Helicopter Noise Impacts on Hospital Development Design

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ABSTRACT

Control of helicopter noise is currently a key driver in the design of facade systems and external building elements within major Australasian hospital developments. However, the issue lacks specific and objective guidance on acceptability within hospital environments from the local scientific and engineering community. This paper explores appropriate criteria for hospital developments, and commonly encountered practical issues in achieving them. From the literature there appears to be consensus that a maximum level around LAmax 45dB is the lower limit to avoid any sleep disturbance for frequent noise events. However, this target is often not practicable to achieve or reasonable in the context of ambient internal conditions and other design requirements. A maximum limit of no less than LAmax 65dB for general hospital wards and sensitive spaces appears reasonable against the likely ambient noise levels from typical activities. Critically sensitive spaces identified as potentially benefiting from further acoustic controls (e.g. NICU / PICU, individual patient wards) should be carefully considered on a case by case basis.

INTRODUCTION

Facilities for patient arrivals and transfers via helicopter are integral to the operation of major hospitals. Because these events are typically an emergency, the helipad and flight paths taken will always be in close proximity to the hospital development to provide relatively fast triage.

Noise and vibration concerns associated with the operation of emergency medical transport helicopters near hospitals are not new. However, it is the experience of the authors that briefed requirements for control of helicopter noise ingress associated with major Australasian hospitals in recent years have become more stringent.

This paper discusses some of the considerations that have to be made in design for any new healthcare development potentially with a helipad. As any target noise level criteria will be subject to considerable debate between the end-client and developer / designer (and their respective acoustic consultant representatives), this paper gives some background to applicable standards and research to applicable criteria. Comments are made on design / construction criteria for developments where the authors have permission to do so.

This paper reviews common sources used to establish end-target internal acoustic criteria, and discusses other considerations that have to be understood by the design team. Comments are given on modelling approaches and practical limitations of facades are discussed. Finally, recommendations are given for setting appropriate internal criteria.

Structural vibration issues and internal noise generated primarily via the base building structure can be significant but are outside the discussion scope of this paper.

CRITERIA

It is important when setting internal criteria that the subjective brief requirements for health outcomes are kept in mind and appropriately matched to the activities that will occur within each room.

Setting criteria too coarse in application and extent (e.g. two or three values project wide) usually does not recognise the variation in different sensitivities, and usually leads to conservative design and excessive material cost in acoustic controls and facade construction. Setting criteria too fine and prescriptive in application can over-complicate design processes and confuse the design team, and/or reduce production economies of scale.

The establishment of project criteria also needs to account for the rate of occurrence of helicopter movements, which will depend on where the hospital fits within the long term strategic health delivery plan for the region.

There is also anecdotal evidence as to the potential positive nature of helicopter rescue flights, particularly with hospitals for children. A design feature of the recently completed Royal Children's Hospital in Melbourne is a patient view-deck of the helipad as a feature of the development.

For over-night stay patient ward areas, the targeted health benefit will be to avoid sleep awakening as much as possible. Typically the risk of sleep awakening is viewed by various studies as a percentage increase in chance of awakening for progressively higher maximum noise levels.

Spaces with critical hospital functions (for example surgery, mental health, ICU, emergency and consultation rooms) typically have criteria established set to minimise disturbance and/or annoyance, and be independent of time period. Finally, hospitals may have specialist facilities such as research or animal holding rooms, which may have specific frequency dependent / vibration criteria, further to the above mentioned spaces.

Relevant standards

The following discusses various standards for internal noise levels as they apply to hospitals, and to other similar sensitive spaces.

Europe

The UK healthcare facilities document, 'Acoustics: Technical Design Manual 4032:0.6 for healthcare facilities' (4032:0.6, 2012), which supersedes Health Technical Manual (HTM) 08-01, makes several comments in regards to helicopters;

> Hospitals are often affected by noisy but sporadic events such as vehicle sirens, helicopters and aircraft. … It is unlikely that the criteria in Table 1 (see below) (night – day) will be achievable with helicopter movements included, so helicopters may cause some disturbance. Careful planning of the hospital layout and flight path can, however, reduce the effects of helicopter noise.

Relevant criteria from Table 1 of 4032:0.6:2012 is reproduced in Table 1 below.

Table 1: 4032:0.6 recommended noise intrusion criteria

Rooms	Criteria for Noise Intrusion
Single-bed ward, single-bed recovery areas and on-call room, relatives' overnight stay	40 $L_{Aeq, 1hr}$ daytime 35 $L_{Aeq, 1hr}$ night 45 L_{AmaxF} night
Multi-bed wards, recovery areas	45 $L_{Aeq, 1hr}$ daytime 35 $L_{Aeq, 1hr}$ night 45 L_{AmaxF} night
Operating theatres	40 $L_{Aeq, 1hr}$ 50 L_{AmaxF}

In further comments on the set criteria, 4032.0:6 notes;

> A L_{AmaxF} limit for short-term events is included for sleeping areas and operating theatres. The intention is that this should apply to events that occur several times during the night (for example passing trains) rather than sporadic events *(specifically helicopters)*

We note there are no maximum noise level criteria for other private areas, such as consultation rooms or public areas such as waiting rooms.

By commenting that noise level targets are unlikely to be achieved in the event of helicopter movement, it appears that acoustic controls for helicopter noise ingress is not part of the detailed design scope for new UK hospital developments, and only is broadly considered in the concept / planning stage.

In the authors' experience, this benchmark reflects a wider scope for European healthcare facilities, where the trend is to exclude helicopter noise from internal acoustic provisions to be delivered.

US

Following a major study, the US Environmental Protection Agency (EPA) (EPA, 1974) reported that

> For the protection of the public health, the US Environmental Protection Agency has proposed a Day-Night Level (DNL) of ... 45dB in daytime and 35dB at night in hospitals.

It is important to note the descriptor used is the day/night level. This is significant as sets the criteria as an exposure, rather than maximum / peak levels. We note the DNL value is not correlated to a maximum event level in the US EPA study.

Furthermore the American Academy of Paediatrics: Committee on environmental health (American Academy of Pediatrics, 1997) also notes the following in its recommendations for Neonatal Intensive Care Units (NICU) in reference to the recommended DNL values of the US EPA;

> Paediatricians are encouraged to monitor sound in the NICU and within incubators. A noise level greater than 45 dB is of concern.

Australia / New Zealand

AS/NZS 2107 (Standards Australia 2000) recommends continuous equivalent (L_{Aeq}) levels for background noise. This document is a common reference for establishing satisfactory goals for quasi-static mechanical and external traffic noise ingress. AS/NZS 2107 sets a 'Satisfactory' level of L_{Aeq} 35 dB for wards, and L_{Aeq} 40 dB for operating theatres, surgery and consultation rooms.

Although AS/NZS 2107 sets a useful starting benchmark, the recommended values are explicitly stated as quasi-static, not for short term or transitory events, such as helicopter arrivals and departures. The standard is however useful in quantifying the relative differences in expectations between sensitive spaces.

The Australian Standard for aircraft noise, AS 2021 (AS 2021:2000) sets out recommended indoor design sound levels for aircraft noise reduction for hospitals and nursing homes at L_{Amax} 50dB for wards, theatres, treatment and consulting rooms. The commentary to AS 2021 notes recommendations are average maximum levels judged to be non-intrusive or annoying by the listener.

We note a major limitation in applying noise from helicopters to AS 2021 is that its development was specific to fixed-wing aircraft / commercial airports. These values are therefore not necessarily representative for less frequent (but potentially longer event duration) helicopter events.

Locally, the soon to be published NSW Health Engineering Services Guidelines: TS11 (Hospitals) are understood to cover this aspect and should be consulted when released.

Both of the US studies referenced above were quoted by the New Zealand Ministry of Health in setting criteria for NICU facilities. The end criteria used by the Ministry of Health was a maximum level of L_{Amax} 70dB inclusive of all noise sources within the space, and a continuous target of L_{Aeq} 50dB. Anecdotal evidence from the authors' peers in designing to these criteria has been generally satisfactory according to staff and patients.

Research guidelines on sleep disturbance

The most recent edition of the World Health Organisation (WHO) guidelines for community noise (Berglund et. al., 1999) includes comments on healthcare facilities. The WHO guidelines note;

> 'If the noise is not continuous, sleep disturbance correlates best with *LAmax*, and affects have been observed at 45dB or less.'

The recommendations from the WHO guidelines are listed in Table 2.

Table 2: WHO guidelines for healthcare facilities

Specific Environment	Critical Health Effects	Noise Limit
Hospital, ward rooms indoors	Sleep disturbance	40 L_{Amax} 30 L_{Aeq} Night-time
Hospital, treatment rooms, indoors	Interference with rest and recovery	As low as possible

Some comments on the criteria recommended in the WHO guidelines by Shiers (2011) is that, in a wide-review of studies by Busch-Vishinac *et al.* (2005), none of the reviewed studies showed noise levels in the hospital complying with the above WHO guidelines for hospital noise. Shiers notes this raises the question of the validity of these particular guidelines in application.

The Federal Interagency Committee on Aviation Noise (FICAN) (FICAN, 1997) conducted studies on aircraft noise impacts in terms of a sleep awakening rate, due to a sound exposure level (SEL). The FICAN study produced an upper limit equation for predicting sleep awakening rates based on an amalgamation of studies as (1).

$$\textit{Awakenings} = 0.0087 \times (\text{SEL-30})^{1.79} \quad (1)$$

The FICAN study is applicable to residential areas exposed to aircraft, advising conclusions apply to long-term exposure.

As an upper estimate the FICAN study is particularly important in quantifying the relative difference expected in comparing different noise level criteria. For example a maximum level of L_{Amax} 65dB compared to L_{Amax} 45dB is predicted to have a sleep awakening rate of 8% compared to 3%.

The 1999 NSW Environmental Criteria for Road Traffic Noise (EPA, 1999) notes that there are some unresolved points regarding sleep disturbance and maximum noise levels. Regardless, this document following a review of the literature concluded that one or two noise events per night, with maximum internal noise levels of L_{Amax} 65 to 70dB, are not likely to affect health and wellbeing significantly, and maximum internal noise levels below L_{Amax} 50 to 55dB are unlikely to cause awakening reactions.

These guidelines discuss the probability of awakenings to an exposed maximum noise level, and cite the work of Bullen *et al.*, as reproduced in Figure 1. This figure indicates that the mean number of awakenings to a level of L_{Amax} 65dB is approximately 5 in every hundred. It should be noted that these estimates are based on transient road and rail sources.

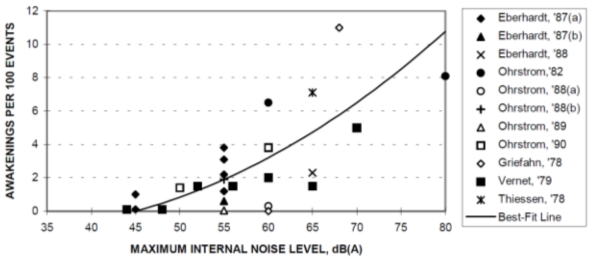

Figure 1: Summary of studies of sleep awakening events to maximum noise levels, reproduced (Bullen *et al.*, 1996)

Ambient internal noise levels in hospitals

Any setting of internal criteria (including helicopter noise ingress) must be considerate of the existing hospital acoustic environment to avoid design in isolation. Hospitals have characteristically high background noise levels from occupants, medical equipment and alarms.

An extensive study of noise levels by Shiers (2011) within new and existing hospital developments presented daytime $L_{Aeq,16hr}$ levels in the order of 50-52dB and night-time $L_{Aeq,8hr}$ of 41-49dB. Maximum levels were noted to be typically in the range of L_{Amax} 70-80dB and highly dependent on hospital layout, furniture and medical equipment.

Shiers lists the major noise sources causing annoyance as alarms and tones emitted by medical equipment, followed by nurse call, internal telephone, ward doorbell and medical equipment. These sources, along with typical ward activities such as conversational noise and equipment handling all resulted in measured values in excess of L_{AmaxF} 70dB. Elsewhere, high pressure cleaning and maintenance processes of existing laboratory facilities have been measured as between L_{Amax} 75 to 95dB (Zoontjens 2012).

MODELLING

For new developments, the size and appearance of the built form is one of constant evolution in the design process right through to construction. The acoustic design input therefore should be expected to consider multiple design iterations in early concept and schematic design and be expected to validate and further refine assumptions during detailed design.

Physical location of sensitive sources away from the helipad and scheduled flight areas of authority remain the strongest design tools to contain helicopter noise exposure. Final control often then lies with the facade.

Modelling can conceptually be broken into the following components;

- Source characteristics, including selection of the design helicopter, noise level and area of flight authority.
- Typical environmental propagation modelling methods, include facade and internal room corrections
- Facade transmission loss performance, and finally
- Consideration of other, non-acoustic design parameters

These aspects are discussed below.

SOURCE CHARACTERISTICS

Helicopter noise ingress design starts with confirming the helicopter operational parameters and usage.

In a hospital development, it is important to define the most appropriate aircraft to be modelled. Structural or fire considerations are more substantial for significantly larger helicopters, and may result in the larger helicopters becoming the briefed aircraft for the project. However from an acoustics viewpoint, design to such larger aircraft, which may only participate in a rare event, may not be appropriate.

The design helicopter and its area of flight authority are typically advised by a specialist aviation consultant. Whilst a reference helicopter for design will be identified, in practice a wide variety of helicopter makes and models are potentially visitors. The most likely will of course be the Emergency

Medical Services (EMS) variant of a selected aircraft platform.

The Australian military S-70A Blackhawk / S-70B Seahawk and replacement MRH90 / NH90 NFH helicopters are often considered for major state hospitals as a potential vehicle for emergency transportation; however it is the experience of the authors that the likelihood is judged too remote to warrant any additional cost of compliance.

Helicopters in use on offshore platforms or remote rural areas potentially can be used for transporting emergency patients, however few are in range of major state hospitals and in advice received, in almost all cases the patient is transported by helicopter to an intermediate location and arrives at the hospital via ambulance or EMS carrier.

Example helicopter noise levels

Helicopter noise levels can be an important parameter to define in an analysis, and is often difficult to source for specific aircraft due to limited publically available test data. In very broad terms, sound power levels of modern EMS helicopters are generally of the order of L_{wA} 127dB at idle in the human audible range, increasing 7 to 12dB at takeoff and also in the final stages of approach (flare).

Western Australia currently has as the State rescue helicopter Bell 412 EP which is among the loudest current EMS helicopter operating in Australia, with future civil EMS types (AW139/EC175/AW609) understood to have a smaller noise emissions envelope than the Bell 412.

Norman Disney & Young have conducted noise levels measurements of Bell 412 aircraft landing and taking off from a helipad. Typical noise level measurement results are listed in Table 3.

Table 3. Bell 412 typical take-off and landing L_{maxF} at 100m distance from helipad

Aspect	Octave Band Centre Frequency (Hz)							A-wt Sum dB(A)
	63	125	250	500	1k	2k	4k	
Helicopter path perpendicular to observer to helipad								
Take off	95	92	91	87	86	82	76	91
Landing	91	85	87	83	80	82	74	87
Helicopter path directly overhead								
Take off	89	98	95	92	91	87	81	95
Landing	96	98	97	96	89	84	77	96

This table shows that noise levels between take-off and landing vary; this is believed to be due to differences in both engine power levels and the locations at which they occur. Note also that helicopters have significantly different power profiles in take-off and landing.

Values in Table 3 are averages for multiple passes; we note a large variability in measured results, which should be taken into consideration for sensitivity analysis. The expanded uncertainty of measurement from these measurements is estimated to be U_{95} 3.2dB, k=2.0.

Transient noise phenomena

"Blade slap" is a phenomenon that can occur when rotor blades pass through the wash of the previous blade. It is most common during descending flight at moderate speed and in turns and is characterised by a repeated 'whack' or 'cracking' sound substantially louder than normal.

The blade slap condition can be generally avoided by the pilot during normal flight. However it is not completely unavoidable and may occur for a period of time in some approach flight regimes.

Area of flight authority

Flight paths should be defined early on by the aviation consultant. Preferred flight paths will be nominated depending on prevailing wind conditions and the surrounding building structure.

The area of flight authority will be carefully documented and designed into the helipad lighting and traffic controls. Unfortunately for the acoustic consultant, this defined area is in closer proximity to the helipad than the area that needs to be considered for noise propagation.

In practice, the helicopter pilot will make final decisions regarding landing approaches given the local weather and flight conditions (particularly wind direction and gust) and any specific safety considerations at the time. A preferred approach will be landing 'into the wind', once within the final approach stages to the helipad.

ENVIRONMENTAL NOISE PROPAGATION

Modelling of environmental noise source propagation is well covered elsewhere, however the aviation flight data employed in the US Federal Aviation Administration's (FAA) Integrated Noise Model (INM), in conjunction with an environmental noise modelling package can be very effective at establishing sound attenuation and shielding effects. Regular points of interest along each defined flight path may be identified and assessed as individual 'snapshots' of approximate incident helicopter noise.

Figure 2 presents an example model output of one such snapshot of assessed incident helicopter noise upon a hospital in Perth.

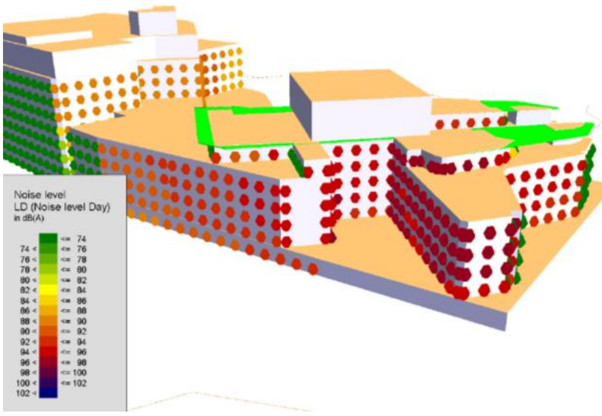

Figure 2: Example of incident helicopter noise model output (source location not indicated: above frame of viewpoint)

There are various assumptions that can be made to estimate the facade performance from laboratory test transmission loss data available elsewhere.

Internal room corrections should be made on an estimate of typical ward finishes being medical grade ceiling and wall finishes and hard-wearing resilient type flooring. Bacterial control requirements may limit opportunities for additional sound absorption treatments.

FACADE PERFORMANCE

Modelling of external noise ingress for a helicopter with a flight path that is in close proximity to the facade typically will require the facade to have good low-frequency performance (i.e. in the order of 25-30dB in the 63Hz and 125Hz octave bands) to achieve target internal levels.

For glazed partitions, sufficient low-frequency performance often requires Insulated (double) Glazed Units (IGUs). Care should be taken by the acoustic consultant to review claims of low-frequency performance via demonstration of the testing methodology, flanking through framing and commercial availability.

Based on the authors experience, the practical limits of commercial IGUs within curtain walling is a unit approximately 50mm thick *inclusive* of glazing and air cavities. The sound reduction performance of commercial IGUs is typically optimised for helicopter noise spectra when the laminated panes are each in the order of 11mm to 14mm thick, are not equal and utilise ‘double’ or ‘triple’ (e.g. 0.76mm or 1.14mm) lamination interlayers.

Furthermore, maintenance / accessibility requirements can limit performance of any double glazed element. Sealed integrated units of 12mm, 20mm and 24mm air spaces are usually commercially available. In the authors’ experience, for any void greater than 25mm, some ventilation is required for control of moisture and thermal convection effects, and the structural movement tolerances usually cannot guarantee a sealed airspace.

Generally, an operable or removable type jockey sash arrangement is almost certainly required for large air spaces. Extreme performance applications may employ jockey sash glazing and lined reveals in conjunction with a (double glazed) IGU and bespoke structural and framing treatments.

NON-ACOUSTIC DESIGN CONSIDERATIONS

As with any major project with input from the majority of the design team, noise control provisions need to be defined clearly and early to ensure they inform the design process without delay.

Other non-acoustic considerations that will influence design are aesthetics, building services requirements and environmentally sustainable design (ESD) initiatives.

Facade aesthetics

The facade aesthetics can set the boundary for acoustic design and even design acoustic criteria as the extent of glazing and design intent for the non-glazed sections can set limitations for facade attenuation. It is therefore important this is discussed early in design to avoid unrealistic expectations for the facade performance.

Particular attention should be made to the location of external balconies which are common in many hospital developments and services / openings in the facade where noise may then breakout into adjacent sensitive spaces.

Services requirements

Services requirements can limit facade performance if not adequately considered early in design. Services penetrations can impose requirements for facade penetrations, for example via smoke spill fans and outside air requirements for mechanical services. These should conceptually be identified early on by relevant disciplines.

Facade thermal performance is an important consideration for the mechanical services design and overall building energy efficiency. IGU thickness, spacing and ventilation will significantly alter thermal performance parameters.

Consideration will need to be given to the maintainability and fire separation requirements of the facade, including the need for operable elements and natural ventilation. Maintainability requirements should be identified by early on by the facade engineer. To avoid impossible design solutions, manufacturer claims to performance of operable / adjustable elements for maintainability vary substantially and should be always verified by test data in-situ in critical areas.

Large atria typically will require considerable additional fire services penetrations (and potentially fans) at both high and low level to achieve minimum required smoke ventilation rates.

Environmentally sustainable design initiatives

Historically seen as unusual for hospital developments, the application of ESD initiatives is now integral to the development of facade systems in major hospital developments.

Typically, the initiatives that may impact the acoustic design are not new materials or technologies, but are an application of existing technologies to situations that were previously considered not cost effective or difficult to maintain, such as double skin and/or active shading element facades.

Initiatives include those which reduce energy consumption, such as double (ventilated) facades and night purge, and those initiatives that promote the internal environment quality such as natural ventilation and daylighting. Input from the acoustic consultant may range from review of facade performance for various design solutions, to assessment of wind-generated noise.

Major cross-discipline sustainable design initiatives will typically be considered in the conceptual stage, and may require early assessment by the acoustic consultant.

SUMMARY DISCUSSION AND RECOMMENDATIONS

Control of helicopter noise ingress is a substantial design issue within the context of Australian and New Zealand buildings. The authors note the issue lacks specific and objective guidance on acceptability within hospital environments from the local scientific and engineering community.

The facade orientation and location of sensitive spaces relative to the helipad, notwithstanding operational requirements, should be the primary control mechanism pursued in concept and schematic design.

From the literature there appears to be consensus that a maximum level of L_{Amax} 40 to 45dB is the lower limit to avoid any sleep disturbance for frequent noise events. However, it has been clearly demonstrated that a target of L_{Amax} 45dB is well below typical measured internal noise levels in existing modern hospital developments *in the absence of helicopter noise*. Furthermore, it appears impracticable: the authors are not aware of any operational hospital with an integral and operational helipad that has successfully demonstrated robust compliance with L_{AmaxF} 55dB with helicopter systems above 7,500kg in weight.

Also, designing helicopter noise control to the same standard as road noise sources (with relatively lower L_{Amax}) has potential to adversely impact the internal acoustic environment. This is because facade design to control incident helicopter noise levels (in excess of say L_{Amax} 95dB outside incident level) will most likely over-perform against more common yet quieter external events such as road traffic (at L_{Amax} 75-80dB or less outside incident), removing a potentially useful source of sound masking. It is the authors' experience that very high performance facades designed to control helicopter noise to the same requirement as road (and even rail) traffic can result in spaces feeling unusually quiet and removed or isolated from the outside. Occupants report their attention being drawn to noise sources in the room and adjacent spaces that would otherwise be inaudible or unintelligible. This is particularly important in the context of passive chilled beam building air conditioning systems. The implementation of mechanical/electronic sound masking controls and increased airborne sound isolation of internal partitions is then expected to compensate the loss of acoustic privacy.

The authors' experience is that setting a maximum limit of L_{Amax} 65dB is appropriate for wards and sensitive spaces where some administrative control of noise from other activities is possible. Design execution will of course vary depending on the design reference helicopter, building arrangement, extent of glazing, facade system etc. However, for a full height glazed arrangement, under worst case conditions this usually results in utilising a standardised commercial 50mm IGU facade system (e.g. 11.14mm/24mm air space/13.14mm) and an additional internal glazed jockey sash to the most critical spaces in close proximity and/or direct line of sight.

A reduced target of L_{Amax} 55dB in limited circumstances is considered the practicable limit for the most critical NICU/PICU individual patient wards where helicopter traffic is anticipated. It is perhaps a reasonable target where the activities and noise sources within can be robustly controlled with certainty to L_{Amax} 55dB.

CONCLUSIONS

A review of applicable standards and research has been presented for helicopter noise ingress into new hospital developments with EMS helicopter access.

A maximum limit of no less than L_{Amax} 65dB for general hospital wards and sensitive spaces appears reasonable against the likely ambient noise levels from typical activities. Selected spaces identified as potentially benefitting from further acoustic controls (e.g. NICU / PICU, individual patient wards) should be carefully considered on a case by case basis.

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