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Heating, ventilation and air conditioning: Validation of system cleaning initiation criteria under real conditions

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Chemical Substances and Biological Agents

Studies and Research Projects

REPORT **R-666**

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ABSTRACT

Dust accumulation in the components of HVAC systems is a potential source of contaminants. To date, very little information is available on recognized methods for assessing dust build-up in these systems. The few existing methods are either objective in nature, involving numerical values, or subjective in nature, based on experts' judgments. It is therefore difficult for building managers to assess the proposals made by specialized cleaning companies.

An earlier project aimed at assessing different methods of sampling dust in ducts was carried out in the IRSST's laboratories. The goal was to reproduce different levels of dust accumulation in non-porous metal ducts in the laboratory, to compare the different methods of sampling surface dusts cited in the literature, to compare numerical evaluation methods with the visual inspection method, and to establish application procedures. This laboratory study showed that all the sampling methods were practicable, provided that a specific surface-dust cleaning initiation criterion was used for each method. However, these conclusions were reached on the basis of ideal conditions in a laboratory using a reference dust from the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). The conclusions reached therefore required validation under real conditions.

The objective of this study was to validate these laboratory results in the field. To this end, the laboratory sampling templates were replicated in real ducts and the three sampling methods (the IRSST method, the method of the American organization National Air Duct Cleaner Association (NADCA) and that of the French organization Association pour la prévention et l'étude de la contamination (ASPEC)) were used simultaneously in a statistically representative number of systems. The air return and supply ducts were also compared.

The cleaning initiation criteria under real conditions were found to be 6.0 mg/100 cm² using the IRSST method, 2.0 mg/100 cm² using the NADCA method, and 23 mg/100 cm² using the ASPEC method. In the laboratory study, the criteria using the same methods were 6.0 for the IRSST method, 2.0 for the NADCA method, and 3.0 for the ASPEC method. The laboratory criteria for the IRSST and NADCA methods were therefore validated in the field. The ASPEC criterion was the only one to change. Moreover, no statistical differences were found between the return and supply ducts.

The ASPEC method therefore allows for the most accurate evaluation of dust accumulation in HVAC system components. It is also the method that cleaning companies instinctively prefer as it most closely resembles customary cleaning processes. We therefore recommend using the latter method to objectively assess dust accumulation levels in HVAC systems.

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1. INTRODUCTION

Dust accumulation in the components of HVAC systems may be a potential source of contaminants. Building occupants are becoming increasingly adamant that their systems be free of dirt and dust. However, there is little information available on recognized or standardized methods for assessing dust accumulation in these systems. It is therefore difficult for building managers to evaluate the proposals made by specialized cleaning companies, as no recommended objective methods exist for assessing dust concentrations on duct surfaces. Ideally, HVAC systems should be maintained at optimum cleanliness levels. To do so, it is important to have the necessary tools for measuring the amount of dust deposited in the components of these systems. An objective diagnostic process helps prevent abuses and unnecessary system cleaning (1).

In the United States and Canada, the initiation of air system cleaning is currently based on visual inspection (2-4). However, these criteria are subjective and impractical when large-scale cleaning work is involved (5). In 2006, the American organization National Air Duct Cleaner Association (NADCA) published criteria for post-cleaning cleanliness acceptance. However, these criteria are inadequate if someone wants to know when to initiate cleaning of the components of HVAC systems (4).

France's Association pour la prévention et l'étude de la contamination (ASPEC, or association for the prevention and study of contamination) has also published a guide on methods for maintaining cleanliness in non-porous air systems for clean rooms and associated controlled environments (1). This guide reports on the cleaning initiation criteria for buildings in the tertiary sector (e.g. office buildings) and dust-sampling methods used in different countries. Table 1 presents these criteria.

In this table, the criteria cited refer to different dust sampling methods, thus making comparisons difficult. According to ASPEC, these methods can only be applied in rigid, non-porous ducts that are sufficiently large, i.e. round components that are larger than 30 cm in diameter; the ducts must also be horizontal and the walls dry (1). Samples must be taken from a layer of dust distributed on the bottom surface and not from dust piles (1). The sampling methods were found to have certain deficiencies, including primarily the absorption of moisture from the air by the cellulose ester membranes and dust adhesion to the walls of the cassettes and sampling tubes.

Table 1: Criteria for initiating cleaning of non-porous ducts

Country	Cleaning initiation criterion based on surface density (g/m^2)	Cleaning initiation criterion based on thickness (µm)	Post-cleaning acceptance criterion (g/m^2)	Sampling method
United States (NADCA 2006)	-	-	0.075	Surface sampling on membrane at 15 L/min (open cassette)
Great Britain (1998)	Blowing: 1 Exhaust: 6	Blowing: 60 Exhaust: 180	0.1	Surface sampling on membrane at 15 L/min
Finland (2001)	Blowing: 2 Exhaust: 5	-	0.1	Surface sampling on membrane at 10L/min (with sampling tube)
France ASPEC (2004)	Blowing: 0.4 Exhaust: 6	-	0.1	Surface sampling on membrane at 15L/min (with sampling tube)

One method designed to reduce these problems involves weighing the entire cassette system and using as the sampling head the pre-weighed IOM cassette with a 25-mm diameter (SKC Inc. Eighty Four, PA, USA) equipped with a polyvinyl chloride (PVC) membrane with a pore size of 0.8 µm. This sampling method was compared in the laboratory to the methods cited in the literature in order to determine which was the most accurate (5). The objectives of the earlier project (see IRSST Report R-525) were to reproduce different levels of dust accumulation in a non-porous metal duct in the laboratory, to compare different surface-dust sampling methods, to compare numerical evaluation methods to visual inspection methods, and to determine application procedures.

All sampling methods were shown to be practical, provided that the corresponding surface-dust cleaning initiation criterion is used. Using the visual inspection method, for an average expert's rating of 2 on a scale of 3, the corresponding values were 2.0 mg/100 cm² using the NADCA method, 3.0 mg/100 cm² using the ASPEC method, and 6.0 mg/100 cm² using the IRSST method (5). Level 2 signified a uniform layer and localized dust accumulations in the ducts and therefore that cleaning was required. Level 1 corresponded to a relatively clean duct, and level 3 to an extremely dirty duct. These methods yielded surface sampling values that differed significantly from one method to the other ($p \leq 0.05$). The dust used was the standard dust recommended by ASHRAE (6).

The main objective of this actual project was to validate, under real conditions in the field, the results obtained in the laboratory study regarding the criteria for initiating cleaning of non-industrial HVAC systems (IRSST Report R-525) (office buildings, schools and hospitals), using the dust deposited in the components of the HVAC systems of such buildings following normal system use. To do so, we reproduced the laboratory sampling templates in real ducts and repeated the three sampling procedures simultaneously (the IRSST, ASPEC, and NADCA methods) in a statistically representative number of systems. We chose the method yielding the most accurate results and the smallest standard deviation. The air supply and return ducts were also compared.

2. METHOD

The advantages and disadvantages of the three methods evaluated are reported in Table 2. Contrary to the laboratory study, in this field study the IOM cassette (IRSST method) was made of stainless steel rather than plastic, which eliminated the weight fluctuations attributable to the moisture absorption associated with plastic.

Table 2: Advantages and disadvantages of the methods

NADCA Vacuum test (0.8 µm cellulose ester membrane in an open cassette 37 mm in diameter; 15 L/min.; vacuumed duct surface of 100 cm²) (2006)	Advantage	- Method recognized in industrial hygiene
	Disadvantages	- Dust deposited on the inside walls of the cassette - Cellulose ester membrane fragile and sensitive to moisture
French method ASPEC (0.8 µm cellulose ester membrane in a closed cassette 37 mm in diameter; connected to a bevelled tube; 15 L/min.; vacuumed duct surface of 100 cm²) (2004)	Advantages	- Bevelled tube facilitates sampling - The fact of being able to stick the sampling tube on the duct surface makes it easier to aspirate all the dust
	Disadvantages	- Cellulose ester membrane sensitive to moisture - Adhesion to the inside walls of the sampling tube of the cassette
Method being developed by the IRSST (0.8 µm PVC membrane in an IOM stainless steel cassette 25 mm in diameter; 15 L/min.; vacuumed duct surface of 33.82 cm²) (2009)	Advantages	- Membrane made of PVC (less sensitive to moisture) - No loss of dust through adhesion to the inside walls because the whole cassette is weighed
	Disadvantages	- The template needs to be adapted to the circumference of the cassette sampling head

The earlier results obtained in the laboratory study established that the minimum number of samplings required to demonstrate a difference between two geometric means was 5 (n = 5) for an acceptable error of 10% and a confidence level of 95% (t = 1.96) (5,7). First, some 30 HVAC systems that had no interior insulation, and a maximum of three HVAC systems per building, were identified. This step was facilitated by the involvement of members of the follow-up committee (cleaning companies and building managers).

Three simultaneous sampling procedures were performed for each of the systems, using the three previously evaluated methods described in Table 2 (5). Insofar as possible, the samples were taken from the supply diffusers in the rooms, at a reasonable distance from the last elbow and at the furthest accessible point in the air duct. Weighings were performed using the IRSST's standard method (8). Figure 1 shows a duct undergoing evaluation using a template.

Figure 1: Return duct outfitted with sampling template

Samplings were also taken from the return ducts in each building. The literature mentions the need to clean such ducts when surface dust concentrations exceed 50 to 60 mg/cm² of surface (1,5). The final step involved subjective assessment through the visual inspection of cleanliness levels by the same sub-committee of experts that took part in Project R-525. This evaluation consisted of the visualization of the deposits shown in photographs that were taken from angles both parallel to and perpendicular to the ducts evaluated. A three-level rating scale was used, in which level 1 was normal, meaning clean ducts or those with a thin, uniform layer of dust; level 2, or above normal, corresponded to a uniform layer of dust and localized accumulations; and level 3, or serious, corresponded to significant dust accumulations (5,9). The sub-committee of experts had seven members. Given the discrete nature of the ratings, the median value was used to calculate an average rating for each system, with a value of 2 corresponding to the initiation of cleaning.

Forty-four different sites were evaluated, giving a total of 132 samples (44 sites X 3 methods each). Eleven of these sites involved return ducts. Two-factor (ducts and methods) and three-level (surface dust concentrations obtained using three methods) variance analyses (ANOVA) were performed on the value logarithms to determine whether there were statistically significant differences ($p \leq 0.05$) (10). Regressions were then performed, and the degree of correlation was calculated in order to assess the relationship among the three sampling methods. Similarly, inter-expert agreement in terms of their visual inspections was quantified using Krippendorff's alpha index (11). An index of 1 indicated that the experts came up with the same rating for each system evaluated. An index of 0 indicated the absence of concurrence among their evaluations.

3. RESULTS AND DISCUSSION

Table 3 shows the results obtained by the seven experts and the weighings obtained in mg/100 cm² for the 44 ducts. The weighing detection limit was 0.02 mg, i.e. the minimum value reported for the method, divided by the square root of 2 (12,13).

Table 3: Median of the seven experts' ratings (ratings 1 to 3) and corresponding weighings in mg/100cm²

IRSST	ASPEC	NADCA	Median of the experts' ratings	Duct no.
9.11	7.16	2.69	2	1[r]
1.00	2.95	0.76	1	2
0.92	2.00	0.42	1	3
1.51	4.04	0.63	1	4
0.21	27.9	1.68	2	5
0.24	0.39	0.018	2	6
0.56	8.45	1.09	2	7
0.74	1.09	1.35	1	8
3.58	2.23	1.35	2	9[r]
2.84	5.20	0.51	1	10
1.18	0.90	0.17	1	11
55.38	155.25	155.75	2	12[r]
0.89	6.74	0.26	1	13
0.13	1.62	0.07	1	14
23.99	17.89	1.23	1	15
13.99	28.25	1.67	1	16
1.42	29.08	4.66	2	17[r]
19.94	36.16	2.26	2	18
10.27	46.55	24.54	2	19[r]
1.92	6.57	3.32	1	20
14.44	7.56	0.66	1	21
7.23	13.61	2.28	1	22
2.37	42.13	2.92	3	23
51.2	62.31	2.28	1	24
67.27	67.09	15.55	1	25[r]
110.63	218.33	57.98	2	26
0.56	7.12	0.02	2	27
281.38	333.77	112.69	3	28[r]
3.98	1.97	1.31	1	29[r]
22.78	2.70	0.70	2	30
0.71	7.60	0.05	1	31
13.45	8.47	3.22	1	32
8.58	14.56	1.49	2	33

15.95	23.29	1	1	34
7.13	0.14	0.02	1	35
0.12	2.80	0.12	1	36[r]
0.68	5.00	0.34	1	37
0.95	3.43	0.14	2	38[r]
1.54	58.75	2.61	2	39
87.73	159.18	32.64	2	40[r]
169.41	159.97	53.37	2	41
68.16	237.97	21.25	2	42
1.6	29.57	1.12	2	43
16.07	32.75	1.02	2	44

[r] = air return duct

3.1 Inter-expert agreement

One of the objectives of this project was to replace the subjective evaluation of the cleanliness levels of HVAC systems (the rating method) by a more objective method based on weighings. To demonstrate the degree of subjectivity of the ratings, we compared the seven experts' ratings of the same ducts.

Taking the ratings as a whole, some experts' ratings differed in a statistically significant manner from the ratings given by other experts ($p<0.001$; $F = 6.2$) (log-ANOVA test) (10). "F" represents Fisher's test statistic. The higher F was, the greater the difference in the experts' ratings.

Based on a Tukey-Kramer multiple comparison test, Expert One cast gave significantly higher ratings (1) ($p\leq0.05$) than the six other experts, while Expert Five gave significantly lower ratings than both experts One and Two ($p\leq0.05$) (10).

Another criterion used in our study to measure the reliability of the different experts' ratings was Krippendorff's alpha index (11). The index was calculated at 0.37. At the very most, this corresponds to moderate agreement among the experts and also shows the subjective nature of the ratings.

3.2 Criteria for initiating cleaning

Table 3 shows that 20 out of 44 ducts obtained a median rating of 2, hence a recommendation that cleaning be carried out. Table 4 shows the geometric means and geometric standard deviations of these values.

A log-ANOVA test on these values showed statistically significant differences among the three sampling methods ($p<0.001$; $F = 9.5$).

Table 4: Dust concentrations (in mg/100 cm²) in the ducts to be cleaned

IRSST	ASPEC	NADCA	Median of the ratings	Duct no.
9.11	7.16	2.69	2	1
0.21	27.9	1.68	2	5
0.24	0.39	0.018	2	6
0.56	8.45	1.09	2	7
3.58	2.23	1.35	2	9
55.38	155.25	155.75	2	12
1.42	29.08	4.66	2	17
19.94	36.16	2.26	2	18
10.27	46.55	24.54	2	19
110.63	218.33	57.98	2	26
0.56	7.12	0.02	2	27
22.78	2.7	0.7	2	30
8.58	14.56	1.49	2	33
0.95	3.43	0.14	2	38
1.54	58.75	2.61	2	39
87.73	159.18	32.64	2	40
169.41	159.97	53.37	2	41
68.16	237.97	21.25	2	42
1.6	29.57	1.12	2	43
16.07	32.75	1.02	2	44
6.48	22.56	2.39	**Geometric mean (cleaning initiation criterion)**	
7.91	5.48	10.93	**Geometric standard deviation**	

The cleaning initiation criteria corresponding to the geometric mean obtained using each of the three methods for the 20 ducts were therefore 6.0 mg/100 cm² for the IRSST method (geometric mean of 6.48), 2.0 mg/100 cm² for the NADCA method (geometric mean of 2.39) and 23 mg/100 cm² for the ASPEC method (geometric mean of 22.56). In the laboratory study, the criteria for these same methods were 6.0 for the IRSST method, 2.0 for the NADCA method and

3.0 for the ASPEC method (5). The field criteria obtained were therefore similar to the laboratory criteria with respect to both the IRSST and NADCA methods. Only the ASPEC criterion changed. It must be recalled that the two other methods did not involve direct contact with the dust. In fact, there was a distance of 0.381 mm between the cassette and the duct surface (4,5), such that only the surface dust was aspirated and aspiration was incomplete. By contrast, the ASPEC method allows virtually the entire dust deposit to be scraped and collected. All the dust is therefore dislodged and aspirated. This method also yields the smallest geometric standard deviation (Table 4) and thus, the most reliable results.

A statistically significant correlation exists among these three methods. The correlation coefficient between the IRSST and NADCA methods is 0.74, with a value of $F = 51.01$ and a $p<0.001$. The correlation coefficient between the ASPEC and NADCA methods is 0.83, with a value of $F = 90.89$ and a $p<0.001$. Lastly, the correlation coefficient between the IRSST and ASPEC methods is 0.67, with a value of $F = 33.68$ and a $p<0.001$. These correlation coefficients confirm that any of the three methods can be used, provided that its specific initiation criterion is applied.

3.3 Return ducts

Of the 44 ducts evaluated, 11 were return ducts (see Table 3). It should be recalled that the main objective of this study was to validate the cleaning initiation criteria for HVAC systems. However, further to a recommendation made by the project's follow-up committee, we also tested the hypothesis that the air return ducts always have greater dust accumulation than the supply ducts. We therefore compared the two types of ducts and obtained surprising results. A log-ANOVA analysis did not establish any statistically significant difference between the dust deposits measured in the return and supply ducts, using both the IRSST method ($p = 0.23$; $F = 1.45$) and the ASPEC method ($p = 0.25$; $F = 1.37$). However, using the NADCA method, the difference was statistically significant ($p = 0.01$; $F = 6.25$). We were thus able to formulate the hypothesis that the sensitivity of the different methods played a significant role in the differences found between the two types of ducts. The more sensitive the method, as was the case of the ASPEC method, the fewer differences there appeared to be. Although the number of ducts involved was sufficient to make such a comparison, it would be relevant to push this comparison further in a possible future study of broader scope.

4. SCOPE AND LIMITATIONS

As stated in the introduction, the NADCA and ASPEC methods underestimated the real concentrations of dust due to losses. In fact, the dust that adheres to the inside walls of the cassettes, and more specifically, inside the sampling tube used in the ASPEC method, is not weighed. Moreover, the NADCA and IRSST methods vacuum only the surface dust. By contrast, the ASPEC method is the one that most closely resembles the cleaning processes used by HVAC cleaning companies (12). It is also the one that gives the best geometric standard deviation. We therefore recommend that the ASPEC method, with its specific cleaning initiation criterion of 23 mg/100 cm^2, be used to objectively assess cleanliness levels of HVAC systems. The value proposed by ASPEC in Table 1 for initiating duct cleaning is 4.0 mg/100 cm^2 (0.4 g/m^2). However, given that the methodology is not described in its entirety, we are not in a position to discuss it. Regarding the other two methods, it is the first time that a cleaning initiation criterion has been proposed.

Eventually, the ASPEC method could also be improved, for example, by using an Accucap® membrane in the sampling cassette. With this membrane, all the dust removed is weighed and there are no losses. The aspiration tube should also be included in the weighing. In this case, the losses would be virtually nil.

With regard to the return ducts, we simply compared them to the supply ducts. Even though there was a sufficient number of ducts to allow for such a statistical comparison, it would be advisable to do a systematic comparison in the context of another research project, by using, for example, ducts in the same HVAC systems and the ASPEC method, in order to determine the presence of any statistically significant differences, as well as the factor or number of times bigger the concentrations are in the return ducts than those in the supply ducts, if indeed there are any differences at all.

5. CONCLUSION

This study was carried out under real dust-accumulation conditions inside the components of non-industrial HVAC systems (e.g. schools, office buildings, or hospitals). We established HVAC-system cleaning initiation criteria for these conditions. These criteria were 23 mg/100 cm² for the ASPEC method, 6.0 mg/100 cm² for the IRSST method, and 2.0 mg/100 cm² for the NADCA method. These criteria were identical to those obtained in the laboratory for the IRSST and NADCA methods. All three methods can therefore be used, provided that their specific cleaning initiation criterion is applied. Using the ASPEC method under real conditions, although the criterion differs from that determined in the laboratory, this method aspirates most of the surface dust in the duct and is therefore a preferable option to the other two, which aspirate only the surface dust. In conclusion, it is this method that yields the most accurate results and the smallest standard deviation. It is also the one we recommend.

6. BIBLIOGRAPHY

1. ASPEC. 2004. *Maintien en propreté des réseaux aéraulique pour salles propre et environnements maîtrisés apparentés*, Association pour la prévention et l'étude de la contamination, France, March. (In French only)
2. BROSSEAU, L.M., Vesley, D., Kuehn et al. 2000. Methods and Criteria for Cleaning Contaminated Ducts and Air-Handling Equipment. *ASHRAE Transaction* 4335:88-199.
3. LAVOIE, J. and Lazure, L. 1994. *Guide for the Prevention of Microbial Growth in Ventilation Systems,* Institut de recherche Robert-Sauvé en santé et en sécurité du travail du Québec, Technical Guide RG-089.
4. NADCA. 2006. *Assesssment, Cleaning, and Restoration of HVAC Systems*. ACR 2006. National Air Duct Cleaner Association, Washington, DC, 44 p.
5. LAVOIE, J., Gravel, R., Cloutier, Y., Bahloul, A. 2007. *Critères de déclenchement du nettoyage des systèmes de chauffage, de ventilation et de conditionnement d'air d'édifices non industriels.* Institut de recherche Robert-Sauvé en santé et en sécurité du travail du Québec, Studies and Research Projects, Report R-525, 20 pages. (In French only)
6. ASHRAE. 1992. *Gravimetric and dust-spot procedures for testing air cleaning devices used in general ventilation for removing particulate matter*. Atlanta, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ANSI/ASHRAE Standard 52.1-1992).
7. BOHS. 1993. *Sampling Strategies for Airborne Contaminants in the Workplace.* British Occupational Hygiene Society Technology Committee Working Group, H and H Scientific Consultants Ltd., Leeds, UK, 84 p.
8. IRSST. 1985. *Mesure de concentrations pondérales en poussières respirables et totales*. Institut de recherche Robert-Sauvé en santé et en sécurité du travail, Notes et rapports scientifiques et techniques, méthode 48-1, Montréal. (In French only)
9. GOYER, N., Lavoie, J., Lazure, L., et al. 2005. *La qualité de l'air dans les établissements du réseau de la santé et des services sociaux*. Institut de recherche Robert-Sauvé en santé et en sécurité du travail du Québec, Guide RG-410, 148 pages. (In French only)
10. NCSS 2007. Statistical and Power Analysis Software, Kaysville, Utah, USA.
11. KRIPPENDORFF, K. 2008. Content Analysis: An Introduction to Its Methodology. Sage Publications, Thousand Oaks, CA, 481 p.
12. FINKELSTEIN, M.M. and Verma, D.K. 2001. Exposure estimation in the presence of non-detectable values: another look. American *Industrial Hygiene Association Journal* Vol. 62, (2) pp.195-198.