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Title Page

Title of article: A comparison of sound levels in open plan versus pods in a Neonatal Intensive Care Unit

Authors:

Karlie Ramm RN Grad Cert NICC. Dip. Int. Design

Clinical Nurse, Neonatal Intensive Care Unit, Women's and Children's Hospital, Adelaide, South Australia

Corresponding author: Trudi Mannix RN RM NICC BN MN Grad Dip Hlth Couns. EdD

Lecturer, School of Nursing and Midwifery, Flinders University, Adelaide, South Australia

Telephone: +61 8 82013469

Email: trudi.mannix@flinders.edu.au

Yvonne Parry RN BA MHSM Grad Cert Edu. PhD

Senior Lecturer, School of Nursing and Midwifery, Flinders University, Adelaide, South Australia

Mary P Gaffney RN RM NICC Grad Cert Hosp. Service Mgt

Clinical Nurse/Midwife, Neonatal Intensive Care Unit, Women's and Children's Hospital, Adelaide, South Australia

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A comparison of sound levels in open plan versus pods in a Neonatal Intensive Care Unit

Introduction

The clinical healthcare environment can impact on the health and wellbeing of patients and their recovery time (Lawson & Phiri, 2003). **Many studies have shown that environmental noise is a primary stressor for sick premature neonates, families/caregivers and staff within the neonatal intensive care unit (NICU) setting** (Shepley, 2014). Without protection of uterine structures, premature infants are exposed to auditory experiences for which their central auditory nervous system is unprepared (Graven, 2006). Sick neonates are vulnerable to the effects of high noise levels due to their inability to filter and process noxious stimuli (Zahr, 1995, in Wachman & Lahav 2013). Intense sounds across the frequency spectrum may permanently damage immature sensorineural systems. Lahav and Skoe (2014) reported that excessive exposure to high frequency noise during critical periods disrupts the functional organization of auditory cortical circuits.

A recent Cochrane systematic review found that hearing impairment affects between 2% and 10% of preterm infants compared to 0.1% of the general paediatric population (Almadhoob & Ohlsson, 2015). Loud noise was found to potentiate toxic reactions to structures of the inner ear of preterm infants receiving aminoglycosides (Zimmerman & Lahav 2013). Wachman and Lahav reviewed the effects of noise on preterm infants in NICUs and found that heart rate, blood pressure, oxygen saturation, respiratory rate and sleep were all deleteriously affected (Wachman & Lahav, 2010). Similar impacts on vital signs have been reported by Cardosa et al. (2015) and Shimizu and Matsuo (2016). Intense noise levels (>55-60dB) disrupt sleep states and interfere with brain development and organization. Furthermore, minimising exposure to high levels of background ambient noise can encompass neurodevelopment and neuro-protection of vulnerable neonates, and their fragile brains, contributing to improving outcomes for the future. Ambient noise needs to be low enough for the infant to distinguish the maternal voice to optimize auditory development (Verklan & Walden, 2015).

Ambient noise levels in a NICU should not exceed an hourly Leq of 40-45db (Australasian Health Infrastructure Alliance, 2013; White, Smith, & Shepley, 2013). Recommended standards for newborn ICU design established that the usual noise level should not exceed Leq 45 decibels on an A-weighted scale (dBA) and 65dBA on the Lmax scale (White, 2007). Unfortunately, noise in the NICU environment has often been found to exceed these limits, either as a result of conversation, equipment (i.e., heating, ventilation and cooling (HVAC) systems, therapeutic equipment), communication devices (i.e., overhead speaker systems, telephones, pagers), or non-acoustical surfaces (i.e., flooring and ceiling) (Krueger, Schue, & Parker, 2007), and staff are often unaware of how loud the noise actually is (Darcy, Hancock, & Ware, 2008).

The three main designs of NICUs are open plan bays with potentially dozens of cots, single family rooms (SFR) and pod arrangements with 4-6 cots. The open bay environment facilitates communication and team work between staff, allows nurses to monitor several neonates at once, but noise levels can be excessive. SFRs have been found to be superior for family satisfaction, increasing bonding opportunities such as skin to skin contact, in a quieter environment (Shahheidari & Homer, 2012). There is however, recent evidence from Pineda et al. (2014) that suggests that less noise in SFRs could actually contribute to sensory deprivation, and that this could be detrimental to neurodevelopmental outcomes. Pods however, could present a combination of the positive attributes of the sensory stimulation of safe noise levels due to staffing levels that necessitate verbal communication between staff and parents, as well as the increased capacity for privacy and bonding opportunities. However, **the noise levels in pods have not yet been reported, or compared with that in the NICU open plan setting. This observational study sought to compare the noise levels between a 6-bed pod and an 11-bed open plan NICU**.

Methods:

Ethical approval to mount the dosimeter meters and record the decibels was granted through the Hospital's Ethics Committee. Staff were informed of the project and its rationale, both in writing in the communication book and verbally during education in-service sessions. Staff and parents were reassured that the meter recorded noise levels only and not individual voices.

Setting

The study was conducted in a large tertiary hospital in Australia, which manages a high risk maternity service, and provides care for women with complex pregnancies and their newborns. The hospital provides the highest level of neonatal services (Level 6) , with a NICU providing medical, surgical and cardiac stabilisation for neonates born preterm from 23 weeks gestation, up to and including the sick term neonate (SA Maternal and Neonatal Clinical Network, 2014). In addition the NICU staff work closely with the retrieval service to receive sick and preterm infants from outlying regional areas. There are two level 6 NICU settings in the hospital, called NICU 1 (open plan - to be hereafter referred to as 'NICU') and NICU 2 (a pod – to be hereafter referred to as 'the pod'), separated by a corridor. Neonatal nursing/midwifery staff and the multidisciplinary healthcare team work across both areas.

The NICU (circa 1995; see Figure One) is an 11-bed open plan unit with an isolation room requiring 8-9 neonatal nurses per shift. This area had an occupancy rate of 100% during the study period, and is 160m^2 including the staff base (see Figure One). The entry/exit is via a front sliding frosted glass door and a back door opening into/out of unit accessible via an electronic card/push button. Access to the unit for parents/visitors is via a bell.

The pod (circa 2006: see Figure Two) is a six-bed area staffed by 3-5 neonatal nurses per shift, also had a 100% occupancy during the study period, and is 94m^2 including the staff base. Entry/exit is via a front sliding frosted door and a rear wooden slide door accessed with an electronic card/push button. Access to the pod for parents/visitors is via a bell.

In NICU, a glass partition at the nurses' desk shields the majority of bed spaces from desk conversations and ringing phones, and similarly, a desk partitioned from the pod with a glass wall shields all six beds from phone/conversations. There is a phone on the wall next to bed space 12 and 13 in the pod, and occasionally a cordless phone is used near the bed spaces in both areas. There are glass windows along the whole length of NICU covered by venetian blinds to protect the Unit from direct sunlight, and in the pod, the only windows start at two metres high facing onto the outside corridor with no direct sunlight. Both areas have non-recordable meters which alert staff to noise by flashing red when decibels (dB) exceed set limits of 55dB. There are three of these monitors in NICU (located 7-12 metres apart), and one in the pod, above the hand washing sink (see their exact location on the figures).

Each occupied bed space in both NICUs is exactly the same, containing a myriad of equipment, which, on any given day may include an incubator/open bed/cot, a ventilator (providing nasal continuous positive airway pressure (CPAP), conventional or high frequency ventilation (HFOv)), bubble continuous positive airway pressure (BCPAP), humidified high flow oxygen (HFO), monitors (MP70/MP30), 1 – 9 infusion pumps, a phototherapy unit, suction regulators, blenders, t-piece resuscitators, nitric oxide delivery system, screens, chairs, stools, breast pumps, maternal bed/wheel chair and weigh scales. Typical to both NICUs, procedures performed include intubation (when the ECG monitor volume is increased), line insertions, blood taking from arterial lines/capillary heel pricks, ultrasounds/ x-rays, and emergency resuscitation etc.

Ward rounds in NICU with the multidisciplinary team are from 9:00 AM – 10:00 AM, and from 7:00 PM – 8:00 PM. The ward round in the pod follows that in NICU. Nursing handover at the bedside in both areas is from 7:00 AM – 7:30 AM, 2:00 PM – 2:30 PM and 9:00 PM – 9:30 PM. In each area there is a ‘Quiet Time’ with lights dimmed from 12:00 PM to 1:00 PM daily, and at night, all lights are dimmed. Despite a series of teaching sessions to instruct staff over time about the need for a quieter environment, and the implementation of various techniques to reduce noise levels, they remained a concern. This situation provided another impetus for the current study.

Data Collection

A dosimeter (Extech Sound Level Datalogger) was placed in each room above a sink in a high traffic area frequently used for hand washing/surgical scrubs. The dosimeter was positioned 0.5 metre from the ceiling and 2.16 metres from the floor between two bed spaces in NICU and in the pod (see Figures One and Two). The dosimeters recorded the dB continuously for 4 weeks, and stored data of the minimum and maximum dBs every 60 seconds. The dosimeters were taken down for logging of data and a battery check once a week, with a resultant break in data collection for less than an hour.

Observational data was collected by 2 researchers independently during the study period at both low and peak periods of clinical workflow, such as the early hours of the morning, and during nursing and medical handovers, double staff times, neonatal admissions and procedural tasks; to identify the factors that may potentially contribute to a difference in dB recordings.

Data Analysis

Data was analysed and compared between specific periods, as well as across the entire 4 week period. There are basic assumptions with $\chi2$ that should be checked e.g. random sample and independent observations. A $\chi2$ test was used to assess the significance and direction of the relationship between the time of the day and the level of noise within each area, analysing noise measurements between:

- 1:00 AM - 2:00 AM (anticipated to be a quiet period)
- 9:00 AM - 10:00 AM (multidisciplinary ward round in NICU – anticipated to be a time of increased noise)
- 10:00 AM - 11:00 AM (multidisciplinary ward round in the pod – anticipated to be a time of increased noise), and
- 2:00 PM - 3:00 PM (nursing handover in both areas (anticipated to be a time of increased noise).

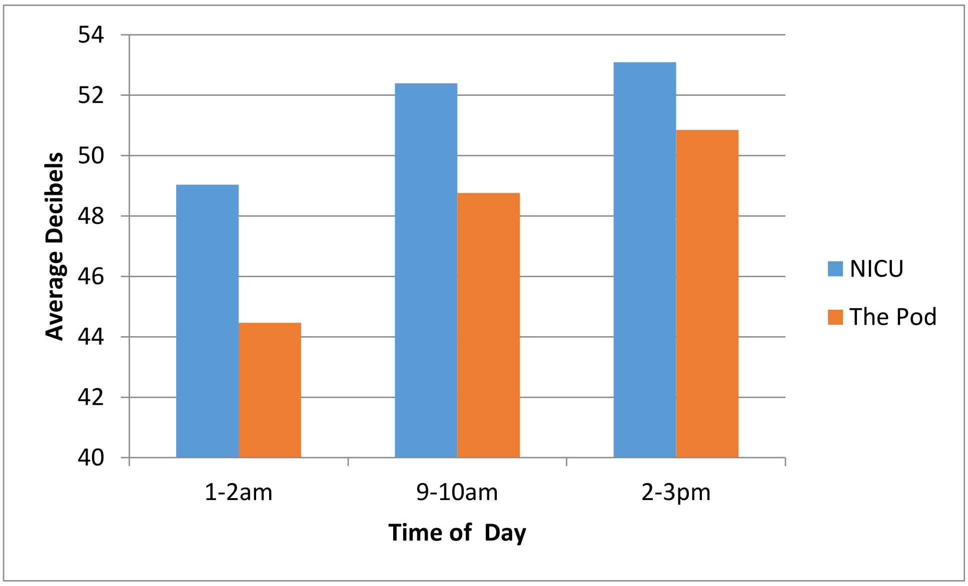
Results

The mean dB reading across the whole 4 week study period in NICU was 48.99773dB, and in the pod it was 47.29533dBs lower by 1.7024dBs than NICU. The average decibel recording for NICU for the time period between 1:00 AM - 2:00 AM (quiet time) was 49.05dBs, and in the pod the reading was 44.5dBs, lower by 4.55dBs when compared to the NICU.

Between 9:00 AM and 10:00 AM during the ward round in the NICU, the decibel reading was 52.4dBs, and between 10:00 AM and 11:00 AM during the ward round in the pod, the decibel reading was 48.8dBs lower by 3.6dBs when compared to the NICU.

The noisiest time period was at nursing handover between 2:00 PM and 3:00 PM, when decibel recordings in NICU were an average of 53.1dBs and in the pod, 51dBs, lower by 2.1dBs when compared to the NICU. Isolated peak levels reached 74.5dbs in NICU, and 75.9dbs in the pod. These findings are presented in Table 1.

Table 1: Differences in decibel readings (between 40-54dBa) between NICU and pod at different times of day



This finding showed that decibels in both areas in all time frames were consistently above the upper limit of 45dbs, except for in the pod during the 1:00 AM to 2:00 AM

period, when it fell within the acceptable range, and that isolated spikes in decibels were present.

The range of dBs recorded in NICU was 26.3 to 74.5dBs, while in the pod it was 26.5 to 75.9dBs. In addition, there were significant differences in the decibel ranges between the two settings from 1:00 AM to 2:00 AM, and from 9:00 AM to 10:00 AM (r= 0.641, n = 54, p = 0.001). The correlation also indicated a strong relationship between these two variables. However the data for each area separately showed the NICU comparisons between 1:00 AM to 2:00 AM and 9:00 AM to 10:00 AM as r= 0.244, n = 35, p = 0.002, and while this relationship is significant, the correlation is not as strong. Conversely the pod readings showed no significant decibel difference for the same time period. In conclusion the noise levels in NICU seemed to have influenced the data, and NICU is statistically significantly noisier than the pod across all time periods.

Furthermore there was a significant difference in the noise levels between 9:00 AM and 10:00 AM and from 2:00 PM to 3:00 PM in both areas (r= 0.524, n = 53, p = 0.001) compared to 1:00 AM to 2:00 AM. Again NICU, when analysed separately shows r= 0.241, n = 35, p = 0.002, and the pod shows no significant decibel correlation.

During the time period from 1:00 AM to 2:00 AM in comparison to 2:00 PM to 3:00 PM in both areas, results indicated that while the relationship between the dBs and the time frame is significant, it is not a strong relationship (r= 0.364, n = 53, p = 0.007). Again in NICU, the noise difference is significant between the two time periods (r= 0.372, n = 35, p = 0.028), however in this time period analysis there is a significant difference in the pod with r= -0.486, n = 18, p <0.041. This may suggest that in both areas there is a significant difference in the levels of noise between the 1:00 AM to 2:00 AM period when compared to the noise levels in the 2:00 PM to 3:00 PM time period for both NICU and the pod.

An example of the observational data collected during the study period which shows the correlation of noise levels with activities such as admissions, rounds and handovers is provided in Table 2. It details the typical activities that lead to peaks in noise in both areas, essentially alarms ringing continually, ward rounds, conversations, equipment noises such as ventilators and a neonate in an open cot crying. In contrast, at quiet times during the observation period, there were no visitors, alarms rang only intermittently and movement in the areas was less.

Time	Date	dB	Area	Observation
0100-0200	29/07/2014	43.67	NICU	Low pitched alarms for physiological monitoring ringing intermittently, decreased workflow activity, no visitors, no allied healthcare teams, lights dimmed
0900-1000	13/08/2014	55.29	NICU	Low and high pitched alarms for physiological monitoring ringing continuously, ward round with medical staff, increased workflow activity, several ventilated neonates, BCPAP, chest drain 1x neonate
1400-1500	29/07/2014	54.84	NICU	Cot alarming (high pitched), increased workflow activity, blender gases checked (high pitched noise), door bell rang several times, alarms for physiological monitoring ringing continuously, nursing conversation constant, several neonates on respiratory support BCPAP, ventilated
0100-0200	25/05/2014	42.96	Pod	Dimmed lights, low pitched alarms for physiological monitoring ringing continuously, no visitors

0900-1000	18/06/2014	53.08	Pod	Nursing care of neonate in open cot, infant crying, low and high pitched alarms for physiological monitoring ringing continuously, manoeuvring equipment, handwashing, several neonates on respiratory support 1x ventilator
1400-1500	4/06/2014	50.11	Pod	Constant parent/nursing conversation, low pitched alarms for physiological monitoring ringing continuously, door bell rang

Table 2: Observational data

Discussion

This is the first published study to compare sound levels in a pod with those in an open plan NICU setting. **The results confirmed firstly that it is quieter in the pod, and the difference is statistically significant. Although the <u>average</u> noises were lowest in the pod, the lowest actual single recording was in the NICU, and the highest single recording was in the pod. The second significant finding was that noise levels in both areas exceeded the recommended ranges.** The observational data confirmed that busy periods such as ward rounds and handover periods contribute to spikes in noise.

The pod design may be quieter because there are less cots and less staff, however both areas were at 100% occupancy during the study period, and the nurse:patient ratios are the same in both areas, hence for the size, the density of activity was equivalent. The strength of this study is the homogeneity between the two settings: the building materials and furnishings are comparative, the cot set-ups are identical, the same staff worked in both areas, the model of care and ward routines and clinical procedures are the same. This means that the excessive noise is most likely due to the same reasons in both areas, either due to the structural components of the rooms, or behavioural reasons, and it may also mean that any intervention to decrease noise levels should be equally successful in both areas.

With peak levels reaching 74.5dbs in NICU, and 75.9dbs in the pod, there are serious impacts for the vulnerable neonates in the room, especially if any of them were either out of their closed cots at the time, or if the doors of their cots were open. Such effects have been recently confirmed by Shimizu and Matsuo (2016) who found that high noise levels adversely influenced that capacity for preterm neonates to self-regulate, and could cause tachycardia, bradycardia, increased intracranial pressure, and hypoxia.

The fact that low dB readings were recorded during the study period in NICU of 26.3dBs, and in the pod of 26.5dBs means that this low level of noise can be reached. Dos Santos et al. (2015) found that during ‘quiet times’, the noise levels inside the incubators did fall, suggesting that behavioural changes such as this can be facilitated across all time frames. Average levels need to be reduced to within the accepted range more consistently. In designing new infrastructure, specific considerations to workflow traffic, where noise generating activities occur, will be important. Acoustic privacy will need to be factored in, including speech privacy for medical and nursing handovers, changeover of shift (double staff time), procedures and interventions. Equipment storage, office equipment, and restocking trolleys will be acoustically isolated from infant areas. Waste handling/linen disposal will be minimised, and soft closing systems with insulation and separate corridor access behind internal walls with built in chute systems, will reduce foot traffic. A reasonable amount of sound can be removed from the NICU by thoughtful design as simple as selecting ceiling tiles with noise reduction co-efficient (NRC) of at least 0.65 hertz, vinyl faced acoustic material, carpets to reduce noise generation from traffic moving across it (White, 2007), caulking (watertight and airtight), sensor taps with instant warm water will assist with minimising use time, acoustic duct baffles and panels (White, 2007).

Furthermore, vigilant selection of equipment and materials through deliberation of absorptive surfaces of mechanical systems and reducing noise generating activities (overhead paging with silent annunciators on equipment) can reduce decibel frequency and duration. Monitor alarms should be converted from audio to wireless alerts when the upgrade of facilities is planned (White, 2007). While this study only measured the noise *outside* the neonatal incubators, consideration of the noise inside incubators (which can reach levels up to 10 times louder than those recommended) should also be taken into consideration in any intervention designed to reduce the potential damage from this internally generated environmental noise (Marik, Fuller, Levitov, & Moll, 2012).

Dealing with behavioural change to further reduce noise levels provides the impetus for the next stage of this study. Obviously having the continuous presence of the non-recordable meters alerting staff to noise by flashing when decibels exceed set limits of 55dBs does not have the desired impact on staff behaviour. Other interventions are needed to manage this issue. Informing staff of the importance of the effects of noise on the neonatal physiology and neurodevelopment during in-service education sessions, and then communicating the audit results to staff in these sessions, as well as in writing, would be required to facilitate short term behaviour change. Staff should be encouraged to consider strategies themselves to reduce noise to enhance their commitment and motivation to the interventions. The strategies and related evidence should be shared with new staff in orientation packages as soon as they begin working in the unit. Unfortunately Carvalhais, Santos, Vieira da Silva, and Xavier (2015) found that even after implementation of the training program, noise levels remained unchanged. **Our results concur that a suite of measures to reduce noise levels in any**

neonatal intensive care unit environment need to be considered. In the short term, education may result in behavioural change. In the long term, behavioural changes may facilitate a cultural shift towards a quieter environment.

Conclusion

While this study has shown that decibel levels in a pod setting are statistically significantly lower than an open plan design NICU, the overall noise levels in both areas were over the recommended levels, and the peaks reached well exceeded recommended levels.

The noise emanating from physiological monitoring, respiratory support, manoeuvring equipment and discussion amongst health professionals cannot be completely eliminated. Specific consideration to schematic planning and thoughtful design of traffic flow, layout and workstations can help to minimise noise. Furthermore, absorptive surfaces, mechanical systems, and noise reduction strategies can reduce dB frequency and duration. Hence, careful consideration of internal infrastructure through vigilant selection of equipment and materials, with the resultant potential to decrease noise pollution, can contribute to lowering adverse outcomes for the neonate. Consequently, interior designers/architects, hospital administrators, healthcare planners are in need of information that will provide evidence based design regarding environmental impact.

More research is needed on the impacts of noise on the neonate and interventions to reduce environmental noise in any NICU setting to below 45 dB. This includes further research to ascertain if staff can work quieter in pods to allow families to take advantage of the family-centred benefits offered in this configuration. All data involved in this study can be accessed by communicating by email with the corresponding author.

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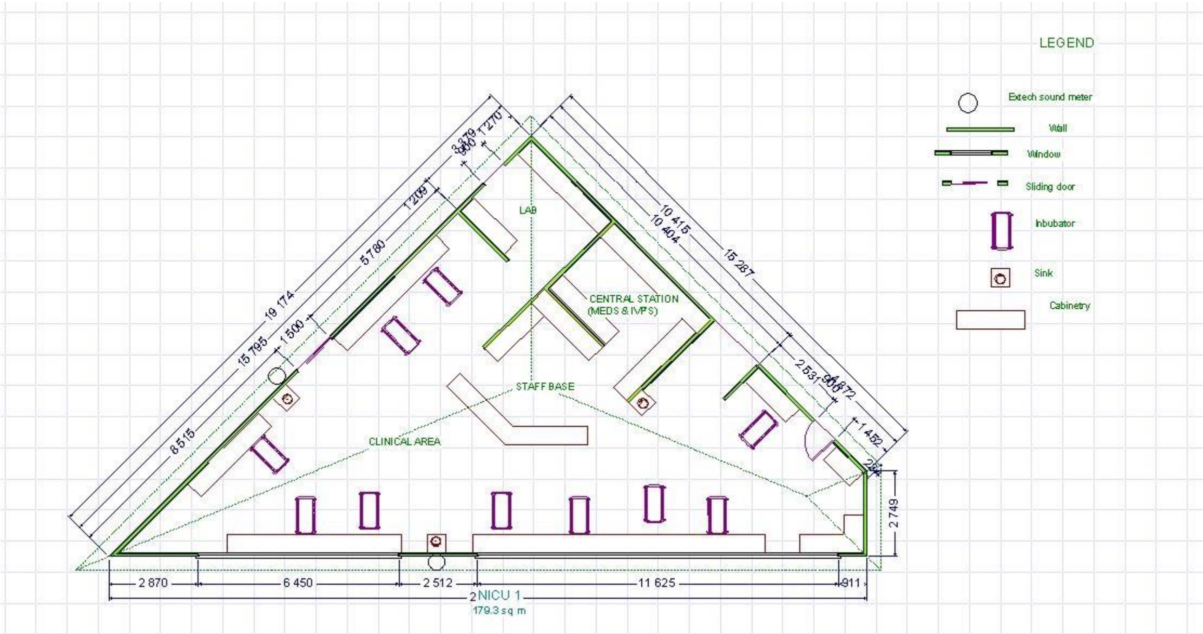

Figure 1: NICU

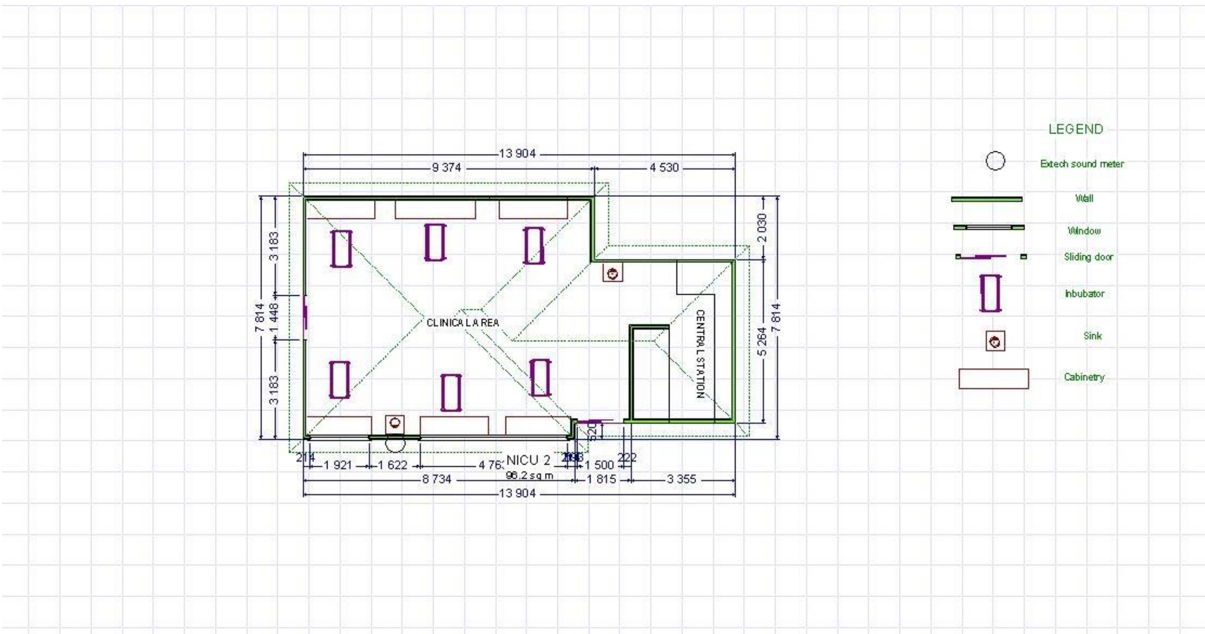

Figure 2: The Pod