Scottish Hospital Inquiry

RHCYP/DCN Critical Care Ventilation Systems Review

Scottish Hospitals Inquiry

Job No:	1034279
Doc ref:	1034279-CDL-VENT_SYSTEMS_REVEW _001
Revision:	A
Revision date:	13 December 2023

Project title	Scottish Hospital Inquiry	Job number
Report title	RHCYP/DCN Critical Care Ventilation Systems Review	1034279

Document revision history

Revision ref	Issue date	Purpose of issue / description of revision

Document validation (latest issue)

13/12/2023

X 

Principal author

Signed by: Stephen Maddocks

Executive summary

This report is a review of the design, commissioning and validation documents associated with the Ventilation Systems for Critical Care and Isolation rooms at the Royal Hospital for Children and Young People and the Department of Clinical Neurosciences in Edinburgh ("RHCYP/DCN"). The report considers the design at Financial Close, at the point Settlement Agreement No1 was entered into, and at the point of Settlement Agreement No 2 (which contains the final specification for the ventilation system). The review covers briefing information, published design guidance and commissioning and validation results.

The final design of the ventilation system for the Critical Care (rooms 1-B1-065, 075, 063, 037, 031, 021, 020, 019, 009 and Isolation Rooms 1-B1-016, 017, 026, 036) and Haematology and Oncology (rooms 3-C1.4-059, 057, 055, 046, 032, 018, 016, 013, 010, 074, 076, 078, 084 and 061 and Isolation Rooms 3-C1.4-040, 043, 049, 052. 072) at the RYCHP/DCN complies with published guidance and best practice. In particular, the design complies with the requirements of SHTM 03-01.

The ventilation system in the Critical Care and Isolation Rooms at the RYCHP/DCN was independently validated by IOM Limited ("IOM") in 2021. The 2021 Independent Validation reports by IOM have confirmed that ventilation system for critical care rooms and Isolation Rooms at the RHCYP/DCN, as per Settlement Agreement No 2, is operating so as to fully comply with published guidance (SHTM 03-01) and best practice.

The ventilation system in Critical Care and Isolation Rooms at the RHCYP/DCN has been designed, tested, commissioned and validated in compliance with published guidance (SHTM03-01) and best practice. The ventilation system has therefore been checked and demonstrated to be in accordance with the design requirements detailed in SHTM03-01. From an engineering perspective, the ventilation system in the Critical Care and Isolation Rooms in the RHCYP/DCN is adequate for its intended purpose. The Critical Care and Isolation Rooms provide a suitable environment for the delivery of safe, effective person-centred care.

I understand that the specific contractual requirements for the original design are controversial. I do not offer any opinion on that issue. However, I understand that certain passages in the original documents issued by NHSL required compliance with SHTM 03-01. NHSL also provided an Environmental Matrix (EM) to bidders. The guidance notes page on the original EM stated that the Critical Care Department required 10 ac/hour, yet room-by-room line entries on the matrix contained contradictory information, namely 4 ac/hour.

IHSL confirmed compliance with SHTM's in their Project Co Proposal specification but then issued a Room Data Sheets pack with the EM data for a lower ac/hr rate carried through. Anomalies in the EM were the subject of a derogation schedule to be developed as Part of the RDD process. The air change requirements were later clarified by email and agreed between Project Co and NHSL.

The original reasoning for including 4 ac/hr on the EM was not documented, or satisfactorily closed out, pre-Financial Close. The EM was agreed to be carried through as a Reviewable Design Data item which should **not** have happened due to the significant impact of clarifying an error in a fundamental piece of briefing documentation with the ramifications that have since come to light. I note that a sample of agreed Room Data Sheets were generated for the Financial Close using the Activity Data Base system, which also carried the 4 ac/hr error. THE ADB systems generates air change rate and other environmental criteria based on HTM requirements, but this can be edited/customised for local preferences, which appears to have happened in this case.

The validation testing of the original system undertaken by IOM Ltd, i.e. – post Settlement Agreement No 1, design identified a number of rooms where the 10 ac/hr rate (as per SHTM 03-01 and not the agreed design figure of 4) were not being met.

A number of manufacturing defects were noted with the AHU manufacture that have been corrected to an agreed (with NHSL) standard.

Separate Isolation room Ahu's could have been considered (with financial and planning impacts) for the level 3 isolation rooms but would have been a significant challenge for the Critical Care level 1 rooms due to proximity of rooms to risers. The strategy should have been agreed pre-Financial Close.

Key lessons

1. Follow the procedures detailed in NHS Scotland Key Stage Assurance Review process (see Section 6).
2. Set up a Ventilation Safety Group (and others listed in KSAR) to take decisions on the requirements for key engineering systems.
3. Keep one set of environmental briefing data to avoid discrepancies (note a matrix of engineering specific. requirements can be extracted from the ADB System to avoid a separate manually created matrix).
4. Agree clear environmental briefing data with operational and clinical staff prior to issuing documents to tender in case local practice is required to overwrite the SHTMs.
5. Have a clear and unambiguous set of technical requirements at Financial Close. Don't carry over key design issues beyond a contract signing data.
6. Independent design validation and Ventilation Safety Group sign off as adopted by the very latest SHTM 03-01 and the NHS Scotland KSAR process currently in place, will help mitigate issues in the future.
7. Discuss with the authorities that publish statutory documents such as Building Regulations that industry specific requirements i.e. SHTM's, CIBSE and other industry codes are cross-referenced into the appropriate regulations.as currently written into the Building Regulations England i.e. Approved Document F1 - Ventilation

Contents

1.0

Introduction

1.0 Introduction

1.1 Scope of Report

1.1.1 I have been asked to comment, from the perspective of an engineer, on the adequacy of the ventilation system in Critical Care and Isolation Rooms in the RHCYP/DCN. I have been asked to comment on whether, from an engineering perspective, the ventilation system in these spaces provides a suitable environment for the delivery of safe, effective patient centred care. To address this, I will consider whether the ventilation system in critical care complies with published guidance and current best practice.

1.1.2 This report is limited to a review of the ventilation systems design, installation, commissioning and validation of systems in the Critical Care Departments on Levels 01 and Haematology/Oncology on Level 03 only with associated mechanical ventilation plant that supplies these areas at the RHCYP/DCN.

1.1.3 The review covers the design of the ventilation system for Critical Care and Isolation Rooms at the following stages of the RHCYP/DCN project:

1.1.3.1 Design Briefing documents review – Financial Close

1.1.3.2 Project Co Proposals- Financial Close offer - Settlement Agreement No 1

1.1.3.3 Post July 2019 Design - High Value Change - Settlement Agreement No 2

1.1.4 I shall then address various changes that have been made in the relation to procedures for the briefing and design of a new hospital. This shall include the creation of NHS Assure. I shall then outline some lessons that I consider can be learnt from the issues that arose on the Project.

1.2 Disclaimer

1.2.1 This report is based on review of documents supplied by the Scottish Hospitals Inquiry team with no supporting site reviews being undertaken. The review also reviews industry standards, codes and best practice design principles applicable to ventilation systems.

1.3 Glossary of Terms

Glossary	
ac/hr	air changes per hour (air change rate for ventilation)
CAMHS	Child and Adult Mental Health Service
DCN	Department of Clinical Neurosciences
DGHSC	Director General of Health and Social Care
DSSR	Engineering Consultants
EM	Environmental Matrix
FC	Financial Close
FM	Facilities Management

Glossary	
HAI-Scribe	Healthcare Associate Infection Systems for Controlling Risk in the Built Environment
HDU	High Dependency Unit
HFS	Health Facilities Scotland (part of National Services Scotland)
IHSL	IHS Lothian Limited the Project Company or private partner to NHSL to deliver the new hospital
IOM	Institute for Occupational Medicine, third party validators for ventilation
IPC	Infection Prevention and Control
IPCT	Infection Prevention and Control Team
IT	Independent Tester
ITU	Intensive Treatment Unit (also referred to as Intensive Care Unit)
NHSL	National Health Service Lothian
NNU	Neonatal Unit
MM	Mott MacDonald, NHSL's technical advisors
MPX	Brookfield Multiplex
PICU	Paediatric Intensive Care Unit
PG	Production Group (Clinical User Groups)
PG RDD	Production Group Review Procedure for Clinical User Groups
Project Co	Project Company (IHSL and its extended supply chain)
RDD	Reviewable Design Data
RDS	Room Data Sheets
RFI	Request for Information
RHCYP	Royal Hospital for Children and Young People (name given to the new children's hospital)
SA1	Settlement Agreement 1 (Project Agreement Supplementary Agreement 1)
SG	Scottish Government
SHBN	Scottish Health Building Notes
SHFN	Scottish Health Facility Notes
SHTM	Scottish Health Technical Memorandum
SHPN	Scottish Health Planning Notes
QEUH	Queen Elizabeth University Hospital

2.0

NHS Briefing Document Review

2.0 NHS Briefing Documents Review

2.1 Design Brief Documents

2.1.1 I understand that the status of various documents issued during the tender process is controversial. In particular, the status of the EM issued during the tender process. As an engineer, I do not offer any comment on that matter. In this section of the report, I have proceeded on the basis of the documents that the designers, TUV-SUD, consider were the relevant briefing documents.

2.1.2 It is noted in the TUV-SUD document, Critical Care Briefing Review April 2022, that the following documents were considered to be the briefing documents that they referenced/referred to in order to develop the Engineering Design.

a) B1 Critical Care Clinical Output based Specification September 2014
b) H&K Reference Design Briefing Environmental Matrix with guidance notes. Note Rev C of this document is dated September 2012
c) HBN 04-02 Critical Care Units
d) HBN 57 Critical Care (old doc))
e) SHPN 04 Supplement Isolation suites
f) HTM 2025 (old doc)
g) SHTM 03-01 Appendix 1: Table A1 February 2014
h) HBN 04 Supplement 1
i) Ward Layout Drawing
j) HBN 23 Hospital Accommodation for children and young people (not referenced)

2.1.3 I have been asked by the Inquiry Team to proceed on the assumption that, during the competitive tender process, the competing companies were provided with items (a) and (b) together with the Boards Construction Requirements (BCR). BCRs are used on most PFI projects. They provide a flexible framework for competing Project Companies to offer different solutions to meet the brief, but it is also typical to include the HTM's and HBN's (or equivalent Scottish versions) as a mandatory requirement within the BCR.

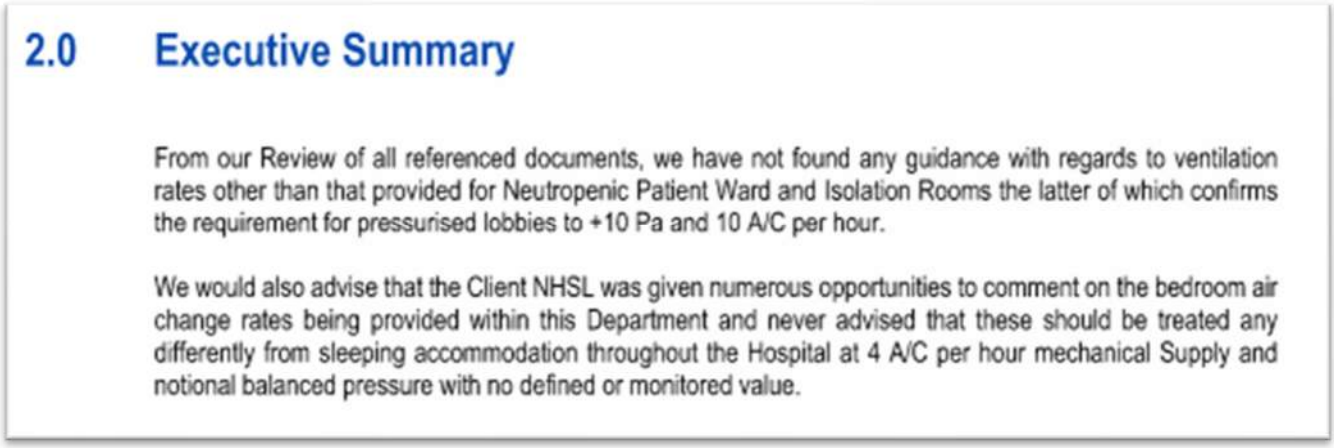
2.1.4 A Clinical Output Based specification (item (a) above) is difficult for an engineer to interpret. The clients detailed engineering/technical design requirements, especially in a suite of Technical Requirements, is generally referenced in the form of a requirement for compliance with published guidance (e.g SHBN'/SHTM's). An engineering/technical design proposal would generally demonstrate or confirm, that the offer was based on SHBN/SHTM requirements. However, that would be subject to any specific requirements stated by the client, derogations or other agreements.

2.1.5 I do not offer any view on the status of the EM. However, the production of a project specific EM would, in my opinion, be viewed by an engineer as a statement of the client's specific requirements unless the contrary intention was clearly stated. There would be no point in issuing such a document unless it contained a client specific project brief. There would be no point in a client issuing a "draft" EM that could not be relied on by the engineer.

2.1.6 I have been advised that the EM was a manually created spreadsheet, rather than being generated by an established data base system/product[1]. The engineer that produced it confirmed that it complied with published guidance. However, in evidence to the Inquiry, the engineer stated this was an error.

2.1.7 A suite of detailed Room Data Sheets, using a system such as Activity Data Base, would be developed once a single Preferred Bidder consortium had been selected. A selection of RDS for certain generic and key rooms were prepared in advance of financial close.

2.1.8 The executive summary of the above TUV-SUD document states.



2.0 Executive Summary

From our Review of all referenced documents, we have not found any guidance with regards to ventilation rates other than that provided for Neutropenic Patient Ward and Isolation Rooms the latter of which confirms the requirement for pressurised lobbies to +10 Pa and 10 A/C per hour.

We would also advise that the Client NHSL was given numerous opportunities to comment on the bedroom air change rates being provided within this Department and never advised that these should be treated any differently from sleeping accommodation throughout the Hospital at 4 A/C per hour mechanical Supply and notional balanced pressure with no defined or monitored value.

Figure 1-Extract TUV-SUD Document April 2022

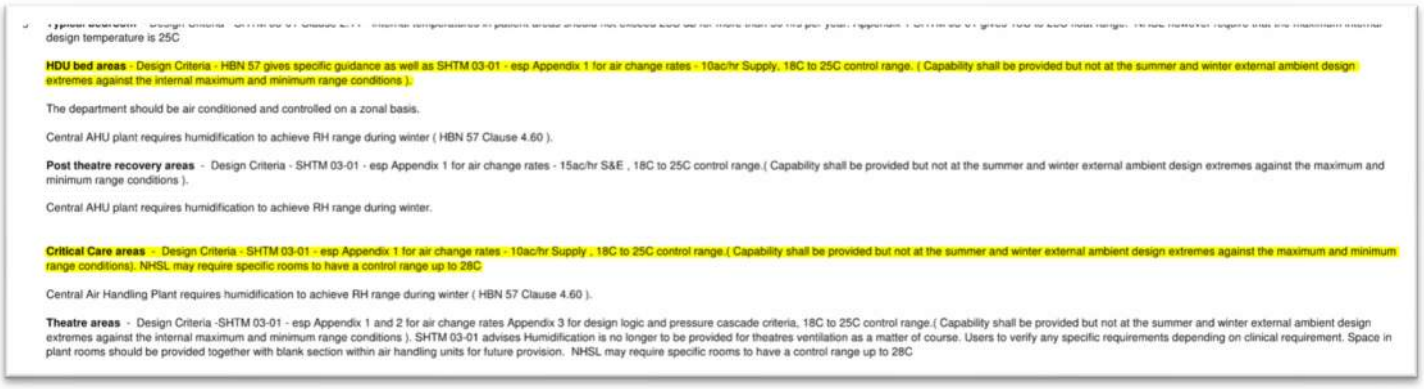
[1] The producers of the of the Activity Data Base software (Talon Solutions) have confirmed (16/11/2023 email correspondence) that their systems can generate a dedicated EM from the agreed RDs that would make design work easier for an engineer. It has not been checked if the earlier versions had that level of functionality.

2.1.9 The first paragraph of the above statement states that they have found no guidance with regards to ventilation rates other than that provided for Neutropenic Patient Ward and Isolation rooms, which is contrary to the following documents that are referenced in the briefing documents listed in 2.1.1

2.2 Environmental Matrix Review

2.2.1 H&K Reference Design Briefing Environmental Matrix (H&K-EM) was taken by TUV-SUD to be a key briefing requirement, note Rev C of this document is dated September 2012 and was generated when 3 consortia were bidding the scheme, and this formed the base design requirements that led to the eventual selection of IHSL/MPX as preferred bidder.

2.2.2 The Guidance Notes on page 2 of the matrix give clear direction for bedrooms noting for clarity that "*Critical Care areas - Design Criteria - SHTM 03-01 - esp Appendix 1 for air change rates - 10ac/hr Supply , 18C to 25C control range.(Capability shall be provided but not at the summer and winter external ambient design extremes against the maximum and minimum* range conditions). *NHSL may require specific rooms to have a control range up to 28C*". There is also an air change rate clarification for HDU beds.



design temperature is 25C

HDU bed areas - Design Criteria - HBN 57 gives specific guidance as well as SHTM 03-01 - esp Appendix 1 for air change rates - 10ac/hr Supply, 18C to 25C control range. (Capability shall be provided but not at the summer and winter external ambient design extremes against the internal maximum and minimum range conditions).

The department should be air conditioned and controlled on a zonal basis.

Central AHU plant requires humidification to achieve RH range during winter (HBN 57 Clause 4.60).

Post theatre recovery areas - Design Criteria - SHTM 03-01 - esp Appendix 1 for air change rates - 15ac/hr S&E , 18C to 25C control range.(Capability shall be provided but not at the summer and winter external ambient design extremes against the maximum and minimum range conditions).

Central AHU plant requires humidification to achieve RH range during winter.

Critical Care areas - Design Criteria - SHTM 03-01 - esp Appendix 1 for air change rates - 10ac/hr Supply , 18C to 25C control range.(Capability shall be provided but not at the summer and winter external ambient design extremes against the maximum and minimum range conditions). NHSL may require specific rooms to have a control range up to 28C

Central Air Handling Plant requires humidification to achieve RH range during winter (HBN 57 Clause 4.60).

Theatre areas - Design Criteria -SHTM 03-01 - esp Appendix 1 and 2 for air change rates Appendix 3 for design logic and pressure cascade criteria, 18C to 25C control range.(Capability shall be provided but not at the summer and winter external ambient design extremes against the internal maximum and minimum range conditions). SHTM 03-01 advises Humidification is no longer to be provided for theatres ventilation as a matter of course. Users to verify any specific requirements depending on clinical requirement. Space in plant rooms should be provided together with blank section within air handling units for future provision. NHSL may require specific rooms to have a control range up to 28C

Figure 2 - Environmental Matrix General Notes

2.2.3 The table below is an extract of details within the EM, on a room-by-room basis for all rooms however contain a different set of criteria for Dept B1 PICU/HDU beds as follows just focussing on the air change rate issue. However, the notes section states "see guidance notes".

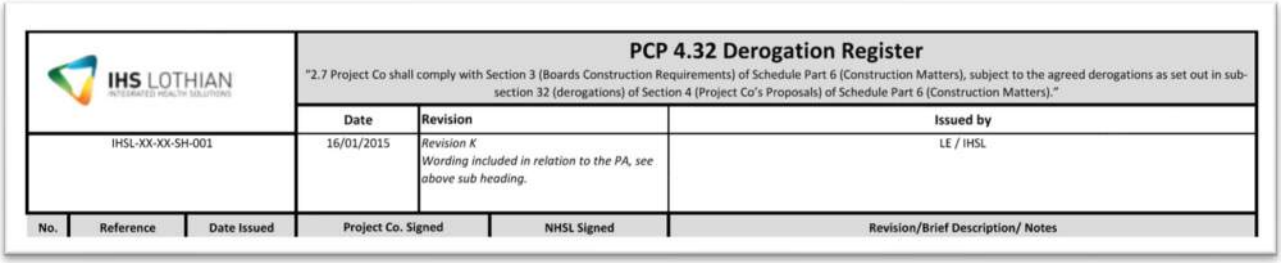
Dept Sub Group	Room Name	Cooling Type	Ventilation Type	Ventilation Supply ac/hr	Ventilation Extract ac/hr	Relative Pressure
PICU 8 Beds	Sigle Bed Isolation Cubicle	Comfort Cooled Fresh Air	HBN 4 Dependent	HBN 4 Dependent	HBN 4 Dependent	Balanced
PICU 8 Beds	Single Bed Cubicle	Comfort Cooled Fresh Air	Central Supply and Extract	4	0	Positive
PICU 8 Beds	Open plan bay (4 beds) also called Multi Bed Wards	Comfort Cooled Fresh Air	Central Supply and Extract	4	0	Positive

2.2.4 The same entries apply to Low Acuity and High Acuity Sub Departments. This air change parameter differs from the clear briefing data in the SHTM -03-01 and the general notes that are an introduction to the H&K-EM. It is unclear why this wasn't resolved when selecting preferred bidder or why it wasn't closed out sooner. The EM became a key part of IHSL's tender but this inherent ambiguity was not resolved by the time the contract was signed and financial close was achieved. Accordingly, in my view, there was a lack of clarity in the requirements for the ventilation system for Critical Care rooms. It is therefore not surprising that this resulted in a dispute at a later stage in the Project.

2.2.5 It is notable that finalising of the Environmental Matrix (EM), which is a fundamental briefing tool to the ventilation designer (apart from the overall Boards Construction Requirements), took a long time and ventilation ductwork was being moved on site without an apparent agreement to the EM. This lack of agreement, and sign-of, should have prevented any ductwork being designed.

2.2.6 The Inquiry has produced a Provisional Position Paper 8 (PP8) that provides a lot of narrative on many revisions of the Environmental Matrix and the debates between MPX and NHSL personnel (Estates and Clinicians) regarding interpretations of the SHTM's and EM about the correct design criteria, as the EM was listed as Reviewable Design Data. Putting the EM into the RDD process, post financial close was the start of the disputes resulting in the Settlement Agreement which should in my opinion have been resolved prior to contract award due to the design and commercial impact on the scheme of changes to such a key briefing document. The decision to include the EM as RDD meant that there was no finalised agreement on the parameters for the ventilation system at financial close.

2.2.7 A derogation schedule was produced by IHSL (part snap shot shown) below



IHS LOTHIAN

PCP 4.32 Derogation Register

"2.7 Project Co shall comply with Section 3 (Boards Construction Requirements) of Schedule Part 6 (Construction Matters), subject to the agreed derogations as set out in sub-section 32 (derogations) of Section 4 (Project Co's Proposals) of Schedule Part 6 (Construction Matters)."

	Date	Revision	Issued by
IHSL-XX-XX-SH-001	16/01/2015	*Revision K* *Wording included in relation to the PA, see above sub heading.*	LE / IHSL

No.	Reference	Date Issued	Project Co. Signed	NHSL Signed	Revision/Brief Description/ Notes

Figure 3- Part extract IHSL Derogation Schedule of 143 items

2.2.8 The derogations listed below related to the MEP Engineering Systems and derogation IHSL-MEP-015 is most critical as it clearly references the EM.

020	IHSL-MEP-002	05/09/2014	13/11/2014	14/11/2014	02 25% Cabling Capacity
021	IHSL-MEP-003	05/09/2014	13/11/2014	14/11/2014	03 Clinical Equipment Alarms-Rewording Accepted
023	IHSL-MEP-005	05/09/2014	13/11/2014	14/11/2014	01 DRAFT Routes through common services
027	IHSL-MEP-009	05/09/2014	13/11/2014	14/11/2014	01 Luminaire Colour/Temperature
028	IHSL-MEP-010	05/09/2014	13/11/2014	14/11/2014	01 Sprinkler Protection
029	IHSL-MEP-011	05/09/2014	13/11/2014	14/11/2014	03 Fibre Optic Cables
033	IHSL-MEP-015	05/09/2014	13/11/2014	14/11/2014	03 Environmental Matrix REWORDED 12.11.14
034	IHSL-MEP-016	05/09/2014	13/11/2014	14/11/2014	02 Sustainability

Figure 4 - MEP Related Derogations

2.2.9 The detail of IHSL-MEP-015 notes that the EM is to be further developed with the board, post Financial Close through the RDD process.

IHS LOTHIAN
INTEGRATED HEALTH SOLUTIONS

RHSC + DCN Edinburgh

Derogation Request

Date	Notes MER	Reference
05/09/2014	*03 Environmental Matrix REWORDED 12.11.14*	IHSL-MEP-015

BCR Clause

8 Mechanical & Electrical Engineering Requirements

Project Co shall provide the Works to comply with the Environmental Matrix

Relevant Regulation - HBN, SHTM, Building Regulations etc

Not Applicable

Requirement

8 Mechanical & Electrical Engineering Requirements

Project Co shall provide the Works to comply with the Environmental Matrix

Derogation

Anomalies within the environmental matrix have been reviewed and proposals incorporated within the room data sheets (refer to schedule for proposed variations).

Proposal

Anomalies within the environmental matrix have been reviewed and proposals incorporated within the room data sheets (refer to schedule for proposed variations).This shall be further developed in conjunction with the board on the basis of the schedule of comments contained in Section 5 (RDD) Part IV.

Reference Docts - Sketches, drawings, reference material extracts etc

Room Data Sheets

Figure 5 - Derogation referencing the EM being developed during RDD

2.2.10 A derogation (or clarification) would be a change (or clarification) from the briefing documents or agreed design codes or standards with a reasoning why the change is proposed. They would often be agreed by all parties and summarised in a register such as the one noted above.

2.3 SHTM 03-01 Status Design Criteria

2.3.1 SHTM 03-01 is referenced in the documents as a part of the brief and is cross referenced in the BCRs**.** SHTM 03-01 Appendix 1 Refers to Critical Care Areas at 10A/C per hour with +10 Pa and has a specific note re Isolation Rooms but only in relation to the pressure being different i.e. negative to surrounding areas to the main Critical Care Area which is positive (3rd column) . Whereas Isolation Rooms also on the table are referred to HBN 04-01, see note above.

2.3.2 In my opinion the reference to Critical Care Areas [2]would generally be interpreted by an engineer as referring to the spaces within any space with in a complete Critical Care Department including single and multi-bed ward bedrooms, with the exception of specific rooms such as listed in Appendix 1 of SHTM 03-01 which are typically encountered across many other departments in a hospital which are in a Critical Care Unit. Common spaces such as Toilets, Bathrooms, Staff Base, Dirty Utility, Clean Utility, Offices, Linen Bays, Waiting Ares and Seminar rooms, where the environment, particularly ac/hr, is different to the bed areas where Critical Care nursing is administered.

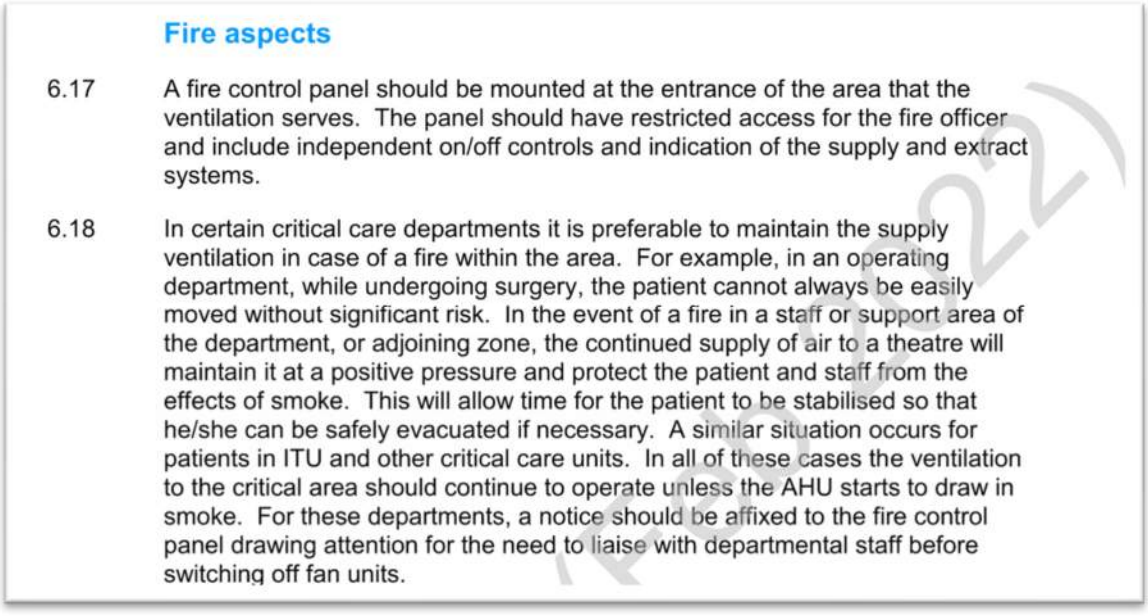
Health Facilities Scotland — SHTM 03-01: Part A – Design and Validation — NHS National Services Scotland

Appendix 1: Recommended air-change rates

Application	Ventilation	ac/Hour	Pressure (Pascals)	Supply Filter	Noise (NR)	Temp (°C)	Comments For further information see Section 6
General ward	S / N	6	-	G4	30	18-28	
Communal ward toilet	E	10	-ve	-	40	-	
Single room	S / E / N	6	0 or –ve	G4	30	18-28	
Single room WC	E	3	-ve	-	40	-	
Clean utility	S	6	+ve	G4	40	18-28	
Dirty utility	E	6	-ve	-	40	-	
Ward Isolation room	-	-	-	-	-	-	See SHPN 4; Supplement 1
Infectious disease Iso room	E	10	-5	G4	30	18-28	Extract filtration may be required
Neutropenic patient ward	S	10	+10	H12	30	18-28	
Critical Care Areas	S	10	+10	F7	30	*18-25*	Isolation room may be –ve press

Figure 6 - SHTM 03-01-Part A Feb 2014 Appendix 1 Part extract

2.3.3 In my opinion, the entry for Critical Care Areas with air change rate and positive pressure requirements are clear with only a reference to isolation rooms in the comments column being negative pressure see above but the column cross refers to section 6 which covers Automatic Controls and refers to how the ventilation plant shall operate in a fire alarm situation to maintain pressure regimes and states. This does not refer to a different air change rate.



Fire aspects

6.17 A fire control panel should be mounted at the entrance of the area that the ventilation serves. The panel should have restricted access for the fire officer and include independent on/off controls and indication of the supply and extract systems.

6.18 In certain critical care departments it is preferable to maintain the supply ventilation in case of a fire within the area. For example, in an operating department, while undergoing surgery, the patient cannot always be easily moved without significant risk. In the event of a fire in a staff or support area of the department, or adjoining zone, the continued supply of air to a theatre will maintain it at a positive pressure and protect the patient and staff from the effects of smoke. This will allow time for the patient to be stabilised so that he/she can be safely evacuated if necessary. A similar situation occurs for patients in ITU and other critical care units. In all of these cases the ventilation to the critical area should continue to operate unless the AHU starts to draw in smoke. For these departments, a notice should be affixed to the fire control panel drawing attention for the need to liaise with departmental staff before switching off fan units.

Figure 7 - SHTM 03-01-2014 Part A -part Extract section 6

[2] Comprehensive Critical Care Department of Heath 2000 stipulates 3 levels of care. Level 1—Ward based care where the patient does not require organ support (for example, they may need an IV, or oxygen by face mask). Level 2—High dependency unit (HDU) .Level 3—Intensive care.

2.3.4 It is worth noting that HTM 2025 was revised to become the first edition of HTM03-01-Part A in 2007 and the table that lists recommended Air Changes didn't change from 2007 to the SHTM 03-01 2014 requirements, part extract below hence this had been an established design criteria for a number of years.

Appendix 2 – Recommended air-change rates

Application	Ventilation	AC/hr	Pressure (Pascals)	Supply filter	Noise (NR)	Temp (°C)	Comments (for further information see Chapter 6)
General ward	S/N	6	–	G4	30	18–28	
Communal ward toilet	E	6	–ve	–	40	–	
Single room	S/E/N	6	0 or –ve	G4	30	18–28	
Single room WC	E	3	–ve	–	40	–	
Clean utility	S	6	+ve	G4	40	18–28	
Dirty utility	E	6	–ve	–	40	–	
Ward isolation room	–	–	–	–	–	–	See Health Building Note 04-01 (Supplement 1)
Infectious diseases isolation room	E	10	–5	G4	30	18–28	Extract filtration may be required
Neutropeanic patient ward	S	10	+10	H12	30	18–28	
Critical care areas	S	10	+10	F7	30	*18–25*	Isolation room may be –ve pressure

Figure 8- HTM03-01-Part A 2007 Part Extract Appendix 2 Recommended air-change rates

2.4 Conclusion

2.4.1 In my opinion, a requirement to comply with SHTM 03-01 would communicate to an engineer that 10 air changes per hour and +10 pascals of pressure would be required for all critical care spaces. However, these requirements were not reflected in the room-specific entries in the EM (either the version issued to tenderers, or the version included in the Project Agreement as RDD). The EM provided an ambiguous lower figure. The fact that the EM was included as RDD left that issue unresolved at financial close, holding it over for resolution within the contractual RDD procedures. In my opinion, the specific parameters for the ventilation system should have been clarified and confirmed much earlier in the project and certainly before Financial Close.

3.0

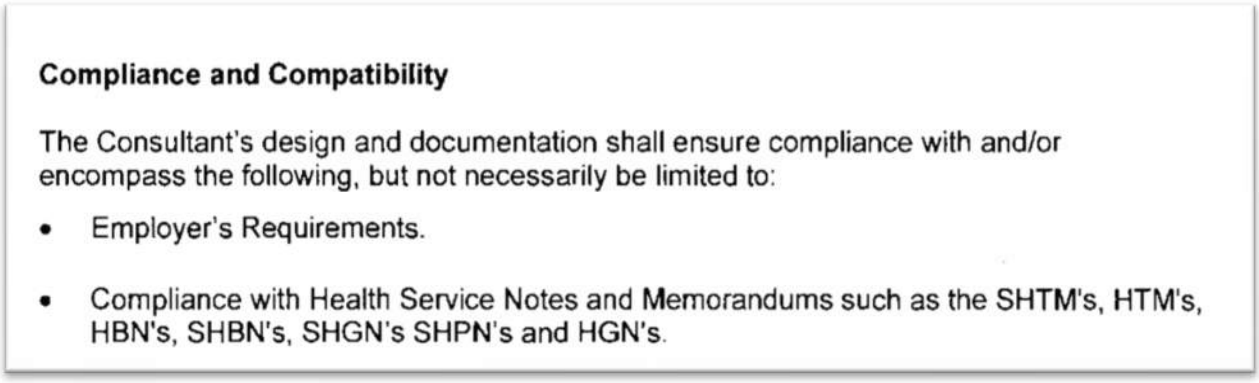
Project Co Proposals

3.0 Project Co Proposals

3.1 Designers and Sub Contractor Appointment review

3.1.1 Multiplex engaged TUV-SUD Wallace Whittle as Consulting Building Services Engineers for Design and Construction stage support of the project, under a bespoke agreement prepared by Brookfield Multiplex and signed by TUV-SUD Wallace Whittle dated February 2015.

3.1.2 Within the appointment there is a requirement in the Scope of Services section that compliance with SHTM's is required. However as noted in Section 2, a project specific EM was produced which contains some entries that are at odds with published documentation. There was ambiguity in relation to the design requirements. If best practice had been followed, a formal derogation would have been in place recording that NHSL required a system that performed to a lower standard than SHTM 03-01.



Compliance and Compatibility

The Consultant's design and documentation shall ensure compliance with and/or encompass the following, but not necessarily be limited to:

- Employer's Requirements.
- Compliance with Health Service Notes and Memorandums such as the SHTM's, HTM's, HBN's, SHBN's, SHGN's SHPN's and HGN's.

Figure 9 - Part extract Brookfield Multiplex – TUV-SUD Wallace Whittle Appointment

3.2 Design Development and response to the Brief.

3.2.1 To put some context to the scale of the rooms under review in this report, those single and multi-bed, rooms in the critical care department which were subject to Settlement Agreement No 1 are listed in the table below (this is based on my reviews of a number of documents and marked on a plan of the entire first floor).

Department	Room Name	Room Number
B1 PICU/HDU/ NNU	Single-bed cubicle	1-B1-019
	Single-bed cubicle	1-B1-020
	Single-bed cubicle	1-B1-021
	Single-bed cubicle	1-B1-037
	Single cot cubicle (with ensuite)	1-B1-075
	Open Plan Bay (4 beds)	1-B1-009
	Open Plan Bay (4 beds)	1-B1-031
	Open Plan Bay (4 beds)	1-B1-063
	Open Plan Bay (3 cots)	1-B1-065

Figure 10 - First Floor Ventilation Strategy

3.2.2 TUV-SUD issued ventilation strategy drawings, first floor example above ref WW-SZ-01-PL-524-001, for agreement dated 19 November 2013 (whilst in the competitive bid stage alongside 2 other bidders) that indicates a strategy for how they were proposing/offering to ventilate the hospital. The drawing produced is not untypical of a strategy drawing at the early-stage development of a project that would demonstrate the thought process for agreement with the client body before developing the design much further, see Figure 11 it does not provide a list of air changes but demonstrates a design intent (to someone engaged to undertake a technical review of a Contractors Proposal on behalf of the Client) , that mechanical ventilation is confirmed for the areas in question. I have annotated the drawing with red boxes indicating the extent of the rooms covered by the 4 ac/hr/10ac/hr ambiguity. It is necessary to zoom into the drawings to read the exact room number as at a readable scale the drawing would have been printed off at 1189mm by 841mm so is quite large to reproduce.

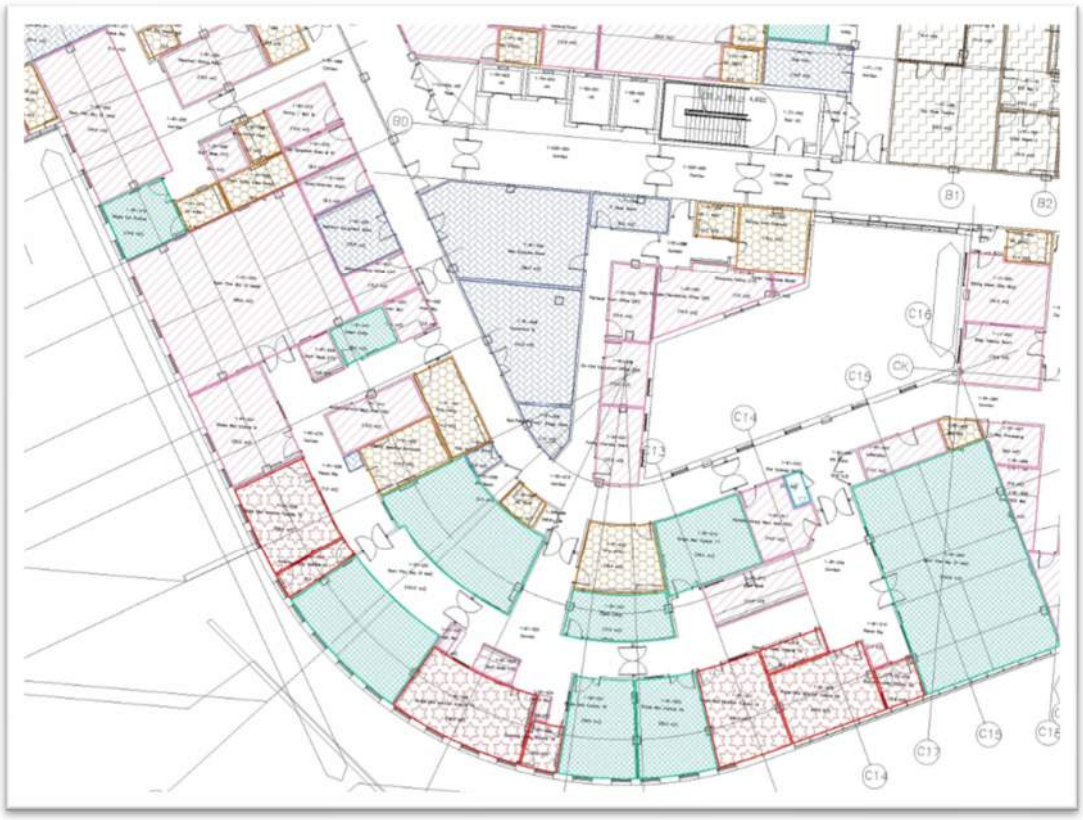


Figure 11 -Close up of B1 PICU/HDU/NNU

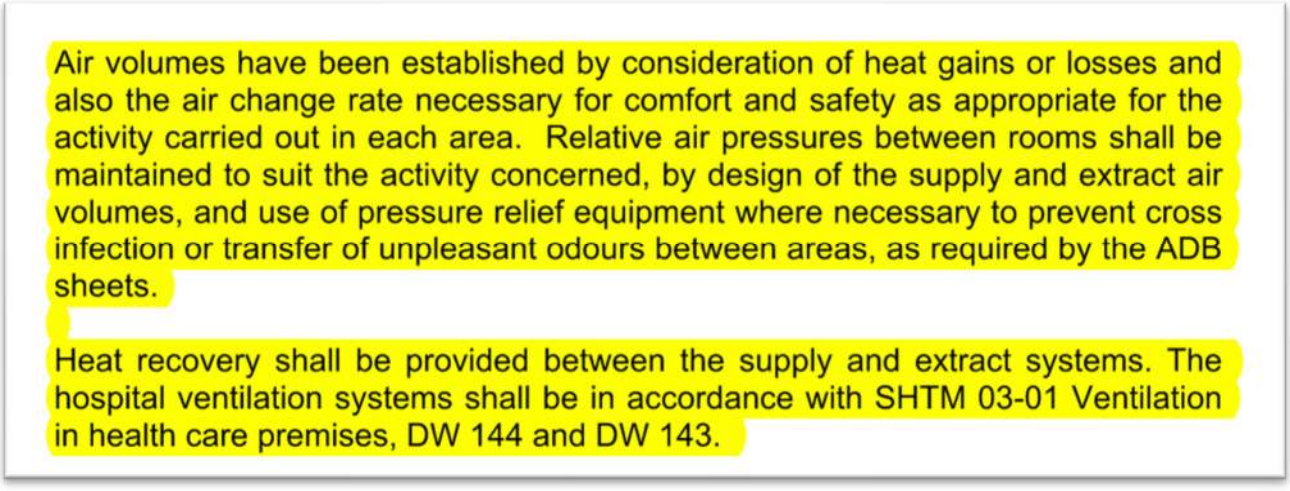
3.2.3 The coloured hatching shown on the drawings indicates the exact nature of the planned strategy and is shown in the drawing legend repeated as follows.

Figure 12-Ventilation legend

3.2.4 The rooms identified below and allocated to the Department Code B1 - Critical Care/HDU/Neonatal Surgery are ventilated as follows (interpreted by myself, using the legend allocated to the drawing)

Department	Room Name	Room Number	Ventilation Strategy
B1 PICU/HDU/ NNU	Single-bed cubicle	1-B1-019	Central Supply Air (i.e positive pressure)
	Single-bed cubicle	1-B1-020	Central Supply Air (i.e positive pressure)
	Single-bed cubicle	1-B1-021	Central Supply Air (i.e positive pressure)
	Single-bed cubicle	1-B1-037	Central Supply and Extract
	Single cot cubicle (with ensuite)	1-B1-075	Central Supply Air (i.e positive pressure)
	Open Plan Bay (4 beds)	1-B1-009	Central Supply and Extract
	Open Plan Bay (4 beds)	1-B1-031	Central Supply and Extract
	Open Plan Bay (4 beds)	1-B1-063	Central Supply and Extract
	Open Plan Bay (4 beds)	1-B1-065	Central Supply and Extract

3.2.5 The details in Project Co's proposals including their submitted specification[3], and drawings, demonstrate to someone (NHSL or appointed advisors) reviewing the proposals, a compliant solution was being offered, but without details.



Air volumes have been established by consideration of heat gains or losses and also the air change rate necessary for comfort and safety as appropriate for the activity carried out in each area. Relative air pressures between rooms shall be maintained to suit the activity concerned, by design of the supply and extract air volumes, and use of pressure relief equipment where necessary to prevent cross infection or transfer of unpleasant odours between areas, as required by the ADB sheets.

Heat recovery shall be provided between the supply and extract systems. The hospital ventilation systems shall be in accordance with SHTM 03-01 Ventilation in health care premises, DW 144 and DW 143.

Figure 13 - Part extract Section U10, page 61 of 752 Project Co's Proposals see foot note 1

[3] Section 4.23 Specification Building Services July 2014 3rd Revision dated August 2014 produced by IHSL

3.2.6 IHSL issued, in addition to a Performance Specification and drawings, a 572-page document[4] containing Room Data Sheets that utilised the NHS Activity Data Base as part of Project Co's proposals. The Room Data Sheets created at Financial Close (comprising typically 4 pages of detailed requirements titled Room Description, Room Environmental Data, Room Design Character and Schedule of Components by Room) consisted of details for 29 Generic Rooms and 96 Key Rooms throughout the hospital. Creating a full set of RDSs for the entire hospital would have been challenging pre-Financial Close and it would have been accepted practice for the Client and Project Co to agree what rooms were to be produced as being representative for the project. Below are the rooms relevant to Critical Care Department for which RDSs were supplied in the project agreement at financial close. In my experience and interpretation of SHTM 03-01 the AC/HR rates stated in these RDSs for the 4-bed low acuity, 3 bed cot bay, 4 bed high acuity and single bed cubicles/rooms are contradictory. Furthermore, a note has been added stating that natural ventilation is acceptable which in my experience is not acceptable in a Critical Care area.

Key Rooms

Code	Description	Room Number
B1609-01	4 beds Low Acuity	1-B1-031
G0510-01	Gowning Lobby: Isolation Room	1-B1-033
B1401-01	Single-bed cubicle: Isolation	1-B1-036
B1401	Single-bed cubicle	1-B1-037
B1609-02	4 beds High Acuity	1-B1-063
B1407-01	Open Plan Bay 3 cots: Neonatal	1-B1-065
B1421	Single cot cubicle: neonatal	1-B1-075

Figure 14 - extract from IHSL Document Room data Sheets for Generic and key Rooms for Financial Close see footnote 4.

[4] IHSL Document Room Data Sheets for Generic and Key Rooms at Financial Close, Doc ref HLM-SZ-SL-RD-40-001 Rev 01, Dated 18.09.14

3.2.7 ADB has a set list of parameters derived from HTM and HBN requirements, but adjustments can be made using the software (it is based on a Microsoft database format rather than a row/column spreadsheet format such as Microsoft Excel). If there were differences within say SHTM's/SHBN's or project specific requirements, then in the case of Critical Care Departments, manual adjustments were made to reflect what Project Co felt was the agreed brief requirements, along with a note that Natural ventilation was appropriate see extracts below of some spaces.

ADB	Room Environmental Data	B1401

Project:	11072	RHSC & DCN
Department:	01	Key Rooms (Financial Close)
Room:	B1401	Single-bed cubicle
Room Number:	1-B1-037	**Revision Date:** 18/09/2014

AIR	Requirements	Notes
Winter Temperature (DegC):		Permissible space temperature range (dry bulb) (degC) : 18-25
Summer Temperature (DegC):		
Mechanical Ventilation (Supply ac/hr):	4.0	Ventilation Type: Natural & Central Supply Air
Mechanical Ventilation (Extract ac/hr):		via ensuite
Pressure Relative to Adjoining Space:	Positive	
Filtration (%DSE and % Arrestance):	/	G4 - Minimum
Humidity (%RH):		

General Notes: Heating Type: Radiant Panels with TRV Remote Head Adj. Cooling: Comfort Cooled Fresh Air

Figure 15 - Single Bed (None Isolation) Cubicle 4.0 ac/hr natural and mechanical ventilation

ADB	Room Environmental Data	B1401-01

Project:	11072	RHSC & DCN
Department:	01	Key Rooms (Financial Close)
Room:	B1401-01	Single-bed cubicle: Isolation
Room Number:	1-B1-036	**Revision Date:** 18/09/2014

AIR	Requirements	Notes
Winter Temperature (DegC):		Permissible space temperature range (dry bulb) (degC) : 21-25
Summer Temperature (DegC):		
Mechanical Ventilation (Supply ac/hr):	10.0	Supply via lobby
Mechanical Ventilation (Extract ac/hr):		
Pressure Relative to Adjoining Space:	Balanced	
Filtration (%DSE and % Arrestance):	/	F7 - minimum
Humidity (%RH):		

General Notes: Heating type: Adjacent space transfer air with BMS Adjustable Sensor. Cooling: Comfort Cooled Fresh Air

Figure 16 - Single Bed Isolation cubicle 10 Air Changes Mechanical

ADB	Room Environmental Data	B1609-01

Project:	11072	RHSC & DCN		
Department:	01	Key Rooms (Financial Close)		
Room:	B1609-01	4 beds Low Acuity		
Room Number:	1-B1-031		**Revision Date:**	18/09/2014

AIR	Requirements	Notes
Winter Temperature (DegC):		Permissible space temperature range (dry bulb) (degC) : 18 - 25
Summer Temperature (DegC):		
Mechanical Ventilation (Supply ac/hr):	4.0	Ventilation Type: Natural & Central Supply Air
Mechanical Ventilation (Extract ac/hr):		
Pressure Relative to Adjoining Space:	Positive	
Filtration (%DSE and % Arrestance):	/	G4 - minimum
Humidity (%RH):		

Figure 17 - 4 Bed Bay 4ac/hr ventilation natural and mechanical.

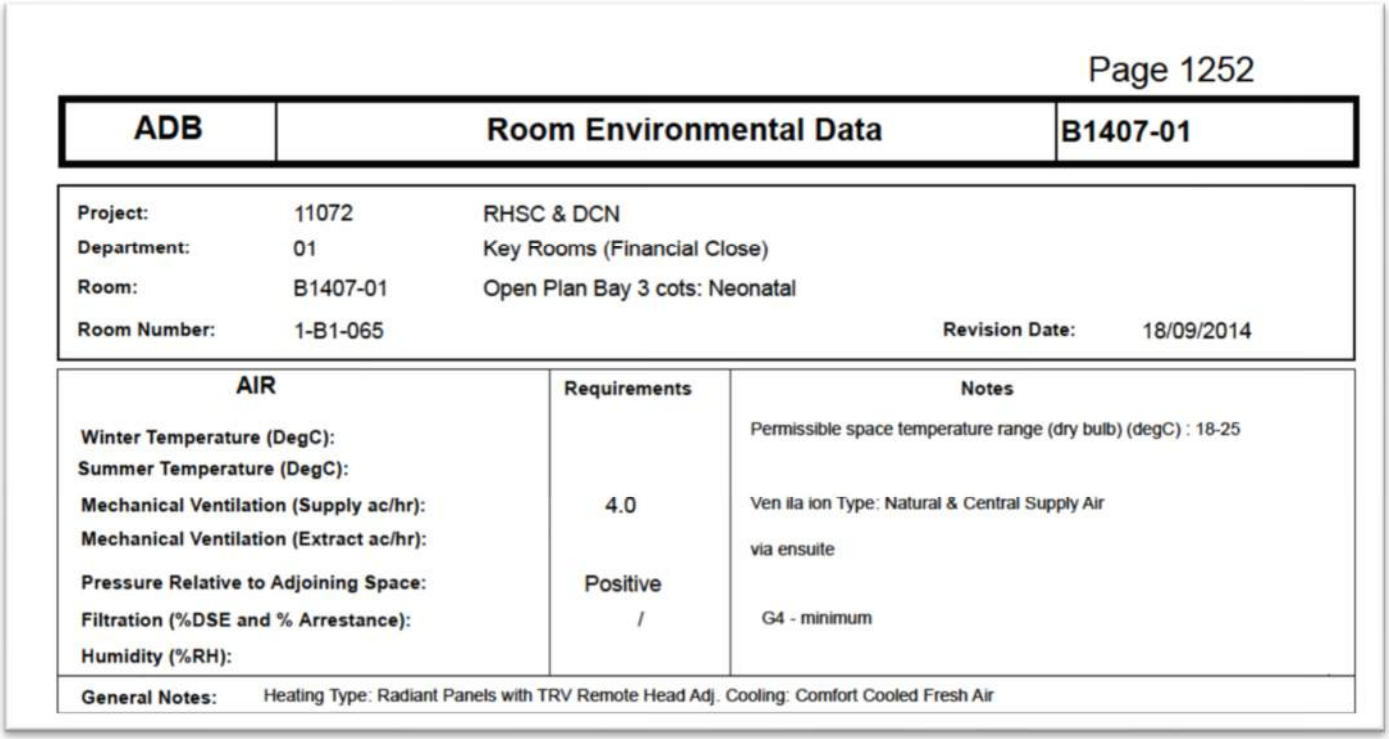
Page 1248

ADB	Room Environmental Data	B1609-02

Project:	11072	RHSC & DCN		
Department:	01	Key Rooms (Financial Close)		
Room:	B1609-02	4 beds High Acuity		
Room Number:	1-B1-063		**Revision Date:**	18/09/2014

AIR	Requirements	Notes
Winter Temperature (DegC):		Permissible space temperature range (dry bulb) (degC) : 18 - 25
Summer Temperature (DegC):		
Mechanical Ventilation (Supply ac/hr):	4.0	Ven ila ion Type: Natural & Central Supply Air
Mechanical Ventilation (Extract ac/hr):		
Pressure Relative to Adjoining Space:	Positive	
Filtration (%DSE and % Arrestance):	/	G4 minimum
Humidity (%RH):		
General Notes:	Heating Type: Radiant Panels with TRV Remote Head Adj. Cooling: Comfort Cooled Fresh Air	

Figure 18 - 4 beds high acuity 4 ac/hr ventilation natural and mechanical



Page 1252

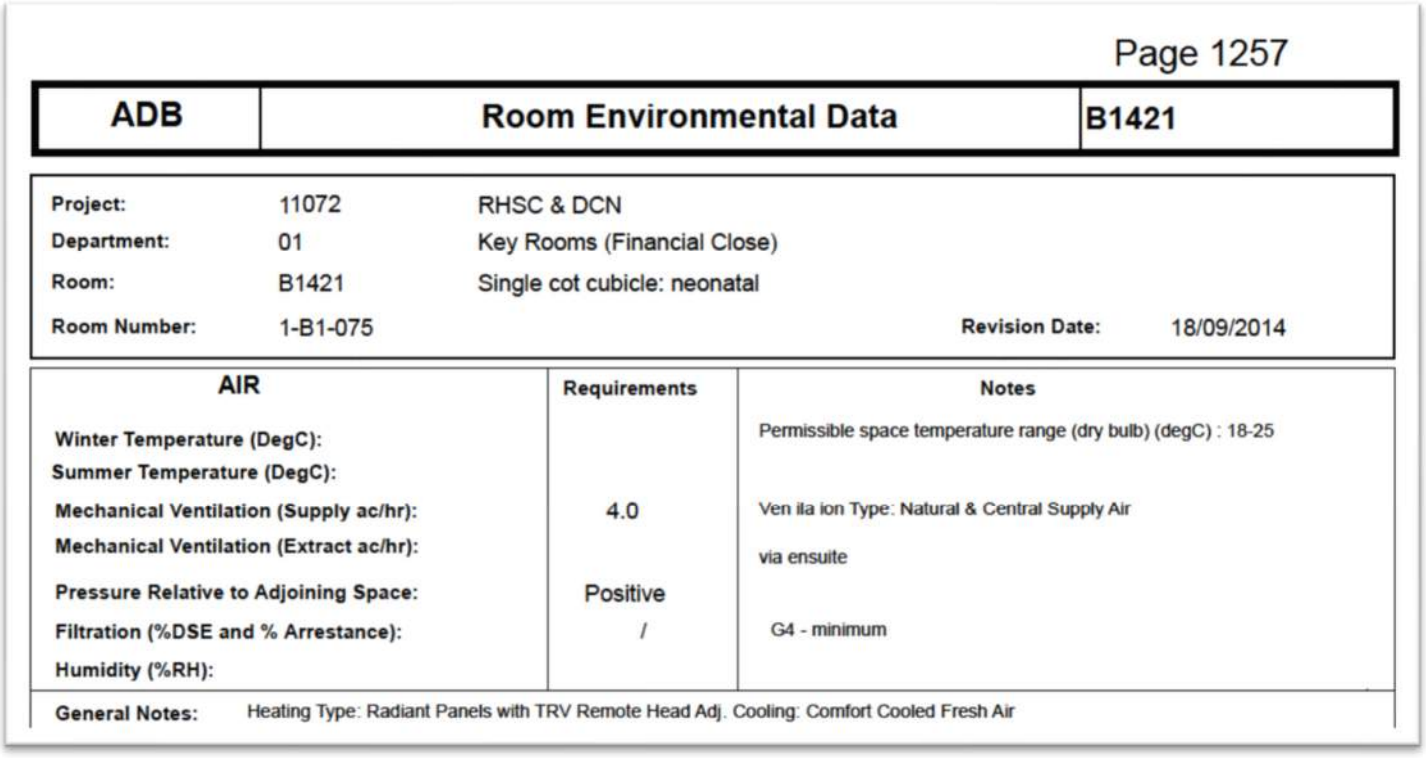
ADB	Room Environmental Data	B1407-01

Project:	11072	RHSC & DCN
Department:	01	Key Rooms (Financial Close)
Room:	B1407-01	Open Plan Bay 3 cots: Neonatal
Room Number:	1-B1-065	**Revision Date:** 18/09/2014

AIR	Requirements	Notes
Winter Temperature (DegC):		Permissible space temperature range (dry bulb) (degC) : 18-25
Summer Temperature (DegC):		
Mechanical Ventilation (Supply ac/hr):	4.0	Ven ila ion Type: Natural & Central Supply Air
Mechanical Ventilation (Extract ac/hr):		via ensuite
Pressure Relative to Adjoining Space:	Positive	
Filtration (%DSE and % Arrestance):	/	G4 - minimum
Humidity (%RH):		

General Notes: Heating Type: Radiant Panels with TRV Remote Head Adj. Cooling: Comfort Cooled Fresh Air

Figure 19 - 3 cot bay Neonatal 4ac/hr ventilation natural and mechanical.



Page 1257

ADB	Room Environmental Data	B1421

Project:	11072	RHSC & DCN
Department:	01	Key Rooms (Financial Close)
Room:	B1421	Single cot cubicle: neonatal
Room Number:	1-B1-075	**Revision Date:** 18/09/2014

AIR	Requirements	Notes
Winter Temperature (DegC):		Permissible space temperature range (dry bulb) (degC) : 18-25
Summer Temperature (DegC):		
Mechanical Ventilation (Supply ac/hr):	4.0	Ven ila ion Type: Natural & Central Supply Air
Mechanical Ventilation (Extract ac/hr):		via ensuite
Pressure Relative to Adjoining Space:	Positive	
Filtration (%DSE and % Arrestance):	/	G4 - minimum
Humidity (%RH):		

General Notes: Heating Type: Radiant Panels with TRV Remote Head Adj. Cooling: Comfort Cooled Fresh Air

Figure 20 - Single cot cubicle Neonatal 4ac/hr ventilation natural and mechanical

3.2.8 Project Co's room data sheets clearly follow the values included in the body of the EM. I understand that there was no adverse comment by NHSL or its advisors on the content of these room data sheets. Based on the above extracts it is understandable, from an engineering perspective, why Project Co and their advisors were of the understanding that their solution was based (and agreed) on the lesser standards of 4ac/hr as it is clearly stated so in the rooms under review.

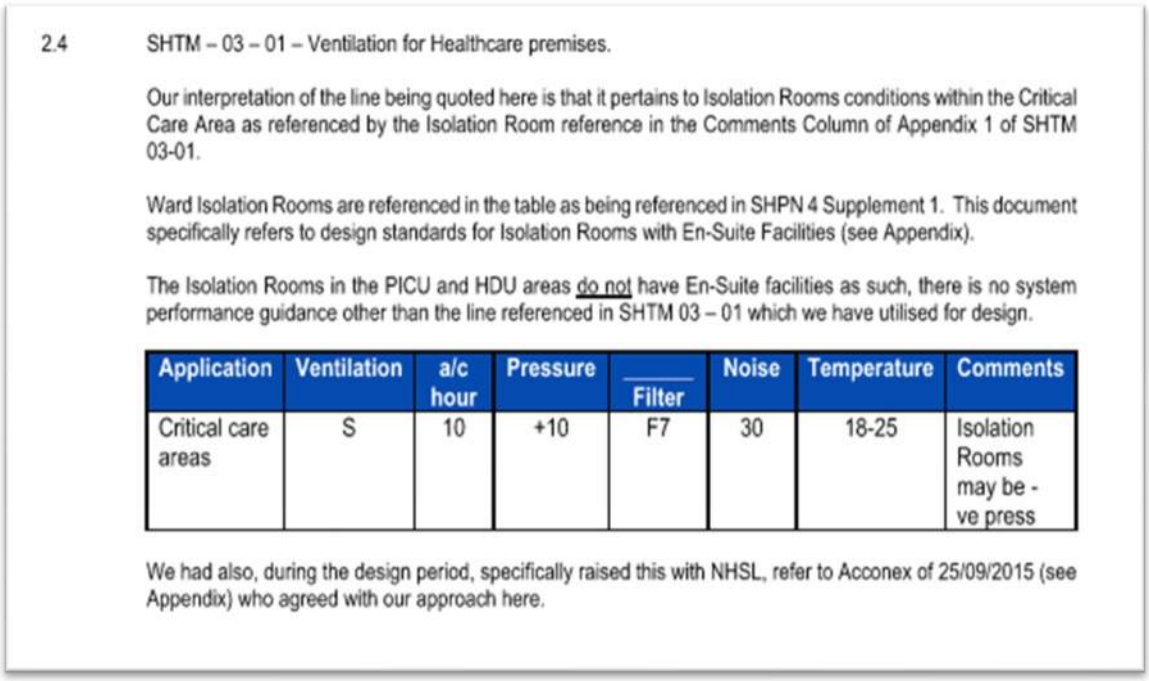
3.2.9 There were obviously some concerns relating to the environmental matrix and the placing of the EM as an item to fall under the Reviewable Design Data. This should not have been permitted as this was delaying resolution of the final agreed parameters for the ventilation system.

3.2.10 In my experience, Financial Close and contract programme are significantly impacted by time pressures as the PFI funders want a return on their investment as quickly as possible so the period from FC (release of funds) and operational date (repayment by means of "rental" by NHSL) is a key factor in any PFI project. Therefore, agreeing key parameters at financial close, and resolving issues as early as possible, is of critical importance to the success of a project.

3.2.11 In my opinion, based on my experience, RDD should have been reserved for elements that would not have had a significant impact on building the project. Typically, a provisional sum or budget cost could have been made for a range of options on say furniture allowance or paint colour, something that wasn't fundamental to the construction building of the hospital. All parties would need to be in agreement to the scope and impact of potential changes that may happen through the RDD sign-off process, so the full impact can be assessed.

3.3 Post Financial Close Design Development

3.3.1 It is clear from the TUV-SUD document Review of Ventilation Provisions for (B1) PICU and HDU Departments July 2019 and the chronology of events listed in PPP8, there was significant discussion relating to NHSL's requirements after Financial Close.



2.4 SHTM – 03 – 01 – Ventilation for Healthcare premises.

Our interpretation of the line being quoted here is that it pertains to Isolation Rooms conditions within the Critical Care Area as referenced by the Isolation Room reference in the Comments Column of Appendix 1 of SHTM 03-01.

Ward Isolation Rooms are referenced in the table as being referenced in SHPN 4 Supplement 1. This document specifically refers to design standards for Isolation Rooms with En-Suite Facilities (see Appendix).

The Isolation Rooms in the PICU and HDU areas do not have En-Suite facilities as such, there is no system performance guidance other than the line referenced in SHTM 03 – 01 which we have utilised for design.

Application	Ventilation	a/c hour	Pressure	Filter	Noise	Temperature	Comments
Critical care areas	S	10	+10	F7	30	18-25	Isolation Rooms may be - ve press

We had also, during the design period, specifically raised this with NHSL, refer to Acconex of 25/09/2015 (see Appendix) who agreed with our approach here.

Figure 21- Part Extract TUV-SUD Document

3.3.2 SHTM-03-01 in my opinion, clearly states Critical Care Areas, as requiring 10 air changes as acknowledged in the TUV-SUD Ventilation review document. However, TUV SUD, as is apparent from the note in the Comments column (see section 2.3) only applied these parameters to Isolation Rooms. They have interpreted SHTM 03-01 in one particular way and they record that NHSL were aware of their interpretation of this specific issue. TUV-SUD have supplied copies of emails lodged on the Aconex Document Management system in September 2015, that they state support their position although details of what process agreed and signed off this position unclear.

3.3.3 TUV-SUD also make reference to the air change rate as being 4 air changes in an email 12 April 2018, which is confirmed in an email between representatives of NHSL and IHSL dated 18 April 2018 as being the client's brief. This is verified by a document entitled Bedroom Ventilation Update meeting dated 24 February 2017 attended by the Client (and advisors) and Project Co (and its designers). It is not known why such a difference between air changes rates from published SHTM to EM occurred or was accepted.

3.4 Design Commentary process

3.4.1 The design review and sign-off process is detailed in PPP8, and in accordance with normal design review processes on many construction projects (conventional and PFI procurement routes) we would anticipate that design packages by way of drawings/(plans/schematics) and reports were submitted and drawings given Status A, B or C as it is far easier to clearly identify the acceptance or otherwise of an interpretation of text than by email chain. To shed light on how the agreement to the lower AC/HR contained in the Financial Close RDS was accepted, other than the clarification emailing in April 2018, the Settlement Agreement No 1 signed 22 February 2019, Schedule 1 Part 1 Technical Schedule items 4 and 7, identifies ventilation as still being in dispute. However, under Item 7 a list of drawings granted Status B are provided. Status B is understood (from a review of PPP8) to have meant - *Proceed subject to amendment as noted; Project Co to make amendments as noted and continue next level of design or to implement the works without re-submitting documents*. I have not seen the nature of the comments made.

3.4.2 The design commentary process would often involve the Client's technical advisors checking the Project Co submission and passing comment, each submission would not ordinarily be reviewed by the Client engineers or Infection Prevention and Control (IPC) team as it would be assumed the brief had been agreed by these parties prior to any design being commenced. Therefore, if the Clients advisors were of the view that 4 ac/hr was proposed in the original EM then this had been agreed with Client Engineers and IPC. It is not known if the Client Team or IPC had agreed the 4 ac/hr. Any such reduction should have been supported by either previously agreed locally agreed practice or scientific evidence. Some NHS Trusts have different design solutions, but this requires to be agreed and documented. For example, in Northern Ireland, they design isolation rooms differently to the HTM/HBN but issue a design specification endorsed by NHS Engineers, IPC team and Microbiologists to any party involved in designing and constructing Isolation rooms. I have not seen any similar documentation in relation to the RHCYP/DCN which suggests that there was a deliberate intention to depart from the requirements set out in SHTM 03-01 for rooms in Critical Care.

3.4.3 The 2022 Edition of SHTM 03-01 requires any future ventilation system design or changes from those set out in the guidance to be agreed the Ventilation Safety Group that typically comprises Engineers/IPC's/Clinicians/Authorising Engineers/Authorised Persons. The sign off and approval process is very specific and clear. These new procedures may mitigate the risk of such ambiguities arising in future projects.

4.0

Settlement Agreement No 1 - Initial Installed Ventilation System Review

4.0 Initial Installed System Design Review

4.1 Introduction

4.1.1 I understand that after financial close NHSL and IHSL entered into a settlement agreement (Settlement Agreement 1). This set out that 4 ac/h were required for certain Critical Care Rooms. From an engineering perspective, in my opinion, this was a mistake. It meant that the system had ventilation parameters for Critical Care Rooms that did not comply with SHTM 03-01. I am not aware of any risk assessment, or any assessment by IPC professionals, which justified these ventilation parameters. In future, any such decision would be taken with involvement from the Ventilation Safety Group. Therefore, this should mitigate against the risk of similar issues happening on a future project.

4.1.2 This section covers a review of ductwork systems associated with one of the rooms under consideration to demonstrate the design process and how impactful a change in ac/hr rate has been, to also explain the approach to designing a ventilation ductwork system and answer the question could the ductwork systems as installed accommodate a higher air change rate?

4.2 Critical Care Rooms Installed Design Review – Functionality and Capacity.

4.2.1 The design process for a ventilation system, follows a sequential process.

1) Agree design criteria for air requirements in a space, (either a defined air change rate or air volume to mitigate heat losses/gains),
2) Determine air flow regimes required to maintain negative, positive or balanced condition in spaces, (and any pressure differentials)
3) Measure room volume - if air change rate is agreed parameter. Key task is to verify proposed ceiling height with Architect,
4) Assess and plan how ductwork is to be distributed to the rooms in questions,
5) Calculate air volumes for all spaces using agreed parameter and assess air flow rates between spaces of differing pressures,
6) Add up air volumes,
7) Calculate duct sizes using agreed parameters, note duct size will have a maximum depth to fit within ceiling voids, (see below)

4.2.2 Determining a duct size has 3 defined criteria:

1) Air volume,
2) Design velocity - The noise level generated by airflow in ductwork is very sensitive to the velocity. The duct velocities should therefore be kept as low as possible,
3) Agree maximum pressure drop per metre of ductwork – required to ensure fan power efficiencies meet Building Regulation Energy Efficiency standards typically 1.0 pascal/metre max

4.2.3 Ductwork systems in hospital applications are generally low pressure and low velocity systems due to criteria 2 and 3 listed above. Generally accepted design practice uses design velocities as follows.

Table 2.16 Recommended maximum duct velocities for low-pressure ductwork systems where noise generation is the controlling factor

Typical applications	Typical noise rating (NR)*	Velocity / m·s^{-1}		
		Main ducts	Branch	Run-outs
Domestic buildings (bedrooms)	25	3.0	2.5	<2.0
Theatres, concert halls	20–25	4.0	2.5	<2.0
Auditoria, lecture halls, cinemas	25–30	4.0	3.5	<2.0
Bedrooms (non-domestic buildings)	20–30	5.0	4.5	2.5
Private offices, libraries	30–35	6.0	5.5	3.0
General offices, restaurants, banks	35–40	7.5	6.0	3.5
Department stores, supermarkets, shops, cafeterias	40–45	9.0	7.0	4.5
Industrial buildings	45–55	10.0	8.0	5.0

* See CIBSE Guide A (2015a), Table 1.16

Figure 22 - Table 2.16 from CIBSE Guide B2 Ventilation and Ductwork 2016. Highlighted row would be used in a healthcare environment.

4.2.4 The above has been standard industry practice, whilst published in 2016 similar design principles have been in use for many years and **it is not** common practice, to oversize ducts for future increase in air to be delivered through a ventilation duct network, unless specifically advised in a client brief. Maximum allowances would be typically 5-10% which is chosen to cover future duct leakage due to failing joint gaskets.

4.2.5 Example of duct serving room 1-B1-037 Critical Care Single Bed Cubicle

4.2.5.1 The room below is a single bedroom under review of approximate size 4.55m by 5.73m. In the absence of an architects ceiling strategy engineers would ordinarily assume (for initial sizing) typical bedrooms in a Critical Care Ward would have 3.0m high ceilings (see Figure 14 below). Normal bedrooms in other departments would have a ceiling height of 2.7m (see Figure 15 below) The room height is critical as it determines the room volume which is to be changed per hour by the ventilation system, the higher the ceiling the greater the actual air delivered volume to achieve the ac/hr design rate. The supply air is delivered into the space by the 250ØSD (250mm diameter) supply duct serving supply grille reference 01-418 SG-030.

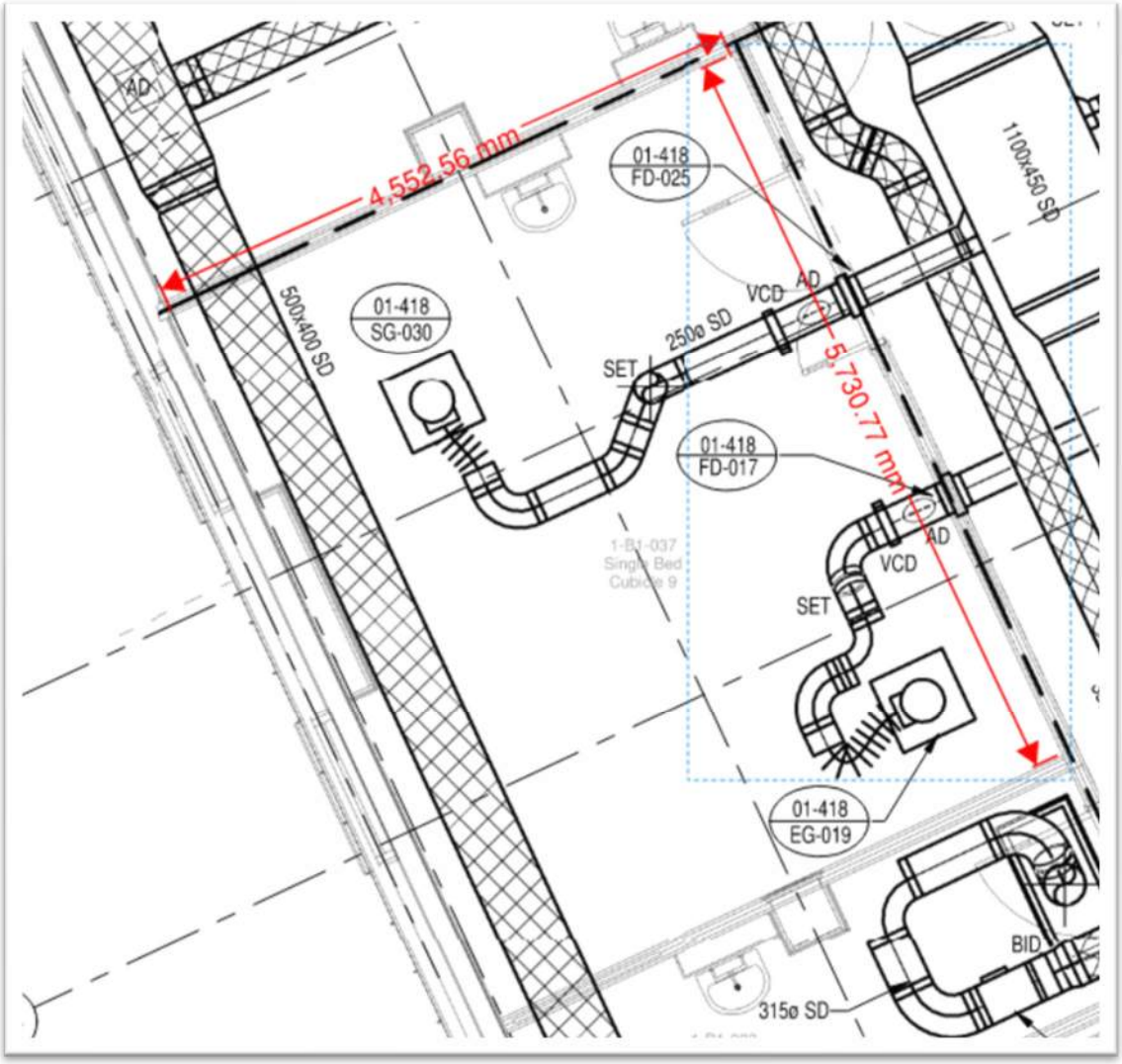
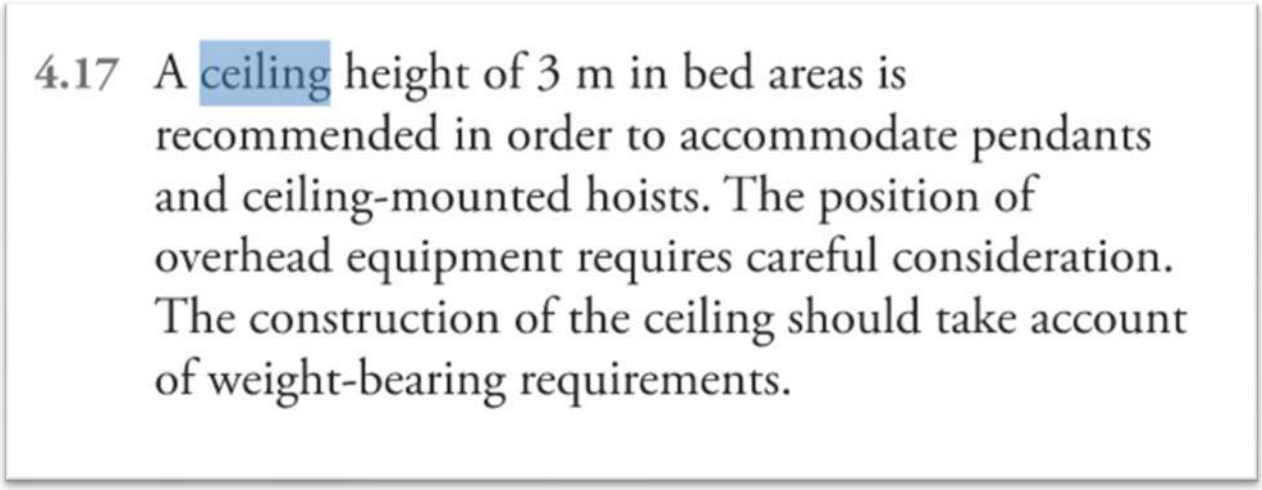
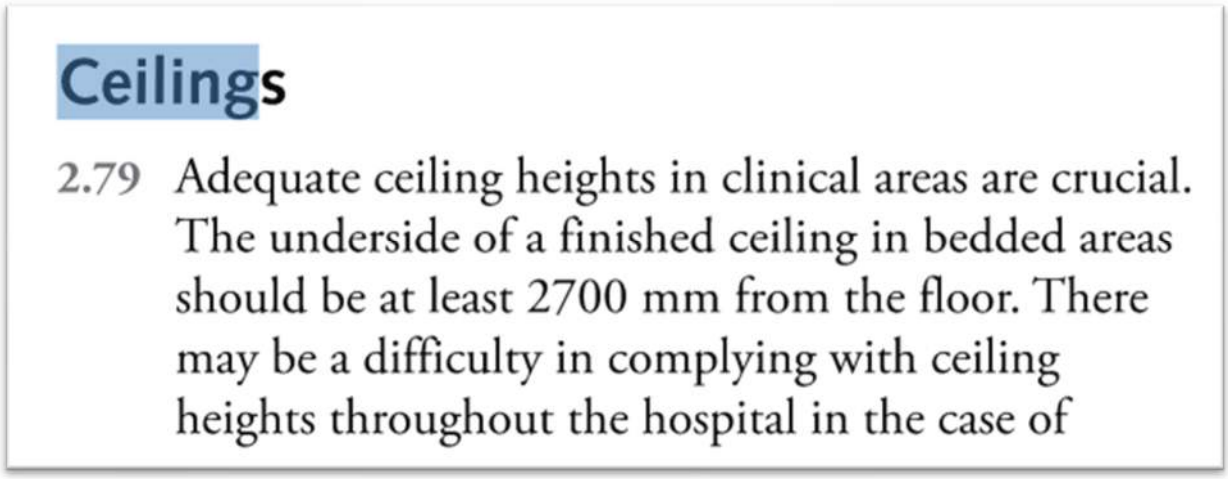


Figure 23 - Part Extract Level 01 Critical Care Area.



4.17 A ceiling height of 3 m in bed areas is recommended in order to accommodate pendants and ceiling-mounted hoists. The position of overhead equipment requires careful consideration. The construction of the ceiling should take account of weight-bearing requirements.

Figure 24 - Part extract HBN-04-02 Critical Care Units Pub -2013



Ceilings

2.79 Adequate ceiling heights in clinical areas are crucial. The underside of a finished ceiling in bedded areas should be at least 2700 mm from the floor. There may be a difficulty in complying with ceiling heights throughout the hospital in the case of

Figure 25 - Part extract HBN 04-01 Adult In-Patient facilities Pub 2009

4.2.5.2 Air Volume calculations at different air changes and resulting velocity in the 250mm diameter supply air duct indicated by the term 250Ø SD in figure 18 above have been made as follows. This was more straightforward than calculating the resulting velocities for a full suite of rooms.

Room Ref	Length	Width	Height	Room Volume	Chosen Air Change Rate	Resulting Air Volume m3/hr	Resulting Air Volume m3/sec	Resulting Air Volume litres/sec	Resulting duct velocity m/sec
1-B1-037	5.73	4.55	3.0	78.2	**4**	312.8	0.0869	87	1.75
1-B1-037	5.73	4.55	3.0	78.2	**6**	469.2	0.130	130	2.6
1-B1-037	5.73	4.55	3.0	78.2	**10**	782.0	0.217	217	4.2

4.2.5.3 If the ceiling height noted above was changed to 2.7m then the room volume becomes 70.4m3, 4 ac/hr would result in a delivery volume of 0.078m3/sec (78litres/sec) further indicating that the ceiling height is a crucial factor in sizing a ventilation system.

4.2.5.4 Based on the above table, at 4 ac/hr the supply duct serving the grille is correctly sized and could accommodate up to 6 ac/hr per hour but 10 ac/hr would not meet acceptable air velocity criteria and would likely result in noise generation within the duct, a 340mm diameter duct would be required to accommodate the higher air change rate using the sizing nomogram in Appendix B.

4.2.5.5 Using this simple example demonstrates that the design as originally proposed was only based on 4 ac/hr. A more detailed study was undertaken under Settlement Agreement 2 to establish what duct networks required amendment to ensure design velocities were maintained within acceptable limits.

4.3 Commissioning and Validation

4.3.1 There is a clear difference between Commissioning and Validation of an engineering system, the following definitions are taken directly from SHTM03-01 Part A 2014.

4.3.2 Commissioning - Commissioning is the process of advancing a system from physical completion to an operating condition. It will normally be carried out by specialist commissioning contractors working in conjunction with equipment suppliers. Commissioning will normally be the responsibility of the main or mechanical services contractor.

4.3.3 Validation - A process of proving that the system is fit for purpose and achieves the operating performance originally specified. It will normally be a condition of contract that “The system will be acceptable to the client if at the time of validation, it is considered fit for purpose and will only require routine maintenance in order to remain so for its projected life.”

4.3.4 Commissioning is often sub-divided into sections e.g., air handling unit, automatic controls, airside balance, building fabric and fittings. Each section may be commissioned by its specialist installer, and they are often accepted in isolation. Validation differs from commissioning in that its purpose is to look at the complete installation from air intake to extract discharge and assess its fitness for purpose as a whole. This involves examining the fabric of the building being served by the system and inspecting the ventilation equipment fitted as well as measuring the actual ventilation performance.

4.3.5 The commissioning therefore was undertaken by the mechanical contractor’s specialist commissioning company – H&V Commissioning Services Ltd (up to July 2019) to the design flow rate figures (indicated on the design drawings and schedules determined from the design brief ac/hr) with no requirement of the commissioning company to verify the systems performance against the SHTM 03-01 design rates of 10ac/hr. These volume flow rate measurements/tests would be carried out towards the end of the building process when a ventilation system ductwork distribution was complete. Often the initial balancing (as it is termed) and checking exercises are undertaken before ceilings are complete so the regulation devices (volume control dampers) are fixed such that the air volumes on the drawings are correctly delivered to the spaces. It is not normally a requirement for the commissioning company to record the ac/hr rate. H&V Commissioning Services will have issued system-by-system reports of their commissioning procedures and results only one relating to the Operating Theatres suite has been seen.

4.4 Installed Validation review and functionality.

4.4.1 IOM issued an independent validation report of the ventilation systems dated October 2019 ref P2739.[5] Their brief was a review of the Air Handling Unit (AHU) construction, and the air flow rates in the installed systems. Note that Mercury Engineering had received a Practical Completion (PC) certificate dated 22 February 2019. There is an Appendix of defects (not seen by Cundall) but the cover notes in the PC Certificate did not draw any attention to areas of concern relating to the Ventilation and Air Handling systems.

4.4.2 Using room 1-B1-037 as our design example, IOM noted in their report that the supply air change rate was only 3.4 ac/hr and **they were advised of a brief derogation** from 10 ac/hr down to 4 ac/hr but as was the case for other 4 bed rooms in the HDU they did not meet the 4 ac/hr so the derogation that was agreed based on IOM's testing the original system, did not meet the amended brief.

High Dependency areas.

Testing of the high dependency areas identified that the air change rates and pressure cascades did not meet the requirements. In early discussion with the Health Boards Technical Advisors (Mott MacDonald) we were advised that there was derogation in place which reduced the requirements from 10 ac/hr to 4.

The test information was summarised in an initial briefing to the Health Board during w/com 2nd July.

It later transpired that there was some confusion on the detail of the derogation and the Construction supply chain and the Health Board began working on both an interim solution to improve the situation and a longer term permanent solution.

The final results for the high dependency areas were as follows.

Area/Room	Room No	Supply Ac/hr rate	Extract Ac/hr rate	Pressure Differential	Comment
HDU 4 bed bay	1-B1-009	3.4	1.3	8 pa	requires 10 ac/hr supply and 10 pa
HDU 4 bed bay	1-B1-031	3.1	1.3	0.5 and 3.2 pa(2 doors)	requires 10 ac/hr supply and 10 pa
HDU 4 bed bay	1-B1-063	3.2	1.9	+1.5 pa	requires 10 ac/hr supply and 10 pa
HDU single bed cubicle	1-B1-037	3.4	1.5	+ 6.3 pa	requires 10 ac/hr supply, design pressure tba

Figure 26 - Part extract IOM Validation Report 4th October 2019

[5] IOM Limited Witnessing of theatre re-balancing and validation summary report Date of Witnessing 20 July 2019 Additional measurements 3 October 2019

4.4.3 IOM also issued separate Ventilation Validation reports for many areas, 52 reports in total, that provided evidence of individual room validation testing with comparisons against the ac/hr criteria in SHTM 03-01. Two Critical Care rooms in particular Rooms B1.031 – 4 bed bay and 1.B1.037 Single Bed Cubicle were tested on 22 June 2019 and 20 June 2019 respectively and final reports issued on 5th November 2019. Neither room was recorded as meeting the SHTM 03-01 10 ac/hr criteria. The individual room test reports make no reference to the original design criteria ONLY the SHTM03-01 criteria.

4.5 AHU Manufacture review.

4.5.1 There are a series of logs/trackers etc that identify manufacturing issues that demonstrated the AHU's were not constructed in accordance with SHTM-03-01. Mercury Engineering as engineering Sub Contractor and procurer of the AHU's undertook remedial works to improve the quality of the AHU's.

4.5.2 A 37-page AHU Remedial Schedule has been produced and each page list issues with every ahu and checked and signed off as being SHTM03-01 compliant in March/April 2020, refer to extract below. This only relates to the construction issues identified in the validation reports and not the air volume performance data.

AHU	ISSUES IDENTIFIED AT FIRST INSPECTION	Date RE-Inspected	Corrected (Y/N)
02-01	Fresh air inlet plenum debris	24.03.20	Y
	Pre-filters & F7 final filters some panels wrong orientation top row		Y
	Pre-filter sliders & spaces missing on floor		Y
	Exposed cables at fans		Y
	Motorised damper not closing fully		Y
	Return filter door clashing with cable tray		Y
	Inaccessible channels for cleaning at metalwork		Y
	AHU not labelled to SHTM standard		Y
	Mud on inside face side of ductwork after final supply VCD non access door		Y
	Muddy footprint on inside top face of ductwork after final supply VC		Y

Date re-inspected - 24.03.20

Satisfactory Y/N - Y

The signatories below confirm that the AHU meets the definition contained in section 8 of SHTM 03-01 as follows:
"The system will be acceptable to the client if at the time of validation it is considered fit for purpose and will only require routine maintenance in order to remain so for its projected life."

Organisation	Name	Signature	Date
NHSL - Commissioning Manager - Hard FM	R HENDERSON		6/5/20
NHSL - Infection Control Lead			
NHSL - Infection Control Consultant Microbiologist			
Technical Advisor - Mott MacDonald			
AE NHSL - Turner PES	JM [illegible]		6/5/20
AE Independant Validation - IOM	PAUL JAMES		6/5/20
HFS			

Figure 27 - AHU Remedial schedule part extract.

4.6 Level 3 Isolation Room Ahu provision.

4.6.1 The level 1 and 3 isolation rooms were initially served from air handling units that also served other rooms. It is noted that HBN 04-Supplement 01[6] stated the following.

2.37 Ideally each isolation suite should have its own dedicated supply and extract system. If two or more suites share a ventilation system, there will be an inevitable increase in the complexity of the system and a corresponding reduction in reliability and serviceability. Routine maintenance or breakdown of the ventilation system will result in failure of all suites that it serves; therefore, ideally each such isolation suite should have its own dedicated AHU.

2.38 In a high-rise building, a common supply and extract system may be the only feasible solution. In this case, run and standby fans would be required for the extract, and a duplicate supply unit may be considered necessary. The common supply and extract systems will need to be controlled to ensure a constant volume in each isolation suite branch regardless of the number in use.

2.39 Ductwork should be kept as direct and simple as possible.

Figure 28 - Part Extract HBN-04-01-2013

[6] Health Building Note 04-01 Supplement 1-Isoaltion facilities for infectious patients in acute settings 2013

4.6.2 The reference to high rise is only strictly defined in the purpose of Fire Safety legislation and is defined as 18 metres from external ground to finished floor level of occupied floor ie level 0 to 3 which is actually 13.35m. The issue should really be considered as the **complexity** of running ductwork from the plant space to the risers and then to the rooms under consideration. The term ideally is not definitive, and some Trusts would accept (**by agreement)** a combined AHU(s) proposal as noted in 2.38 in Figure 28.

4.6.3 The rooms instructed under HVCN-0107 on level 1 are significantly more challenging to serve than those on level 3 due their location and proximity to risers. The rooms on the top floor could have been fed directly from plant on the roof (noting co-ordination issues would exist with plantrooms and helipad) but the strategy could have been dealt with early in the original design process. Individual extracts were incorporated in the design and taken to roof level, so it is not known why individual handling units were not designed in the original scheme.? It is not known if planning permission had any restrictions imposed that may have prevented these key plant items being incorporated onto the roof or if they could have been accommodated in the plantrooms.

4.7 Conclusion

4.7.1 As at early July 2019, the ventilation system for Critical Care Rooms at the RHCYP/DCN did not comply with the requirements of SHTM 03-01.

4.7.2 Sample calculations have shown that the original design, could have met the 4ac/hr design criteria (as set out in Settlement Agreement 1) but the IOM initial validation demonstrated that the installation did not meet the ac/hr rate for Critical Care as listed SHTM 03-01. It was also below the specified ac/hr, in the 4 rooms shown in Figure 16. This could be due to the design air flow rate being calculated on an incorrect ceiling height (room height assumed as being 2.7m not 3.0m) or incorrect capacity in the system. Architectural ceiling heights are not yet available to verify what the installed room height was.

4.7.3 It is not clear why separate isolation room air handling units were not considered particularly for level 3 isolation rooms. Combining rooms onto common systems is allowed with standby provision (which it is understood were provided) but it is ultimately a commercial/risk management issue that should be agreed with the operational and clinical staff.

5.0

Settlement Agreement 2 - Post 2019 High Value Change Impact

5.0 Post 2019 High Value Change Impact

5.1 Instructions issued.

5.1.1 The high value change order HVC 107 issued by NHSL to IHSL as part of Settlement Agreement No 2, and implemented by Imtech and Hoare Lea, provides very clear unambiguous direction to design, manufacture, supply, construct, test, commission and complete amendments to the ventilation systems to deliver 10 ac/hr at +10Pa as per SHTM 03-01 Appendix 1 Table A1 to the following rooms:

Room Number	Room Type
1-B1-065	*Neo Natal 3 cot area* including 1-B1-022 – *Corridor*, 1-B1-069 – *Staff Base*, 1-B1- 066 – *Clean Utility* and 1- B1-071 – *Resus Bay* which are all open to 1-B1-065.This area does not contain an en-suite.
1-B1-075	*Single cot cubicle neo natal* including *1-B1-074 en-suite*
1-B1-063	*Open plan bay 4 bed* This area does not contain an en-suite.
1-B1-037	*Single bed cubicle* This area does not contain an en-suite.
1-B1-031	*Open plan bay 4 bed* This area does not contain an en-suite.
1-B1-021	*Single bed cubicle* This area does not contain an en-suite.
1-B1-020	*Single bed cubicle* This area does not contain an en-suite.
1-B1-019	*Single bed cubicle* This area does not contain an en-suite.
1-B1-009	*Open plan bay 4 bed* This area does not contain an en-suite.

Figure 29 - Part Extract High Value Change Order 107.

5.1.2 HVC 107 also instructs the following changes to provide full compliance with SHTM 03-01

- Isolations rooms in Paediatric Critical Care - changes to provide PPVL, HEPA with dedicated Air Handling Units the ventilation system to isolation rooms 1-B1-016, 017, 026 and 1-B1-036
- Single and Multi-bedrooms in Haematology and Oncology changes to the ventilation systems to deliver 10air changes/hour at +10Pa and provide HEPA filters to rooms 3-C1.4-059, 057, 055, 046, 032, 018, 016, 013, 010, 074, 076, 078, 084 and 061
- Isolation rooms in Haematology and Oncology changes to provide PPVL, HEPA with dedicated Air Handling Units for rooms 3-C1.4-040, 043, 049, 052. 072

5.1.3 In my opinion, from an engineering perspective, the specifications set out above for the rooms in critical care and the isolation rooms should have been the specification for those rooms at financial close unless there was a specific clinical or IPC justification for a different set of parameters.

5.1.4 Re-Design Commentary process

5.1.4.1 We have been supplied with the comprehensive documents by Hoare Lea (via Imtech) which includes minutes of meetings, design process reports taking the client through confirmation of briefing to Concept Design, through Detailed Design and into Technical Design.

5.1.4.2 Stage reports including power point presentations have been issued clearly indicating the proposed plan of work.

5.1.5 Impacts of proposed changes

5.1.5.1 The impact of the change has caused significant impact on many systems e.g., ductwork, fire dampers and controls, controls heating and cooling pipe networks, power, lighting, fire alarms and controls that would never have been envisaged with the original design. Parts of the hospital would have to be declared as no-go areas for staff and patients whilst the remedial work was carried out on levels 1 and 3 and it is envisaged that disruption would be incurred on some of the primary systems such as heating and chilled water networks, electric power and control systems, which whilst this could be programmed could have impacted on clinical functionality in other areas not directly affected by the works.

5.1.5.2 Designs are often required to include margins for improvements later on during a system lifetime or a requirement to build in expandability but nothing of the scale of the re-design could have been envisaged by the original designers.

5.1.6 Isolation Room Air Handling Unit Changes

5.1.6.1 The re-design does enhance the air handling unit provision for isolation rooms taking them from being served by common systems to providing them with their own air handling unit.

5.1.6.2 The original design allocation of AHU's was an interpretation of SHTM's but would not have been uncommon assumption of the original designer especially considering location of the level 1 rooms in question being so far away from risers and plantrooms. It would have been a very difficult challenge to incorporate this strategy into the original building architecture.

5.1.7 Validation review

5.1.7.1 IOM produced an independent validation report in January/February 2021 ref P4884-1 that has retested the system utilising the same principles of measurements checks as carried out in 2019 but as amended under the change order and concluded that at the time of validation the systems are acceptable.

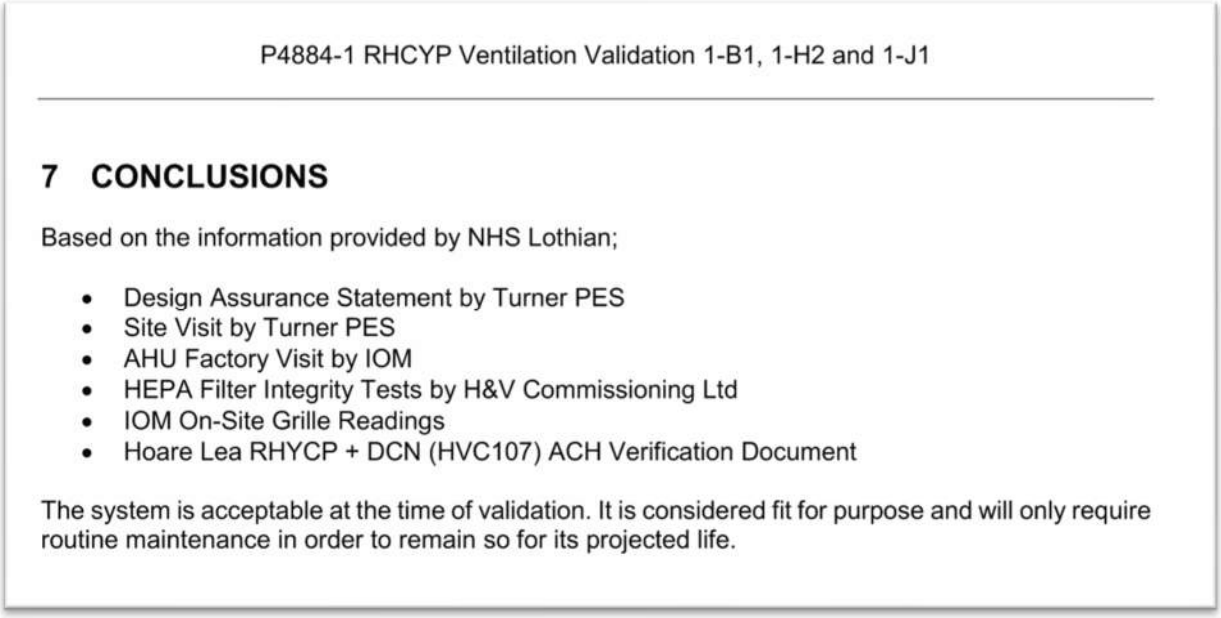
5.2 Conclusion

5.2.1 The amendments carried out under HVC107 have adhered to the processes and sign off procedures identified in SHTM 03-01 and independent validation testing has confirmed the amendments are in compliance with SHTM 03-01 as verified by IOM.

5.2.2 Therefore, the final design of the ventilation system for the Critical Care and Isolation Rooms at the RYCHP/DCN complies with published guidance and best practice. In particular, the design complies with the requirements of SHTM 03-01.

5.2.3 The 2021 Independent Validation reports by IOM have confirmed that ventilation system for critical care rooms and Isolation Rooms at the RHCYP/DCN, as per Settlement Agreement No 2, is operating so as to fully comply with published guidance (SHTM 03-01) and best practice.

5.2.4 The ventilation system in Critical Care and Isolation Rooms at the RHCYP/DCN has been designed, tested, commissioned and validated in compliance with published guidance (SHTM03-01) and best practice. The ventilation system has therefore been independently checked by IOM and demonstrated to be in accordance with the design requirements detailed in SHTM03-01, as noted in Figure 30 below. From an engineering perspective, the ventilation system in the Critical Care and Isolation Rooms in the RHCYP/DCN is adequate for its intended purpose. The Critical Care and Isolation Rooms provide a suitable environment for the delivery of safe, effective person-centred care.



P4884-1 RHCYP Ventilation Validation 1-B1, 1-H2 and 1-J1

7 CONCLUSIONS

Based on the information provided by NHS Lothian;

- Design Assurance Statement by Turner PES
- Site Visit by Turner PES
- AHU Factory Visit by IOM
- HEPA Filter Integrity Tests by H&V Commissioning Ltd
- IOM On-Site Grille Readings
- Hoare Lea RHYCP + DCN (HVC107) ACH Verification Document

The system is acceptable at the time of validation. It is considered fit for purpose and will only require routine maintenance in order to remain so for its projected life.

Figure 30- Conclusion from IOM report

6.0

Lessons Learnt

6.0 Lessons Learnt

6.1 NHS Scotland Assure

6.1.1 NHS Scotland has introduced its own Key Stage Assurance Review (KSARs) with workbooks issued for key stages of a Capital Projects design and procurement process namely Outline Business Case, Full Business Case, Construction and Handover stages.

6.1.2 The reviews cover Project Governance, Water and Plumbing systems, Ventilation Systems, Electrical Systems Medical Gas Systems, Fire Engineering and Infection Control in the Built Environment issues.

6.1.3 KSARs are a process ensuring facilities and the teams using them are able to deliver the standards required to provide the best and safest outcomes for patients, staff and visitors in the built environment.

6.1.4 KSARs deliver an independent peer review. Staff outside the project are engaged to use their experience and expertise to examine the progress and likelihood of successful delivery, with a particular emphasis on the safety of the patients, staff and visitors using the facility.

6.1.5 The reviews require many pieces of evidence and design statements to be in place against key stage checklists but lists Evidence of an Environmental Matrix being present, this **should not be** an independent matrix but one generated through the Activity Data base system which is a mandatory in NHS Scotland to avoid future contradictions or ambiguity between source data. New versions should be created to ensure up to date recommendations are incorporated to avoid cut and paste errors occurring. Only one set of documents should be created.

6.1.6 Any designs aspects that cannot be agreed prior to a commercial agreement deadline must be fully evaluated and the risk and consequence of not making decisions for whatever reasons must be fully evaluated.

6.2 Ventilation Safety Group

6.2.1 The creation of Ventilation Safety Group (and other Safety Group covering other key engineering infrastructure in hospitals) is a welcome improvement to current SHTM's. Each group will comprise Clinical, Estates, Infection Prevention and Control and FM team members. The group shall review competence of designers, future adaptability of schemes, variations and derogations from standards, commissioning proposals, governance arrangement and maintenance proposals. Historically design engineers have not been given the opportunities to sit with the operational staff to understand the day-to-day challenges faced and likewise operational staff have not had the opportunity to inform designers of operational constraints particularly when considering existing hospitals.

6.2.2 The creation of multi stakeholder Safety Groups provides an opportunity before significant time and expenditure is committed for complex engineering systems to be thoroughly reviewed and agreed.to mitigate risks of future projects.

6.2.3 Clarity of a brief to designers is essential to avoid misunderstanding whether this is captured as a specific SHTM compliance requirement or local variations to SHTM. Ensuring the SHTM's are included as part of statutory approval process and are therefore complied with by default will also assist future schemes.

7.0

Conclusions

7.0 Conclusions

7.1.1 The final designed and installed ventilation systems within the hospital Critical Care and Isolation Room areas referenced in this report have been independently tested, confirmed and verified as being compliant with guidance, good practice and most importantly SHTM-03-01. From an engineering perspective, the ventilation system in the Critical Care and Isolation Rooms in the RHCYP/DCN is adequate for its intended purpose. The Critical Care and Isolation Rooms provide a suitable environment for the delivery of safe, effective person-centred care.

7.1.2 In my opinion, on a project like the RHCYP/DCN, by the stage of financial close there should be no scope for confusion or ambiguity in relation to the required parameters of the ventilation system for critical care and isolation rooms. The requirements should be fixed and should not be held over as RDD. Including the EM as RDD had scope to cause significant confusion and ambiguity.

7.1.3 A full suite of room data sheets at financial close was not produced. However, RDS for key rooms were produced which included single and multi-bed rooms in critical care. These clearly specified 4 ac/h rather than 10 ac/h. In my opinion, the air changes per hour stated in the RDS for Critical Care rooms did not comply with the requirements of SHTM 03-01. This discrepancy should have been identified and closely examined before any contract was signed.

7.1.4 I am not clear why NHSL agreed to the specification for Critical Care rooms set out in Settlement Agreement 1. In my opinion, the specification does not comply with SHTM 03-01. I am not aware of whether there was any clinical, IPC or technical input in advance of the agreement being reached. Absent any such input, and a specific clinical justification that had been adequately risk assessed, from an engineering perspective, the ventilation design for Critical Care rooms did not conform to published guidance (namely SHTM 03-01), and good practice. From an engineering perspective, in my opinion, the ventilation system in the Critical Care Rooms did not provide a correct environment.

7.1.5 The lack of recorded involvement of Infection Prevention and Control teams does not surprise me. At the time of the RHCYP/DCN project, it was not unusual - certainly during the design and commissioning stages of projects – for there to be no significant IPC input. This was generally due to prevailing practices and lack of available resource and expertise. This has been addressed with the creation of the ventilation safety groups (in the most recent version of SHTM 03-01) and more importantly for NHS Scotland the Key Stage Assurance Reviews which have been implemented. Therefore, this issue has been largely addressed by changes after the RHCYP/DCN project.

7.1.6 Engineering Systems Safety groups and the KSAR reviews involving multiple stakeholders should hopefully prevent situations like the one experienced at this hospital from happening in the future.

Appendices

Appendices

Appendix A - Biography – Stephen Maddocks

a) I am a chartered building services engineer with over 40 years industry experience having started as an apprentice in the industry in 1981 based in a Building Services Design Consultancy (DSSR).

b) Academically I undertook a technician's certificate on day release whilst undertaking my Apprenticeship as I had left school at 16. I then undertook a Polytechnic Diploma at Newcastle Upon Tyne Polytechnic. In 1988, I started a one day a week degree course at University of Central Lancashire which allowed me to gain my charted status. All three of my key academic qualifications were specifically in Building Services Engineering.

c) I became a member of the Chartered Institute of Building Service Engineers (MCIBSE) in January 1995, a Chartered Engineer (C.Eng.) in April 1996 and a Fellow of the Institute of Healthcare Engineering and Estate Management (FIHEEM) in December 2005.

d) As noted above I started as an apprentice in the industry with DSSR who specialised in the design of Mechanical and Electrical (Building Services) services particularly in Hospitals and Healthcare projects. My first recollection of Hospital Design was collation and managing the documents for what was known as the Department of Health (England) (DoH-E) Exemplar Nucleus Hospital design pack. DSSR were engaged in writing the Building Services aspects of the exemplar design. I was also involved in learning the detailed design of hospital ventilation systems, manually calculating the pressure resistances through systems as we had no computer systems then.

e) I moved on to another consultancy (Hoare Lea) after nine years again specialising in hospitals, examples include major developments at Blackpool Victoria Hospital, Royal Lancaster Infirmary and Hope Hospital (Salford). In 1992 I joined the NHS as a Capital Projects Officer at Trafford General Hospital where I was responsible for new and refurbishment of the building services capital developments looking at building services aspects specifically. Schemes included replacement of an existing operating theatre suite with a new Ultra Clean Operating Theatre to increase Orthopaedic Surgery operations, Clinic refurbishments, Day Surgery unit and management of the replacement of the electrical infrastructure whilst keeping the hospital operational. I stayed at Trafford General for two years before re-joining my previous consultancy picking up on further healthcare work at many sites including Wigan Royal Albert Edward Infirmary, Royal Manchester Children's Hospital, Blackburn Queen Park Hospital, Evelina Children Hospital, Bishop Auckland Hospital, Wharfedale Hospital, North Wales Cancer Treatment Centre, to name a few staying there until 2002. Schemes were both Trust financed, and Private Finance Initiative (PFI) developer led schemes.

f) In 2002 I joined a multidisciplinary design consultancy (BDP) as Associate Director to lead on healthcare for the northwest Building Services team and I was responsible for leading the engineering design team for PFI schemes at Burnley General Hospital and Hexham General Hospital. I stayed there until 2006 when I joined the PFI division of a major contractor/developer (Lend Lease). This position only lasted just short of two years due to the company pulling out of the whole PFI market.

g) In 2008 I joined Cundall as a Partner and Health Sector leader. I have worked on a number of healthcare projects including delivering the Ulster Hospital redevelopment. This was a capital funded project in Northern Ireland with a value of approximately £200 million. The hospital was approximately 60,000 square metres. It was completed in 2 phases and delivered over 500 beds and supports full District General Hospital accommodations including Aseptic Pharmacy, MRI Suites, A&E, Restaurant and kitchen, Mortuary etc. I also assist with early design advice on projects across the globe.

h) I have been invited to give lectures at the University of Sheffield on the master's degree in architectural engineering on the principles of ventilation and air conditioning. I have mentored Architectural Students at Manchester Metropolitan University on the low energy design principles of their final year designs.

i) I've also been called in as a technical expert to look at a range of engineering issues including energy consumption in hospital, life expectancy of steam boiler systems, and nurse call systems.

j) I currently sit on the CIBSE Healthcare Committee and am one of a team of industry authors writing a Healthcare Design Guide to pass knowledge and lessons learnt to fellow designers due to the specialised nature of healthcare design

Appendix B - Duct sizing nomogram

Sizing nomogram reproduced from CIBSE Guide C – Reference Data 2007

Colour	Purpose
Green	Air volume at 4 Air changes per hour
Blue	Air volume at 6 Air changes per hour
Amber	Air volume at 10 Air changes per hour
Red	Resulting duct size 250mm diam (0.25m)

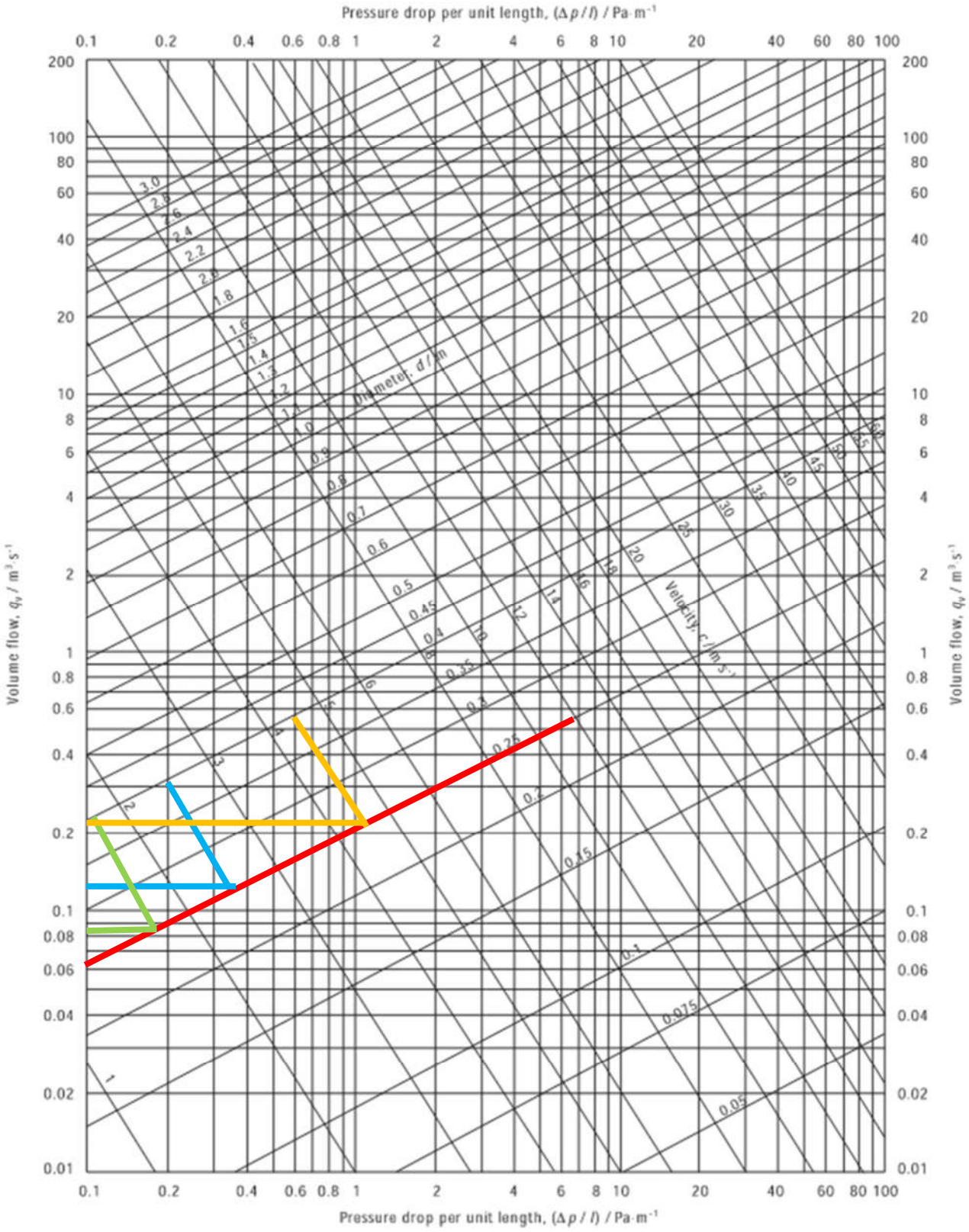


Figure 4.2 Pressure drop for air in galvanised circular ducts (ρ = 1.2 kg·m^{-3}; T = 293 K)

Cundall Johnston & Partners LLP
Fourways House 57 Hilton St Manchester M1 2EJ
Tel:+44 (0)161 244 5660
Asia Australia Europe MENA UK and Ireland
www.cundall.com