Final Report

Assessment of the Impact of Inverter Use in Relation to Store Performance

Ref: R402

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1. Summary

This project, carried out by Sutton Bridge Experimental Unit and Crop Systems Ltd has aimed to demonstrate some of the effects of the use of inverters (also known as variable frequency drives or variable speed drives) on fans in potato stores. It aims to focus on the relative merits of their use whilst minimising (or at the very least alerting users to) any disadvantages.

By adopting a 'one size fits all' approach to store ventilation it is inevitable that compromises are made. In some situations, influenced by a variety of seasonal factors, there is too much air, sometimes there is too little. Usually, more air is needed to dry or pull down and less for recirculation or ambient ventilation once the crop has been stabilised.

Reduction in fan speeds resulted in a linear fall in air delivery in this study across the full range of inverter use from 15 -100% of full speed in six bulk stores which were assessed in 2007/08. However, in 2008/09, when stores were loaded more fully with wetter and dirtier crop so back pressure was therefore increased - this linear response was less evident. Fan performance at higher speeds tended to tail off at speeds beyond 75% of maximum air delivery rate.

An inverter allows demand and supply for air to be matched by changing the speed of the fan. Reducing fan speed can give a proportionately higher saving on electricity use and this was confirmed in this study. However, the optimal level of savings when considered in relation to air delivery was achieved with the inverter set to allow the fan(s) to run at around 75% of its full speed.

Inverters are now also being used successfully to run fans at lower recirculation speeds (30-50% or 0.006-0.01m^3/s/t) to assist in the application of CIPC fog as a result of adopting the results of recent research funded by Potato Council. It is anticipated that this will result in lower rates of chemical use and more even distribution of residues, although findings in box stores are currently less predictable than for bulk.

Many of the stores assessed in 2008/9 again included humidification cells as part of their design. On the basis of observations in years 1 and 2 of this trial, it is apparent that humidification cells can work well with fans – even at lower speeds - providing the fan has been adequately specified to cope with the static pressure demands of the cell at the full range of operating speeds.

Nevertheless, it is recommended that potential users of inverters seek specialist advice before installing systems so that they can be guided in their use to optimise savings whilst avoiding any difficulties which might be associated with their use in specific storage situations.

2. Experimental Section

2.1. Introduction

There has been a significant increase in the use of inverters (variable frequency drives) to control ventilation fan speeds in potato storage in recent years.

There are three major benefits associated with inverters:

- Provision of savings on energy costs by running at lower fan speeds
- For distributing CIPC fog to the crop (as in Potato Council study R265)
- Use with humidification to mitigate against weight loss in long term storage

However, there is a lack of information in the public domain about their use. Without such data, it is impossible to provide independent information and advice on the value of such systems.

There is also a range of possible problems associated with their use which could have an overriding effect on crop quality and these, if substantiated, need to be brought to the attention of levy payers and store managers. Concerns include:

- The use of lower fan speeds may seriously affect air throw and travel and therefore impede uniform air circulation in stores where inverters are fitted
- There is an absence of information on the distribution of air in stores where inverters are used (for example, the effect on air flow may not be linear).
- There is a wide difference in specification of equipment fitted in stores and the recommended airflow of $0.02m^3/s/t$ at 500Pa (40 cfm/t at 2in water gauge) is not always sold as a standard, so there are dangers that under-specified systems used with inverters will not perform satisfactorily. There are a large number of existing stores for which air volume/capacity/specification differs widely and which, for many, the details are unknown.

2.2. Materials and methods

Following on from the tests conducted in year 1 (2007/08), the air distribution in six commercial stores, where inverters were fitted, was analysed.

Four of the stores were the same ones as used in 2007/08; two were new. For those stores which were analysed for a second time, it was anticipated that differences would be seen due to the different nature of the crop in 2008 harvest, compared with the previous year. This was expected due to the very wet nature of the harvest season, with high amounts of soil going into store, whereas the previous season was much drier with very little soil evident in the pile.

Trials were undertaken in stores with a range of design attributes, including existing stores that have been modified and updated with inverters, new stores that were built for potatoes but using lower design pressures than normal practice and new stores that were 'over-designed' for potatoes due to the inclusion of higher pressure ventilation equipment for use on cereals, oilseeds and onions. The different types of store ventilation equipment present offered the chance to capture as wide a range of data as possible to evaluate where potential problems might arise from the use of inverters.

Comparisons with data from 2007/08 were made where relevant.

The evaluations in Year 2 were completed between 6 February and 12 May 2009. The stores evaluated are summarised in Table 1.

Store identifier	Date visited	Store design size (tonnes)	Calculated quantity of potatoes in store at the time of evaluation (t)	% loading of design size	Assessed in 2008?
A	6/2/09	1850	2206	119%	Y
B	6/2/09	2500	2131	85%	Y
C	Not assessed in 2009	2300	2488	N/A	Y
D	12/5/09	2500	2495	100%	Y
E	Not assessed in 2009	2500	2495	N/A	Y
F	19/2/09	2000	2181	109%	Y
G	18/3/09	1300	1300	100%	N
H	18/3/09	450	450	100%	N

Table 1: Summary of bulk potato stores assessed

The data to be collected was agreed between the collaborators. This was based around measurement of duct air flows and pressures at different positions along the main duct together with duct cross-sectional areas and air speeds into laterals at predetermined positions along the duct. In addition, air speeds and areas were measured at the mixing louvre(s) in each store. Air flows and pressures for all stores were measured over the range of settings normally used in commercial stores; the range of inverter speed settings assessed was therefore 15% (min) up to 100% (max).

Measurements were made with anemometers and manometers calibrated and traceable to national standards (PCL Sutton Bridge, ISO9001 quality management system). These included the parameters listed in Table 2, which were recorded for each store.

Parameter	Assessment
1	Store width
2	Store length
3	Store eaves height
4	Store ridge height
5	Store design tonnage
6	Condition of main fans (good/fair/bad)
7	Number of main fans
8	**Current drawn by all main fans (i.e. total amps)**
9	Main fans: rating (kilowatts)
10	Main fans type
11	Main fans speed
12	Number of inlet louvres
13	Inlet louvre width
14	Inlet louvre height
15	Number of recirculation louvres
16	Recirculation louvre width
17	Recirculation louvre height
18	Average air speed through recirculation louvre
19	Number of exhaust louvres
20	Exhaust louvre width
21	Exhaust louvre height
22	Main duct width external
23	Main duct height external (excluding hand rails)
24	Main duct length
25	Main duct height (storage)
26	Main duct air speed fan end 1m from fan
27	Main duct air speed 4 m from fan
28	Main duct air speed 8 m from fan
29	Lateral type
30	Lateral quantity
31	Lateral width
32	Lateral height
33	**Lateral 10% distance air speed**
34	**Lateral 30% distance air speed**
35	**Lateral 50% distance air speed**
36	**Lateral 70% distance air speed**
37	**Lateral 90% distance air speed**
38	**Duct pressure 0% distance in duct**
39	**Duct pressure 100% distance in duct**
40	Calculated tonnage in store
41	Main fans' airflow at 100% speed at mixing louvre
42	Main fans' airflow at 100% speed at laterals

TABLE 2: SUMMARY OF RECORDINGS MADE FOR EACH STORE ASSESSED

Attributes in **bold** were measured at a range of fan speed control settings on the inverters (i.e. 100%, 87.5%, 75%, 62.5%, 50%, 32.5% and 15% of full running speed)

2.3. Results

Raw data for each store can be found in the Appendix.

The total air flow, measured from laterals, in relation to fan speed, is summarised in Figure 1.

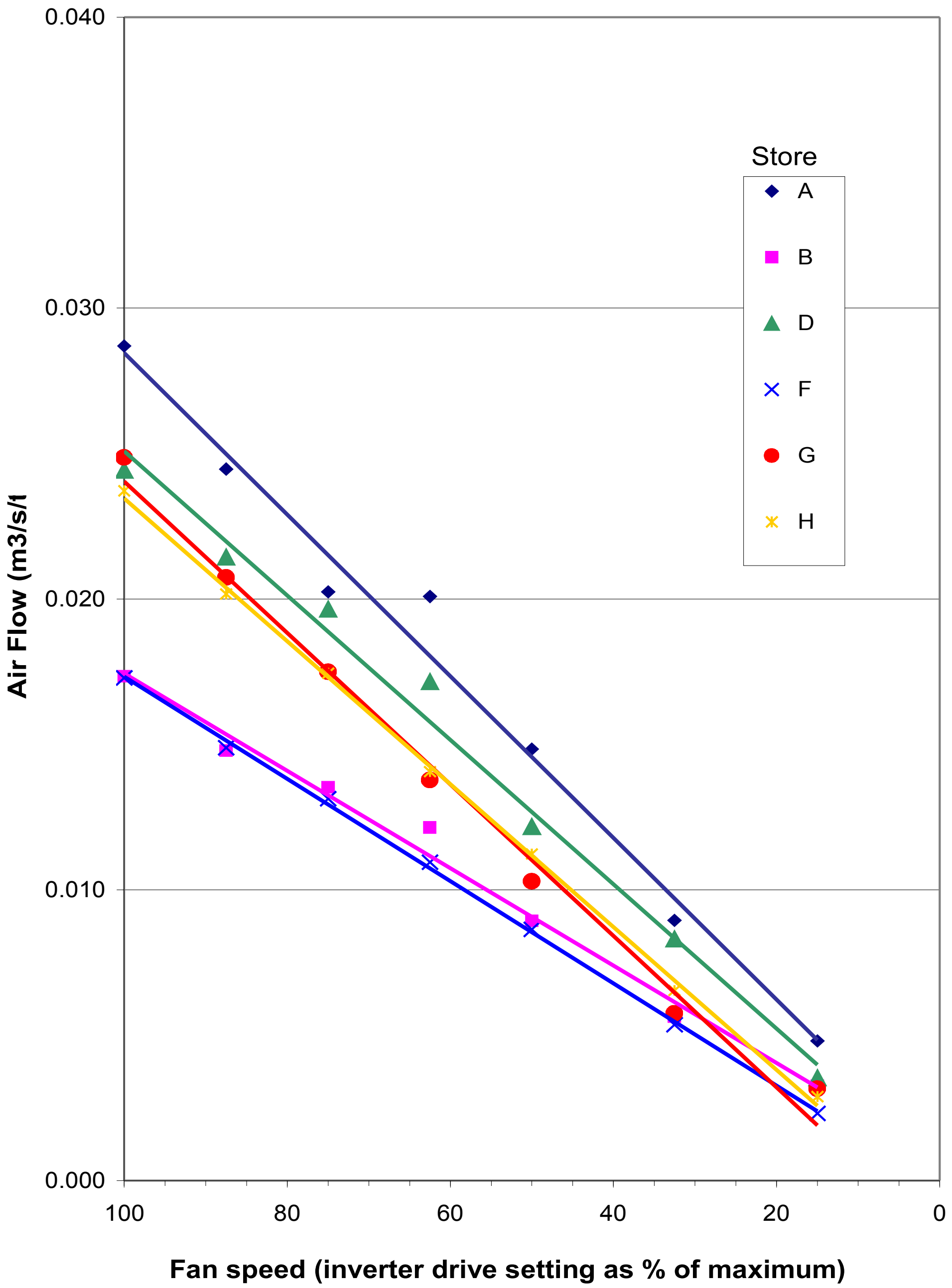

FIGURE 1. AIR FLOW IN RELATION TO FAN SPEED

The static pressure measured between the air delivery and suction sides of the ventilation system in each of the six stores, in relation to fan speed, is summarised in Figure 2. Note the high level of back pressure observed in Store D.

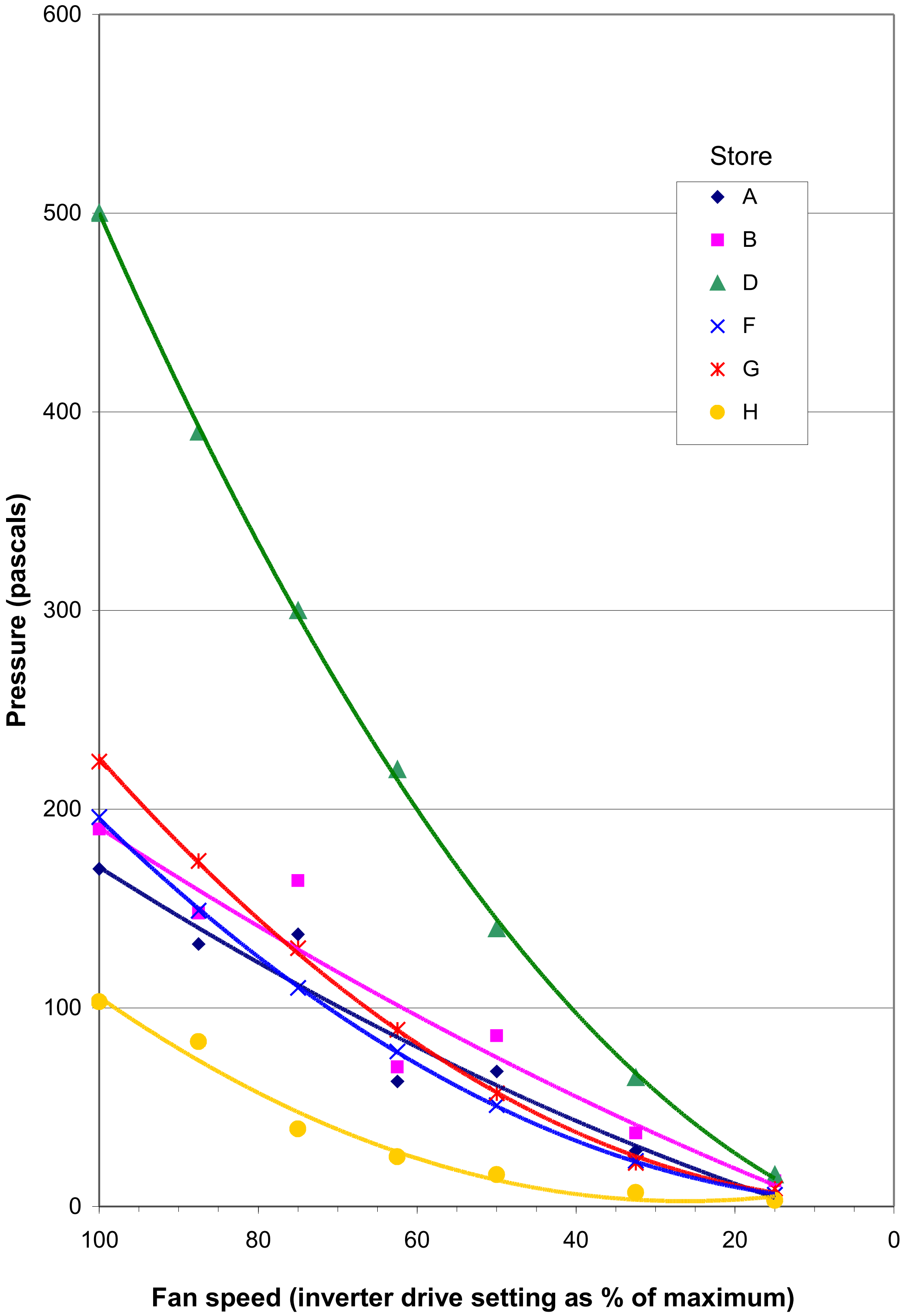

Figure 2. Static pressure in relation to fan speed

The total electrical current drawn by the fans for each of the six stores, in relation to fan speed, is summarised in Figure 3.

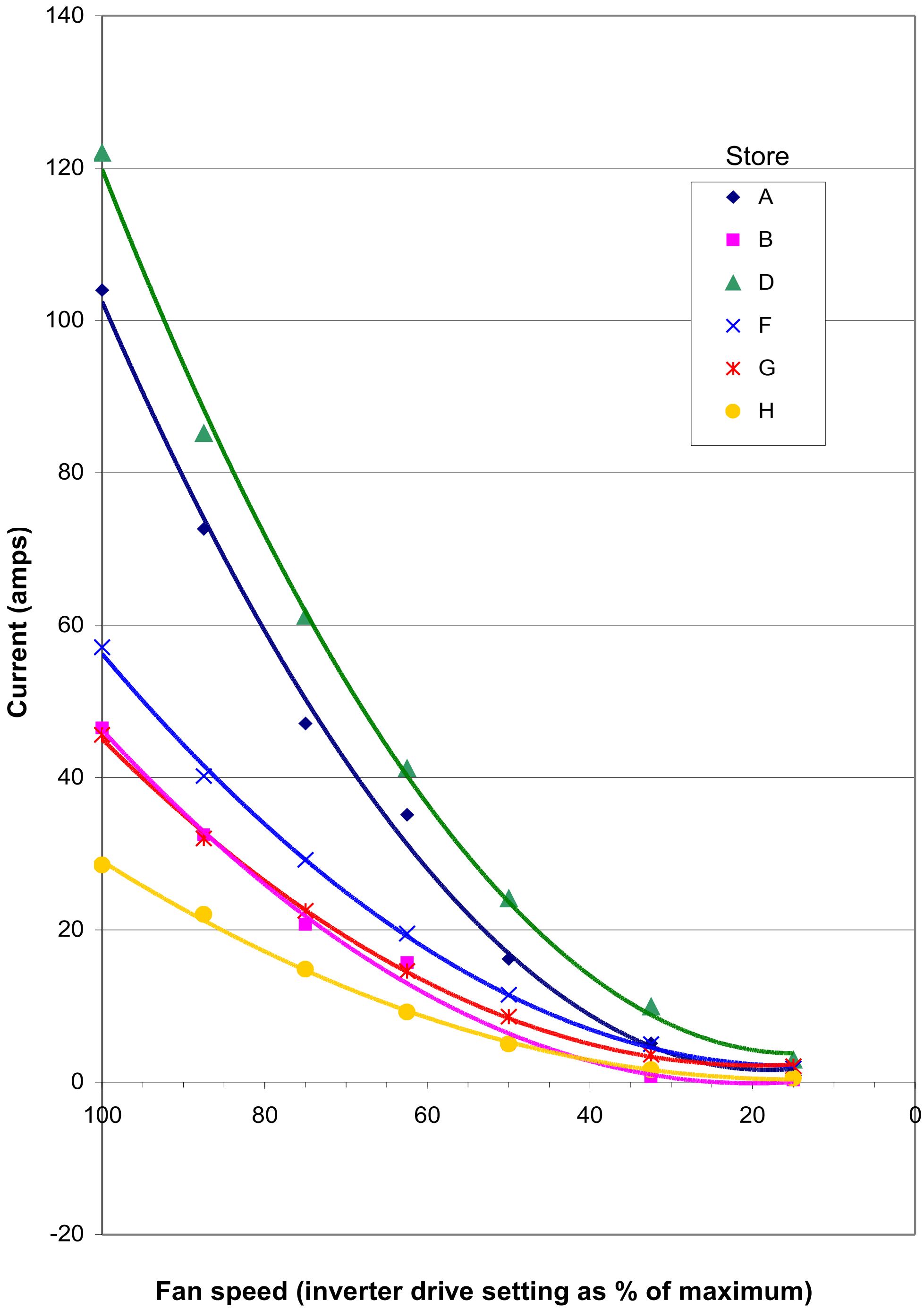

Figure 3. Electrical current in relation to fan speed

2.4. 2 year data comparisons

In some cases, year-on-year data analysis showed significant differences in store performance, whilst others showed only minimal changes. These differences could largely be attributed to store and crop management. Crops were often loaded deeper in 2008/9 because of higher yields. Equally the harvest period was wetter and so more soil was loaded into store reducing air gaps between tubers and thus inhibiting air flow.

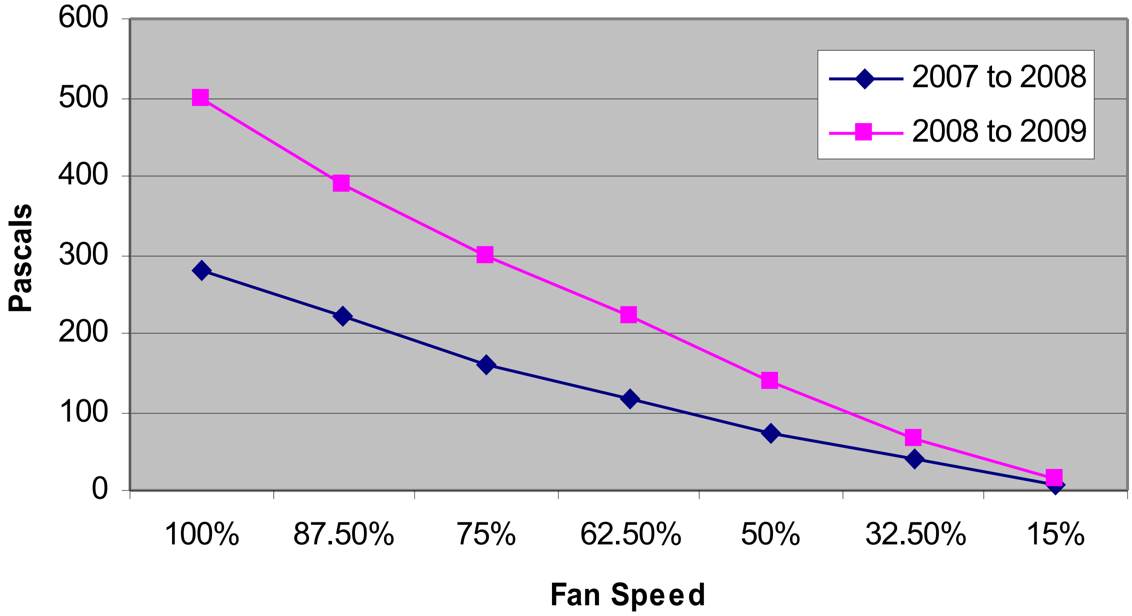

Figure 4. Duct pressure in store D

Figure 4 shows greatly increased duct pressure (measured close to the fan) because of such conditions measured in 2008/9 compared with 2007/8. The consequences of this are increased electrical load (Figure 5), and reduced air speed and hence flow (Figure 6).

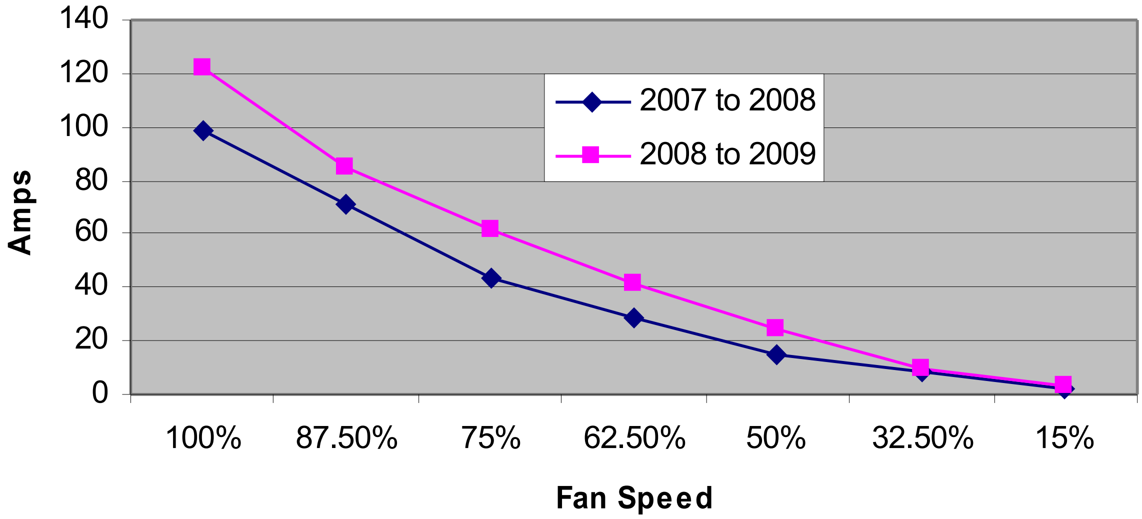

Figure 5. Electrical load in store D.

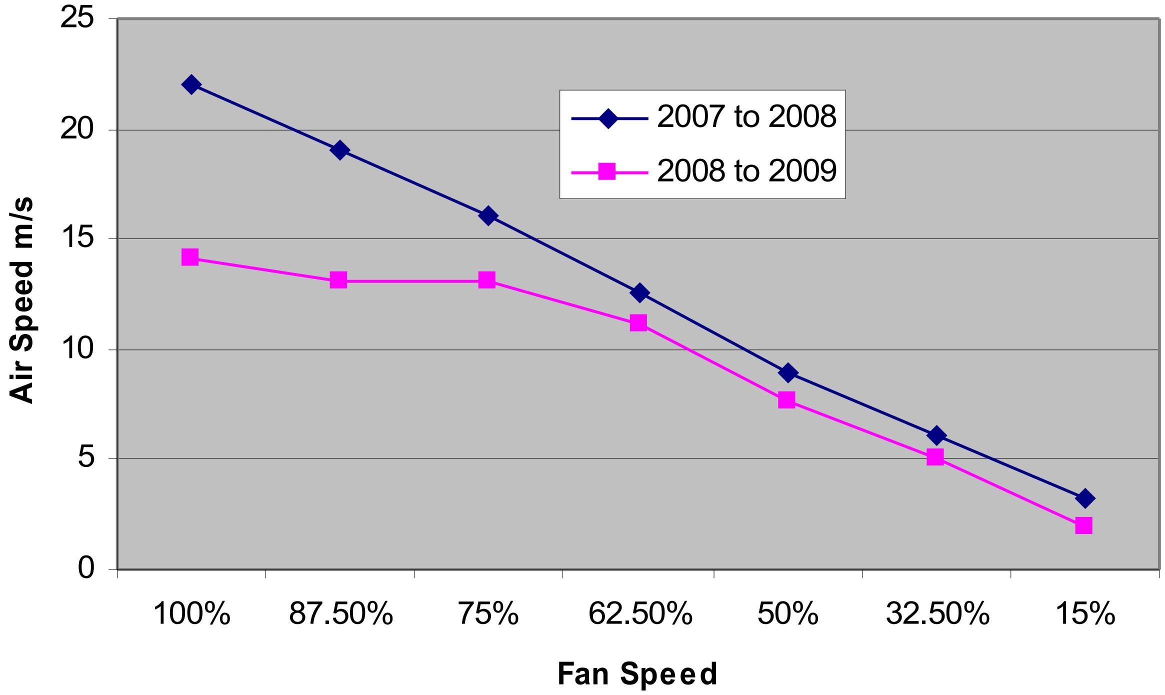

Figure 6. Air speed in main duct for store D.

Further analysis of the above charts in this instance showed little benefit in operating the fans at more than 75% capacity. Due to the higher back pressure, any gains in air flow were minimal whilst electrical load and duct pressure increased considerably.

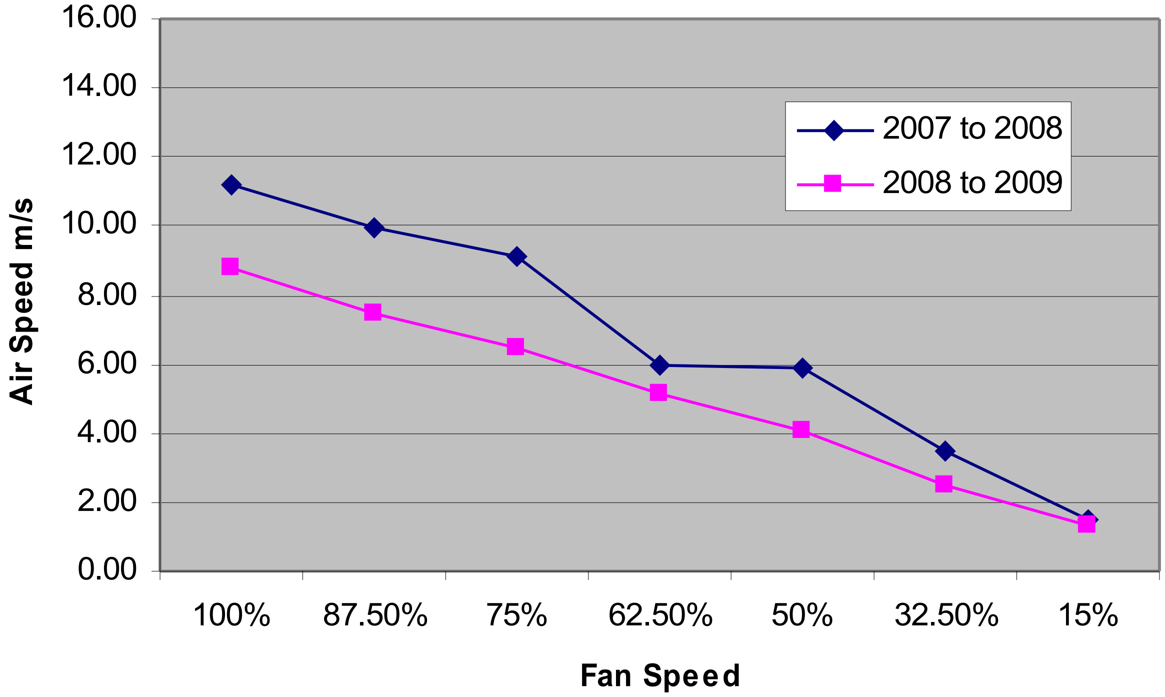

Figure 7. Air speed in main duct for Store F.

In Store F, a similar pattern was observed. Figure 7 shows a higher air flow for the 2007/8 season but, once again, the air speed in 2008/9 is less. The reasons are less clear cut than with Store D but a slightly higher duct pressure was measured (Figure 8) and electrical load was also around 20% higher (Figure 9).

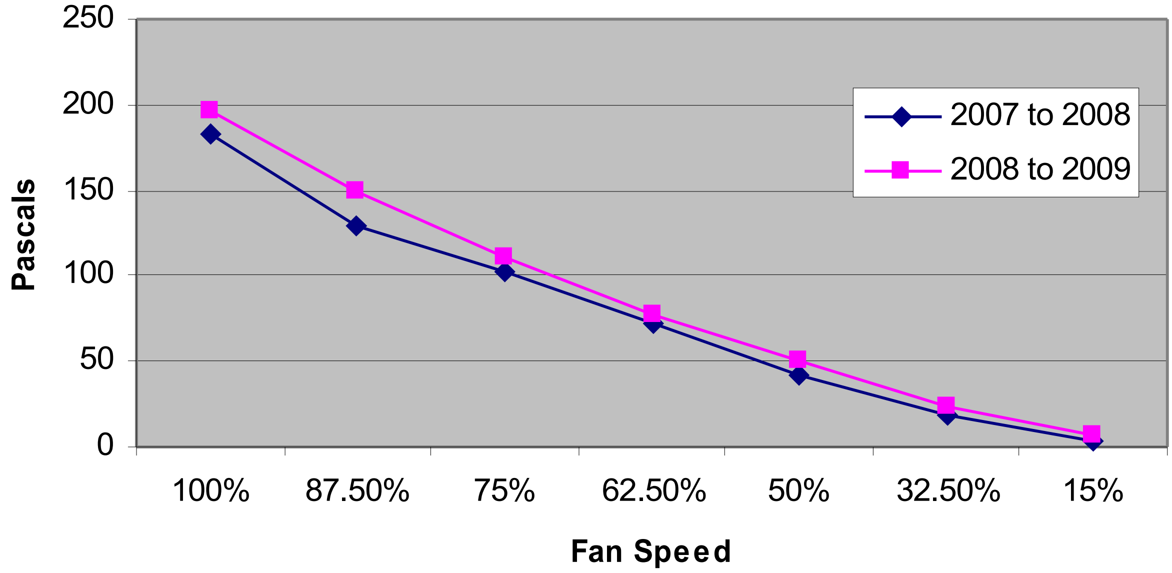

FIGURE 8. DUCT PRESSURE IN STORE F

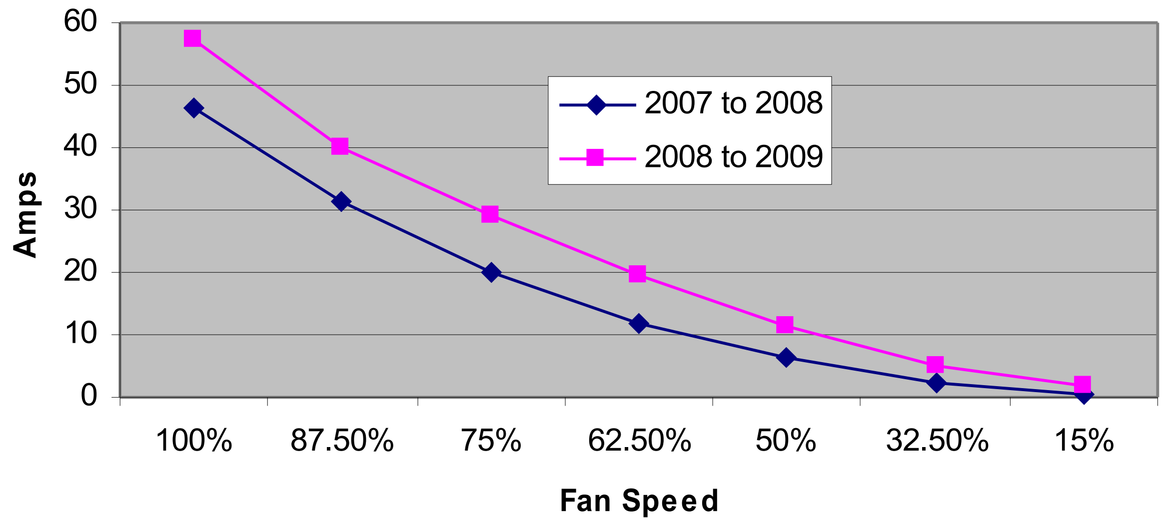

FIGURE 9. ELECTRICAL LOAD IN STORE F

2.5. Discussion

Changes in airflow as a result of inverter use did not always reflect the linear relationship observed across the full inverter operating range in 2007/8.

Static pressure within the six stores varied more widely in 2008/9, due to duct design, crop size, soil content and storage depth and this resulted in a range of responses, with a very high reading noted in store D. Slowing the fan down resulted in a predictable and significant reduction in pressure across the system (Figure 2), quickly falling to levels which could potentially have a significant impact on evenness of air distribution if this isn't taken account of in the design of the store, for example, in the design of lateral duct outlet areas.

Electrical consumption was, unsurprisingly, significantly influenced by duct pressure and this is evident in the recordings of current drawn by the fan(s) in each store (Figure 3). In store D, consumption was as high as 120 amps at full speed, running against the substantial back pressure of 500 Pa (2 inches WG). This prevented the fan delivering maximum airflow (measured at 0.03 m^3/s/t in 2007/8). A reading of 0.025m^3/s/t was the maximum achieved. Reducing the fan speed to 75% showed no significant drop off from this figure but electrical consumption fell significantly. This is a potential benefit of the use of inverters, providing the system installed in the store is designed accordingly and – most importantly – the crop condition is not in any way compromised by the use of less air. Wherever inverters are used this will be the case, compared with running the fan at 100%, but it would be unwise to reduce air volumes below, say 0.025 m^3/s/t where there is a need for rapid drying.

Data collected in 2007/8 showed that even a small reduction in air volume can provide significant savings and, for the six stores evaluated in 2008/09, the greatest benefit – again calculated here as % energy saving (desirable) per % reduction in airflow (less desirable) – produced a near identical curve (Figure 10). As in 2007/08, the optimum was again achieved with inverter settings of around 70 – 80% of full fan speed.

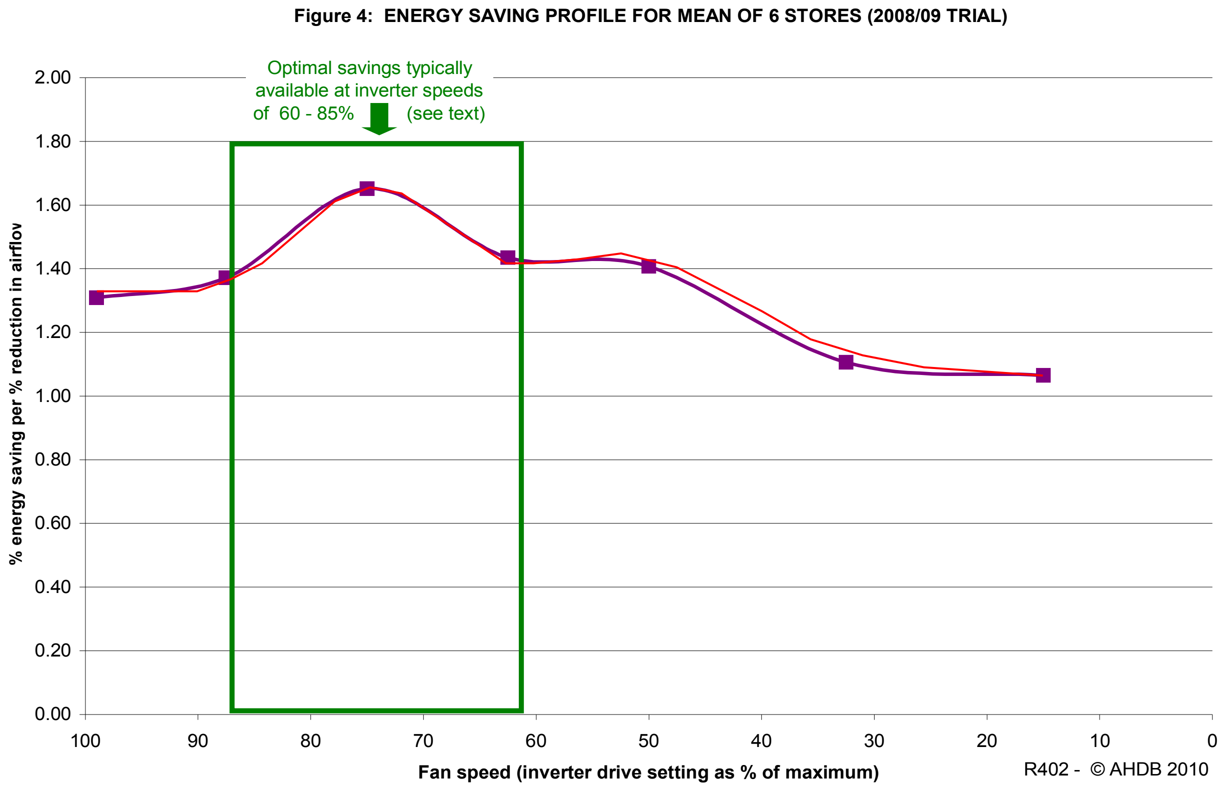

FIGURE 10. ENERGY SAVING PROFILE FOR MEAN OF SIX STORES (RED LINE 2007/08; PURPLE 2008/09)

To illustrate the possible benefits, *where crops are not under threat*, a 20% reduction in fan speed will increase ventilation time to deliver the same amount of air by the same amount, i.e. 20% (e.g. 12 days instead of 10 days) but the energy saving will be closer to 40% as, whilst reductions in airflow are linear, the reduction in energy use is not. Where the ventilation equipment is over-specified, as is often the case (e.g. on multi-crop installations such as Stores A and D), there is significant room to use this approach to reduce electricity use without any material effect on potato quality.

In situations where specifications are more attuned to the true requirements, e.g. Store F, the scope to improve store efficiency is much more limited unless – as is the case in this store – steps are taken to allow the use of lower airflows (and therefore extended ventilation times) through the installation of humidification equipment to put moisture back into the air. This allows inverters to be used to achieve lower running costs but at the same time minimises the dehydration effect normally caused by longer ventilation times.

2.6. Conclusions

In the first two years of the project, emphasis has been placed on gathering data and assessing its repeatability. Over the two seasons, the data gathered are remarkably similar even where store conditions have been significantly different.

The second year's findings have borne out the year 1 conclusion that the use of inverters can offer significant benefits in terms of lower energy consumption. This is especially the case at settings of 60 – 85% and this has the added benefit of lowering the carbon footprint of storage (as measured in PCL project R401). Additionally, it should also be made clear that most inverters offer potential to reduce fan speeds much further to allow fan use with CIPC, which can offer major cost savings (as evidenced in PCL project R265).

More importantly perhaps the second year data has illustrated the need for systems capable of coping with a wide range of storage circumstances. The variable control offered by inverters can come into its own here although more data gathering is required – e.g. automated measurement of pressure – to regulate this in future control systems.

Currently, care still needs to be taken and potato store managers, looking to adopt inverter technology as part of their store control systems, must be made fully aware of any potential disadvantages, such as lower drying capability, as well as the possible benefits that the use of inverters can offer. The requirement for expert assistance is strongly emphasised as a caveat for those considering what can be a very worthwhile investment in fan speed control systems.

3. Knowledge transfer activities

R402 included in article:

Will gels or oils replace fog? *Potato Review*. March/April 2009

R402 included in presentations made to:

Best practice in potato storage. East Midlands Potato Day at QV Foods - presentation by Adrian Cunnington. July 2009.

Energy savings presentation. Seminar at BP2009, Harrogate by Adrian Cunnington. November 2009.

4. APPENDIX

4.1. Raw Data

% SAVING ADJUSTED							
SPEED %	**100**	**87.5**	**75**	**62.5**	**50**	**32.5**	**15**
A	0	24.26	42.69	46.05	45.74	32.03	15.54
B	0	23.63	39.45	41.72	40.53	30.25	17.87
D	0	24.67	39.53	41.02	39.49	29.24	17.67
F	0	24.66	42.09	43.01	40.04	28.11	14.05
G	0	23.70	40.63	42.26	39.67	26.38	10.57
H	0	26.25	42.90	42.96	43.86	30.85	13.54
Mean	0	24.53	41.21	42.84	41.56	29.48	14.87
Current (AMPS)							
SPEED %	**100**	**87.5**	**75**	**62.5**	**50**	**32.5**	**15**
A	104	72.63	47.1	35.12	16.2	5.1	1.3
B	46.5	32.48	20.7	15.70	5	0.7	0.27
D	122	85.2	61.2	41.2	24.1	9.9	2.9
F	57.1	40.2	29.2	19.5	11.5	5	1.8
G	45.6	32	22.5	14.6	8.6	3.6	2.1
H	28.5	22	14.8	9.2	5	1.6	0.5
Mean	67.28	47.42	32.58	22.55	11.73	4.32	1.48
Power (kW)							
SPEED %	**100**	**87.5**	**75**	**62.5**	**50**	**32.5**	**15**
A	93.60	65.37	42.4	31.61	14.6	4.6	1.2
B	53.62	37.45	23.9	18.11	5.8	0.8	0.3
D	44.40	31.0	22.3	15.0	8.8	3.6	1.1
F	22.20	15.6	11.4	7.6	4.5	1.9	0.7
G	44.00	30.9	21.7	14.1	8.3	3.5	2.0
H	22.20	17.1	11.5	7.2	3.9	1.2	0.4
Mean	46.67	32.91	22.19	15.59	7.63	2.61	0.94
Time to deliver equivalent air							
SPEED %	**100**	**87.5**	**75**	**62.5**	**50**	**32.5**	**15**
A	1.00	1.17	1.42	1.43	1.93	3.21	5.98
B	1.00	1.17	1.28	1.43	1.94	3.08	5.31
D	1.00	1.14	1.24	1.42	2.01	2.94	6.92
F	1.00	1.16	1.32	1.58	2.00	3.22	7.48
G	1.00	1.20	1.42	1.81	2.42	4.32	7.87
H	1.00	1.18	1.36	1.69	2.11	3.63	8.21
Mean							

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kW to deliver equivalent air							
SPEED %	**100**	**87.5**	**75**	**62.5**	**50**	**32.5**	**15**
A	93.60	76.68	60.10	45.16	28.20	14.72	6.99
B	53.62	43.93	30.60	25.87	11.20	2.48	1.65
D	44.40	35.33	27.69	21.35	17.60	10.59	7.30
F	22.20	18.15	14.95	11.96	8.94	6.27	5.23
G	44.00	37.03	30.86	25.44	20.06	15.02	15.95
H	22.20	20.15	15.67	12.08	8.22	4.52	3.20
Mean							

Cumulative Saving							
Saving per 1% reduction in air speed							
SPEED %	99	87.5	75	62.5	50	32.5	15
A	1.43	1.45	1.43	1.38	1.40	1.25	1.09
B	1.43	1.45	1.72	1.38	1.58	1.41	1.14
D	1.43	1.63	1.51	1.38	1.21	1.13	0.98
F	1.38	1.46	1.31	1.23	1.19	1.06	0.90
G	1.40	1.27	1.19	1.12	1.09	0.98	0.75
H	0.83	0.74	1.18	1.22	1.26	1.18	1.01
Mean	1.32	1.33	1.39	1.29	1.29	1.17	0.98
SD	0.24	0.31	0.21	0.11	0.18	0.15	0.14

airflow m3/s/t							
SPEED %	**100**	**87.5**	**75**	**62.5**	**50**	**32.5**	**15**
A	0.0287	0.0245	0.0202	0.0201	0.0148	0.0089	0.0048
B	0.0173	0.0148	0.0135	0.0121	0.0089	0.0056	0.0033
D	0.0244	0.0214	0.0197	0.0172	0.0122	0.0083	0.0035
F	0.0173	0.0149	0.0131	0.0110	0.0086	0.0054	0.0023
G	0.0249	0.0207	0.0175	0.0138	0.0103	0.0057	0.0032
H	0.0237	0.0202	0.0174	0.0141	0.0112	0.0065	0.0029
Mean	0.0227	0.0194	0.0169	0.0147	0.0110	0.0068	0.0033

Airflow m3/h/t							
SPEED %	**100**	**87.5**	**75**	**62.5**	**50**	**32.5**	**15**
A	103.3100	88.0718	72.8670	72.3170	53.4227	32.2107	17.2838
B	62.4313	53.2227	48.6964	43.7019	32.1521	20.2902	11.7579
D	87.9555	77.1855	70.7534	61.7783	43.8282	29.9169	12.7147
F	62.2251	53.5735	47.2512	39.4314	31.1126	19.2998	8.3189
G	89.5044	74.6356	62.9738	49.5627	37.0263	20.6997	11.3703
H	85.3742	72.6172	62.8040	50.6358	40.4301	23.5515	10.4019
Mean	81.8001	69.8844	60.8910	52.9045	39.6620	24.3281	11.9746

kW to deliver 1m3/t for 1h							
A	0.9060	0.7422	0.5817	0.4371	0.2729	0.1425	0.0677
B	0.8589	0.7036	0.4902	0.4143	0.1793	0.0398	0.0265
D	0.5048	0.4017	0.3148	0.2427	0.2001	0.1204	0.0830
F	0.3568	0.2917	0.2403	0.1923	0.1437	0.1007	0.0841
G	0.4916	0.4137	0.3448	0.2842	0.2241	0.1678	0.1782
H	0.2600	0.2360	0.1836	0.1415	0.0963	0.0529	0.0374
Mean	0.5630	0.4648	0.3592	0.2854	0.1861	0.1040	0.0795

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Pressure (near fan)

SPEED	100	87.5	75	62.5	50	32.5	15
A	170	132	137	63	68	28	6
B	190	148	164	70	86	37	13
D	500	390	300	220	140	65	16
F	196	149	110	78	51	23	6
G	224	174	130	89	57	22	9
H	103	83	39	25	16	7	3
Mean	230.5	179.33	146.67	90.83	69.67	30.33	8.83
Pressure (far most from fan)							
A	89	67	52	35	24	11	2
B	285	216	116	111	51	21	8
D	167	126	95	67	44	20	4
F	146	110	84	62	38	18	4
G	164	120	85	56	35	11	6
H	76	61	45	31	21	9	3
Mean	154.5	116.67	79.50	60.33	35.50	15.00	4.50