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Original Research Paper

Management

RETROFITTING OF EXISTING ROOMS IN HEALTHCARE FACILITIES FOR CREATION OF NEGATIVE PRESSURE ISOLATION ROOM IN WAKE OF COVID19 IN RESOURCE CONSTRAINT SETTINGS : A TECHNO- FINANCIAL ANALYSIS

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ABSTRACT

Introduction: Emergence of COVID- 19 has highlighted the gross inadequacy in healthcare in terms of Infrastructure required to provide adequate care to all infected cases. Even the existing hospitals are not adequately equipped with HVAC (Heating Ventilation and Air Conditioning) system to handle these types of patients. Guidelines recommend that an infected case of COVID-19 has to be housed in a Negative Pressure Isolation Room(NPIR) or air borne infection isolation room (AIIR) . Technical know-how and financial resources are available universally for retrofitting an existing single occupancy room into an NPIR. Simple tests like smoke tests exist for validating the result. The present study aims to address the semantic barrier among the health care managers and to provide them with a cost-effective practical plan for retrofitting a single occupancy room to an NPIR without any external support in the Indian context. **Materials & Methods:** The present descriptive concurrent study was carried out over a duration of fifteen days at a tertiary care hospital, as a project to study and develop a plan for converting an existing single room to an NPIR for admitting COVID 19 cases with an aim of providing a safer environment to the HCW. The study was conducted with the objective to define the technical requirements in an understandable manner and present a layout of feasible solutions for retrofitting a single occupancy room to an NPIR and ascertain the financial implications of the same. Review of literature and interviews of different stakeholders were conducted for documenting the requirements. The traditional method of Cost Analysis was used to arrive at cost estimates for the Financial Year 2020 – 21. **Observation and Result:** The negative pressure of 1.25 mm H2O was achieved with the help of an exhaust fan of 300 CFM power after all the windows are sealed using cello tape/micropore and cotton. The total cost of retrofitting ranges between just Rs. 14,725 per room to Rs.21,800 by applying ingenious strategies and locally available resources. ITI qualified masons and electricians can easily achieve the task in hand. Monitoring and validation can be performed in a cost-effective manner within the available and accessible resources with ease. **Conclusion:** Retrofitting of an existing single room to an NPIR can be achieved with the help of locally available technical and financial resources in a cost-effective manner.

KEYWORDS : COVID-19, Air Borne Infection Isolation Room (AIIR), Negative Pressure Isolation Room, retrofit

INTRODUCTION

Evolution of COVID 19, an infectious disease, caused by Severe Respiratory Syndrome coronavirus-2 (SARS-CoV-2) [1-4], brought the world to standstill and the governments across the globe are compelled to take note of the disease. The pandemic also brought in the realization that the existing healthcare infrastructure is highly inadequate to tackle the issue facing the globe at present.

India despite taking stringent measures of a complete lockdown, even before the country experienced 100 cases has over 2 lakh cases with over 5 thousand mortalities as on date. [5,6] Reports from various countries have shown that amongst the infected cases in China 15–20%, Italy and Spain 40–55% of COVID-19 cases require hospitalization, approximately 5% cases in China and 7-12% in Italy and Spain require intensive care. [7, 8]

Health Care Worker's vulnerability: Like other respiratory viral pathogens, COVID-19 is a highly infectious disease and spread by the droplet, causing high vulnerability of health care workers (HCW) particularly those exposed to the infection during the patient care. Up to 20% of HCW are getting infected in countries like Italy, Spain, and the USA. Not only the mortality of the workforce is unfortunate but the infected HCW is liable to spread the infection to other patients and have to be isolated for 14 days, paralyzing the already stained Health infrastructure. [9,10]

Guidelines for the isolation room. : Plethora of guidelines have been issued across the globe by ECDC, CDC, WHO, SCCM, etc stating the requirement of an NPIR room for the purpose of admitting a COVID-19 patient [11,12,13]. The majority of the government hospitals including teaching institutions are not prepared to provide isolated care to COVID-19 patients while keeping their staff safe. Looking at the current scenario it can be understood that the COVID-19 virus is here to stay for a long time. Countries across the globe are facing a daunting challenge to establish infrastructure to accommodate the increasing number of cases. According to the Guidelines on Clinical Management of COVID-19 published by the Ministry of Health and Family Welfare, Government of India, it is recommended that all aerosol-generating procedures whenever required are to be conducted in an adequately ventilated single rooms meaning NPIR with a minimum of 12 air changes. [13] Further, The American Society for Healthcare Engineering (ASHE) [14] and the Centre for Disease Control (CDC) have repeatedly reiterated that all patients infected with COVID-19 are to be isolated in NPIR [15].

Limitation in the execution of the recommendation: -

The hospital administrator is duty-bound to try to provide NPIRs as recommended for symptomatic cases to contain the spread of disease to HCW. The majority of the government hospitals including teaching institutions are not prepared to provide isolated care to COVID-19 patients while keeping their staff safe.

Need for this study: During the discussion with Medical Superintendents of the various hospital, including Teaching hospitals, it was noted that understanding about NPIR is lacking in general. The availability of a hospital engineering wing is a luxury and is not available in most of the hospitals. The current study was needed to address the semantic barrier among the health care managers and to provide them with a workable plan for creating NPIR without any external technical experts. The study was conducted with the objective to define the technical requirements and present a layout of feasible solutions for retrofitting a single occupancy room to an NPIR and ascertain the financial implications of the same. It was also decided to study the financial and technical requirements for retrofitting an existing room into NPIR and the tests required for validating the results.

Methodology

The present descriptive concurrent study was carried out over a duration of fifteen days at a tertiary care hospital, as a project to develop and validate a plan for converting an existing single room to an NPIR to isolate cases of COVID-19 reporting to the hospital, in an environment safer for HCW. Further, given the constraints in the current scenario, alternates were tested to convert these rooms with the available engineering support. Only equipment available at the local market is used.

The estimate of the cost of modification of an existing single room to NPIR. For documenting the requirements, literature was reviewed (using Pubmed and google scholar search engines) and different stakeholders were interviewed. The traditional method of Cost Analysis at current market rates was used to arrive at cost estimates for the F.Y. 2020–21. Focus Group Discussions were held with the engineers in two phases to devise various requirements to achieve the objectives of the study. First phase of focussed group discussions were held with the in- house engineers wherein a basic plan was charted. Subsequently, after testing the decisions taken in the first phase, second phase of focussed group discussions were held with two external experts to validate the results. The cost of material for retrofitting an existing single room into an NPIR in an existing hospital infrastructure was done by market survey. Manpower costs were determined by taking into consideration the prevalent Minimum Wages as published by the Labour Commissioner. Land costs and costs for support services have not been considered as the hospital is already functional. However, costs of renovation have been considered after due deliberations and in-depth analysis of the costs incurred by the Engineers at the hospital.

RESULTS

A brief understanding of the following broad topics is required before retrofitting is attempted:

1. Basic requirements and architecture of NPIR
2. The basic design of the private hospital room.
3. Necessary modifications required to convert Private room to NPIR

Basic requirements and architecture of NPIR American Society for Healthcare Engineering (ASHE) has defined an NPIR as "designed to isolate a patient who is suspected of, or has been diagnosed with, an airborne infectious disease. The NPIR, therefore, is designed to help prevent the spread of a disease from an infected patient to others in the hospital."[13]

Design considerations of a Negative Pressure Rooms

NPIR are standard patient care rooms with certain specific engineering requirements in order to enable admission of an infected patient in the room preventing exposure of other patients and staff to the infection. Design considerations specific to an NPIR are as follows:

Location

Ideally should be located at the entrance of an inpatient ward so that the infected patient doesn't have to travel across other areas [16, 17, 18].

Anterooms

An Anteroom is an area attached to the isolation room which acts as a barrier against any potential loss of pressurization and acts as an area where staff or attendants can don or doff personal protective equipment (PPE) upon entry/exit from the room. International facilities guidelines Institute state that NPIR does not necessarily require an anteroom. An organization should ensure that there is the provision of space outside the isolation room to enable donning and doffing of PPE [13, 14, 15]. In the paucity of space or in the absence of an anteroom, the same provisions could be kept on an instrument trolley with PPE kept on the top shelf of the Trolley and waste collection bins housed on the lower shelf of the trolley.

Ensuite

Ensuite (Shower with toilet) is recommended to be included as a part of the NPIR so that the patient doesn't travel across the facility to access toilet facilities. However, if all the rooms on a single floor are being utilized to isolate patients potentially suffering from the same infectious disease, then rooms without toilet facilities could also be utilized for the purpose of Isolation. We, therefore, consider both types of rooms for modification into NPIR.

Pressure Differentials and air changes.

The pressure in an NPIR is lower than the adjoining rooms or corridor. Pressure differentials should not be less than 5 Pa or 1.25 mmH2O between isolation rooms and the surrounding. [16, 17, 18, 21]. At least 12 air changes per hour are recommended by most recommendations.

It is pertinent to mention here that it is not the negative pressure only that matters. Basically, it is the unidirectional airflow over the patients bed which matters the most. If we have a sealed room with no entry of air inside it, it will unsuitable for admitting a COVID-19 patient. Because no air movement will be achieved over the patient bed and a laminar flow pattern wherein the air moves from the clean to dirty side can be maintained. Only when sufficient air is extracted from the room from one side and simultaneously sufficient air is allowed to enter from the other side the purpose of unidirectional airflow can be achieved in short the principle of Supply air< Return air + Exhaust air is achieved thereby maintaining negative pressure. Airflow in an NPIR is depicted in Figure 'No. 1.

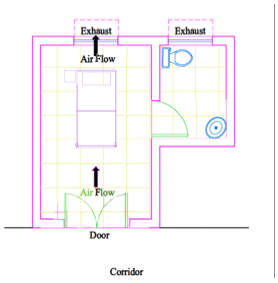

Figure No. 1.: Airflow in a NPIR

The basic design of the private hospital room: The private room in most hospitals is a single occupancy room with or without the attached washroom. The size is usually between (15*12*12 feet) 2100-2500 cubic feet. An entry outer door and a window are situated on the outer wall. The room usually has only one door and the bed is situated between the door and the outer wall. The door size is usually 4'2" and 7'.

Necessary modifications required to convert a single occupancy room to NPIR

After discussion it was decided to consider hospital wing having single corridor and isolation rooms on both sides of the corridor. The present modality is suitable for the hospital built on an open space away from the crowded place, it is most suitable for the district hospitals where rooms are built on both side of single corridors and enough free space is available for exhausting the air to outside the building as the virus get rapidly inactivated in outdoor air.

Exclusion criterion: The technical and calibration requirements, for the rooms where direct exhaust to the outdoor is not possible, are more complex and Hospital administrators are advised to take HVAC engineering experts for the same.

Following broadheads were studied to ascertain the necessary modifications required to convert a single occupancy room to NPIR:

A. Engineering changes

1. Electrical work
2. Civil work
3. Wooden work

B. Manpower requirements with the minimum educational qualification required for the given task.

C. Cost estimate and financial implications.

D. Requirements for the Monitoring / validating the results

A. Engineering changes

1. Fitting of Exhaust Fans/ electrical work. This is the heart of the NPIR.: Each room must have a dedicated exhaust fan which should be situated on the external wall of the room, just opposite to the door. If the isolation room has an attached ensuite, then an exhaust fan of an adequate quantity is to be installed separately in the washroom/ ensuite. The capacity of the exhaust fan required for a patient room of size 10 ft x 15 ft. x 12 ft is 300 CFM(cubic feet per minute), while for the attached ensuite the capacity of the same is 100 cfm. It is recommended that these exhaust fans are positioned approximately 150–300 mm above floor level to discharge vertically upward to the outside air [16]. It is to be ensured that the air being exhausted NPIR is not connected to the exhaust system of the building. To ensure the same, the duct system can be easily constructed in areas where the rooms don't have an outside wall.

2. Civil work: corresponding civil work for fitting exhaust fan/fans will be required to be done.

3. Sealing of the window and doors: This can be achieved using the humble micropore and cotton. Every staff nurse posted in OT is skilled to perform this activity.

4. Installation of pressure sensors: The pressure sensor is available in the local electric shops. These Pressure sensors were installed on the door and the level of the exhaust fans. The same were coded and embedded with controls in order to increase or decrease the speed of air being exhausted on the basis of pressure differential being created due to opening or closing of doors.

5. Fitting the grill flap on the entry door and washroom door: The grille flaps (Shown in Figure No.2) which open only when the exhaust fan is operational have to be fitted in the entry door as well as on the washroom door, so that negative pressure is created in the room after fans are operated. Carpenter will be required for the job.The direction of the opening of the entry gate should be kept within the room to ensure that no air is exiting the room

6. Air changes: in the present modal if it is not possible to measure the air changes per hour. However, if all the window and other doors are sealed and Air is allowed from the one door with grill flap, will be sufficient to allow cross-ventilation with the exhaust fan of 300 CFM capacity.

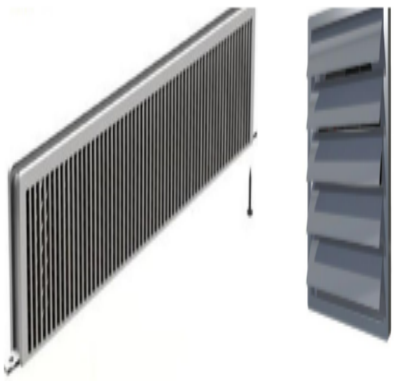

Figure No.2 Type of grill

7. Other requirements [16,17,18,19]

- The room should be sealed from all sides besides the entry/exit.
- Entrance Door to both the room and the washroom should be self-closing and should open within the room to ensure the maintenance of the desired pressure differential.
- A basin with an elbow operated tap or hands-free operation should be provided in the isolation room.

B. Manpower planning for the suggested modifications.

The manpower required for retrofitting an existing single room within the healthcare facility are primarily electricians, carpenter, and mesons. The task primarily to be performed is civil work including whitewash/painting of wall, installation of exhaust fans, fitting grille flap on the doors, installation of pressure sensors if required, installation of monitoring equipment, and testing of the equipment installed. The cost of manpower required to undertake these activities reduces if the number of rooms to be converted is more than one. For the ease of understanding and calculation, authors have considered retrofitting of only one room in the facility. The wages paid to this personnel are calculated based on the existing payment criteria utilized by the Public Works Department (PWD) [20]. Minimum educational qualification possessed by the manpower being deployed to execute the job is given in Table no.1.

Table no. 1. Level of the manpower expertise requirements for the changes desired are as under

Type of isolation room	Exhaust ducts required	Engineering manpower requirements (minimal qualification)
Single occupancy without washroom	Without exhaust air duct	ITI pass out in the trade of (electricians, carpenter, mason)
	With exhaust air duct	Expert in HVAC
	With pressure monitoring	Junior Engineer
Single occupancy with wash room	Without exhaust air duct	ITI pass out in the trade of (electricians, carpenter, mason)
	With exhaust air duct	Expert in HVAC
	With pressure monitoring	Junior Engineer

The electrician will be required for fitting the exhaust fan and installing the electronic atmosphere pressure monitor and connecting it with the exhaust fan.

Carpenter will be needed for fixing grill flap and meson will be doing the civil work needed for fixing exhaust fan in the wall.

C. Cost estimate and Financial implications

The tables below provide an overview of the expenditure incurred in retrofitting an existing single room while making structural adjustments. The costs given below include the cost of the specialized equipment required in addition to the manpower required to successfully execute the plan. The cost was determined after consulting the engineering division as well as different equipment manufacturers and suppliers. Land costs and costs for support services have not been considered as the hospital is already constructed and is functional. However, the costs of renovation have been considered. The total cost determined to retrofit a single room to an NPIR has been calculated for the following room specifications/ requirements:

1. Retrofitting a single room without an attached washroom/ ensuite (Table No. 2)
2. Retrofitting a single room with an attached washroom/ ensuite (Table No.3)
3. Retrofitting a single room with embedded controls to ensure monitoring and corrections of deviations in Pressure differentials but without an attached washroom/ ensuite (Table No.4)
4. Retrofitting a single room with an attached washroom/ ensuite and embedded controls to ensure monitoring and corrections of deviations in Pressure differentials (Table No.5)

Table No. 2: Cost estimate for Retrofitting a single room without an attached washroom/ ensuite

Equipment (A)	Cost per unit (INR)	Number required		Total Cost (INR)
Exhaust Fan 300 CFM	2000	01		2000
Seal tape	200	03		600
Cotton roll	150	02		300
Door closure	2000	02		4000
Nuts, bolts, etc.				1000
Grille Flap	1500	01		1500
Total (A)				9400
Manpower (B)	Salary day (in INR)	Number required	No. of days	Total (INR)
Meson	525	01	01	525
Electrician	525	01	01	525
Carpenter	525	01	01	525
Helper	350	03	01	1050
Total (B)			2625	
Total (A+B)			12025	

Table No. 3: Cost estimate for Retrofitting a single room with an attached washroom/ ensuite

Equipment (A)	Cost per unit (INR)	Number required		Total Cost (INR)
Exhaust Fan 300 CFM	2000	01		2000
Exhaust Fan 100 CFM	950	01		950
Seal tape	200	03		600
Cotton roll	150	02		300
Door closure	2000	02		4000
Nuts, bolts, etc.				1000
Grille Flap	1500	02		3000
Total (A)				11850
Manpower (B)	Salary per day (in INR)	Number required	No. of days	Total (INR)
Meson	525	1	02	1050
Electrician	525	1	02	1050
Carpenter	525	1	02	1050
Helper	350	3	02	2100
Total (B)				5250
Total (A+B)				17100

Table No.4: Cost estimate for retrofitting a single room with exhaust air ducting without an attached washroom/ ensuite and embedded controls to ensure monitoring and corrections of deviations in Pressure differentials

Equipment (A)	Cost per unit (INR)	Number required		Total Cost (INR)
Exhaust Fan 300 CFM	2000	01		2000
Exhaust air ducting	900/mt	03 mts.		2700
Seal tape	200	03		600
Cotton roll	150	02		300
Door closure	2000	02		4000
Nuts, bolts, etc.				1000
Grille Flap	1500	01		1500
Total (A)				12100
Manpower (B)	Salary per day (in INR)	Number required	No. of days	Total (INR)
Meson	525	01	01	525
Electrician	525	01	01	525
Carpenter	525	01	01	525
Helper	350	03	01	1050
Total (B)				2625
Cost for Embedded controls for pressure monitoring (C)	1500	01		1500
Total (A+B+C)				16225

Table No.5: Cost estimate for Retrofitting a single room with exhaust air ducting with an attached washroom/ ensuite and embedded controls to ensure monitoring and corrections of deviations in Pressure differentials

Equipment (A)	Cost per unit (INR)	Number required		Total Cost (INR)
Exhaust Fan 300 CFM	2000	01		2000
Exhaust Fan 100 CFM	950	01		950
Exhaust air ducting	900/mt	3 mts.		2700
Seal tape	200	03		600
Cotton roll	150	02		300
Door closure	2000	02		4000
Nuts, bolts, etc.				1000
Grille Flap	1500	02		3000
Total (A)				14550
Manpower (B)	Salary per day (in INR)	Number required	No. of days	Total (INR)
Meson	525	1	02	1050
Electrician	525	1	02	1050
Carpenter	525	1	2	1050
Helper	350	3	02	2100
Total (B)			5250	
Cost for pressure sensor monitoring (C)	1500	02	3000	
Total (A+B+C)			19800	

D. Monitoring

The question to be answered here is "How do we assure that the desired pressure is being maintained in the NPIR" or "Is air leaking outside the room

1. The simplest test will be the feel of the air while entering the room. If we feel the air at our face while opening the door, we are on the negative side of the door.

2. Pressure monitoring: International Health Facilities Guidelines Institute recommends the installation of Differential air pressure instrumentation panels adjacent to the corridor entry door) [13]. In the current constrained scenario, where retrofitting of the facility is being done the same can be achieved using the following ingenious solutions:

- A sensor synchronized with the exhaust fan can be installed which could sense the air pressure in the room and enabling exhaust fan speed adjustment so that pressure differential is maintained.

- Indigenous mechanical solution: In the absence of commercially available monitors, the following solution can also aid in monitoring pressure:

- Fix 2 glass tubes each having a length of at least 10 cm and a diameter of at least 5 mm. on both sides of a window pan with the help of any adhesive device such as adhesive tape in such a manner that both tubes are visible from both sides.

- Preferably the tubes are fixed in a vertical position.

- Drill a hole large enough to allow passage of a rubber tube/catheter at a position lower than the lower end of the tube.

- Pass a rubber tube or catheter through this hole and fix them, At lower ends of both the tubes.

- Fill both the tubes with colored water.

- Ensure no air bubbles are trapped between columns of the water.

Reading

- The water level is equal on both sides of the tube: Neutral pressure
- The water level in the tube within the room is higher to that present outside the room: Negative pressure
- The water level in the tube within the room is lower to that present outside the room: Positive pressure

The difference between the water level of the two tubes will be the pressure difference in mmH2O achieved between the surrounding and the room.

3. Leak Detection: The smoke test is the recommended test. Traditionally, for smoke testing, smoke is introduced through the system intake. Smoke being introduced has to have a color and should readily blend with atmospheric air, enabling one to identify leaks in the system [21, 22]. The authors suggest that the same can be easily conducted using the humbly available agarbatti or incense stick [23].

Retrofitting the ward

If no single room isolation facility is available, the entire ward can be considered for modification. However the number of beds have to be decreased so that only one or two beds are placed per cubicles, and every cubicle is fitted with one exhaust fan. The condition is that the window on the opposite side is opened for air entry. The side on the exhaust side can be used for admitting patient while the other half will have to be kept empty.

DISCUSSION

Health care managers hold a unique position by virtue of the fact that they not only have knowledge about various branches of medical field but they also have technical knowhow on healthcare engineering and hospital planning. This expanse of knowledge can be utilised to bring maximum efficiency and effectiveness in the healthcare system, thus resulting in far better healthcare outcomes and quality of care.

Solutions for Covid -19 not only lie with the medical community but also require a lot of work from the engineering division as containment of such infections require environmental modifications. The bigger question then is "How do we retrofit an existing single room into a NPIR"

India is a country with a large geographical area which has mandated the government to create a considerable number of health centres ensuring healthcare access to all. This has resulted in the creation of a large number of public sector hospitals having at least 100-200 beds and Community and Primary Health Centres manned by skilled and motivated medical officers.

Guidelines for management for COVID-19 across the world have emphasised on the requirement of NPIR for the purpose of isolating a COVID-19 patient [11, 12, 13]. Properly designed for unidirectional air flow, NPIR, can provide advantage of reducing chances of infection to the treating staff. However, existence of a NPIR doesn't substitute the function of quality PPE. A room is called a NPIR when the pressure in the room is lower to that of its adjacent surroundings [16]. A room can be designated as a NPIR when in addition to the pressure differentials, the room has a single entry/exit with all windows intact and sealed. According to the gas principle $PV = nRT$,

where P = Pressure of air in the Room,
V = Volume of the room,
n = Number of molecules in the room,
R is Universal Gas Constant and
T is temperature on the scale of Kalvin [24].

In accordance with the aforesaid principle, if the number of molecules in the room are reduced either the volume will reduce or the pressure will reduce. But in case of a hospital isolation room, volume is fixed and cannot be reduced. Hence, in this case only the pressure will reduce. In isolation room, this can be achieved easily by fitting an exhaust fan because the exhaust will be instrumental in extracting air from the room thereby reducing the number of molecule, resulting in creation of a negative pressure in comparison to the surrounding areas.

Monitoring and validation techniques have been discussed by the authors in the result as is suggested that a simple inexpensive incense stick a.k.aagarbatti can be used to conduct the smoke test which is primarily done to ascertain the direction of movement of air and leaks. In case of a leak, as is commonly practiced by the nurses in India, the same can be sealed with the help of cotton and micropore.

Another ingenious solution offered for the same is similar to the technique adopted by the Mason for measuring the level of the floor. To measure the same the exhaust fan is switched off. The pipe is then filled with water. One end of the pipe is kept in the room while the other is kept in the corridor. Now close the door and start the exhaust fan, if the level of the water in the tube in the room is higher in comparison to the tube in the corridor, then it is deemed that negative pressure has been achieved in the room and there are no leaks.

CONCLUSION

The need of the hour is to design hospitals and the capability of providing safe, effective and efficient care to the patients while keeping the healthcare personnel safe from

occupational hazards. Design of the facility determines the success of protocol implementation and creation of an environment which is safe for all, major determinants of which are space, functional design, appropriate equipment and trained staff. Keeping in view the statistical projections of growth in the cases of COVID-19 across the globe, it is the urgent need of the hour to consider retrofitting existing healthcare facilities for management of these cases. Although hospitals would be incurring an initial cost in such retrofitting's, in the long run, they would overrun their value in terms of patient needs and satisfaction, which indeed is the ultimate goal in healthcare.

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