Air Handling Unit Condition and Risk Based Monitoring Briefing Document

The following document has been issued by SVHSoc. to help clarify Healthcare Ventilation maintenance requirements for air handling plant which is in excess of its "normal" 20 year average life expectancy (as defined in HTM 03-01 Part A clause 4.4) or has been identified through risk assessment as having critical risk of single point catastrophic failure.

It highlights a number of commonly encountered problems and provides specific guidance and advice on the minimum standards to be provided to ensure patient safety in healthcare premises.

Acknowledgments

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Introduction

Following concerns and recent incidents of ventilation system catastrophic failures during use, primarily around operating theatre plant and the potential impact on patient safety this paper has been produced to outline the options available to maintainers of healthcare premises who may have high risk, vulnerable or ageing ventilation plant or systems which need addition consideration / monitoring to minimise the risk of catastrophic failure in use.

The anticipated working life expectancy of an air handling unit is influenced by a range of factors;

- location
- environment
- maintenance
- hours of operation

HTM 03-01 Part B clause 3.1 / 4.1 requires that all ventilation systems should be inspected annually to ensure conformity with minimum requirements. The purpose of the inspection is to establish that:

- the system is still required
- the AHU conforms to the minimum standard
- the fire containment has not been breached
- the general condition of the system is adequate for purpose
- the system overall is operating in a satisfactory manner.

For any critical ventilation systems Clause 4.4 requires that systems should be inspected quarterly and verified at least annually. In some circumstances the verification may need to be carried out more frequently.

In practice the HTM represents the minimum recommended standards and ventilation systems should be assessed based on overall risk to establish the appropriate level of inspection, maintenance and performance verification.

If the loss or failure of a system has potentially critical implications for patient safety then frequencies or extent of maintenance practices may need to be altered. The older the system / unit or more critical the area served then an increased level of maintenance may be required.

There have been cases within the recent past where in court expert forensic evidence found:-

- Poor alignment and over tension of drive belts
- Crack propagation from thread roots in taper lock pulley
- Crack propagation in welds on fan assembly (blades to boss)
- Missing balance weights from fan – out of balance
- Fracture to 'plummer block' top cap, showing signs of poor installation / maintenance practices

The Trust were found to be failing to undertake appropriate maintenance or ensuring the maintenance staff were adequately trained. The court’s opinion was that it was not unreasonable to expect at some stage a catastrophic failure of a rotating assembly that had been in service significantly in excess of the HTM and CIBSE life cycle recommendations.

Background & Guidance

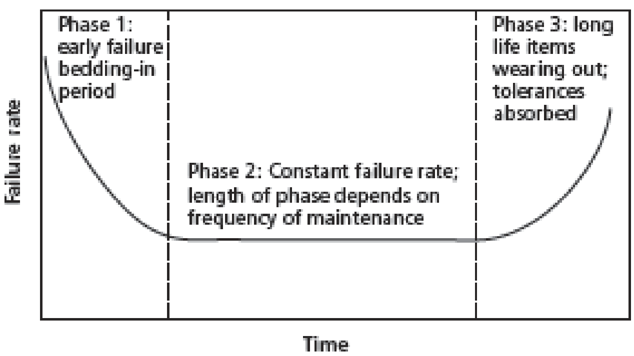
Healthcare facilities can have a wide range air handling units both in terms of age, condition, and criticality. Existing research evidence states an average life expectancy for air handling plant of anywhere between 10 to 25 years dependent upon the type of system and components used. Typically it is not unusual to find air handling plant in excess of the upper limit within healthcare settings and, whilst this reflects the good level of maintenance generally provided and the performance of these older units may still achieve acceptable standards, the risks and likelihood of breakdowns and failures does increase with age.

The 'bathtub' curve is frequently used as a model to describe the reliability and likelihood of failure of units over their life. Failure is commonly understood to be that point when the equipment can no longer provide the required performance. The bathtub curve is empirical and has been found to apply to composite products, systems or subsystems with components that are subject to wear, such as rotating machinery. Other components may be subject to 'random' failures. These may increase with age or continue to occur at a steady rate throughout an asset's life. With building services, the bathtub curve can be applied to entire systems and major assets, such as fans, air handling units, packaged air conditioning systems etc. Maintenance such as replacement of parts may reduce the impact of wear. There are typically three distinct phases in the life:

(1) Decreasing failure rate: this occurs when the system is new and is a consequence of teething problems, such as design and installation errors, faulty components and manufacturing faults, among other matters.

(2) Constant failure rate: in maintained systems, after the early failure period, the system will be in a settled state. Random isolated faults and failures will occur, and parts that wear will need repair and/or replacement from time to time as part of preventative maintenance. Such parts typically include bearings, seals, printed circuit boards, control components, motors, heat exchanger components and compressors on air conditioners.

(3) Increasing failure rate: this is the point where major components begin to fail and random failures increase with time. At this stage the cost of repair of the asset begins to exceed the cost of replacement. The useful life would be the period of time before the onset of Phase 3, i.e. before there is any significant increase in the risk of failure rate. However, useful life may extend into the period when failures start to increase if there is no significant consequence as a result of the failure occurring. Useful life may also be extended by increasing planned preventative maintenance or inspections to reduce the risk of failure.



HTM 03-01 Part A clause 4.4 states that air handling units may have a working life of 25 to 30 years. It can be anticipated that over this period there will be a need to access every element.

CIBSE Guide B (2002) clause 2.1.4 Building performance references that there has been growing evidence for a number of years that the effectiveness of building ventilation has a significant effect on the performance of those working in the building. Over a ventilation systems life of 10 to 15 years.

CIBSE Guide M (2014)

The indicative life expectancy table below is intended primarily for evaluation analysis and is likely to provide a conservative prediction, particularly when assets have been in use for some years and have been well maintained.

Equipment Item	**Indicative Life / Years**	**Comments**	**BCIS cost Group**	**HVCA SFG/20 Reference**
split systems	10		5F	59
VAV terminal units	15		5F	59
VRV units	10		5F	-
Fans - axial	15		5E	20
Fans - centrifugal	20		5E	20
Ductwork - galvanised	40		5G	16
Ductwork - flexible	15		5G	16
Attenuators	25		5G	16
Aluminium finned coils (heating & cooling)	15	Dependant on water treatment regime	5E/F/G	29
Copper finned coils (heating & cooling)	25	Dependant on water treatment regime	5E/F/G	29
coils (electric)	10		5G	29
Dampers - manual	20		5G	16
Dampers - automatic	15		5G	16
Eliminators - stainless steel	20		5E/F/G	16
External louvres - Aluminium	25		5G	26
External louvres - painted steel	20		5G	26
Filters frames	20		5G	21
HEPA filters	2		5G	21
Fire Dampers	10		5G	16
Grilles & Diffusers	30		5G	26
Plate recuperators	20		5G	29
Humidifiers (steam)	10	Dependant on water treatment regime	5G	33
Humidifiers (electrical generation)	8	Dependant on water treatment regime	5G	33
Packaged air handling units (external)	15		5F/G	03
Packaged air handling units (internal)	20		5F/G	03

All building service equipment has a projected life expectancy based on a number of factors (location, environment, maintenance, and hours of operation).

All of the predicted life expectancies are based on averages over a range of applications and as such the estimation of healthcare working life (as referenced in HTM 03-01) represents the evidence of good maintenance procedures within healthcare and the reality that a large percentage of healthcare ventilation systems are in use well beyond the average within other sectors.

The average predicted life expectancies are also effected by component replacement or refurbishment, for example where AHUs are generally in good condition and compliant in respect of performance, components, coils, filtration, metal work, they can be refurbished with new fan, motors etc., however it should be considered best practice to replace the AHU if possible because of the other benefits such as improved energy efficiency, and reliability. Where this is not possible the potential risk needs to be assessed and recorded and accepted by the organisation as an operational risk.

Practical Aspects

From a practical stand-point there are a number of steps and options to assess and address or mitigate the risks of unplanned failures of critical ventilation systems. Whilst these risks can never be completely avoided they can be controlled and minimised.

The initial stage is to identify all of those systems which are critical to patient safety and clinical activities within the site. Using this list undertake a system analysis and risk assessment to identify those systems which have known risk factors, such as AHU's in excess of 20 years of operation or plant with potential single points of failure. Having risk assessed the systems it will be possible to identify areas where addition action or mitigation may be required.

Risk Assessment

Full and detailed risk assessments with emergency actions and contingency plans should be provided for all critical ventilation systems. The use of a standard 5x5 impact and likelihood scoring system should enable estates staff to identify and prioritise those systems at greatest risk, although it is recommended to ensure the assessment is a multi-disciplinary team assessment involving both Infection Prevention Control and Clinical team members to ensure a comprehensive review.

Risk Rating Definitions

Impact

Catastrophic (5) A rating of catastrophic should be interpreted as incurring an extreme / critical risk in the event of failure. This would be a death, or multiples, legal prosecution, or significant/ permanent loss of service / business capacity. It also is connected with the overall cost implications.

Major (4) A rating of major should be interpreted as incurring a major / critical risk in the event of failure. This could be a major injury or dangerous occurrence, HSE prohibition, legal prosecution, or significant loss of service / business capacity. It also is connected with the overall cost implications.

Moderate (3) A rating of moderate should be interpreted as incurring a significant risk in the event of a failure. This could include time loss injury, HSE improvement notices or investigation, or a loss of service / business capacity. It also is connected with the overall cost implications.

Minor (2) A rating of minor should be interpreted as incurring a manageable risk in the event of a failure. This could include minor injury, near misses with potential HSE investigations / reports, or a minor loss / interruption of service / business capacity. It also is connected with the overall cost implications.

Insignificant (1) A rating of insignificant should be interpreted as incurring a minimal risk in the event of a failure. This could include a near miss with no potential of injury, or a minor interruption of service / business capacity. It also is connected with the overall cost implications.

Likelihood - The likelihood of any occurrence is also scored against a 5 category probability system of: - Rare (1), Unlikely (2), Possible (3), Likely (4), & Almost Certain / Certain (5).

Overall Risk Rating

These two scoring systems are then multiplied to ascertain an overall risk rating for any given issue.
High A rating of high should be interpreted as incurring a major / critical risk in the event of failure. This could be a death, legal prosecution, or significant loss of service / business capacity. It also is connected with the overall cost implications and likelihood of occurrence.

Medium A rating of medium should be interpreted as incurring a significant risk in the event of a failure. This could include serious injury, HSE prohibition notices, or a minor loss of service / business capacity. It also is connected with the overall cost implications and likelihood of occurrence.

Low A rating of low should be interpreted as incurring a minimal risk in the event of a failure. This could include minor injury, HSE investigation, or a minor loss of service / business capacity. It also is connected with the overall cost implications and likelihood of occurrence.

	Likelihood Assessment				
Impact Assessment	**Rare (1)**	**Unlikely (2)**	**Possible (3)**	**Likely (4)**	**Certain (5)**
Insignificant Minimal Impact on service delivery (1)	1	2	3	4	5
Minor Some Impact on service delivery (2)	2	4	6	8	10
Moderate Potentially significant Impact on service delivery (3)	3	6	9	12	15
Major Highly Significant Impact on service delivery (4)	4	8	12	16	20
Catastrophic Extreme Impact on service delivery (5)	5	10	15	20	25

Following completion of the assessment of risk control measures can be considered to minimise or mitigate the risks.

Options for Risk Minimisation

Having established a prioritised schedule of 'at risk' systems there are a number of options available to address the issues, these include;

- Increase the frequency of existing PPM inspections and maintenance
- Increase the scope and remit of existing PPM's
    - Including taking and recording of key indicators to enable trend analysis
- Monitor and tread reactive failures and breakdowns
- Include all critical 'at risk' plants on Trust risk registers and backlog investment programmes

Increasing the frequency of routine inspections and testing should improve the condition monitoring of the plant and potentially provide better early warning of a failure, however it relies upon the skill and experience of the craftsmen undertaking the work to have a consistent approach and is likely to be a significant burden to achieve within existing resources (time and personnel).

By increasing the level of detail undertaken within existing PPM programmes, it is likely to have minimal impact on resources. If key indicator readings can be incorporated into the task schedule then, after the initial procurement of some essential measuring / test equipment it can provide vital information and trend analysis to assist in accurately predicting failures before they happen. Key indicators could include; monitoring of fan and motor bearings for noise, vibration, and temperature (see below), belt tension and alignment measurement to record movement and electrical motor currents / load. All of these measurements can be collated to produce a condition over time analysis to assist in profiling the deterioration of the plant and predict and prevent failures.

Monitoring breakdown and failures is unfortunately a reactive rather than proactive approach and will only really tell after something has gone potentially catastrophically wrong. Often used in post incident investigations but of little use in prevention.

The final option should be done as a matter of course to ensure that adequate contingency plans are in place and understood, so that in the event of an issue, patient safety can be maintained. They should include where safe alternative locations for critical clinical services can be delivered and how repairs can be achieved with achievable target timescales (if practical). This could include reviewing and establishing a maximum theatre usage / capacity limit to ensure that in a situation where multiple theatres are co-located a theatre is always left available to act as an emergency decant in the event of a catastrophic failure. This could be achieved by accepting a short notice suspension of planned short duration operations in order to accommodate a more intrusive / lengthy procedure affected by a system failure. This approach should have a minimal impact on patient treatment whilst ensuring contingency plans are available in the event of an issue.

From the options above it should be considered that if plant replacement is not a viable option then increasing the remit of current PPM activities and ensuring quantifiable measurements are taken and tracked provides the best value solution to the operation of ageing or 'at risk' critical ventilation systems.

Methods for Monitoring Bearing Condition

A range of traditional and advanced options are available to monitor AHU fan and motor bearings.

The condition of bearings is critical to the reliability and performance of air handling plant. With appropriate condition monitoring, imminent failures can be identified and corrected. Conversely, without a sound monitoring program in place and subsequent corrective actions not being taken when needed, a single bearing failure can result in a catastrophic failure of a critical ventilation system.

Bearing monitoring is guided by three main human senses: sight, sound and touch. Basic monitoring is typically conducted through observations. This type of monitoring is however subjective and if different people undertake the monitoring over time it can delay or obscure the findings. Fortunately there are a number of highly sensitive tools that can provide a quantifiable and consistent means of measuring these observations.

Visual monitoring:

Monitoring bearings visually through classical methods includes observing lubricant condition, corrosion and deterioration. Mounted bearings that are lubricated properly will purge grease from their seals. The condition of the grease upon purging can indicate improper re-lubrication intervals and/or contamination. Dark, cakey or milky grease are visual signs that re-lubrication intervals and procedures may be improved.

Evidence of corrosion can also be a valuable monitoring tool. High levels of corrosion can degrade material strength and performance. Deterioration of the surface, seals or obvious physical dimensional characteristics indicate the need for further investigation. These observations are often signals of wear, heat and other abnormal performance prior to total bearing failure.

Audible monitoring:

Traditionally, audible monitoring is one of the most common methods of fan and motor bearing monitoring. That's because unusual or louder than normal running noises are obvious indicators of improper operation. This type of monitoring is conducted quickly through routine plantroom inspections by maintenance personnel. After all, if an AHU bearing doesn't sound well, it usually isn't.

There can be two potential issues with this type of audible observation. Firstly, such observations usually identify the later stages of bearing failure, and secondly, audible feedback of a single bearing can be masked by the overall noise of its environment. This is where instruments such as stethoscopes (with amplification) and decibel-level meters are advantageous. Both are available with a wide range of features, including quantified readings and recording capabilities that allow users to trend bearing condition. These tools are also more useful at identifying improper operation at a less-threatening stage of failure.

AHUs should run quietly and smoothly, anything else could reflect a flaw in or problem with the unit itself. Noises such as grinding or banging should be investigated quickly. These noises may indicate bearing failure and continued use may lead to catastrophic failure. Bearing noises like light clicking and squealing may indicate looseness, faults or skidding, and should be inspected for cause and rectification.

Audible evaluation is not as sensitive as other monitoring techniques, it's more of a method of identifying failure than identifying poor or degrading condition. It should also be recognised that audible monitoring in the early stages of failure is more noticeable at higher rotational operating speeds than lower speeds.

Physical monitoring:

Monitoring bearings by touch and then trending the observations against historical performance is by far the most useful and accurate means for assessing bearing condition and predicting failure. The touch method can be used to monitor temperature and vibration, provided it can be achieved safely.

Operating temperature is the most practical monitoring method for fan and motor bearings because expensive tools are not required.

The most common tools for doing this include thermocouples and resistance temperature detectors (RTDs)—both of which can be permanently mounted to locations on the bearing housing for continuous real-time monitoring. Portable thermal imaging tools offer a quick and efficient means of monitoring bearing condition. These devices use infrared (IR) thermography to visually identify variations in temperature, the most common being the infrared thermometer. Utilizing a portable temperature measuring tool, like a thermal imaging gun, can help accurately monitor bearing temperature.

As a bearing fails, its temperature will continually increase. Trending temperature over time can help identify a bearing in the early stages of failure

Consideration could be given to retrofit permanently mounted sensors to monitor key bearings within an AHU to provide a means of monitoring which does not require the unit to be isolated or opened. This may be more practical to specify in new units as part of the strategic contingency planning process for the whole life evaluation of capital investment to maximise the expected working life of a critical ventilation system.

In addition to temperature monitoring vibration analysis is the most information-rich method available for bearing condition analysis.

Consideration of vibration measurement instruments to not only identify stages of bearing failure, but to also identify overall AHU condition and problems. Sensors mounted to the units' bearings may include permanently mounted or portable magnetic-base accelerometers, displacement probes or velocity pickups. Sensor selection is dependent upon the bearing speed, sensitivity requirements and the application. Although vibration feedback is highly desirable, proper training is important due to the complexity in data collection and interpretation.

Training and Competency

This type of specialist preventative maintenance must be completed by suitably trained and experienced service engineers who not only have the technical knowledge of the subject matter, and the ability to collect, collate, and interpret the measurements and results of air handling unit maintenance monitoring.

HTM 03-01 Part B re-enforces this requirement within the following clauses / sections.

Competent Person (Ventilation) (CP (V))

2.10 The CP (V) is defined as a person designated by management to carry out maintenance, validation and/or periodic testing of ventilation systems.

Training

2.18 Routine inspection and maintenance procedures can cause risks to the health of staff carrying out the work and those receiving air from the plant. All those involved should be made aware of the risks, and safe systems of work should be agreed. Suitable safety equipment should be provided as necessary, and training in its use should be given.

2.19 Any training given should be recorded, together with the date of delivery and topics covered.

2.20 Training in the use of safety equipment and a safe system of work will need to be repeated periodically in order to cater for changes in staff.

All training and proof of competency must be recorded and available to demonstrate that anyone engaged in the management or maintenance of healthcare engineering systems must be competent to undertake the duties required of them.

References

Building Regulations Approved Document B, Volume 2: 2006

HTM03-01 Specialised ventilation for healthcare premises. Part A Design and installation

HTM03-01 Specialised ventilation for healthcare premises. Part B Operational management and performance verification

Health Technical Memorandum 00 - Policies and principles of healthcare engineering 2014 edition

Health Building Note 00-07 - Planning for a resilient healthcare estate 2014 edition

CIBSE Guide B: 2002 Heating, ventilating, air conditioning and refrigeration

CIBSE Guide M: 2014 Maintenance engineering and management

National Health Service Model Engineering Specification C04 – Mechanical Ventilation & Air Conditioning Systems (Revision 3: 1997)

HVCA SFG 20 – Standard Maintenance Specification for Services in Buildings