Luxury Mixed Use Hotel

Southeast U.S.

Thesis – Assignment 2

Ventilation & Thermal Comfort

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Executive Summary

The following report evaluates compliance of the luxury mixed-use hotel with standards for indoor air quality and thermal comfort. ASHRAE Standards 62.1 and 55 from 2013 were used to check compliance. This project was designed to ASHRAE Standard 62.1 2010, but for the purposes of this project, it was checked against 2013. Standard 55 was not used during the design of the project, but the report details how it would comply with the thermal comfort guidelines.

Section 5 and 6 of ASHRAE 62.1 were reviewed specifically for compliance. Section 5 contains guidelines for ventilation systems and equipment, considering aspects like adjustable airflows, controls, access for maintenance, capture of contaminants, and separation distances for air intakes. Overall, the design complies with Section 5 except for the separation distances between the air intakes and kitchen exhaust fans found on one of the roofs. The main goals of Section 5 are to maintain good air quality by keeping the air and the distribution system clean.

Section 6 of Standard 62.1 is for the ventilation rate procedure. It outlines through different charts and equations how to calculate the minimum airflow for a space. The airflow is dependent on the people, area and occupancy category of a space. For the hotel, some of the main occupancy spaces are bedrooms, lobbies, and restaurants. There are different equations for different types of ventilation systems, so this project had many calculations for all the zones. 100% outdoor air systems have a different equation than the one used for multiple-zone recirculating systems. In Standard 6, minimum exhaust rates are also specified based on the occupancy category. The main areas that need exhaust in this project are bathrooms, laundry, and kitchens. For private guestroom toilets, exhaust fans were selected that exhaust 50 CFM when turned on. The exhaust fans are connected through vertical shafts to exhaust fans on the roof of the tower levels. This project has carefully documented exhaust and ventilation rates in the design drawings.

ASHRAE Standard 55 focuses on thermal comfort of the occupants. The goal of the standard is to ensure that at least 80% of the people in the space are satisfied with the environment, based on factors such as temperature, thermal radiation, humidity, air speed, clothing and activity. This hotel was not designed to this standard because thermal comfort is subjective and difficult to measure. Too many factors that are not under the control of the designer are involved. This report goes through Section 5 of the standard, Conditions that Provide Thermal Comfort, and addresses whether the current design meets those conditions. There will be a great variety of activities and clothing levels in the mixed-use hotel, but it is possible to make most of the people thermally comfortable. This is especially true since the guestrooms have thermostats to adjust their own temperature. A thermal comfort chart was created to show that the design conditions met ASHRAE Standard 55 for a range of clothing insulation values from 0.5 to 1.0 clo.

Building Summary

This project is a 516-room mixed-used hotel located in the Southeast U.S. There will be amenities such as ballrooms, meeting rooms, a spa, fitness center, and restaurants. The bottom three levels host most of the amenities and the tower levels have the guestrooms. It has a very modern design with a large portion of glass as the building enclosure. With 350,000 square feet of lodging area; 180,000 square feet of public area; and 43,000 square feet of back of house area, it is about 575,000 total square feet.

Mechanical Overview

Since the hotel is such a large building with many different occupancy types, it has a large mechanical system with many different components. Overall, it is a chilled water system with two chillers and two cooling towers. There are no boilers because the heating season is so short; all heat needed is produced by electric resistive heat. There is a central energy plant located in the parking garage with the main refrigeration equipment. Each chiller has a dedicated condenser pump to send water to the cooling towers, and there is a bypass for water that is at a temperature too low to go through the cooling tower. Another energy recovery method on the condenser water side is a heat exchanger that removes heat from the condenser water to pre-heat the domestic water. The chilled water loop supplies the terminals units with chilled water to cool the air. There is a pressure de-couple heat exchanger to separate the pressures between the podium levels and the guestroom tower levels.

Guestrooms have fan coil units to control the space temperature. They are two-pipe fan coils because there is just chilled water. To ventilate the guestroom and corridor spaces, there are dedicated outdoor air units (DOAS) with hot gas reheat. There are six DOAS units on the roof. Serving the public spaces are air handling units. Some are constant volume and some are variable. The air handling units serving the ballroom have a desiccant wheel to help handle the high latent load. There are 30 air handling units without the desiccant wheel and 11 with one.

Exhaust is needed for bathrooms, elevator lobbies, laundry, and housekeeping. The guestroom exhaust ducts have vertical distribution through vertical shafts in the hallway. These shafts also house the supply ducts for the outside air. Vertical distribution helps reduce overall ductwork and save space in the ceiling cavity. There are fire and smoke dampers where necessary to maintain the appropriate fire rating.

There is a building automation system (BAS) to help monitor space conditions and identify if any adjustments need to be made to the mechanical equipment. Different sequences of operation control which pieces of equipment are on at what time. There are a few energy saving sequences utilized in the building such as the cold bypass on the condenser water loop, condenser water reset temperature, and chiller evaporator overflow. Different sensors throughout the mechanical system report back to the BAS to begin these sequences. Having the building automation system helps save energy and keep the hotel maintained well.

ASHRAE Standard 62.1- Section 5: Systems and Equipment

5.1 Ventilation Air Distribution

Section 5.1 requires that ventilation systems can be controlled to the minimum ventilation rate prescribed by ASHRAE 62.1. It also requires that the design documents provide proof of the assumptions made for calculating ventilation rates and air distribution.

This luxury mixed use hotel complies with Section 5.1. All ventilation systems have methods to control the airflow so that there is always the minimum airflow per ASHRAE 62.1. For the dedicated outside air systems (DOAS) that serve the guestrooms and corridors, there are motorized dampers to control the amount of air entering the unit. The units also include a fan with a variable frequency drive to control the airflow as seen in *Figure 1*. Differential pressure sensors on both sides of the fan control the speed. While the zones are occupied, the airflow will meet the ASHRAE standards at a minimum for the DOAS units. Air handling units that serve public spaces have motorized controlled dampers at the unit's return plenum. Those dampers can close until the minimum airflow requirements are met based on the pressure and temperature sensor readings. Lobbies, restaurants, and other miscellaneous areas have variable volume air handlers that are equipped with variable frequency drive control. The variable frequency drive is controlled by temperature and differential pressure sensors to modulate the amount of air being sent through the unit. There are also motorized dampers. For guestrooms, the fan coil units control ventilation air with occupancy sensors.

Ventilation systems have ducted connection of the ventilation air, so the system is in compliance with the plenum systems section. The ventilation rates are calculated and documented in the design documents and meet the ASHRAE 62.1 requirements and the hotel standards (which are more strict than ASHRAE 62.1).

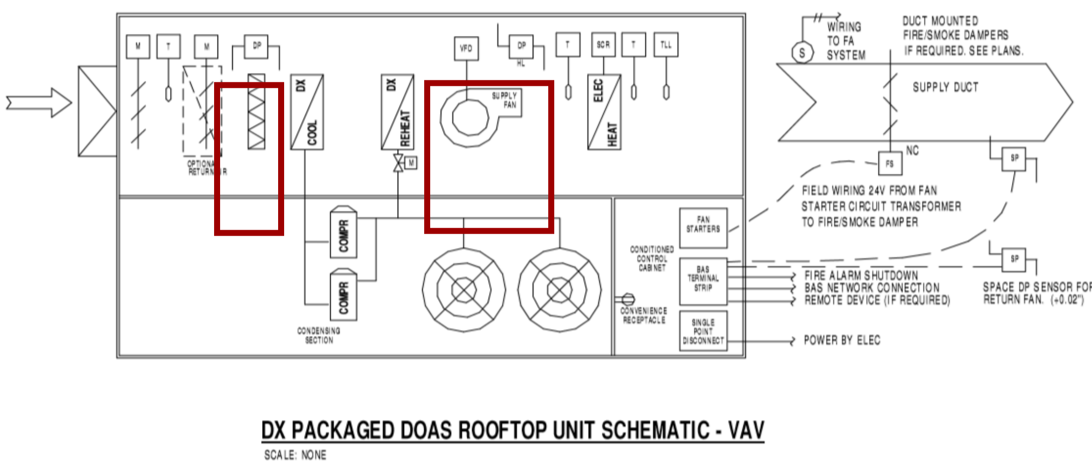

Figure 1: Control schematic of a DOAS Rooftop Unit showing the differential pressure sensors controlling the variable frequency drive on the fan.

5.2 Exhaust Duct Location

Exhaust ducts are negatively pressurized to ensure that contaminants do not leak out into occupied spaces. All exhaust ductwork is connected to exhaust fans at the roof to maintain the negative pressure. The ductwork is also constructed in accordance with SMACNA standards to prevent leakage. Any joint will be sealed tightly and a representative portion of ductwork will be pressure tested.

5.3 Ventilation System Controls

As discussed in Section 5.1, the mechanical ventilation systems have controls to maintain no less than the outdoor air intake flow mandated by Section 6. All ventilation systems have automatic controls that are regulated by differential pressure and temperature sensors. VAV systems have modulating air dampers that will keep no less than the prescribed outdoor air levels.

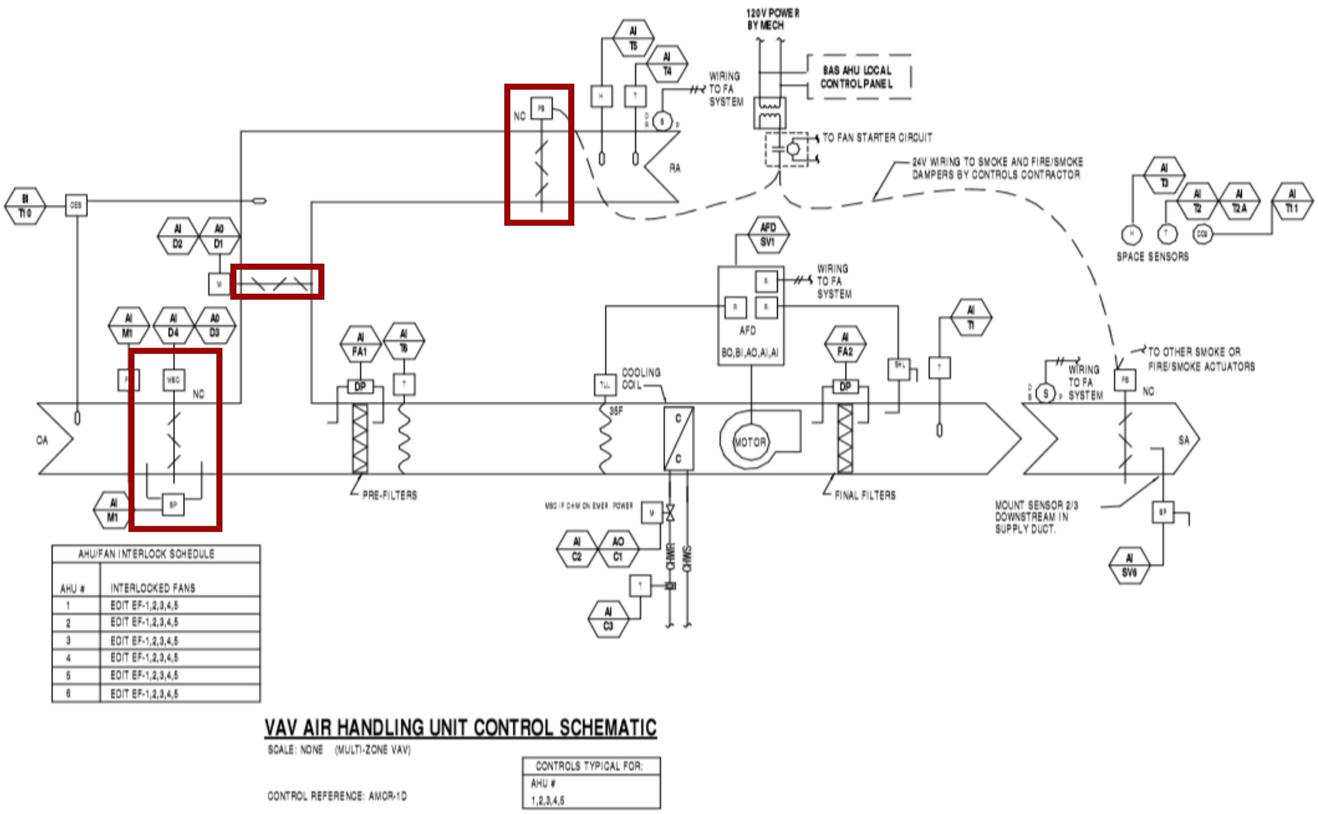

Figure 2: A control schematic of a variable air volume air handling unit highlighting the motorized dampers to control airflow.

5.4 Airstream Surfaces

All airstream surfaces in HVAC equipment or ductwork must resist mold growth and erosion. Galvanized sheet metal will be used for supply, return, ventilation air, toilet and other exhaust systems, which complies with this section. Flexible ductwork will be insulated UL-181 Class 1 air ducts.

5.5 Outdoor Air Intakes

All air intakes will be provided with screens to protect from birds and debris. To protect from rain, rooftop units are specified to include a factory rain hood or AMCA louver at the inlet and relief air sections. Since the project is located in the Southeast U.S., the climate does not dictate snow entrainment.

Every air intake has to meet the minimum separation distance requirements set by Table 5.5.1 located in the Appendix (Table A-1). The main concerns are the separations from the different class exhaust and relief air since there are many intakes and outlets on the roof near each other. Commercial kitchen grease hoods deliver air that is Class 4. Any intake must be at least 30 feet from the outlet. Exhaust from bathrooms is considered Class 2 air, so it must be 10 feet away from any inlet. After checking some exhaust fan locations, it was apparent that at this point in design, not all separation distances are compliant. The 10 feet separation between the bathroom exhaust fans and the inlets of the DOAS units for the guestrooms are compliant; however, not all of the kitchen exhaust fans are thirty feet away from the inlets of air handlers. *Figure 3* below shows the measurements between the exhaust fans to the inlets of the air handling units. Exhaust Fan 3.22 is a kitchen exhaust fan that falls about 10 feet short of the minimum separation distance. Kitchen exhaust fan 3.21 also falls about four feet short of the required 30 feet of separation. Fortunately, this has yet to be constructed, so changes can be made to make this layout compliant.

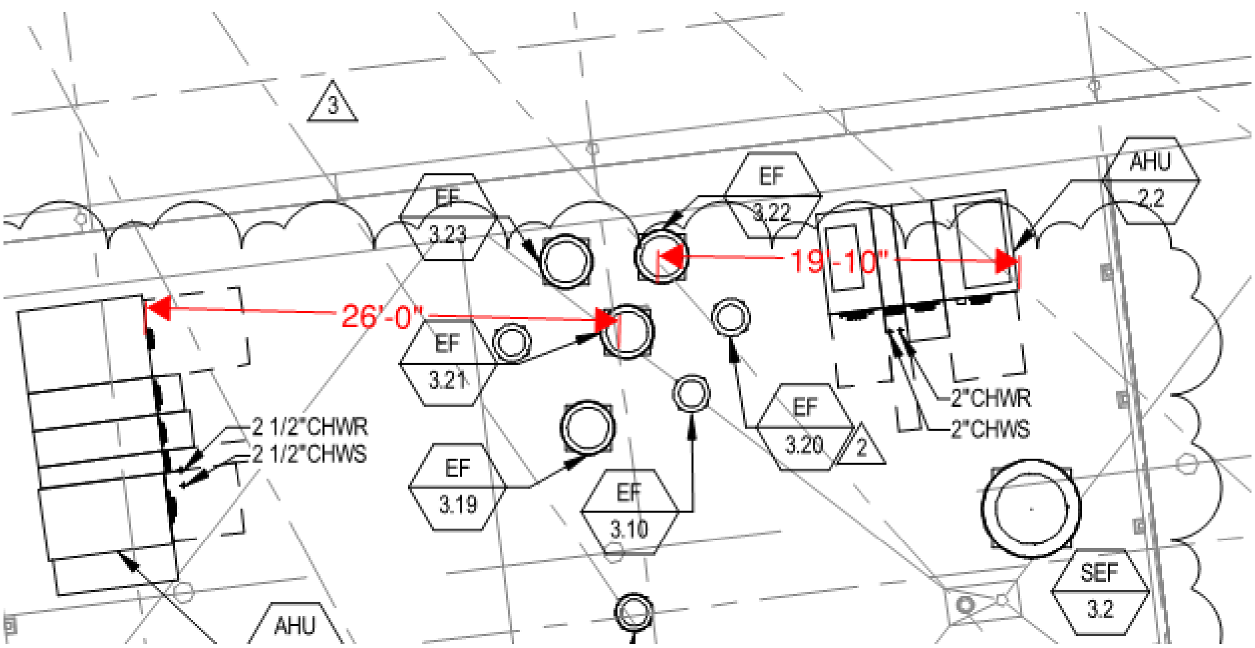

Figure 3: Measurements from the kitchen exhaust fans to the inlets of the air handling units are less than the required 30 feet apart.

5.6 Local Capture of Contaminants

In this luxury hotel, the only non-combustion equipment that needs ventilation are the commercial dryers in the laundry room. There are two exhaust fans on the second level roof that are dedicated to the dryers. 1000 CFM of laundry exhaust is directly vented outside to exhaust fan 3.14 and another 250 CFM is directly vented to exhaust fan 3.18.

5.7 Combustion Air

Fuel-burning applications need to have enough air for combustion and a method for adequate removal of the combustion products. Kitchen appliances in the hotel are considered to make combustion air. These appliances that are fuel burning have kitchen hoods to trap grease and other contaminants. Ducts bring this contaminated air directly to the roof through kitchen exhaust fans. In the kitchen hood system, there are supply fans for makeup air to help continue combustion and maintain the necessary pressures after the exhaust air is removed.

5.8 Particulate Matter Removal

All air delivery systems have a 2" pleated 30% efficient pre-filter and a 4" 65% efficient final cartridge filter. This corresponds to a MERV value of 8 for the pre-filter and a MERV value of 11 for the final filter. Section 5.8 requires a filter upstream of all cooling coils or other wetted surfaces through which air is supplied to an occupied space to have a filter with a MERV value of at least 8, so this building is compliant.

5.9 Dehumidification Systems

60% is the maximum relative humidity that the space can reach before the controls will turn on dehumidification load until the relative humidity drops below 56%. These levels comply with ASHRAE's restriction of 65% relative humidity. In the DOAS units, there are DX units with hot gas bypass to reheat the air after it is cooled to dehumidify. This reheat ensures that the supplied air will not be overcooled to get the proper humidity. Areas of concern for humidity problems are the ballrooms. Ballrooms typically have a higher latent load than other spaces, so to combat this issue, the air handling units serving the ballrooms contain desiccant wheels to help dehumidify the entering air.

From calculations, it was determined that the minimum outdoor air intake for the tower levels of the hotel (30,395 CFM) was slightly under the maximum tower exhaust airflow (30,500 CFM). However, with the CFM from the stair pressurization fans leaking into the tower levels and the air intake from the podium levels, the overall airflow complies with ASHRAE 62.1. There is not much exhaust at all compared to the air intake on the podium levels, so the building as a whole will follow that requirement.

5.10 Drain Pans

Drain pans intended to collect condensate will be assembled with a slope of at least 0.125 in/ft toward the drain outlet. At the lowest point will be the drain outlet that has a diameter large enough to prevent overflow. These drain pans will have a P-trap to prevent ambient air from entering the drain in cases of negative static pressure. The pan will be under the equipment that produces condensate and will extend a minimum of 6 inches from each side of the equipment.

5.11 Finned-Tube Coils and Heat Exchangers

Drain pans will be provided underneath all dehumidifying cooling coil assemblies and heat exchangers that produce condensate. The finned-tube coils have been selected appropriately to ensure no more than 0.75 in. wg combined dry-coil pressure drop at 500 fpm face velocity.

5.12 Humidifiers and Water-Spray Systems

This section is not applicable because there are no humidifiers or water-spray systems in this luxury mixed-use hotel project.

5.13 Access for Inspection, Cleaning and Maintenance

Ventilation equipment was placed so that there is sufficient work space for inspection and maintenance. While modelling the equipment, the required space in front of the access panel was shown in Revit so that walls or other obstructions would not get in the way. The air handling equipment has panels and doors to allow maintenance for the components inside. All other parts of the air distribution system will have access doors, panels or other means to allow for easy access for maintenance, inspections, and cleaning.

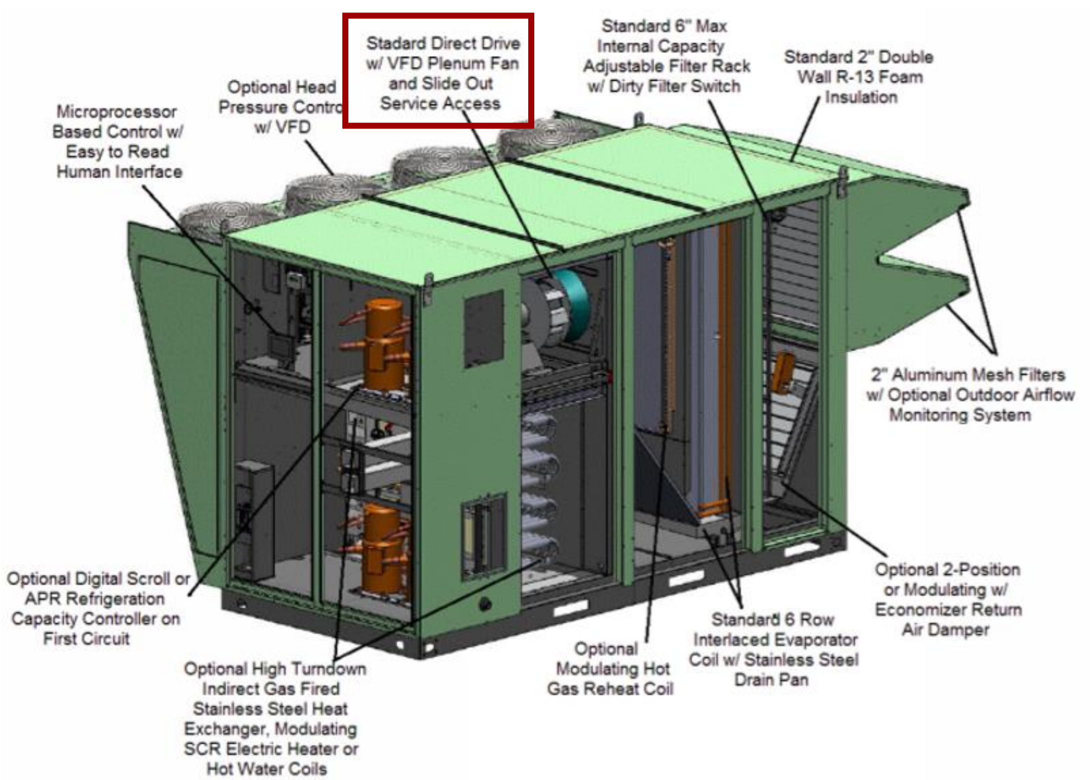

Figure 4: A typical DOAS unit highlighting the slide out service access.

5.14 Building Envelope and Interior Surfaces

The building exterior has a weather barrier to prevent water penetration into the building. Piping and ductwork will be installed with insulation to prevent condensation forming on the surfaces in case the temperatures fall below dew-point temperatures.

5.15 Buildings with Attached Parking Garages

A minimum ventilation rate of 0.05 CFM/ sq. ft. of exhaust will be required to maintain a negative pressure in the attached parking garage. This will prevent the garage air with p ollutants from cars from entering the occupiable spaces. In the garage there will be carbon monoxide (CO) sensors that will increase the ventilation rate if the CO concentration is over the exposure limits.

5.16 Air Classification and Recirculation

All air in this project was classified based on Tables 5.16.1, 6.2.2.1, and 6.5 in ASHRAE 62.1. In the kitchens, there are commercial kitchen grease hoods, which are categorized in Air Class 4. This caused the minimum distance from the exhaust fans to the inlet of an air handling unit to be 30 feet. The restaurants will be considered Class 2 air, which can only be recirculated to other Class 2 or Class 3 regions that are used for similar purposes. Most of the other spaces like guestrooms and lobbies are Class 1 air, which has low contaminant concentration, low sensory-irritation intensity, and inoffensive odor. Class 1 air can be recirculated to any space.

TABLE 5.16.1 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
Hydraulic elevator machine room	2

Figure 5: Table 5.16.1 from ASHRAE Standard 62.1 showing the air class for different airstreams.

5.17 Requirements for Buildings Containing ETS Areas and ETS-Free Areas

Environmental Tobacco Smoke Areas are not relevant to this project because the hotel is a non -smoking hotel.

ASHRAE Standard 62.1-Section 6: Procedures

6.1 General

All outdoor air intake rates were calculated based on the prescriptive design procedure in Section 6.2. Rates are determined by space type, occupancy, and floor area. Other system design parameters in the building are based on contaminant concentration limits.

6.2 Ventilation Rate Procedure

The project is located in an area with acceptable outdoor air, so extra filters and cleaning devices are not necessary. There are not any concerns about high ozone levels either. In order to calculate the zone parameters, the breathing zone outdoor airflow was used. The calculation is as follows:

$$\mathbf{V_{bz}=R_p*P_z+R_a*A_z}$$

A_z: zone floor area, the net occupiable floor area of the ventilation zone, ft^2

P_z: zone population, the number of people in the ventilation zone during typical usage

R_p: outdoor airflow rate required per person as determined from Table 6.2.2.1

R_a: outdoor airflow rate required per unit area as determined from Table 6.2.2.1

The R_p and R_a values can be found in Table 6.2.2.1, which is in the Appendix of this report (Table A-2), for each different space type. P_z represents the peak number of people in the zone at a given time. To ensure compliance, spreadsheets were created to input every zone in the building and calculate the breathing airflow depending on the area and number of people. Then, following Table 6.2.2.2, the zone air distribution effectiveness (E_z) can be found.

TABLE 6.2.2.2 Zone Air Distribution Effectiveness

Air Distribution Configuration	E_z
Ceiling supply of cool air	1.0
Ceiling supply of warm air and floor return	1.0
Ceiling supply of warm air 15°F (8°C) or more above space temperature and ceiling return	0.8
Ceiling supply of warm air less than 15°F (8°C) above space temperature and ceiling return provided that the 150 fpm (0.8 m/s) supply air jet reaches to within 4.5 ft (1.4 m) of floor level	1.0
Note: For lower velocity supply air, E_z = 0.8.	
Floor supply of cool air and ceiling return, provided that the vertical throw is greater than 50 fpm (0.25 m/s) at a height of 4.5 ft (1.4 m) or more above the floor	1.0
Floor supply of cool air and ceiling return, provided low-velocity displacement ventilation achieves unidirectional flow and thermal stratification, or underfloor air distribution systems where the vertical throw is less than or equal to 50 fpm (0.25 m/s) at a height of 4.5 ft (1.4 m) above the floor	1.2
Floor supply of warm air and floor return	1.0
Floor supply of warm air and ceiling return	0.7
Makeup supply drawn in on the opposite side of the room from the exhaust and/or return	0.8
Makeup supply drawn in near to the exhaust and/or return location	0.5

Figure 6: Table 6.2.2.2 from ASHRAE 62.1 containing zone air distribution effectiveness.

E_z is used to calculate the zone outdoor airflow (V_{oz}).

$$V_{oz}=V_{bz}/E_z$$

The zone outdoor airflow is the minimum rate that must be provided to that calculated zone. The design outdoor air intake flow (V_{ot}) is equivalent to V_{oz} for single-zone systems. For 100% outdoor air systems, like the DOAS units in this project, the design outdoor intake flow is equal to the sum of all of the zone outdoor airflow of all the zones. For air that recirculates, the primary outdoor air fraction (Z_{pz}) needs to be used.

$$Z_{pz}=V_{oz}/V_{pz}$$

V_{pz} is the zone primary airflow from the air handler that is composed of both outdoor and recirculated air. The maximum airflow fraction determines the system ventilation efficiency (E_v), which is listed in Table 6.2.5.2.

TABLE 6.2.5.2 System Ventilation Efficiency

Max (Z_p)	E_v
≤0.15	1.0
≤0.25	0.9
≤0.35	0.8
≤0.45	0.7
≤0.55	0.6
>0.55	Use Appendix A

Figure 7: Table 6.2.5.2 showing system ventilation efficiency.

The following three equations are then used to calculate the airflow quantities for recirculating systems:

$$V_{ou}=D\Sigma_{all\ zones}(R_p*P_z) + \Sigma_{all\ zones}(R_a*A_z)$$

$$D=P_s/\Sigma_{all\ zones}P_z$$

$$V_{ot}=V_{ou}/E_v$$

D: Occupant diversity ratio

P_s: System population, how many people in the zone being served

V_{ou}: Uncorrected outdoor intake

Every zone was broken down for this project and was given calculations based on the type of ventilation system it had. Using the above equations, different minimum airflow rates were found. Figure 8 below shows an example of part of a calculation chart for a zone. This project complies with the ventilation requirements.

AHU-1.7 VENTILATION TABULATION - AIA GUIDE LINES (2006)						ASHRAE 2013 STANDARDS										
									Occup.		Outdoor Air	Zone Air	Zone	Minimum	Zone	Zone
ROOM	ROOM	VAV		ACTUAL CFM		CFM/	CFM/	CFM/	Density	Occup.	Flow	Dist. Effect.	Outdoor	Airflow %	Primary	Primary
NAME	Type	BOX				RM	SF	Person	Pers./			Ez	Airflow		Airflow	Air Fraction
			S.A.	R.A.	E.A.											
HR	Offices, Commercial - General	1.7.1	165	165	0	0	0.06	5	10	3	28.8	0.8	36	0.5	82.5	0.44
BOH Corridor	Corridors	1.7.2	2100	2100	0	0	0.06	0	10	35	210	0.8	262.5	0.5	1050	0.25
Receiving Gen Stor	Occupiable Storage for Dry Materials	1.7.3	385	385	0	0	0.06	5	2	2	53.8	0.8	67.25	0.4	154	0.44
Receiving Off	Offices, Commercial - General	1.7.3	150	150	0	0	0.06	5	10	3	27.6	0.8	34.5	0.4	60	0.58
Serving Pantry	Occupiable Storage for Dry Materials	1.7.5	900	900	0	0	0.06	5	2	3	105	0.8	131.25	0.3	270	0.49
Flower Shop	Sorting, packing, light assemly	1.7.7	580	580	0	0	0.12	7.5	7	4	81.6	0.8	102	0.4	232	0.44
Serving Corridor	Occupiable Storage for Dry Materials	1.7.5	400	400	0	0	0.06	5	2	2	50.2	0.8	62.75	0.3	120	0.52
Loss Prevention	Offices, Commercial - General	1.7.4	160	160	0	0	0.06	5	10	3	30.6	0.8	38.25	0.5	80	0.48
Security Director	Offices, Commercial - General	1.7.4	70	70	0	0	0.06	5	10	1	10.7	0.8	13.38	0.5	35	0.38
Office Holding Room	Offices, Commercial - General	1.7.4	80	80	0	0	0.06	5	10	1	10.7	0.8	13.38	0.5	40	0.33
Housekeeping	Occupiable Storage for Dry Materials	1.7.6	730	730	0	0	0.06	5	2	2	66.4	0.8	83	0.3	219	0.38
Director of HR	Offices, Commercial - General	1.7.1	100	100	0	0	0.06	5	10	2	16.3	0.8	20.38	0.5	50	0.41
HR Coordinator	Offices, Commercial - General	1.7.1	60	60	0	0	0.06	5	10	1	8.6	0.8	10.75	0.5	30	0.36
Storage	Occupiable Storage for Dry Materials	1.7.1	50	50	0	0	0.06	5	2	1	9.8	0.8	12.25	0.5	25	0.49
Applicant Screening	Offices, Commercial - General	1.7.1	75	75	0	0	0.06	5	10	1	9.5	0.8	11.88	0.5	37.5	0.32
Unisex RR	*Toilets - Public (light)	1.7.1	0	0	100	0	0	0	0	0	0	0.8	0	0.5	0	0
Nurse	Offices, Commercial - General	1.7.1	100	100	0	0	0.06	5	10	2	17.2	0.8	21.5	0.5	50	0.43
Exam Room	Offices, Commercial - General	1.7.1	120	120	0	0	0.06	5	10	2	16.3	0.8	20.38	0.5	60	0.34
Temp Cooler Storage	Occupiable Storage for Dry Materials	1.7.7	100	100	0	0	0.06	5	2	1	14.6	0.8	18.25	0.4	40	0.46
Women RR	*Toilets - Public (light)	1.7.	0	0	100	0	0	0	0	0	0	0.8	0	0.3	0	0
Men RR	*Toilets - Public (light)	1.7.	0	0	100	0	0	0	0	0	0	0.8	0	0.3	0	0
Custodial	Janitor, Trash, Recycle	1.7.	0	0	100	0	0	0	0	0	0	0.8	0	0.3	0	0
			6325	6325											Vps	Max Zp
									Total=	69		Total=	959.63		6325	0.58

Figure 8: Outdoor air calculation for OA AHU 1.7 containing the required ASHRAE equations.

6.3 Indoor Air Quality (IAQ) Procedure

In certain areas of the building, there are contaminants of concern, so there are sensors that monitor the concentration to ensure the levels don't exceed the set level. For example, in the garage there are carbon monoxide sensors that will adjust the ventilation airflow if the concentration is too high.

6.4 Natural Ventilation Procedure

This section of ASHRAE 62.1 is not applicable to this project because there is not a natural ventilation system.

6.5 Exhaust Ventilation

The requirements in Table 6.5 determined the design exhaust levels for the different spaces in this project. The primary areas of concern for exhaust are the toilets, laundry, kitchens and parking garages. All guestroom toilets have a unit that can be turned on by the occupant that exhausts 50 CFM. Table 6.5 is shown below with the areas of concerned outlined in red.

TABLE 6.5 Minimum Exhaust Rates

Occupancy Category	Exhaust Rate, cfm/unit	Exhaust Rate, cfm/ft^2	Notes	Exhaust Rate, L/s·unit	Exhaust Rate, L/s·m^2	Air Class
Arenas	—	0.50	B	—	—	1
Art classrooms	—	0.70		—	3.5	2
Auto repair rooms	—	1.50	A	—	7.5	2
Barber shops	—	0.50		—	2.5	2
Beauty and nail salons	—	0.60		—	3.0	2
Cells with toilet	—	1.00		—	5.0	2
Copy, printing rooms	—	0.50		—	2.5	2
Darkrooms	—	1.00		—	5.0	2
Educational science laboratories	—	1.00		—	5.0	2
Janitor closets, trash rooms, recycling	—	1.00		—	5.0	3
Kitchenettes	—	0.30		—	1.5	2
Kitchens—commercial	—	0.70		—	3.5	2
Locker/dressing rooms	—	0.25		—	1.25	2
Locker rooms	—	0.50		—	2.5	2
Paint spray booths	—	—	F	—	—	4
Parking garages	—	0.75	C	—	3.7	2
Pet shops (animal areas)	—	0.90		—	4.5	2
Refrigerating machinery rooms	—	—	F	—	—	3
Residential kitchens	50/100	—	G	25/50	—	2
Soiled laundry storage rooms	—	1.00	F	—	5.0	3
Storage rooms, chemical	—	1.50	F	—	7.5	4
Toilets—private	25/50	—	E, H	12.5/25	—	2
Toilets—public	50/70	—	D, H	25/35	—	2
Woodwork shop/classrooms	—	0.50		—	2.5	2

Figure 9: Table 6.5 from ASHRAE 62.1 listing minimum exhaust rates.

6.6 Design Documentation Procedures

Design criteria and assumptions are well documented in the design drawings so that everything will be operated properly.

ASHRAE Standard 55: Thermal Comfort

5.1 General Requirements

Section 5 of this standards has guidelines to design for 80% of the building occupants to be thermally comfortable in a space. There are six factors that affect how comfortable an occupant will be: metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity. The luxury mixed-use hotel did not use this standard for design, but the following section of the report explains how the design complies with the thermal comfort requirements.

5.2 Method for Determining Occupant Characteristics

Table 5.2.1.2 contains data for the metabolic rates for typical tasks; the chart can be found in the appendix of this paper as Table A-4. For this mixed-use hotel, some common activities are sleeping, standing, and walking slowly, which have metabolic rates of 13, 22, and 37 BTU/hr*ft^2, respectively. Specific rooms like the ballroom will have different activities to consider, such as dancing. It is important to consider each space type separately in terms of thermal comfort because there will be many different activities happening in this hotel. For individuals participating in many activities for less than an hour, doing a time weighted average is permissible. If the activities last longer than an hour, they will be considered two separate metabolic rates. Since the hotel has guests and employees participating in a wide range of activities, it will be too difficult to ensure that everyone is comfortable; however, it is possible to try to make the majority of people comfortable. Considering that the guests' comfort is more important for the business of the hotel, calculating thermal comfort based on the guests is optimal.

Clothing insulation makes a large difference for an occupant's thermal comfort. I_{cl} is the clothing insulation value measured in clo. Clothing insulation values increase with the amount of body coverage. A standard men's suit is 1 clo. In this climate region, the main concern for thermal comfort is the occupants being too hot. During the cooling seasons, we would expect occupants to have a clothing insulation value around 0.5 or less. Most of the guests are tourists and will probably be wearing shorts and T-shirts, but using 0.5 is more conservative. I_{cl} is for occupants that are not moving, so to account for motion, it is necessary to calculate $I_{cl,active}$:

$$I_{cl,active}=I_{cl}*(0.6+0.4/M)$$

$$1.2 \text{ met} < M < 2.0 \text{ met}$$

In this equation, M is the metabolic rate. Table 5.2.2.2B includes a more specific list of garments to calculate specific ensembles by adding the individual items together. Table 5.2.2.2C adds insulation for sitting on a chair. This table could be useful for guests seated at the restaurants or employees seated at their desks. Both Table 5.2.2.2B and 5.2.2.2B can be found in the appendix of this paper. Throughout the year, I_{cl} values can be predicted based on climate data to calculate thermal comfort as seen in the chart below.

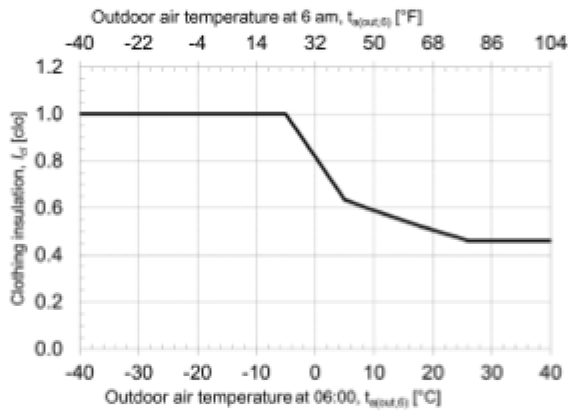

FIGURE 5.2.2.2 Representative clothing insulation (I_{cl}) as a function of outdoor air temperature at 06:00 a.m.

Figure 10: Clothing insulation values depending on outside air temperature.

5.3 General Method for Determining Acceptable Thermal Conditions in Occupied Spaces

Standard 55 developed a graphical method to predict thermal comfort based on the Predicted Mean Vote (PMV) model. The method shows information for occupants with a metabolic rate between 1.0 and 1.3 met and clothing insulation between 0.5 and 1.0 clo. 0.2 m/s is the average air speed used, but Section 5.3.3 accounts for air speeds greater than that. Comfort zones are calculated using the linear interpolation between the following equations:

$$\mathbf{t_{min,Icl}=[(I_{cl}-0.5\ clo)t_{min,1.0clo}+(1.0\ clo-I_{cl})t_{min,0.5clo}]/0.5\ clo}$$

$$\mathbf{t_{max,Icl}=[(I_{cl}-0.5\ clo)t_{max,1.0clo}+(1.0\ clo-I_{cl})t_{max,0.5clo}]/0.5\ clo}$$

$t_{max,Icl}$: *upper operative temperature (t_o) limit for clothing insulation (I_{cl})*

$t_{min,Icl}$: *lower operative temperature (t_o) limit for clothing insulation (I_{cl})*

I_{cl}: *thermal insulation of the clothing in question, clo*

UC-Berkeley created a CBE Thermal Comfort Tool that incorporates the equations suggested by ASHRAE to create thermal comfort graphs. Although this project does not have a PMV control system, for an operative temperature setpoint of 75°F, relative humidity of 50%, and 0.1 m/s air speed for cooling season, the figures below would be the corresponding thermal comfort charts for I_{cl} values of 0.5 and 1.0 clo, respectively.

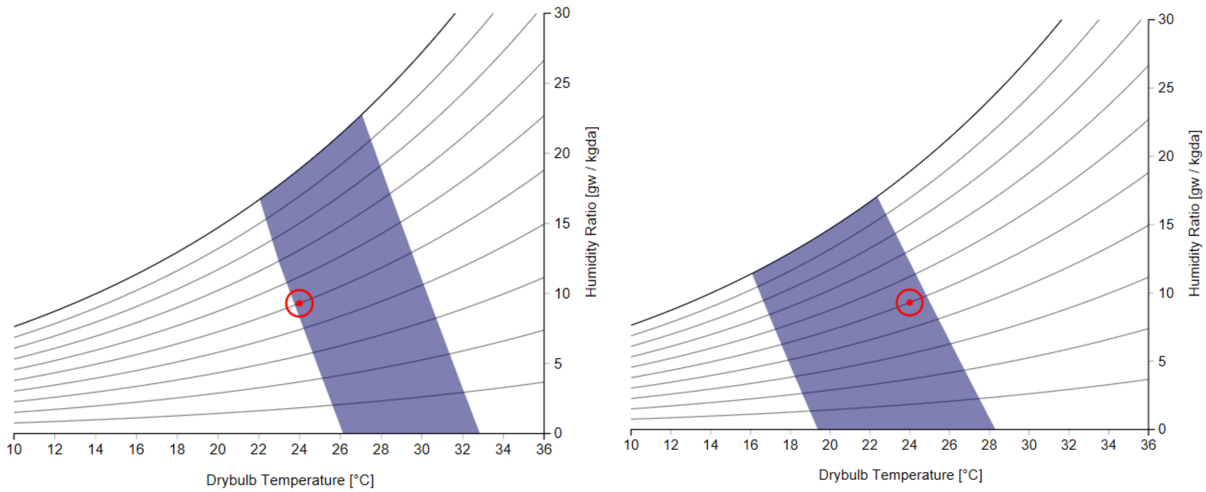

Figure 11: On the left is a thermal comfort chart with an I_{cl} value of 0.5. The chart on the right shows an adjusted clothing insulation value of 1.0 clo.

Both thermal comfort charts are acceptable for ASHRAE Standard 55. On the left, 9% of people are dissatisfied and the PMV is -0.46. On the right, 8% of people are dissatisfied with a PMV of 0.39. The design setpoints for this project comply with the standard.

It is also important not to have radiant temperature asymmetry or large temperature drifts with time. Having minor fluctuations of temperature helps avoid "thermal boredom"; however, Table 5.3.5.3 below gives the maximum temperature changes allowed for a certain period of time. Table 5.3.4.2 gives the available temperature asymmetry between surfaces of a space. This project did not consider these factors during design.

TABLE 5.3.4.2
Allowable Radiant Temperature Asymmetry

Radiant Temperature Asymmetry °C (°F)			
Ceiling Warmer than Floor	Ceiling Cooler than Floor	Wall Warmer than Air	Wall Cooler than Air
<5 (9.0)	<14 (25.2)	<23 (41.4)	<10 (18.0)

TABLE 5.3.5.3
Limits on Temperature Drifts and Ramps

Time Period, h	0.25	0.5	1	2	4
Maximum Operative Temperature (t_o) Change Allowed, °C (°F)	1.1 (2.0)	1.7 (3.0)	2.2 (4.0)	2.8 (5.0)	3.3 (6.0)

Figure 12: Allowable radiant temperature asymmetry chart (left) and limits on temperature drifts (right) from ASHRAE Standard 55.

Designing for thermal comfort is very challenging because comfort is very subjective and has so many influencing factors. Especially in a building like this one, there are many different activities, so it is difficult to make sure everyone is comfortable. Also, controlling the temperature for comfort depends on input from the occupants, which can be expensive and impractical. The public spaces will be controlled based on setpoints determined by the engineers and the guestrooms have thermostats so that the guests can control their own spaces. This will allow the guests to control their thermal comfort, which is very important for the success of the business of the hotel.

Appendix

Table A-1: ASHRAE 62.1 Table 5.5.1

TABLE 5.5.1 Air Intake Minimum Separation Distance

Object	Minimum Distance, ft (m)
Class 2 air exhaust/relief outlet (Note 1)	10 (3)
Class 3 air exhaust/relief outlet (Note 1)	15 (5)
Class 4 air exhaust/relief outlet (Note 2)	30 (10)
Plumbing vents terminating less than 3 ft (1 m) above the level of the outdoor air intake	10 (3)
Plumbing vents terminating at least 3 ft (1 m) above the level of the outdoor air intake	3 (1)
Vents, chimneys, and flues from combustion appliances and equipment (Note 3)	15 (5)
Garage entry, automobile loading area, or drive-in queue (Note 4)	15 (5)
Truck loading area or dock, bus parking/idling area (Note 4)	25 (7.5)
Driveway, street, or parking place (Note 4)	5 (1.5)
Thoroughfare with high traffic volume	25 (7.5)
Roof, landscaped grade, or other surface directly below intake (Notes 5 and 6)	1 (0.30)
Garbage storage/pick-up area, dumpsters	15 (5)
Cooling tower intake or basin	15 (5)
Cooling tower exhaust	25 (7.5)

Table A-2: ASHRAE 62.1 Table 6.2.2.1

TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s·person	
Correctional Facilities									
Cell	5	2.5	0.12	0.6		25	10	4.9	2
Dayroom	5	2.5	0.06	0.3		30	7	3.5	1
Guard stations	5	2.5	0.06	0.3		15	9	4.5	1
Booking/waiting	7.5	3.8	0.06	0.3		50	9	4.4	2
Educational Facilities									
Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6	2
Daycare sickroom	10	5	0.18	0.9		25	17	8.6	3
Classrooms (ages 5–8)	10	5	0.12	0.6		25	15	7.4	1
Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7	1
Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3	1
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3		150	8	4.0	1
Art classroom	10	5	0.18	0.9		20	19	9.5	2
Science laboratories	10	5	0.18	0.9		25	17	8.6	2
University/college laboratories	10	5	0.18	0.9		25	17	8.6	2
Wood/metal shop	10	5	0.18	0.9		20	19	9.5	2
Computer lab	10	5	0.12	0.6		25	15	7.4	1
Media center	10	5	0.12	0.6	A	25	15	7.4	1
Music/theater/dance	10	5	0.06	0.3		35	12	5.9	1
Multiuse assembly	7.5	3.8	0.06	0.3		100	8	4.1	1
Food and Beverage Service									
Restaurant dining rooms	7.5	3.8	0.18	0.9		70	10	5.1	2
Cafeteria/fast-food dining	7.5	3.8	0.18	0.9		100	9	4.7	2
Bars, cocktail lounges	7.5	3.8	0.18	0.9		100	9	4.7	2
Kitchen (cooking)	7.5	3.8	0.12	0.6		20	14	7.0	2
General									
Break rooms	5	2.5	0.06	0.3		25	7	3.5	1

TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone *(Continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/ person	L/s· person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/ person	L/s·person	
Coffee stations	5	2.5	0.06	0.3		20	8	4	1
Conference/meeting	5	2.5	0.06	0.3		50	6	3.1	1
Corridors	—	—	0.06	0.3		—			1
Occupiable storage rooms for liquids or gels	5	2.5	0.12	0.6	B	2	65	32.5	2
Hotels, Motels, Resorts, Dormitories									
Bedroom/living room	5	2.5	0.06	0.3		10	11	5.5	1
Barracks sleeping areas	5	2.5	0.06	0.3		20	8	4.0	1
Laundry rooms, central	5	2.5	0.12	0.6		10	17	8.5	2
Laundry rooms within dwelling units	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies/prefunction	7.5	3.8	0.06	0.3		30	10	4.8	1
Multipurpose assembly	5	2.5	0.06	0.3		120	6	2.8	1
Office Buildings									
Breakrooms	5	2.5	0.12	0.6		50	7	3.5	1
Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5	1
Occupiable storage rooms for dry materials	5	2.5	0.06	0.3		2	35	17.5	1
Office space	5	2.5	0.06	0.3		5	17	8.5	1
Reception areas	5	2.5	0.06	0.3		30	7	3.5	1
Telephone/data entry	5	2.5	0.06	0.3		60	6	3.0	1
Miscellaneous Spaces									
Bank vaults/safe deposit	5	2.5	0.06	0.3		5	17	8.5	2
Banks or bank lobbies	7.5	3.8	0.06	0.3		15	12	6.0	1
Computer (not printing)	5	2.5	0.06	0.3		4	20	10.0	1

TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone *(Continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s·person	
Freezer and refrigerated spaces (<50°F)	10	5	0	0	E	0	0	0	2
General manufacturing (excludes heavy industrial and processes using chemicals)	10	5.0	0.18	0.9		7	36	18	3
Pharmacy (prep. area)	5	2.5	0.18	0.9		10	23	11.5	2
Photo studios	5	2.5	0.12	0.6		10	17	8.5	1
Shipping/receiving	10	5	0.12	0.6	B	2	70	35	2
Sorting, packing, light assembly	7.5	3.8	0.12	0.6		7	25	12.5	2
Telephone closets	—	—	0.00	0.0		—			1
Transportation waiting	7.5	3.8	0.06	0.3		100	8	4.1	1
Warehouses	10	5	0.06	0.3	B	—			2
Public Assembly Spaces									
Auditorium seating area	5	2.5	0.06	0.3		150	5	2.7	1
Places of religious worship	5	2.5	0.06	0.3		120	6	2.8	1
Courtrooms	5	2.5	0.06	0.3		70	6	2.9	1
Legislative chambers	5	2.5	0.06	0.3		50	6	3.1	1
Libraries	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies	5	2.5	0.06	0.3		150	5	2.7	1
Museums (children's)	7.5	3.8	0.12	0.6		40	11	5.3	1
Museums/galleries	7.5	3.8	0.06	0.3		40	9	4.6	1
Residential									
Dwelling unit	5	2.5	0.06	0.3	F,G	F			1
Common corridors	—	—	0.06	0.3					1

TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone *(Continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/ person	L/s· person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/ person	L/s·person	
Retail									
Sales (except as below)	7.5	3.8	0.12	0.6		15	16	7.8	2
Mall common areas	7.5	3.8	0.06	0.3		40	9	4.6	1
Barbershop	7.5	3.8	0.06	0.3		25	10	5.0	2
Beauty and nail salons	20	10	0.12	0.6		25	25	12.4	2
Pet shops (animal areas)	7.5	3.8	0.18	0.9		10	26	12.8	2
Supermarket	7.5	3.8	0.06	0.3		8	15	7.6	1
Coin-operated laundries	7.5	3.8	0.12	0.6		20	14	7.0	2
Sports and Entertainment									
Gym, sports arena (play area)	20	10	0.18	0.9	E	7	45	23	2
Spectator areas	7.5	3.8	0.06	0.3		150	8	4.0	1
Swimming (pool & deck)	—	—	0.48	2.4	C	—			2
Disco/dance floors	20	10	0.06	0.3		100	21	10.3	2
Health club/aerobics room	20	10	0.06	0.3		40	22	10.8	2
Health club/weight rooms	20	10	0.06	0.3		10	26	13.0	2
Bowling alley (seating)	10	5	0.12	0.6		40	13	6.5	1
Gambling casinos	7.5	3.8	0.18	0.9		120	9	4.6	1
Game arcades	7.5	3.8	0.18	0.9		20	17	8.3	1
Stages, studios	10	5	0.06	0.3	D	70	11	5.4	1

Table A-3: ASHRAE 62.1 Table 6.5

TABLE 6.5 Minimum Exhaust Rates

Occupancy Category	Exhaust Rate, cfm/unit	Exhaust Rate, cfm/ft^2	Notes	Exhaust Rate, L/s·unit	Exhaust Rate, $L/s \cdot m^2$	Air Class
Arenas	—	0.50	B	—	—	1
Art classrooms	—	0.70		—	3.5	2
Auto repair rooms	—	1.50	A	—	7.5	2
Barber shops	—	0.50		—	2.5	2
Beauty and nail salons	—	0.60		—	3.0	2
Cells with toilet	—	1.00		—	5.0	2
Copy, printing rooms	—	0.50		—	2.5	2
Darkrooms	—	1.00		—	5.0	2
Educational science laboratories	—	1.00		—	5.0	2
Janitor closets, trash rooms, recycling	—	1.00		—	5.0	3
Kitchenettes	—	0.30		—	1.5	2
Kitchens—commercial	—	0.70		—	3.5	2
Locker/dressing rooms	—	0.25		—	1.25	2
Locker rooms	—	0.50		—	2.5	2
Paint spray booths	—	—	F	—	—	4
Parking garages	—	0.75	C	—	3.7	2
Pet shops (animal areas)	—	0.90		—	4.5	2
Refrigerating machinery rooms	—	—	F	—	—	3
Residential kitchens	50/100	—	G	25/50	—	2
Soiled laundry storage rooms	—	1.00	F	—	5.0	3
Storage rooms, chemical	—	1.50	F	—	7.5	4
Toilets—private	25/50	—	E, H	12.5/25	—	2
Toilets—public	50/70	—	D, H	25/35	—	2
Woodwork shop/classrooms	—	0.50		—	2.5	2

Table A-4: ASHRAE 55 Table 5.5.1

TABLE 5.2.1.2 Metabolic Rates for Typical Tasks

Activity	Metabolic Rate		
	Met Units	W/m²	Btu/h·ft²
Resting			
Sleeping	0.7	40	13
Reclining	0.8	45	15
Seated, quiet	1.0	60	18
Standing, relaxed	1.2	70	22
Walking (on level surface)			
0.9 m/s, 3.2 km/h, 2.0 mph	2.0	115	37
1.2 m/s, 4.3 km/h, 2.7 mph	2.6	150	48
1.8 m/s, 6.8 km/h, 4.2 mph	3.8	220	70
Office Activities			
Reading, seated	1.0	55	18
Writing	1.0	60	18
Typing	1.1	65	20
Filing, seated	1.2	70	22
Filing, standing	1.4	80	26
Walking about	1.7	100	31
Lifting/packing	2.1	120	39
Driving/Flying			
Automobile	1.0–2.0	60–115	18–37
Aircraft, routine	1.2	70	22
Aircraft, instrument landing	1.8	105	33
Aircraft, combat	2.4	140	44
Heavy vehicle	3.2	185	59
Miscellaneous Occupational Activities			
Cooking	1.6–2.0	95–115	29–37
House cleaning	2.0–3.4	115–200	37–63
Seated, heavy limb movement	2.2	130	41
Machine work			
sawing (table saw)	1.8	105	33
light (electrical industry)	2.0–2.4	115–140	37–44
heavy	4.0	235	74
Handling 50 kg (100 lb) bags	4.0	235	74
Pick and shovel work	4.0–4.8	235–280	74–88
Miscellaneous Leisure Activities			
Dancing, social	2.4–4.4	140–255	44–81
Calisthenics/exercise	3.0–4.0	175–235	55–74
Tennis, single	3.6–4.0	210–270	66–74
Basketball	5.0–7.6	290–440	90–140
Wrestling, competitive	7.0–8.7	410–505	130–160

Table A-5: ASHRAE 55 Table 5.2.2.2A

TABLE 5.2.2.2A Clothing Insulation (I_{cl}) Values for Typical Ensembles

Clothing Description	Garments Included*	I_{cl} (clo)
Trousers	1) Trousers, short-sleeve shirt	0.57
	2) Trousers, long-sleeve shirt	0.61
	3) #2 plus suit jacket	0.96
	4) #2 plus suit jacket, vest, T-shirt	1.14
	5) #2 plus long-sleeve sweater, T-shirt	1.01
	6) #5 plus suit jacket, long underwear bottoms	1.30
Skirts/Dresses	7) Knee-length skirt, short-sleeve shirt (sandals)	0.54
	8) Knee-length skirt, long-sleeve shirt, full slip	0.67
	9) Knee-length skirt, long-sleeve shirt, half slip, long-sleeve sweater	1.10
	10) Knee-length skirt, long-sleeve shirt, half slip, suit jacket	1.04
	11) Ankle-length skirt, long-sleeve shirt, suit jacket	1.10
Shorts	12) Walking shorts, short-sleeve shirt	0.36
Overalls/Coveralls	13) Long-sleeve coveralls, T-shirt	0.72
	14) Overalls, long-sleeve shirt, T-shirt	0.89
	15) Insulated coveralls, long-sleeve thermal underwear tops and bottoms	1.37
Athletic	16) Sweat pants, long-sleeve sweatshirt	0.74
Sleepwear	17) Long-sleeve pajama tops, long pajama trousers, short 3/4 length robe (slippers, no socks)	0.96

* All clothing ensembles, except where otherwise indicated in parentheses, include shoes, socks, and briefs or panties. All skirt/dress clothing ensembles include panty hose and no additional socks.

Table A-6: ASHRAE 55 Table 5.2.2.2B

TABLE 5.2.2.2B Garment Insulation (I_{clu})

Garment Description[a]	I_{clu}(clo)	Garment Description[a]	I_{clu}(clo)
Underwear		Dress and Skirts[b]	
Bra	0.01	Skirt (thin) mm	0.14
Panties	0.03	Skirt (thick)	0.23
Men's briefs	0.04	Sleeveless, scoop neck (thin)	0.23
T-shirt	0.08	Sleeveless, scoop neck (thick), i.e., jumper	0.27
Half-slip	0.14	Short-sleeve shirtdress (thin)	0.29
Long underwear bottoms	0.15	Long-sleeve shirtdress (thin)	0.33
Full slip	0.16	Long-sleeve shirtdress (thick)	0.47
Long underwear top	0.20	Sweaters	
Footwear		Sleeveless vest (thin)	0.13
Ankle-length athletic socks	0.02	Sleeveless vest (thick)	0.22
Panty hose/stockings	0.02	Long-sleeve (thin)	0.25
Sandals/thongs	0.02	Long-sleeve (thick)	0.36
Shoes	0.02	Suit Jackets and Vests[c]	
Slippers (quilted, pile lined)	0.03	Sleeveless vest (thin)	0.10
Calf-length socks	0.03	Sleeveless vest (thick)	0.17
Knee socks (thick)	0.06	Single-breasted (thin)	0.36
Boots	0.10	Single-breasted (thick)	0.44
Shirts and Blouses		Double-breasted (thin)	0.42
Sleeveless/scoop-neck blouse	0.12	Double-breasted (thick)	0.48
Short-sleeve knit sport shirt	0.17	Sleepwear and Robes	
Short-sleeve dress shirt	0.19	Sleeveless short gown (thin)	0.18
Long-sleeve dress shirt	0.25	Sleeveless long gown (thin)	0.20
Long-sleeve flannel shirt	0.34	Short-sleeve hospital gown	0.31
Long-sleeve sweatshirt	0.34	Short-sleeve short robe (thin)	0.34
Trousers and Coveralls		Short-sleeve pajamas (thin)	0.42
Short shorts	0.06	Long-sleeve long gown (thick)	0.46
Walking shorts	0.08	Long-sleeve short wrap robe (thick)	0.48
Straight trousers (thin)	0.15	Long-sleeve pajamas (thick)	0.57
Straight trousers (thick)	0.24	Long-sleeve long wrap robe (thick)	0.69
Sweatpants	0.28		
Overalls	0.30		
Coveralls	0.49		

a. "Thin" refers to garments made of lightweight, thin fabrics often worn in the summer; "thick" refers to garments made of heavyweight, thick fabrics often worn in the winter.
b. Knee-length dresses and skirts.
c. Lined vests.

TABLE 5.2.2.2C Added Insulation when Sitting on a Chair
(Applicable to Clothing Ensembles with Standing Insulation Values of 0.5 clo < I_{cl} < 1.2 clo)

Net chair[a]	0.00 clo
Metal chair	0.00 clo
Wooden side arm chair[b]	0.00 clo
Wooden stool	+0.01 clo
Standard office chair	+0.10 clo
Executive chair	+0.15 clo

a. A chair constructed from thin, widely spaced cords that provide no thermal insulation.
b. *Note:* this chair was used in most of the basic studies of thermal comfort that were used to establish the PMV-PPD index.

Figure A-1: ASHRAE 55 Figure 5.3.1

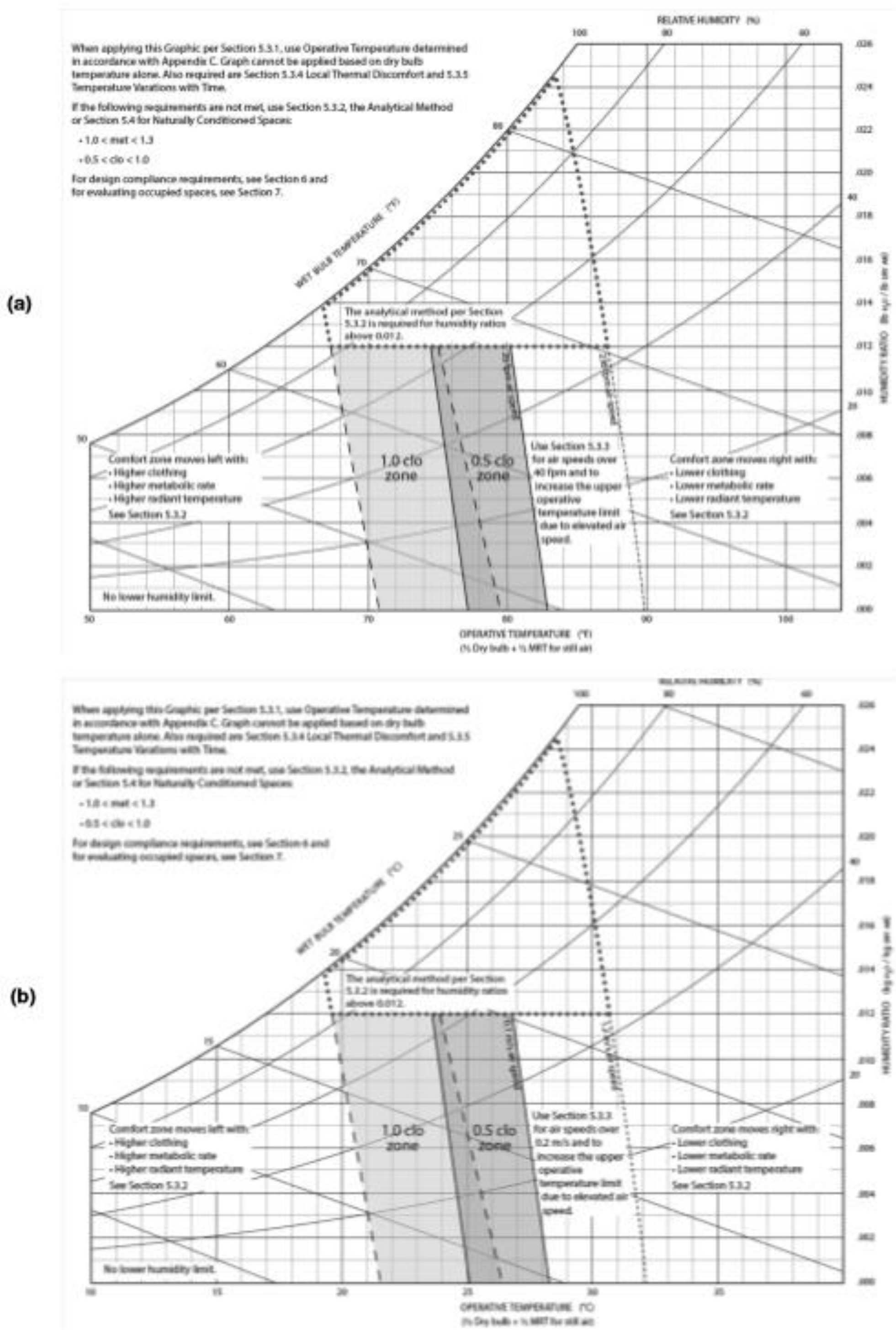

FIGURE 5.3.1 Graphic Comfort Zone Method: Acceptable range of operative temperature (t_o) and humidity for spaces that meet the criteria specified in Section 5.3.1 ($1.0 \leq$ met < 1.3; $0.5 <$ clo < 1.0)—(a) I-P and (b) SI.

Figure A-2: ASHRAE 55 Figure 5.3.3A

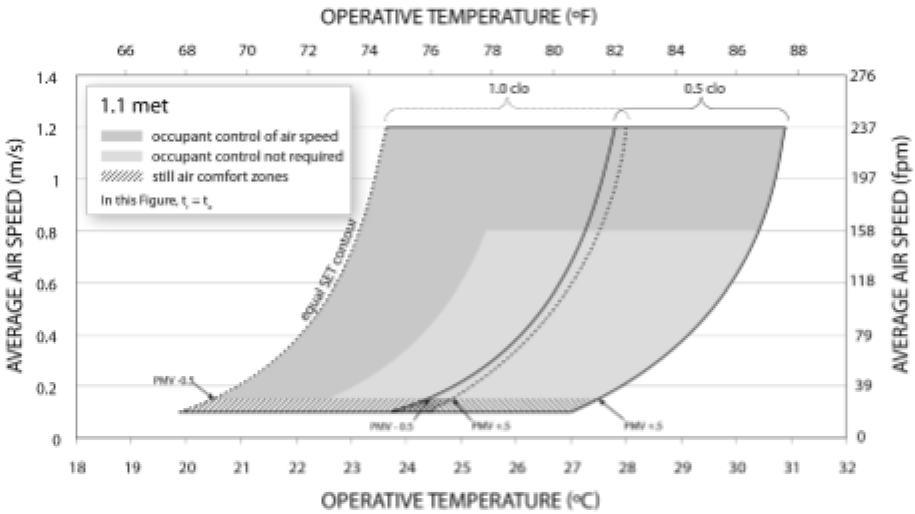

FIGURE 5.3.3A Acceptable ranges of operative temperature (t_o) and average air speed (V_a) for the 1.0 and 0.5 clo comfort zone presented in Figure 5.3.1.1, at humidity ratio 0.010.