THERMAL COMFORT, INDOOR AIR QUALITY AND ENERGY CONSUMPTION STUDIES IN 12 OFFICE BUILDINGS

Fariborz Haghighat and Giovanna Donnini[*]

Centre for Building Studies, Concordia University, Montreal, Canada
[*]ADN Inc. Montreal, Canada

ABSTRACT:

The indoor air quality and thermal comfort were investigated in twelve mechanically ventilated buildings. Measured parameters concerning the quality of indoor air included ventilation rate, concentration of TVOC, CO_2, CO, RH, and formaldehyde. The thermal comfort parameters included room air, mean radiant, plane radiant asymmetry, and dew point temperatures, as well as air velocity and turbulence intensity, etc. Monthly energy consumption data was also gathered for each building.

Ventilation performance, in terms of air flow rate and indoor air quality, was compared with the Standard. The measured and calculated thermal environment results were also compared with the Standard and the Guideline.

1. INTRODUCTION

The quality of indoor air has become a major concern ever since efforts to reduce ventilation rates in buildings started. It has long been recognized that the quality of indoor air should not be improved at the expense of higher energy consumption. However, good indoor air quality and energy conservation practices can be compatible. To achieve a good indoor environment at minimum cost, it is necessary to determine where IAQ, ventilation, and energy conservation are naturally in competition and where they can work together.

The ANSI/ASHRAE Standard 55-92 "Thermal environmental conditions for human occupancy" (ASHRAE, 1992) is used extensively in Canada, as a reference for comfort levels. As more and more studies of Canadian buildings in the cold climate are emerging, it is apparent that the measured parameters satisfy the comfort limits as set out by ASHRAE, yet it is found that less than 80% of the occupants are satisfied (Haghighat et al. 1992). ANSI/ASHRAE Standard 55-92 is based almost entirely on data from climate chamber studies performed in temperate climates. This perhaps explains the discrepancies between occupant satisfaction in a cold climate and satisfaction of workers in a temperate climate.

2. OUTDOOR WEATHER CONDITIONS AND BUILDING CHARACTERISTICS

Measurements were carried out at several workstations of 12 mechanically ventilated buildings. The measurements were performed during normal occupancy. The investigated buildings vary greatly in surface area (3000 to 68 000 m^2), in number of floors (2 to 25 storeys), in date of construction (1945 to 1992), in type of HVAC system (free cooling CAV, double duct VAV), and in type of tenant (police station, court house, private company).

The measurements included physical and chemical monitoring, and assessment of the perceived indoor air quality, thermal comfort, etc. The chemical measurements included concentration of TVOC, formaldehyde, CO_2, and CO. The physical measurements consisted in operative temperature, air temperature, relative humidity, air velocity and ventilation rate. The monthly energy consumption of the building and the daily weather conditions were also recorded.

The mobile system collected concurrent physical data: air temperature, dew-point temperature, vapour pressure, globe temperature, radiant asymmetry, air velocity, turbulence, temperature of air supply, air return, and room, illuminance, carbon monoxide, carbon dioxide, formaldehyde, volatile organic compounds, and tracer gas decay. The transducers and measurement points were placed to represent the immediate environment of the seated subjects.

3. RESULTS AND CONCLUSION

3.1 VENTILATION PERFORMANCE

Outdoor fresh air is needed to maintain acceptable indoor air quality. The outdoor fresh air flow rate was measured using the decay tracer gas technique. The ventilation rate fell within 5 l/s/person, in building #5, and 93 l/s/person in building #4. Results also indicates that the ventilation rate in the majority of the buildings is much higher than the minimum 10 l/s/person recommended by the ASHRAE Standard 62-1989R.

3.2 INDOOR AIR CONTAMINANTS

The concentration of the following contaminants was measured during the heating and cooling seasons: CO_2, formaldehyde, TVOC, and CO. The level of CO_2 concentration was lower than the maximum permitted in the ASHRAE Standard, and was mainly between 450 and 650 ppm, in both seasons. In the investigated buildings, the CO_2 concentration was not a function of the ventilation rate; it is assumed that almost all the buildings were ventilated much higher than the ASHRAE Standard recommended.

The formaldehyde concentration in these buildings varied between 74 ug/m^3 in a large majority of buildings and 2190 ug/m^3 in one building (during both cooling and heating seasons). The concentration levels were significantly different during the heating and cooling seasons. No relationship was found between the ventilation rate and formaldehyde concentration during the cooling season. A relationship between these parameters was observed during the heating season; the HCHO concentration decreased as the ventilation rate increased.

The TVOC concentration level deviated between 36 ug/m^3 in building #6 in summer to 2590 ug/m^3 in the same building in winter, respectively. In some buildings, the variation of TVOC from one workstation to another was more than 100%. In general, no correlation was found between the ventilation rate and TVOC concentration.

The CO concentration level was almost the same as the outdoor CO concentration within all workstations and in all buildings.

3.3 THERMAL COMFORT

Detailed measurements of thermal comfort parameters were carried out at the exact physical position of the occupant in the workstation. The air and globe temperatures, as well as air velocity and turbulence, were measured at three heights (10, 60, 110 cm). The dew point temperature and vapour pressure were measured at one height (60 cm). Radiant asymmetry was also measured. This data was used to calculate the environmental and comfort indices: operative temperature, mean radiant temperature, effective temperature, predicted mean vote (PMV), predicted percentage of dissatisfied (PPD), and predicted percent dissatisfied due to draft (PD). Table 1 shows the statistical summaries of the indoor climate measurements during the cooling and heating seasons, respectively.

Mean air and radiant temperatures, averaged across the three heights, generally fell within 21 and 28°C for the cooling season, and within 20 and 28°C for the heating season. The variation in each individual building was very low; the standard deviation being less than 1°C. It was only from one building to the next that a large difference was seen. Vertical air temperature gradients were, on average, about 0.67°C/m in the occupied zone; which is within the Standard. Average relative humidities fell within 30 and 62%, in the cooling season, and within 10 and 39%, in the heating season. Mean air speeds, averaged over the three heights, were quite low: they averaged 0.09 m/s and ranged from 0.04 to 0.24 m/s during the cooling season, and averaged 0.08 m/s and ranged from 0.03 to 0.29 m/s during the heating season. Similar variations were also observed from one workstation to another, within the same building. The maximum average air speed in the occupied zone is specified by the ASHRAE Standard 55-1992 as 0.15 m/s in heating season and 0.25 m/s in cooling season. This indicates that during the heating season, the air speed in some workstations exceeded the ASHRAE limit. The turbulence intensities fell within 9 and 59% during the cooling season, and 6 and 66% during the heating season (average 32-33% for both seasons).

The ASHRAE Standard 55-1992 uses the operative temperature as the environmental parameter for evaluating global thermal comfort. The Standard then defines a range of operative temperatures and humidities that are acceptable to 80% or more of the occupants. This range is mainly applicable to a sedentary activity, 1.2 met, with normal winter clothing, 0.8-1.2 clo, or summer clothing, 0.6-0.8 clo. The measured parameters were used to calculate the operative temperature using Chapter 13 of the ASHRAE 1993 Fundamentals (ASHRAE, 1993), and the results were superimposed onto the Standard's comfort psychometric charts for both the heating and cooling seasons.

Data shows that only 63.4% of the measurements fall within the Standard's summer comfort zone (cooling season). The remaining 33.3% fall to the left of the comfort zone (within cooler temperatures). These percentages are based on the total amount sampled, and therefore is not an average value. This means that in some buildings, there is less than 63.4% of the occupants that are happy with their environment. Data Also indicates that during the heating season, only 26.9% of the measurements fell within the winter comfort zone (heating). The remaining 73.1% fell below the 2.5°C dewpoint level indicating the difficulty in humidifying buildings in the cold climate. Again, these percentages are based on the total amount sampled, so one might expect worse numbers in some buildings.

Table 2 shows a statistical summary of the thermal comfort indices for both seasons. On average, operative temperature, ET*, and SET values fell within the 22 to 24°C range. The PMV value fell within the -.02 to -.03 range; indicating marginally cooler-than-neutral conditions. The corresponding PPD ranged from 13.1 to 13.6%.

In evaluation of the operative temperature and defining the ASHRAE comfort zone for indoor air studies, two assumptions are made: activity level and clothing value. To verify the validity of the assumptions, the occupants were asked to identify their activity level up to one hour prior to filling the questionnaire. On average, the activity level of 1.2 met was acceptable in both heating and cooling seasons. The clothing insulation of the occupant was evaluated using the garment values published in ASHRAE Standard 55-1992. The intrinsic clothing value averaged 0.62 clo (males) and 0.53 clo (females) in the summer (about 16% higher than the 0.5 clo assumed in the Standard), averaged 0.93 clo (males) and 0.81 clo (female) in the winter (about 3% lower than the 0.9 clo assumed in the Standard).

The garment clo values of the occupants were then corrected by adding the chair clo values. The correction value was proportional to the amount of chair surface area in contact with the body (chair type). This modification increased the average level by 0.22 clo (males) and 0.09 clo (females) in the summer and 0.26 clo (males) and 0.14 clo (females) in the winter; increasing the insulation values to 0.84 clo (males) and 0.62 clo (females) in the summer and 1.19 clo (males) and 0.95 clo (females) in the winter. The clothing insulation values were much higher (about 0.11 clo) for the males than for the females, in both seasons. This difference was even greater when the effect of chairs was included (about 0.23 clo).

Some of the thermal environmental and comfort indices were re-evaluated by including the chair insulation values to the clothing values. The new indices are shown as the last four rows of Table 2. This translates into a 1.2 to 1.3°C increase in SET, and a 0.2 to 0.3% increase in PMV index, that corresponds to a 2.0 to 2.4% decrease in PPD index.

3.4 ENERGY PERFORMANCE

In mechanically ventilated buildings, the energy required to heat, cool, condition, and move the air amounts to from 30% up to 50% of the total building energy consumption. It is therefore, a common perception that energy saving will result in deterioration of indoor air. Data shows that energy cost varies from building to building. The average total energy cost per gross air- conditioned area fell between 0.92 to 6.4 $/m²/year. Data also indicates no apparent correlation between the ventilation rate and total energy cost. There are many reasons for this incoherent result.

The energy required for ventilation is only part of the total energy consumption; the other consumptions include conduction losses through the building envelope, lighting, elevators, office equipment (computers, fax machines, etc). The investigated buildings also used a wide variety of HVAC system types, and energy conservation measures such as heat recovery systems. As well, they used a variety of energy sources: electricity, gas, oil, etc. It was not possible to differentiate the actual amount of energy used solely for the ventilation from the rest of the consumption.

4. REFERENCE

ASHRAE 1992, ANSI/ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy. Atlanta: American Society of Heating, Refrigerating, and Air conditioning Engineers, Inc. USA.

Haghighat, F., Donnini, G. and D'Addario, R. (1992) "Relationship Between Occupants Discomfort as Perceived and as Measured Objectively", Indoor Environment; 112-118.

Measured indoor air parameters

Summer

	building	1	2	3	4	5	6	7	8	9	10	11	12	TOT
	sample size	40	39	40	41	44	41	40	31	40	40	43	6	445
air temperature (C)	mean	23.3	23.3	22.7	24.0	25.1	23.4	23.1	26.4	23.7	25.5	23.4	23.5	23.9
(average of 3 heights)	standard deviation	0.7	0.8	0.5	0.6	0.7	0.7	0.5	0.7	0.7	1.0	0.8	0.6	1.3
	minimum	21.5	21.2	21.7	21.7	23.4	21.7	22.1	24.6	22.1	23.3	21.9	22.6	21.2
	maximum	24.7	25.3	23.4	24.9	26.5	25.1	24.3	27.5	25.2	27.4	25.1	24.3	27.5
mean radiant	mean	22.9	22.5	22.0	23.4	24.8	22.7	22.6	25.3	23.0	24.8	23.0	22.7	23.3
temperature (C)	standard deviation	1.0	0.8	0.4	0.5	0.6	0.6	0.5	0.6	0.6	0.9	1.0	0.7	1.2
(calculated)	minimum	20.9	20.7	21.2	22.3	23.4	21.5	21.6	23.6	21.6	23.0	21.7	22.0	[illegible]
(average of 3 heights)	maximum	26.7	24.4	23.1	24.1	25.8	25.1	23.7	26.4	24.5	26.5	27.1	23.6	27.1
plane radiant	mean	1.4	0.6	1.0	0.6	0.8	0.6	0.9	0.7	0.6	1.3	1.5	0.9	0.9
asymmetry (C)	standard deviation	1.5	0.5	0.7	0.7	0.8	0.5	0.7	0.4	0.4	1.4	1.9	1.0	1.0
(above 1.1 m)	minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	maximum	6.0	2.1	3.3	4.3	3.1	2.2	2.5	1.5	1.6	5.3	10.3	2.9	10.3
dew point	mean	8.9	8.9	13.9	12.5	13.8	8.9	14.7	11.9	10.2	10.4	9.9	10.2	11.3
temperature (C)	standard deviation	1.0	2.2	0.4	1.3	0.8	1.0	0.3	1.4	0.5	1.3	0.6	0.2	2.3
(at 0.6 m)	minimum	7.5	5.4	13.0	9.9	12.5	7.1	14.0	10.2	9.5	9.0	9.3	10.0	5.4
	maximum	10.2	12.5	14.8	14.8	15.4	11.9	15.2	15.1	11.0	12.0	11.3	10.5	15.4
relative humidity (%)	mean	39.5	39.7	56.7	48.3	49.2	39.3	58.7	40.2	42.1	38.6	42.1	42.5	45.0
(calculated)	standard deviation	3.6	5.3	2.0	4.3	2.7	2.8	1.5	3.7	1.6	4.5	3.1	1.5	7.6
	minimum	33.0	29.5	53.5	39.5	45.0	34.3	54.7	36.9	37.2	32.3	37.7	40.3	29.5
	maximum	45.9	47.3	62.2	55.5	54.0	52.2	61.4	49.3	44.6	45.7	50.4	44.8	62.2
vapor pressure (kPa)	mean	1.1	1.2	1.6	1.5	1.6	1.1	1.7	1.4	1.2	1.2	1.2	1.2	1.4
(at 0.6 m)	standard deviation	0.1	0.2	0.0	0.1	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.2
	minimum	1.0	0.9	1.5	1.2	1.5	1.0	1.6	1.2	1.2	1.1	1.2	1.2	0.9
	maximum	1.3	1.5	1.7	1.7	1.8	1.4	1.7	1.7	1.3	1.4	1.3	1.3	1.8
air velocity (m/s)	mean	0.10	0.11	0.09	0.08	0.11	0.08	0.08	0.07	0.09	0.08	0.09	0.09	0.09
(average of 3 heights)	standard deviation	0.03	0.03	0.02	0.03	0.02	0.03	0.02	0.01	0.02	0.02	0.02	0.03	0.03
	minimum	0.06	0.06	0.05	0.05	0.06	0.05	0.04	0.05	0.06	0.05	0.06	0.06	0.04
	maximum	0.21	0.22	0.14	0.24	0.16	0.19	0.11	0.11	0.13	0.14	0.14	0.13	0.24
turbulence intensity (%)	mean	31.6	33.1	31.2	32.0	33.6	30.0	33.6	33.5	34.3	33.0	32.1	34.5	32.6
(calculated)	standard deviation	5.7	5.8	4.7	3.5	5.8	6.0	6.0	7.0	7.3	3.9	4.9	7.9	6.4
average of 3 heights)	minimum	21.0	22.0	22.0	9.0	22.0	20.0	20.0	22.0	23.0	20.0	22.0	23.0	9.0
	maximum	49.0	43.0	44.0	55.0	45.0	45.0	49.0	49.0	59.0	56.0	44.0	46.0	59.0

Winter

	building	1	2	3	4	5	6	7	8	9	10	11	TOT
	sample size	39	38	39	41	44	40	41	30	40	39	40	43
air temperature (C)	mean	22.9	23.2	23.2	[illegible]	23.1	22.8	23.2	22.7	23.7	22.2	23.3	23.0
(average of 3 heights)	standard deviation	0.4	1.0	0.5	0.5	0.7	0.6	0.8	1.0	0.7	1.0	0.7	0.8
	minimum	21.9	21.1	21.9	21.3	21.7	21.2	21.0	21.3	22.2	20.3	21.4	20.3
	maximum	23.9	25.1	24.2	23.7	24.6	23.8	26.3	24.6	24.9	23.7	24.5	26.3
mean radiant	mean	22.7	22.6	22.5	21.5	22.4	21.8	22.2	21.9	22.6	21.5	22.9	22.2
temperature (C)	standard deviation	1.2	0.9	0.5	0.5	0.6	0.5	0.7	0.9	0.6	1.0	0.5	0.9
(calculated)	minimum	21.6	20.8	21.2	19.8	21.2	20.7	20.1	20.2	20.6	19.5	21.4	19.5
(average of 3 heights)	maximum	28.3	24.9	23.6	22.4	23.8	22.8	23.7	23.7	23.7	23.3	23.8	28.3
plane radiant	mean	1.2	1.2	0.6	1.0	1.2	0.7	1.2	0.9	1.4	1.5	0.8	1.1
asymmetry (C)	standard deviation	1.4	1.5	0.4	1.0	1.3	0.5	1.0	0.7	1.1	1.4	0.6	1.1
(above 1.1 m)	minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0
	maximum	5.9	10.0	1.5	3.9	4.2	2.2	4.1	3.0	4.0	5.7	2.6	10.0
dew point	mean	5.5	2.5	1.4	1.4	5.5	3.9	0.7	5.6	5.2	1.2	5.1	3.5
temperature (C)	standard deviation	2.2	2.0	0.8	0.6	2.0	0.6	0.5	1.6	1.0	0.8	0.9	2.5
(at 0.6 m)	minimum	1.3	0.3	0.2	0.1	0.3	2.4	0.1	0.8	3.9	0.1	2.1	0.1
	maximum	9.1	5.8	3.2	2.7	8.8	5.1	2.0	7.8	8.9	4.6	6.7	9.1
relative humidity (%)	mean	16.5	17.8	23.5	19.5	13.7	28.8	22.4	32.7	12.3	20.8	30.5	21.4
(calculated)	standard deviation	8.0	3.0	1.2	1.0	2.8	1.2	1.4	3.5	1.0	1.2	1.7	7.0
	minimum	10.0	11.7	21.5	16.9	10.0	26.0	19.9	21.5	9.7	17.3	26.9	9.7
	maximum	31.5	23.2	26.7	22.9	20.7	31.8	25.9	29.2	34.0	23.3	34.8	39.2
vapor pressure (kPa)	mean	0.5	0.5	0.7	0.5	0.4	0.8	0.6	0.9	0.4	0.6	0.9	0.6
(at 0.6 m)	standard deviation	0.2	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.2
	minimum	0.3	0.3	0.6	0.5	0.3	0.7	0.6	0.6	0.3	0.4	0.7	0.3
	maximum	0.9	0.7	0.8	0.6	0.6	0.9	0.7	1.1	0.4	0.7	1.0	1.1
air velocity (m/s)	mean	0.10	0.11	0.09	0.06	0.08	0.07	0.08	0.07	0.08	0.07	0.09	0.08
(average of 3 heights)	standard deviation	0.03	0.05	0.03	0.01	0.02	0.02	0.04	0.03	0.03	0.03	0.03	0.03
	minimum	0.06	0.05	0.05	0.05	0.05	0.04	0.05	0.03	0.03	0.04	0.05	0.03
	maximum	0.17	0.24	0.20	0.10	0.12	0.12	0.29	0.16	0.15	0.16	0.19	0.29
turbulence intensity (%)	mean	33.0	32.5	33.3	29.6	31.3	30.3	32.0	34.9	30.9	33.4	31.4	31.6
(calculated)	standard deviation	5.8	5.5	4.6	5.5	4.9	5.8	7.1	8.4	9.1	9.2	4.3	6.8
average of 3 heights)	minimum	18.0	21.0	22.0	20.0	21.0	16.0	12.0	19.0	6.0	18.0	21.0	6.0
	maximum	44.0	44.0	44.0	42.0	42.0	46.0	48.0	52.0	54.0	66.0	46.0	66.0

Statistical summary of calculated indoor climatic and thermal comfort indices

		Summer													Winter											
	Building	1	2	3	4	5	6	7	8	9	10	11	12	TOT	1	2	3	4	5	6	7	8	9	10	11	TOT
	sample size	40	39	40	41	44	41	40	31	40	40	43	6	445	39	38	39	41	44	40	41	30	40	39	40	431
operative temperature	mean	23.1	22.9	22.3	22.7	24.9	23.1	22.5	25.3	23.3	25.1	23.2	23.1	23.6	22.8	22.9	22.9	22.1	22.8	22.3	22.7	22.2	23.2	21.9	23.1	22.5
(C)	standard deviation	0.8	0.8	0.4	0.5	0.6	0.6	0.5	0.6	0.6	0.9	0.9	0.6	1.2	0.7	0.9	0.5	0.5	0.6	0.5	0.7	1.0	0.6	1.0	0.6	0.8
	minimum	21.3	21.0	21.4	22.2	23.5	21.7	21.9	24.1	21.8	23.2	21.9	22.3	21.0	21.9	21.1	21.6	20.5	21.5	21.1	20.5	20.9	22.0	19.9	21.5	19.9
	maximum	25.6	24.5	23.1	24.5	26.1	25.1	24.0	26.9	24.9	26.3	25.6	23.9	26.9	25.9	25.0	23.8	23.0	24.2	23.3	23.9	24.2	24.3	23.2	24.1	25.9
ET* (C)	mean	23.0	22.8	22.4	22.6	24.9	22.9	22.9	25.6	23.2	24.9	23.1	23.0	23.5	22.2	22.2	22.3	21.6	22.1	21.9	22.1	22.0	22.4	21.4	22.7	22.1
	standard deviation	0.8	0.9	0.4	0.5	0.6	0.6	0.5	0.6	0.6	0.8	0.9	0.6	1.2	0.8	0.9	0.5	0.5	0.6	0.5	0.7	0.9	0.7	0.9	0.6	0.6
	minimum	21.2	20.9	21.6	22.2	23.5	21.6	22.0	23.7	21.7	23.1	21.9	22.2	20.9	20.9	20.4	21.3	20.2	20.1	20.9	20.2	20.6	20.1	19.5	21.3	19.5
	maximum	25.6	24.5	23.2	24.4	26.5	25.9	24.1	26.8	24.6	26.5	25.7	23.7	26.6	24.8	24.5	23.5	22.5	23.7	22.9	23.6	23.8	23.7	22.9	23.8	24.8
SET (C)	mean	23.3	23.1	23.0	23.0	24.0	23.1	22.7	25.6	23.5	24.3	23.5	24.0	23.5	24.6	25.0	25.0	23.6	24.3	24.1	24.1	23.6	24.5	24.5	25.0	24.4
	standard deviation	1.3	2.0	2.3	1.1	1.2	2.3	1.7	1.7	2.0	1.4	1.5	1.9	1.9	1.8	2.4	2.1	2.1	2.1	1.9	1.9	2.2	2.3	2.1	2.5	2.2
	minimum	20.8	19.4	20.2	21.2	21.9	19.6	20.1	22.9	19.8	21.3	20.4	21.3	19.4	21.0	20.5	20.8	20.0	21.0	21.2	20.7	19.8	20.7	20.7	18.9	18.9
	maximum	27.2	29.2	28.6	25.8	27.4	30.4	27.7	30.6	29.2	29.1	26.7	27.1	30.9	28.1	29.8	29.7	27.7	29.4	29.5	29.0	29.4	30.5	29.3	30.4	30.5
DISC (from 2-node)	mean	-0.1	-0.1	0.0	-0.1	0.0	-0.1	-0.1	0.2	0.0	0.0	-0.1	0.0	0.0	0.1	0.2	0.1	-0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.1
	standard deviation	0.2	0.3	0.3	0.1	0.2	0.3	0.2	0.4	0.3	0.2	0.1	0.2	0.2	0.3	0.4	0.3	0.2	0.3	0.3	0.3	0.3	0.4	0.3	0.5	0.3
	minimum	-0.3	-0.4	-0.3	-0.3	-0.2	-0.5	-0.4	-0.2	-0.4	-0.2	-0.3	-0.2	-0.5	-0.3	-0.3	-0.3	-0.4	-0.4	-0.2	-0.4	-0.4	-0.3	-0.3	-0.6	-0.6
	maximum	0.6	1.1	0.8	0.1	0.6	1.4	0.7	1.6	1.0	0.8	0.4	0.5	1.6	0.8	1.3	1.1	0.6	1.1	1.1	1.0	1.2	1.5	1.1	1.5	1.5
PMVF	mean	-0.4	-0.4	-0.4	-0.4	-0.1	-0.5	-0.4	0.3	-0.4	0.0	-0.3	-0.2	-0.3	-0.2	-0.1	-0.1	-0.5	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.1	-0.2
	standard deviation	0.5	0.6	0.6	0.4	0.4	0.7	0.5	0.5	0.6	0.5	0.5	0.4	0.6	0.5	0.6	0.6	0.6	0.6	0.5	0.6	0.6	0.6	0.6	0.7	0.6
	minimum	-1.7	-2.2	-1.5	-1.3	-1.3	-2.1	-1.9	-0.9	-2.0	-1.0	-1.5	-0.7	-2.2	-1.6	-1.9	-1.6	-1.9	-1.5	-1.2	-1.6	-1.9	-1.4	-1.5	-2.7	-2.7
	maximum	0.5	0.7	0.7	0.4	0.7	0.9	0.8	1.2	0.9	0.9	0.5	0.4	1.2	0.7	0.9	0.7	0.6	0.7	0.7	0.8	0.9	0.8	0.9	0.9	0.9
PPDF (%)	mean	14.3	15.2	15.7	11.0	8.7	18.3	13.5	11.5	15.0	9.8	13.3	8.8	13.1	11.7	12.9	12.0	17.6	13.8	12.4	13.6	14.6	12.9	12.7	14.6	13.6
	standard deviation	12.8	16.4	12.5	8.7	6.6	20.1	12.3	7.9	14.5	5.7	10.9	2.9	12.5	9.8	13.6	10.6	16.7	11.7	8.4	11.7	10.5	9.7	10.2	15.7	12.4
	minimum	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	maximum	60.0	84.0	53.0	42.0	40.0	81.0	68.0	33.0	74.0	54.0	53.0	14.0	84.0	55.0	71.0	56.0	70.0	51.0	35.0	58.0	73.0	46.0	51.0	97.0	97.0
predicted draught	mean	7.5	8.2	6.4	5.0	6.6	4.5	5.4	2.3	5.4	4.3	5.0	6.2	5.7	8.0	8.5	6.3	2.7	5.0	3.3	5.0	3.9	3.9	4.7	6.3	5.2
dissatisfaction (%)	standard deviation	3.1	4.7	2.5	5.5	2.6	3.7	1.9	1.7	1.9	2.7	2.3	2.9	3.5	3.1	5.4	3.0	2.1	2.8	3.1	3.8	3.9	3.0	3.8	3.2	3.6
	minimum	2.3	2.2	0.0	0.0	1.8	0.0	2.4	0.0	2.1	0.0	2.0	2.2	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	maximum	17.6	25.2	11.8	35.3	12.9	16.3	9.8	7.9	9.9	11.3	12.1	10.1	35.3	16.3	23.5	16.1	8.0	10.9	10.5	20.2	15.7	11.1	16.3	16.9	23.5
SET (C)	mean	24.5	24.3	24.5	24.2	25.1	24.4	22.9	26.7	24.5	25.5	24.7	24.5	24.7	25.9	26.2	26.6	24.9	25.5	25.1	25.1	25.3	25.6	26.1	26.1	25.7
(including chair	standard deviation	2.1	2.4	2.8	1.3	1.5	2.7	2.1	2.0	2.4	1.7	1.6	1.9	2.2	1.9	2.7	2.3	2.1	2.2	2.2	2.2	2.3	2.4	2.2	2.7	2.3
insulation)	minimum	20.8	20.4	20.4	21.8	21.9	19.6	20	22.9	19.8	21.3	21.8	21.8	19.3	21.0	20.5	22.4	21.4	21.4	21.6	20.7	21.3	21.5	22.4	20.3	20.3
	maximum	28.7	31.1	31.0	27.2	28.6	32.2	30.5	30.8	31.2	30.2	28.6	27.1	32.2	30.5	31.2	31.3	29.3	30.9	31.4	30.6	31.6	32.1	30.8	31.6	32.1
DISC (from 2-node)	mean	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.4	0.1	0.2	0.1	0.1	0.1	0.2	0.4	0.4	0.1	0.2	0.2	0.1	0.2	0.2	0.3	0.4	0.2
(including chair	standard deviation	0.3	0.4	0.5	0.1	0.3	0.4	0.3	0.5	0.5	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.5
insulation)	minimum	-0.3	-0.3	-0.3	-0.2	-0.2	-0.5	-0.4	-0.2	-0.4	-0.2	-0.2	-0.2	-0.5	-0.3	-0.3	-0.2	-0.3	-0.3	-0.2	-0.4	-0.3	-0.2	-0.2	-0.4	-0.4
	maximum	0.9	1.7	1.6	0.5	0.9	2.0	1.6	1.7	1.7	1.4	0.8	0.5	2.0	1.5	1.8	1.7	1.0	1.6	1.6	1.4	1.9	2.1	1.6	1.9	2.1
PMVF	mean	-0.1	-0.1	-0.1	-0.1	0.1	-0.2	-0.1	0.5	-0.1	0.2	-0.1	-0.1	0.0	0.1	0.1	0.2	-0.2	0.0	-0.1	-0.1	0.0	0.0	0.1	0.1	0.0
(including chair	standard deviation	0.5	0.6	0.6	0.3	0.4	0.7	0.5	0.5	0.6	0.4	0.4	0.4	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.6	0.6	0.5	0.5	0.6	0.5
insulation)	minimum	-1.4	-1.3	-1.0	-0.9	-1.3	-2.1	-1.3	-0.9	-2.0	-0.9	-1.1	-0.7	-2.1	-1.6	-1.9	-1.0	-1.3	-1.4	-1.0	-1.6	-1.4	-1.1	-1.0	-2.0	-2.0
	maximum	0.7	1.0	0.9	0.7	0.9	1.0	1.0	1.2	1.1	1.1	0.7	0.4	1.2	1.0	1.1	0.9	0.7	0.9	0.9	0.9	1.1	0.9	1.0	1.0	1.1
PPDF (%)	mean	10.8	12.6	11.6	7.5	8.6	14.2	10.9	15.3	12.9	10.2	9.1	8.0	11.1	10.2	13.1	10.7	11.6	11.2	9.9	12.0	10.9	10.9	9.7	13.4	11.2
(including chair	standard deviation	8.1	9.9	6.3	3.6	6.5	15.0	12.3	9.7	13.8	6.0	5.6	3.2	9.5	9.8	13.7	5.2	8.3	8.3	5.6	11.1	9.5	6.5	5.6	12.4	9.1
insulation)	minimum	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	maximum	47.0	41.0	27.0	18.0	40.0	79.0	68.0	37.0	74.0	31.0	28.0	14.0	79.0	55.0	71.0	26.0	41.0	48.0	25.0	58.0	43.0	29.0	26.0	79.0	79.0