museums/galleries**	**Multi-use assembly**	**Multi-use assembly**
Floor Area of zone	Az	sf				3,000	100	100	480	450	8620	3240	2500	460	470
Design population of zone	Pz	P	(default value listed; may be overridden)			50	1	1	3	0	344.8	129.6	100	10	10
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm				540	30	200	120	60	7590	1606	960	390	480
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?		Select from pull-down list or leave blank if N/A													
Local recirc. air % representative of ave system return air	Er						75%	75%	75%	75%	75%	75%	75%	75%	75%
Inputs for Operating Condition Analyzed															
Percent of total design airflow rate at conditioned analyzed	Ds	%			100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Air distribution type at conditioned analyzed		Select from pull-down list				CS	CS	CS	CS	CS	CS	CS	CS	CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez					1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep					100%									
Results															
Ventilation System Efficiency	Ev				**0.56**										
Outdoor air intake required for system	Vot	cfm			**10633**										
Outdoor air per unit floor area	Vot/As	cfm/sf			**0.55**										
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p			**16.4**										
Outdoor air as a % of design primary supply air	Ypd	cfm			**89%**										
Detailed Calculations															
Initial Calculations for the System as a whole															
Primary supply air flow to system at conditioned analyzed	Vps	cfm	= VpdDs	=	11976										
UncorrectedOA requirement for system	Vou	cfm	= Rps Ps + Ras As	=	5925										
Uncorrected OA req'd as a fraction of primary SA	Xs		= Vou / Vps	=	0.49										
Initial Calculations for individual zones															
OA rate per unit area for zone	Raz	cfm/sf				0.06	0.06	0.06	0.06	0.12	0.06	0.06	0.06	0.06	0.06
OA rate per person	Rpz	cfm/p				5.00	5.00	5.00	5.00	0.00	7.50	7.50	7.50	7.50	7.50
Total supply air to zone (at condition being analyzed)	Vdz	cfm				540	30	200	120	60	7590	1606	960	390	480
Unused OA req'd to breathing zone	Vbz	cfm	= Rpz Pz + Raz Az	=		430.0	11.0	11.0	43.8	54.0	3103.2	1166.4	900.0	102.6	103.2
Unused OA requirement for zone	Voz	cfm	= Vbz/Ez	=		430	11	11	44	54	3103	1166	900	103	103
Fraction of zone supply not directly recirc. from zone	Fa		= Ep + (1-Ep)Er	=		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		= Ep	=		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		= 1-(1-Ez)(1-Ep)(1-Er)	=		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Unused OA fraction required in supply air to zone	Zd		= Voz / Vdz	=		0.80	0.37	0.06	0.37	0.90	0.41	0.73	0.94	0.26	0.22
Unused OA fraction required in primary air to zone	Zp		= Voz / Vpz	=		0.80	0.37	0.06	0.37	0.90	0.41	0.73	0.94	0.26	0.22
System Ventilation Efficiency															
Zone Ventilation Efficiency (App A Method)	Evz		= (Fa + FbXs - FcZ) / Fa	=		0.70	1.13	1.44	1.13	0.59	1.09	0.77	0.56	1.23	1.28
System Ventilation Efficiency (App A Method)	Ev		= min (Evz)	=	**0.56**										
Ventilation System Efficiency (Table 6.3 Method)	Ev		= Value from Table 6.3	=	n/a										
Minimum outdoor air intake airflow															
Outdoor Air Intake Flow required to System	Vot	cfm	= Vou / Ev	=	**10633**										
OA intake req'd as a fraction of primary SA	Y		= Vot / Vps	=	**0.89**										
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	= Vou / Ev	=	n/a										
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		= Vot / Vps	=	n/a										
OA Temp at which Min OA provides all cooling															
OAT below which OA Intake flow is @ minimum		Deg F	= {(Tp-dTsf)-(1-Y)*(Tr+dTrf	=	53										

Building:	**Harley-Davidson Museum**					
System Tag/Name:	**AHU-R1 Sales**					
Operating Condition Description:						
Units (select from pull-down list)	**IP**					

	Name	Units		System	Potentially Critical Zones	
Inputs for System	**Name**	**Units**		**System**		
Floor area served by system	As	sf		3800		
Population of area served by system (including diversity)	Ps	P	100% diversity	57		
Design primary supply fan airflow rate	Vpsd	cfm		1,120		
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf		0.12		
OA req'd per person for system area (Weighted average)	Rps	cfm/p		7.5		
Inputs for Potentially Critical zones					**Potentially Critical Zones**	
Zone Name			*Zone title turns purple italic for critical zone(s)*		***Retail***	**na**
Zone Tag					**R165**	**na**
Space type			Select from pull-down list		**Sales (except as below)**	**Break rooms**
Floor Area of zone	Az	sf			3,800	0
Design population of zone	Pz	P	(default value listed; may be overridden)		57	0
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm			1,120	0
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?			Select from pull-down list or leave blank if N/A			
Local recirc. air % representative of ave system return air	Er					75%
Inputs for Operating Condition Analyzed						
Percent of total design airflow rate at conditioned analyzed	Ds	%		100%	100%	100%
Air distribution type at conditioned analyzed			Select from pull-down list		CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez				1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep				100%	
Results						
Ventilation System Efficiency	Ev			**1.00**		
Outdoor air intake required for system	Vot	cfm		**884**		
Outdoor air per unit floor area	Vot/As	cfm/sf		**0.23**		
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p		**15.5**		
Outdoor air as a % of design primary supply air	Ypd	cfm		**79%**		

	Name	Units	Formula	System	Zone 1	Zone 2
Detailed Calculations						
Initial Calculations for the System as a whole						
Primary supply air flow to system at conditioned analyzed	Vps	cfm	= VpdDs =	1120		
UncorrectedOA requirement for system	Vou	cfm	= Rps Ps + Ras As =	884		
Uncorrected OA req'd as a fraction of primary SA	Xs		= Vou / Vps =	0.79		
Initial Calculations for individual zones						
OA rate per unit area for zone	Raz	cfm/sf			0.12	0.06
OA rate per person	Rpz	cfm/p			7.50	5.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm			1120	0
Unused OA req'd to breathing zone	Vbz	cfm	= Rpz Pz + Raz Az =		883.5	0.0
Unused OA requirement for zone	Voz	cfm	= Vbz/Ez =		884	0
Fraction of zone supply not directly recirc. from zone	Fa		= Ep + (1-Ep)Er =		1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		= Ep =		1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		= 1-(1-Ez)(1-Ep)(1-Er) =		1.00	1.00
Unused OA fraction required in supply air to zone	Zd		= Voz / Vdz =		0.79	0.00
Unused OA fraction required in primary air to zone	Zp		= Voz / Vpz =		0.79	0.00
System Ventilation Efficiency						
Zone Ventilation Efficiency (App A Method)	Evz		= (Fa + FbXs - FcZ) / Fa =		1.00	1.79
System Ventilation Efficiency (App A Method)	Ev		= min (Evz) =	**1.00**		
Ventilation System Efficiency (Table 6.3 Method)	Ev		= Value from Table 6.3 =	n/a		
Minimum outdoor air intake airflow						
Outdoor Air Intake Flow required to System	Vot	cfm	= Vou / Ev =	**884**		
OA intake req'd as a fraction of primary SA	Y		= Vot / Vps =	**0.79**		
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	= Vou / Ev =	n/a		
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		= Vot / Vps =	n/a		
OA Temp at which Min OA provides all cooling						
OAT below which OA Intake flow is @ minimum		Deg F	= {(Tp-dTsf)-(1-Y)*(Tr+dTrf =	50		

Building:	Harley-Davidson Museum					
System Tag/Name:	AHU-R2 Café					
Operating Condition Description:						
Units (select from pull-down list)	IP					

Inputs for System	**Name**	**Units**		**System**		
Floor area served by system	As	sf		1300		
Population of area served by system (including diversity)	Ps	P	100% diversity	50		
Design primary supply fan airflow rate	Vpsd	cfm		1,600		
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf		0.18		
OA req'd per person for system area (Weighted average)	Rps	cfm/p		7.5		
Inputs for Potentially Critical zones					**Potentially Critical Zones**	
Zone Name			*Zone title turns purple italic for critical zone(s)*		***Café***	**new zone**
Zone Tag					**R115**	**New zone ID**
Space type		Select from pull-down list			**Cafeteria/fast-food dining**	**Office space**
Floor Area of zone	Az	sf			1,300	0
Design population of zone	Pz	P	(default value listed; may be overridden)		50	0
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm			1,600	0
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?		Select from pull-down list or leave blank if N/A				
Local recirc. air % representative of ave system return air	Er					
Inputs for Operating Condition Analyzed						
Percent of total design airflow rate at conditioned analyzed	Ds	%		100%	100%	100%
Air distribution type at conditioned analyzed		Select from pull-down list			CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez				1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep					
Results						
Ventilation System Efficiency	Ev			**1.00**		
Outdoor air intake required for system	Vot	cfm		**609**		
Outdoor air per unit floor area	Vot/As	cfm/sf		**0.47**		
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p		**12.2**		
Outdoor air as a % of design primary supply air	Ypd	cfm		**38%**		

Detailed Calculations						
Initial Calculations for the System as a whole						
Primary supply air flow to system at conditioned analyzed	Vps	cfm	= VpdDs	= 1600		
UncorrectedOA requirement for system	Vou	cfm	= Rps Ps + Ras As	= 609		
Uncorrected OA req'd as a fraction of primary SA	Xs		= Vou / Vps	= 0.38		
Initial Calculations for individual zones						
OA rate per unit area for zone	Raz	cfm/sf			0.18	0.06
OA rate per person	Rpz	cfm/p			7.50	5.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm			1600	0
Unused OA req'd to breathing zone	Vbz	cfm	= Rpz Pz + Raz Az	=	609.0	0.0
Unused OA requirement for zone	Voz	cfm	= Vbz/Ez	=	609	0
Fraction of zone supply not directly recirc. from zone	Fa		= Ep + (1-Ep)Er	=	1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		= Ep	=	1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		= 1-(1-Ez)(1-Ep)(1-Er)	=	1.00	1.00
Unused OA fraction required in supply air to zone	Zd		= Voz / Vdz	=	0.38	0.00
Unused OA fraction required in primary air to zone	Zp		= Voz / Vpz	=	0.38	0.00
System Ventilation Efficiency						
Zone Ventilation Efficiency (App A Method)	Evz		= (Fa + FbXs - FcZ) / Fa	=	1.00	1.38
System Ventilation Efficiency (App A Method)	Ev		= min (Evz)	= **1.00**		
Ventilation System Efficiency (Table 6.3 Method)	Ev		= Value from Table 6.3	= 0.77		
Minimum outdoor air intake airflow						
Outdoor Air Intake Flow required to System	Vot	cfm	= Vou / Ev	= **609**		
OA intake req'd as a fraction of primary SA	Y		= Vot / Vps	= **0.38**		
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	= Vou / Ev	= 792		
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		= Vot / Vps	= 0.49		
OA Temp at which Min OA provides all cooling						
OAT below which OA Intake flow is @ minimum		Deg F	= {(Tp-dTsf)-(1-Y)*(Tr+dTrf	= 27		

Building:		**Harley-Davidson Museum**						
System Tag/Name:		**AHU-R3 kitchen**						
Operating Condition Description:								
Units (select from pull-down list)		**IP**						
Inputs for System	**Name**	**Units**				**System**		
Floor area served by system	As	sf				1600		
Population of area served by system (including diversity)	Ps	P	100% diversity			20		
Design primary supply fan airflow rate	Vpsd	cfm				1,500		
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf				0.18		
OA req'd per person for system area (Weighted average)	Rps	cfm/p				7.5		
Inputs for Potentially Critical zones							**Potentially Critical Zones**	
Zone Name	*Zone title turns purple italic for critical zone(s)*						***Kitchen***	**new zone**
Zone Tag							**R140**	**New zone ID**
Space type		Select from pull-down list					**Cafeteria/fast-food dining**	**Office space**
Floor Area of zone	Az	sf					1,600	0
Design population of zone	Pz	P	(default value listed; may be overridden)				20	0
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm					1,500	0
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?		Select from pull-down list or leave blank if N/A						
Local recirc. air % representative of ave system return air	Er							
Inputs for Operating Condition Analyzed								
Percent of total design airflow rate at conditioned analyzed	Ds	%				100%	100%	100%
Air distribution type at conditioned analyzed		Select from pull-down list					CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez						1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep							
Results								
Ventilation System Efficiency	Ev					**1.00**		
Outdoor air intake required for system	Vot	cfm				**438**		
Outdoor air per unit floor area	Vot/As	cfm/sf				**0.27**		
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p				**21.9**		
Outdoor air as a % of design primary supply air	Ypd	cfm				**29%**		
Detailed Calculations								
Initial Calculations for the System as a whole								
Primary supply air flow to system at conditioned analyzed	Vps	cfm	=	VpdDs	=	1500		
UncorrectedOA requirement for system	Vou	cfm	=	Rps Ps + Ras As	=	438		
Uncorrected OA req'd as a fraction of primary SA	Xs		=	Vou / Vps	=	0.29		
Initial Calculations for individual zones								
OA rate per unit area for zone	Raz	cfm/sf					0.18	0.06
OA rate per person	Rpz	cfm/p					7.50	5.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm					1500	0
Unused OA req'd to breathing zone	Vbz	cfm	=	Rpz Pz + Raz Az	=		438.0	0.0
Unused OA requirement for zone	Voz	cfm	=	Vbz/Ez	=		438	0
Fraction of zone supply not directly recirc. from zone	Fa		=	Ep + (1-Ep)Er	=		1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		=	Ep	=		1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		=	1-(1-Ez)(1-Ep)(1-Er)	=		1.00	1.00
Unused OA fraction required in supply air to zone	Zd		=	Voz / Vdz	=		0.29	0.00
Unused OA fraction required in primary air to zone	Zp		=	Voz / Vpz	=		0.29	0.00
System Ventilation Efficiency								
Zone Ventilation Efficiency (App A Method)	Evz		=	(Fa + FbXs - FcZ) / Fa	=		1.00	1.29
System Ventilation Efficiency (App A Method)	Ev		=	min (Evz)	=	**1.00**		
Ventilation System Efficiency (Table 6.3 Method)	Ev		=	Value from Table 6.3	=	0.86		
Minimum outdoor air intake airflow								
Outdoor Air Intake Flow required to System	Vot	cfm	=	Vou / Ev	=	**438**		
OA intake req'd as a fraction of primary SA	Y		=	Vot / Vps	=	**0.29**		
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	=	Vou / Ev	=	510		
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		=	Vot / Vps	=	0.34		
OA Temp at which Min OA provides all cooling								
OAT below which OA Intake flow is @ minimum		Deg F	=	{(Tp-dTsf)-(1-Y)*(Tr+dTrf	=	14		

Building:	**Harley-Davidson Museum**	
System Tag/Name:	**AHU-R4 Restaurant**	
Operating Condition Description:		
Units (select from pull-down list)	**IP**	

Inputs for System	**Name**	**Units**		**System**		
Floor area served by system	As	sf		4000		
Population of area served by system (including diversity)	Ps	P	100% diversity	100		
Design primary supply fan airflow rate	Vpsd	cfm		5,000		
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf		0.18		
OA req'd per person for system area (Weighted average)	Rps	cfm/p		7.5		
Inputs for Potentially Critical zones					**Potentially Critical Zones**	
Zone Name			*Zone title turns purple italic for critical zone(s)*		***Restaurant***	**new zone**
Zone Tag					**R120**	**New zone ID**
Space type		Select from pull-down list			**Cafeteria/fast-food dining**	**Office space**
Floor Area of zone	Az	sf			4,000	0
Design population of zone	Pz	P	(default value listed; may be overridden)		100	0
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm			5,000	0
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?		Select from pull-down list or leave blank if N/A				
Local recirc. air % representative of ave system return air	Er					
Inputs for Operating Condition Analyzed						
Percent of total design airflow rate at conditioned analyzed	Ds	%		100%	100%	100%
Air distribution type at conditioned analyzed		Select from pull-down list			CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez				1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep					
Results						
Ventilation System Efficiency	Ev			**1.00**		
Outdoor air intake required for system	Vot	cfm		**1470**		
Outdoor air per unit floor area	Vot/As	cfm/sf		**0.37**		
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p		**14.7**		
Outdoor air as a % of design primary supply air	Ypd	cfm		**29%**		

Detailed Calculations								
Initial Calculations for the System as a whole								
Primary supply air flow to system at conditioned analyzed	Vps	cfm	=	VpdDs	=	5000		
UncorrectedOA requirement for system	Vou	cfm	=	Rps Ps + Ras As	=	1470		
Uncorrected OA req'd as a fraction of primary SA	Xs		=	Vou / Vps	=	0.29		
Initial Calculations for individual zones								
OA rate per unit area for zone	Raz	cfm/sf					0.18	0.06
OA rate per person	Rpz	cfm/p					7.50	5.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm					5000	0
Unused OA req'd to breathing zone	Vbz	cfm	=	Rpz Pz + Raz Az	=		1470.0	0.0
Unused OA requirement for zone	Voz	cfm	=	Vbz/Ez	=		1470	0
Fraction of zone supply not directly recirc. from zone	Fa		=	Ep + (1-Ep)Er	=		1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		=	Ep	=		1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		=	1-(1-Ez)(1-Ep)(1-Er)	=		1.00	1.00
Unused OA fraction required in supply air to zone	Zd		=	Voz / Vdz	=		0.29	0.00
Unused OA fraction required in primary air to zone	Zp		=	Voz / Vpz	=		0.29	0.00
System Ventilation Efficiency								
Zone Ventilation Efficiency (App A Method)	Evz		=	(Fa + FbXs - FcZ) / Fa	=		1.00	1.29
System Ventilation Efficiency (App A Method)	Ev		=	min (Evz)	=	**1.00**		
Ventilation System Efficiency (Table 6.3 Method)	Ev		=	Value from Table 6.3	=	0.86		
Minimum outdoor air intake airflow								
Outdoor Air Intake Flow required to System	Vot	cfm	=	Vou / Ev	=	**1470**		
OA intake req'd as a fraction of primary SA	Y		=	Vot / Vps	=	**0.29**		
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	=	Vou / Ev	=	1717		
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		=	Vot / Vps	=	0.34		
OA Temp at which Min OA provides all cooling								
OAT below which OA Intake flow is @ minimum		Deg F	=	{(Tp-dTsf)-(1-Y)*(Tr+dTrf	=	14		

Building:	**Harley-Davidson Museum**
System Tag/Name:	**AHU-R5 Special Event**
Operating Condition Description:	
Units (select from pull-down list)	**IP**

Inputs for System	**Name**	**Units**		**System**		
Floor area served by system	As	sf		6160		
Population of area served by system (including diversity)	Ps	P	100% diversity	100		
Design primary supply fan airflow rate	Vpsd	cfm		7,100		
OA req'd per unit area for system (Weighted average)	Ras	cfm/sf		0.06		
OA req'd per person for system area (Weighted average)	Rps	cfm/p		5.0		
Inputs for Potentially Critical zones					**Potentially Critical Zones**	
Zone Name			*Zone title turns purple italic for critical zone(s)*		***Special Event***	**new zone**
Zone Tag					**R215**	**New zone ID**
Space type			Select from pull-down list		**Multipurpose assembly**	**Office space**
Floor Area of zone	Az	sf			6,160	0
Design population of zone	Pz	P	(default value listed; may be overridden)		100	0
Design total supply to zone (primary plus local recirculated)	Vdzd	cfm			7,100	0
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?			Select from pull-down list or leave blank if N/A			
Local recirc. air % representative of ave system return air	Er					
Inputs for Operating Condition Analyzed						
Percent of total design airflow rate at conditioned analyzed	Ds	%		100%	100%	100%
Air distribution type at conditioned analyzed			Select from pull-down list		CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez				1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep					
Results						
Ventilation System Efficiency	Ev			**1.00**		
Outdoor air intake required for system	Vot	cfm		**870**		
Outdoor air per unit floor area	Vot/As	cfm/sf		**0.14**		
Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p		**8.7**		
Outdoor air as a % of design primary supply air	Ypd	cfm		**12%**		

Detailed Calculations							
Initial Calculations for the System as a whole							
Primary supply air flow to system at conditioned analyzed	Vps	cfm	= VpdDs	=	7100		
UncorrectedOA requirement for system	Vou	cfm	= Rps Ps + Ras As	=	870		
Uncorrected OA req'd as a fraction of primary SA	Xs		= Vou / Vps	=	0.12		
Initial Calculations for individual zones							
OA rate per unit area for zone	Raz	cfm/sf				0.06	0.06
OA rate per person	Rpz	cfm/p				5.00	5.00
Total supply air to zone (at condition being analyzed)	Vdz	cfm				7100	0
Unused OA req'd to breathing zone	Vbz	cfm	= Rpz Pz + Raz Az	=		869.6	0.0
Unused OA requirement for zone	Voz	cfm	= Vbz/Ez	=		870	0
Fraction of zone supply not directly recirc. from zone	Fa		= Ep + (1-Ep)Er	=		1.00	1.00
Fraction of zone supply from fully mixed primary air	Fb		= Ep	=		1.00	1.00
Fraction of zone OA not directly recirc. from zone	Fc		= 1-(1-Ez)(1-Ep)(1-Er)	=		1.00	1.00
Unused OA fraction required in supply air to zone	Zd		= Voz / Vdz	=		0.12	0.00
Unused OA fraction required in primary air to zone	Zp		= Voz / Vpz	=		0.12	0.00
System Ventilation Efficiency							
Zone Ventilation Efficiency (App A Method)	Evz		= (Fa + FbXs - FcZ) / Fa	=		1.00	1.12
System Ventilation Efficiency (App A Method)	Ev		= min (Evz)	=	**1.00**		
Ventilation System Efficiency (Table 6.3 Method)	Ev		= Value from Table 6.3	=	1.03		
Minimum outdoor air intake airflow							
Outdoor Air Intake Flow required to System	Vot	cfm	= Vou / Ev	=	**870**		
OA intake req'd as a fraction of primary SA	Y		= Vot / Vps	=	**0.12**		
Outdoor Air Intake Flow required to System (Table 6.3 Method)	Vot	cfm	= Vou / Ev	=	846	**23.29**	
OA intake req'd as a fraction of primary SA (Table 6.3 Method)	Y		= Vot / Vps	=	0.12	**0.03**	
OA Temp at which Min OA provides all cooling							
OAT below which OA Intake flow is @ minimum		Deg F	= {(Tp-dTsf)-(1-Y)*(Tr+dTrf	=	-67		

APPENDIX C

Lighting Power Densities																
Type	Watt	Qty.	Total Watts	Type	Watt	Qty.	Total Watts	Type	Watt	Qty.	Total Watts	Type	Watt	Qty.	Total Watts	
AF3	67	14	938	EM2	2		0	JF25	240	2	480	T4	100	12	1200	
AF4	198	8	1584	EM3	2	2	4	JF26	120	5	600	T5	100	11	1100	
AF5	29		0	EM4	2		0	JF27	35	8	280	T6	100	23	2300	
AF6	198	1	198	EM5	2		0	LF1			0	TF1	80		0	
AG1	150	24	3600	EY1			0	LF2	90	2	180	TG1	100		0	
AG2	100	18	1800	FG1	250	10	2500	LF3	46	44	2024	WH1	475	21	9975	
AG3	100	8	800	FG2	75		0	LF4	70	5	350	WH2			0	
BF1	17	2	34	FH1	44		0	LF5	31		0	WH3	290	27	7830	
CF1	61	126	7686	FH2	44	12	528	LF6	91		0	WH4	130		0	
CF2	61	25	1525	FM1			0	LF7			0	WH5	475	16	7600	
CF3	140	8	1120	JF1	70	284	19880	LF8	132		0	WH6	215	15	3225	
CF4	61	60	3660	JF2	92	4	368	LF9	90		0	WH7	215		0	
CF5			0	JF3	31	55	1705	MF1			0	WH8	215	4	860	
CF6	61	36	2196	JF4	60	27	1620	MF2	23		0	YF1	33	4	132	
CF7	31		0	JF5	240	4	960	MF3			0	YF2	31		0	
CF8			0	JF6	35	23	805	MF4	19	56	1064	YF3	44	16	704	
CF9	46	12	552	JF7	140	17	2380	MF5	198	6	1188	YF4	33	13	429	
CF10	16		0	JF8	52	16	832	MG1			0	YF5	17	36	612	
CF11	31		0	JF9	52		0	MG2			0	YF6	290		0	
CF12	70		0	JF10	244	33	8052	MG3			0	YF7			0	
CF13	31		0	JF11	63	13	819	MG4	100	3	300	YF8			0	
CF14	16		0	JF12			0	MG5	100		0	YF9	17	4	68	
CF15	42		0	JF13			0	MH1			0	YF10	33	11	363	
CF16	31		0	JF14			0	MH2	167	11	1837	YF11	33		0	
DF1	33	43	1419	JF15	105	5	525	MH3	44	1	44	YF12	33	1	33	
DF2	28	23	644	JF16	120	3	360	MM1			0	YF13	33		0	
DF3			0	JF17	31	35	1085	MM2	2/ft			YF14	44	55	2420	
DF4	33	24	792	JF18	244	33	8052	MM3	81	83	6723	YF15	190	6	1140	
DG1	75	51	3825	JF19	120	17	2040	MM4	8/ft			YG1	50	33	1650	
DG2	100	70	7000	JF20	244	2	488	MM5			0	YG2			0	
DG3	150	10	1500	JF21	120	9	1080	MM6			0	YH1	24	22	528	
DG4	50		0	JF22	120	2	240	T1	100	5	500	YH2	44	40	1760	
DH1	44		0	JF23	92		0	T2	100		0	YH3	44	52	2288	
EM1	2	31	62	JF24	35	7	245	T3	100		0	YH4	44		0	
			40935				54568				15570	YH5	44	12	528	
												YH6	90	6	540	
												YH7			0	
												YH8	90	14	1260	LPD
															48545	1.06412
														Total Watts =	159618	