THE SPACING OF CEILING FANS FOR HUMAN COMFORT IN WARM TEMPERATURE CONDITIONS

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ABSTRACT

Airspeed tests of a commercially popular 52 in. ceiling fan operating at a low speed of 155 fpm provided sufficient airspeed for comfort to 82F in an average floor area of 97.2 $ft.^2$ beneath the fan. When operating at maximum speed, the average floor area increased to 151.0 $ft.^2$. At 85F, the average floor areas for the low speed and maximum speed tests were 31.8 $ft.^2$ and 55.6 $ft.^2$ respectively. The maximum on-center spacing recommended for the tested ceiling fan mounted at 8.5 ft. above the floor, operating at maximum speed, and providing comfort at a room temperature of 82F is 14 ft.; and at a temperature of 85F, it is 9 ft. Future ceiling fans should be designed to create a both a larger main air plume and a larger comfort zone.

The ceiling fan provided relatively high airspeeds throughout the largest floor area in the zone from the floor to the 24 in. height. Since ceiling fans create higher airspeeds near the floor, they should be used cautiously when rooms are comfortably conditioned during all seasons and have children playing in the room or adults sitting on the floor of the room.

This study measured the airspeeds of a ceiling fan and analyzed human comfort conditions within a small room. The purpose was to determine the floor area of the room which was directly beneath the fan where people would be comfortable at two warm room temperatures. In addition, ceiling fan spacing was recommended.

DEFINITION

Effective Temperature (ET* CT*). Effective temperature is the uniform temperature of a radiantly black enclosure at 50% relative humidity, in which an occupant would experience the same comfort, physiological strain and heat exchange as in the actual environment with the same air motion.[1]

This Research was conducted at Texas A&M University in 1983 while the author was completing dissertation research in the Department of Architecture.

DESCRIPTION OF CLASSROOM & EQUIPMENT

The classroom used for the airspeed tests was the east room of the English Annex on the main campus of Texas A&M University. The classroom (Fig.1) was 15 ft. by 18 ft., and the ceiling was 11.75 ft. in height.

The ceiling fan airspeeds were measured with a linear air flow meter and with a nondirectional airspeed probe. The nondirectional airspeed probe was calibrated by the probe manufacturer sixty days prior to the airspeed tests. The ceiling fan was a commercially popular three speed 52 in. blade diameter ceiling fan, and it was controlled by a variable speed fan controller. The fan mounting height was 8.5 ft. from the floor to the center line of the fan blades.

DETERMINATION OF TEST AIRSPEEDS AND TEMPERATURES

Airspeeds were grouped into three ranges titled still air, moderate airspeed and high airspeed (Table 1). Since the ASHRAE Standard 55-1981[1] indicates that still air is less than 50 fpm and Rohles' et al.[2] study showed that the lowest air-

FET*.

Their research[2] also showed that the ASHRAE Standard 55-1981[1] summer comfort zone could be extended to 85 FET* with a mean airspeed of 200 fpm. This airspeed was selected as the lower limit for the moderate range.

The upper limit of 300 fpm for the moderate airspeed zone was selected after reviewing previous research studies (Table 2) which analyzed the comfort conditions that people sense when overhead fans provide air movement. The studies showed that maximum airspeeds of 200 fpm to 300 fpm seemed comfortable to at least 77 percent of the persons tested when dry bulb temperature did not exceed 84F to 85F and the relative humidity was approximately 50 to 60 percent.

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Airspeeds above 300 fpm were selected as the high airspeed region. At these airspeeds, papers from books and magazines begin to be blown about and the moving papers create annoyance for subjects within the airstream[1,7].

The ceiling fan airspeeds were subdivided into zones to illustrate regions of the classroom where comfort was provided to a maximum temperature condition. These zones included the three airspeed regions. The maximum temperatures selected were 82 FET* and 85 FET* to conform to the temperatures used in Rohles' et al. ceiling fan tests with human subjects[2].

AIRSPEED MEASUREMENTS

Airspeed measurements were made at 150 locations within the classroom. The points were selected in order to include ASHRAE's occupied zone in the horizontal plane or plan view of the room, and the dashed line shown in Fig. 1 represents the occupied zone. The occupied zone is the region of space normally occupied by people and is generally considered to be between the floor and 6 ft. above the floor and more than 2 ft. from walls or fixed air conditioning equipment[1].

The vertical heights chosen for airspeed measurements were 4 in., 24 in., 43 in., 67 in., and 88 in. The first four height increments were heights recommended by ASHRAE Standard 55-1981[1] for the evaluation of thermal parameters for sedentary occupants who were sitting and standing. The 88 in. height was added to provide data on airspeed conditions for persons taller than normal. In the horizontal plane, the airspeed measurement locations were 3 ft. on center throughout the room.

The airspeed for each of these points was an average of 100 measurements taken at two second intervals by a nondirectional airspeed probe in accordance with ASHRAE Standard 55-1981[1].

RESULTS OF THE AIRSPEED TESTS

Airspeed contour drawings at 10 fpm intervals were drawn for five horizontal planes, six vertical transverse planes, and five vertical longitudinal planes of the room. A complete set of the drawings which encompass airspeed contour drawings and airspeed zones with temperature limits can be obtained from the College of Architecture and Environmental Design at Texas A&M University[8]. Drawings were prepared for both low speed and maximum speed condi tions of the ceiling fan.

Since the fan design and normal airspeed fluctuations within a room will relocate these maximum temperature zones to an unknown degree, the drawings should be viewed as a point-in-time condition for the test room and may not be representative of the zones in a similar room with a different fan and furnishings.

The low speed tests were conducted when the fan provided 155 fpm measured at 43 in. above the floor and on the center line of the fan blade. The low speed test was established for 200 fpm and the fan operated for a minimum of 15 minutes before tests began, but the actual test measurements showed lower airspeeds. The high speed tests were at the maximum ceiling fan speed. Example airspeed measurements for the 200 fpm were conducted at the 43 in. height prior to the room airspeed tests. These air speeds are shown in Table 3 for three locations on the blade of the fan.

For the low speed ceiling fan test, the fan created a high air speed jet of greater than 300 fpm that was approximately 2.5 ft. in diameter, cone shaped, and extended 2 ft. beneath the fan blade. For the maximum speed ceiling fan test, the jet was approximately 3.5 ft. in diameter and extended 4 ft. beneath the fan blade. The 4 ft. long jet extended 1.3 ft. into the comfort zone.

The main air plume from the fan at low airspeed was elliptical in shape with proportions similar to the room's proportions. This condition existed at the 88 in. airspeed measurement height and continued toward the floor. The air plume widened and encompassed the occupied zone of the room between the 24 in. and the 4 in. airspeed height.

The main air plume generally encompassed the edges of the occupied zone that were nearest to the fan, but the maximum speed fan test had greater main air plume coverage for all heights of the occupied zone edges that were closest to the fan than did the low speed fan test. Both fan tests failed to provide moderate airspeeds at the most distant edge of the occupied zone, located 10 ft. from the fan's center line. The lowest measured room airspeed usually occurred in the corner of the occupied zone which was most distant from the fan.

During the low speed fan test, some still air was measured in the 43 in. to 67 in. height region of the room. The still air had the appearance of an air jet, and it extended from the edge of the occupied zone which was most distant from the fan.

In most cases, the highest airspeeds typically occurred at either the C4 or C5 data points, but the highest measured airspeeds at the 4 in. height occurred at data point B3. This shift may have been caused by air moving down the north wall and along the floor which relocated the high airspeed region. The maximum and minimum measured airspeeds are shown in Table 4. The airspeeds were highest at the 24 in. and the 88 in. height when measured below the edge of the blade, and were highest between the 43 in. and 88 in. heights when measured either below the center of the blade or the center of the fan.

The fan plume dimensions and the airspeeds at the edge of the plume are shown for the low speed ceiling fan test in Table 5 and for the maximum speed ceiling fan test in Table 6. The fan plume edge is considered as the last airspeed contour which is closely grouped. Subsequent airspeed contours generally have increasing distances between the contours. The fan plumes for the low and maximum speed conditions were approximately 5.5 ft. wide and 6.7 to 8.0 ft. in length. The low speed fan test had a floor area coverage which averaged 38.2 $ft.^2$ which was similar to the floor area coverage of the high speed fan test of 42.9 $ft.^2$. The fan plume encompassed a horizontal length which was slightly larger than the diameter of the fan's blade and a vertical length which was between 1-1/2 and 2 times the diameter of the fan's blade. The airspeeds at the edge of the fan plume averaged 73 fpm for the low speed fan test and 105 fpm for the maximum speed fan test. The location of the centroid of the plume was directly beneath the fan.

The fan plume at the 4 in. height spread throughout the floor area of the room and provided airspeeds above 100 fpm in all areas of the floor except for the region of the room most distant from the fan. The low speed fan test allowed airspeeds below 100 fpm in 36 $ft.^2$ or 20 percent of the occupied area. The maximum speed fan test allowed airspeeds below 100 fpm in 2 $ft.^2$ or 1 percent of the occupied area at the 4 in. height.

With the ceiling fan operating at low speed, the areas of the occupied zone where comfort was maintained at temperatures of <82F, 82F, and 85F are shown in Table 7 and for the maximum speed fan test in Table 8. These temperature conditions relate to the three airspeed ranges of <50 fpm, greater than or equal to 50 fpm, and greater than or equal to 90 fpm respectively.

The tests showed that the ceiling fan operating at maximum speed had an effective area of coverage, not including the 4 in. height, of 1.50 to 1.75 times that of the ceiling fan functioning at low speed. The fan provided comfort to 82F in an average area of 97.2 $ft.^2$ for the low speed fan test and in an average area of 151.0 $ft.^2$ for the maximum speed fan test. At a temperature of 85F, this average area decreased to 31.8 $ft.^2$ for the low speed fan test and to 55.6 $ft.^2$ for the maximum speed fan test.

The average dimensions where comfort was maintained at a temperature of 82F and 85F are shown in Table 9 and 10. Table 11 shows the recommended dimensions for spacing a 52 in. diameter ceiling fan mounted at 8.5 ft. above the floor. For a maximum room temperature of 82F, the maximum on-center spacing for a ceiling fan at low speed is 12 ft. and at high speed is 14 ft. When the maximum room temperature is 85F, the maximum on-center spacing for the fan at low speed is 6 ft. and at high speed is 9 ft.

CONCLUSIONS

The ceiling fan tests indicated that the zone beneath the fan was the region of highest comfort when room temperatures were warm. The fan's main air plume from the fan was elliptical in shape with proportions similar to the room's proportions.

The tests showed that the 52 in. ceiling fan operating at low speed provided sufficient airspeed for comfort to 82F in an average floor area of 97.2 $ft.^2$ beneath the fan. When operating at maximum speed, the average floor area increased to 151.0 $ft.^2$. At 85F, the equivalent average floor areas for the low speed and maximum speed tests were 31.8 $ft.^2$ and 55.6 $ft.^2$ respectively.

Rule of thumb approximations for these areas include the zone encompassed by 2.5 to 3.0 diameters of the fan blade for low and maximum fan speeds at 82F. This decreased to 1.1 to 2.1 diameters of the fan blade for low and maximum fan speeds at 85F.

The maximum on-center spacing for a 52 in. diameter ceiling fan mounted at 8.5 ft. above the floor, operating at maximum speed, and providing comfort at a room temperature of 82F is 14 ft. For a temperature of 85F, it is 9 ft. More effective coverage occurs when the on-center spacing is one to two ft. less than the maximum.

The ceiling fan provided relatively high airspeeds throughout the largest floor area in the zone from the floor to the 24 in. height. With these higher airspeeds, children playing and adults sitting on the floor of the room should be more comfortable at warmer air temperatures than would people sitting in chairs or standing. When room temperatures fall, these people would also be susceptible to draft discomfort and slightly cool perceptions more frequently and more quickly than would people in most other room locations. For these reasons, ceiling fans should be used cautiously when rooms are comfortably air conditioned during warm seasons and are heated to normal winter set point temperatures and have children playing in the room or adults sitting on the floor of the room.

Future ceiling fans should be designed to create a larger main air plume. The ceiling fan airspeed contour drawings available from Texas A&M University[8] illustrate high airspeeds within the air plume, but rapid airspeed reductions beyond the edge of the air plume. The design of new blades, louvers, baffles, or other devices to enlarge the fan's main air plume would increase the comfort zone and the efficiency of ceiling fans in relation to human comfort.

REFERENCES

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Fig. 1 Floor Plan of Classroom used for the Tests

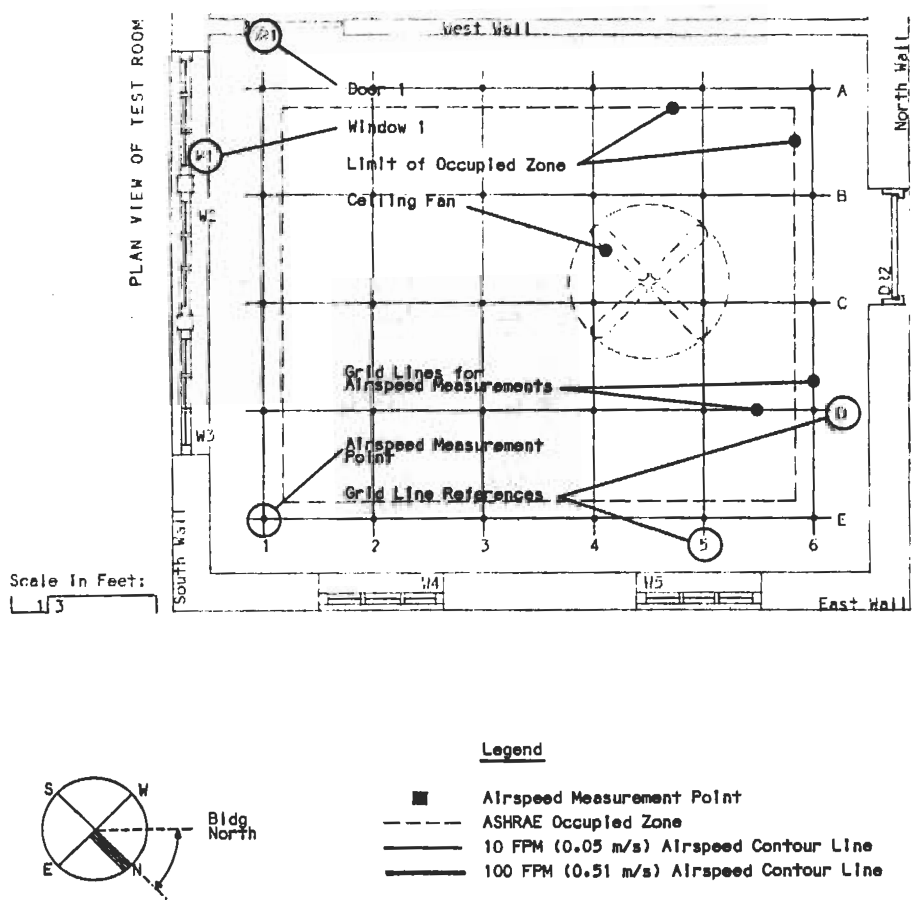

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TABLE 1
Airspeed Zones with Maximum Temperature Limits

Airspeed Zone	Airspeed Description	Airspeed Range fpm	Airspeed Range m/s	Maximum Temp. FET*	Maximum Temp. CET*
1	Still Air	<50	<.25	82	27.8
2	Moderate Airspeed	50-300	.25-1.5	85	29.4
3	High Airspeed	>300	>1.5	85	29.4

TABLE 2
Measured Human Comfort Conditions with Warm Temperatures and High Airspeeds

CONDITION	Fanger[3]*	Rohles[4]	Burton[5]	McIntyre[6]	Rohles[2]
Publication Year of Study	1970	1974	1975	1978	1983
Ceiling Fan Diameter in Inches (m)	(Ducts)	(Ducts)	56 (1.42)	48 (1.22)	52 (1.32)
Fan Height above Floor in Ft. (m)	9.25 (2.80)	12 (3.66)	7.25 (2.21)	6.42 (1.96)	8.50 (2.59)
Fan Distance from Ceiling in FT. (m)			2.33 (0.71)	1.50 (0.46)	1.50 (0.46)
Airspeed Measurement Height in Ft. (m)			4.92 (1.50)	4.33 (1.02)	3.58 (1.09)
Number of Subjects Tested	976	90	6	12	256
Predicted Percent Satisfied (PPS)	79	87	95	77	92
Relative Humidity	50	50	60	50	50
Fan Airspeed in Feet per Minute (m/s)	197 (1.00)	309 (1.57)	236 (1.20)	240 (1.22)	200 (1.02)
Maximum Temperature in F (C)	86.0 (30.0)	85.0 (29.4)	84.0 (28.9)	82.0 (27.8)	85.0 (29.4)
Equivalent Temperature (ET*) in F (C)	86.0 (30.0)	85.0 (29.4)	85.3 (29.6)	82.0 (27.8)	85.0 (29.4)

* Data taken from Tables in Referenced Text

TABLE 3
Airspeeds Measured at Five Heights and at Three Locations on the Blade of the Fan

MEASUREMENT HEIGHT in.	m.	EDGE OF BLADE fpm	m/s	CENTER OF BLADE fpm	m/s	CENTER OF FAN fpm	m/s
04	0.10	114.50	0.582	97.24	0.494	99.05	0.503
24	0.61	174.95	0.889	125.51	0.638	104.70	0.532
43	1.09	118.09	0.600	209.54	1.064	142.52	0.724
67	1.70	118.62	0.603	208.99	1.062	154.62	0.785
88	2.24	170.73	0.673	193.37	0.982	156.60	0.796

TABLE 4
Maximum and Minimum Measured Aispeeds for Ceiling Fan

Test Condition	Minimum Airspeed fpm	m/s	Airspeed Measurement Location	Maximum Airspeed fpm	m/s	Airspeed Measurement Location
Low Speed Fan Test	23.0	0.12	C2 43	345.0	1.75	C5 88
High Speed Fan Test	33.7	0.17	C1 88	381.1	1.94	C4 88

TABLE 5
Fan Plume Dimensions for Low Speed Fan Test

Airspeed Measurement Height		Fan Plume Dimensions & Coverage						Airspeed At Plume Edge	
		Width		Length		Area			
in.	m.	ft.	m.	ft.	m.	$ft.^2$	m^2	fpm	m/s
88	2.23	5.5	1.68	8.1	2.47	44.6	4.14	60	0.30
67	1.70	5.5	1.68	7.8	2.38	42.9	3.99	60	0.30
43	1.09	5.0	1.52	5.2	1.58	26.0	2.42	90	0.46
24	0.61	5.8	1.77	6.8	2.07	39.4	3.66	80	0.41
Average		5.5	1.66	6.7	2.13	38.2	3.55	73	0.37

TABLE 6
Fan Plume Dimensions for Maximum Speed Fan Test

Airspeed Measurement Height		Fan Plume Dimensions & Coverage						Airspeed At Plume Edge	
		Width		Length		Area			
in.	m.	ft.	m.	ft.	m.	$ft.^2$	m^2	fpm	m/s
88	2.23	5.5	1.68	8.4	2.56	46.2	4.53	80	0.41
67	1.70	5.0	1.52	7.0	2.13	35.0	3.43	110	0.55
43	1.09	5.7	1.74	8.2	2.49	46.7	4.58	110	0.55
24	0.61	5.5	1.68	8.2	2.49	43.5	4.27	120	0.61
Average		5.4	1.66	8.0	2.42	42.9	4.20	105	0.53

TABLE 7
Ceiling Fan Test at Low Speed

Airspeed Measurement Height		Area and Percent of Occupied Area Where Comfort was Maintained at a Temperature of								
		<82F (<27.8C)			82F (27.8C)			85F (29.4C)		
in.	m.	$ft.^2$	m^2	%	$ft.^2$	m^2	%	$ft.^2$	m^2	%
88	2.23	89.1	8.28	49.5%	90.9	8.44	50.5%	34.8	3.23	19.3%
67	1.70	80.1	7.44	44.5%	99.9	9.28	55.5%	28.0	2.60	16.1%
43	1.09	79.0	7.34	43.9%	101.0	9.38	56.1%	26.5	2.46	14.7%
24	0.61	83.0	7.71	46.0%	97.0	9.01	54.0%	37.8	3.51	21.0%
4	0.10	1.0	0.09	0.6%	179.0	16.63	99.0%	149.8	13.92	83.2%

TABLE 8
Ceiling Fan Test at Maximum Speed

Airspeed Measurement Height		Area and Percent of Occupied Area Where Comfort was Maintained at a Temperature of								
		<82F (<27.8C)			82F (27.8C)			85F (29.4C)		
in.	m.	$ft.^2$	m^2	%	$ft.^2$	m^2	%	$ft.^2$	m^2	%
88	2.23	34.1	3.17	18.9%	145.9	13.55	81.1%	45.6	4.24	25.3%
67	1.70	30.0	2.79	16.7%	150.0	13.94	83.3%	43.5	4.04	24.2%
43	1.09	51.9	4.82	28.8%	128.1	11.90	71.2%	68.0	6.32	37.7%
24	0.61	0.0			180.0	16.72	100.0%	65.2	6.06	36.2%
4	0.10	0.0			180.0	16.72	100.0%	176.6	16.41	98.1%

TABLE 9

Average Dimensions Where Comfort was Maintained at a Temperature of 82F With Airspeed >50 fpm

Ceiling Fan at Low Speed	Area in $ft.^2$	$m.^2$
Sitting: 11.0 ft. Diameter Oval	99	9.19
Standing: 11.0 ft. Diameter Oval	95	8.83
Ceiling Fan at Maximum Speed		
Sitting: 12.0 by 13.0 ft. Rectilinear Oval	154	14.31
Standing: 12.0 by 12.0 ft. Rectilinear Oval	148	13.74

TABLE 10

Average Dimensions Where Comfort was Maintained at a Temperature of 85F With Airspeed >90 fpm

Ceiling Fan at Low Speed	Area in $ft.^2$	$m.^2$
Sitting: 6.0 to 7.0 ft. Diameter Oval	32	2.97
Standing: 5.0 by 6.0 ft. Rectilinear Oval	31	2.88
Average	31.8	2.95
Ceiling Fan at Maximum Speed		
Sitting: 9.0 ft.Diameter Oval	67	6.22
Standing: 5.0 by 8.0 ft. Rectilinear Oval	45	4.18
Average	55.6	5.17

TABLE 11

Recommended Dimensions for Spacing a 52 in Diameter Ceiling Fan Mounted at 8.5 ft. above the floor and Providing Comfort at Temperatures of 82F and 85F

	Maximum Comfort Temperature		On Center Spacing for Ceiling Fan	
	F	C	$ft.^2$	$m.^2$
Operating at Low Speed	82.0	27.8	11.0-12.0	3.35-3.66
Operating at High Speed	82.0	27.8	12.0-14.0	3.66-4.27
Operating at Low Speed	85.0	29.4	5.0-6.0	1.52-1.82
Operating at High Speed	85.0	29.4	7.0-9.0	2.13-2.74