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Research Article

# Design and development of air ventilated air bed for hospitalized patients

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## ABSTRACT

Proper ventilation is a critical consideration for the comfort of hospitalized patients. Dry skin, skin rashes, weariness, poor sleep, and other concerns caused by insufficient ventilation can all be avoided with proper ventilation. Air-Ventilated Air Beds are used to supply air to the major parts of the patient's body. This air bed is constructed in such a way that air is circulated continually throughout the body of the hospitalized patient. It is especially beneficial for people who are bedridden and need to spend a significant amount of time in bed due to illness. Excessive heat generated between the bed and the patient is perhaps the common cause of bedsores. Sweating is the leading cause of bedsores. Air ventilation is included in the system to prevent sweating and reduce the incidences of bedsores. Dual compressors, rubber tubes, flow control valves, and anti-decubitus mattresses are among the components used. The rubber tubes are used to ventilate the space between the body of the patient and the upper surface of the air bed. Above the mattress, the rubber tube mesh is positioned. The air is first compressed in two compressors before passing through the distribution manifold and through the meshing. The tubes are altered by drilling holes at certain intervals. The air from the compressor is circulated through the pipes before passing through the openings in the pipes. The unrestricted passage of compressed air via a capillary tube lowers the temperature of the air. The air exhausted through the capillary tubes maintains the patient's body temperature stable for a while before lowering it. The air is ventilated throughout the bed in this manner. Bedsore can be avoided by reduction of sweat by using the air in close contact with the patient.

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## INTRODUCTION

The number of patients admitted to hospitals has risen considerably in recent years. Furthermore, the number of individuals hospitalized for weeks or months due to various disorders has increased dramatically [1] . Patients who are hospitalized for weeks or months are in need of a solution to keep their skin dry by reducing the sweat. [2]. The medical profession is one where engineering principles and applications can be used to tackle any challenges or difficulties that arise during the process improvement process [3].

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One of these types of applications is the proposed solution. The solution entails creating and developing an air-ventilated air bed with several components such as compressors, tube mesh, and a comfortable fabric [4, 5]. The primary goal of air beds is to avoid bedsores in hospitalized patients [6, 7]. Constant pressure and moisture build-up between the bed's surface and the patient's body are typical causes of bedsores. Infection from a pressure sore can burrow into joints and bones, causing warmth, redness, and swelling in the affected area. As a result, it is critical to avoid bedsores, which can cause considerable harm to hospitalized patients [8]. Bedsores can be avoided if sufficient ventilation is given. In the regions where it is most needed, an air bed assists in providing good ventilation to hospitalized patients. The patient's neck and thighs are provided with ventilation [9]. The air bed is designed so that the air is provided from the upper side of the bed through a tube mesh, preventing the patient from developing bedsores [10, 11].

For improved outcomes, a wavy surface is given. Because the compressors utilized here are medical compressors, they don't make a lot of noise, which is a big advantage [12]. Rubber tubes are used, which do not prick the patients. The Air bed's surface is wavy, which helps to alleviate pressure between the surface and the hospitalized patients [13, 14]. Other skin problems induced by excessive sweating can be avoided by providing sufficient ventilation to a patient's bedsore. Patients benefit from enough ventilation due to the air bed's dual compressors. To begin, compressed air is used to inflate the air bed. The rubber tube mesh is then positioned above the air bed [15]. Holes are drilled into the rubber tube mesh at regular intervals. The air bed takes about 15 to 20 minutes to inflate. After the air bed has been inflated, the compressors are detached and linked to the rubber tube mesh. The air bed is operated in this manner. The operating and installation processes are both simple. The primary aim of this research work is to provide a simple and user-friendly solution for hospitalized patients which can keep the skin dry and avoid bedsores.

Bed sores are a global issue and remain a substantial concern for healthcare systems [1]. In the medical field, the most important thing for the prevention of bedsores is by keeping temperature and pressure in control between the surface of hospitalized patients and the bed [2]. One of the major causes of bed sores is hard mattresses used in hospitals [3]. For designing beds for patients these factors are taken into consideration. For better control of pressure, knowing patients' sleep positions and behaviour is essential [4]. Alternating low-pressure air mattresses can help avoid bedsores [5]. The effect of the air distributor and the upstream air supply system on the airflow in an air bed affects the overall air bed [6]. In constructing an effective mattress for the prevention of bed sore, three required specifications are contact pressure, power of compressed air, and bumpiness of the air mattress. The contact pressure should be low, the air pressure should have enough power, and the bumpiness of the air mattress should be low [7]. In an experiment carried out, an Intelli-Sense bed system was able to reduce sweat produced by patients for 2 hours but could not stand for long hours [8]. By repositioning of mechanically ventilated patients every 2 hours, which requires a higher nursing workload and increases the likelihood of an adverse effect, may offer no significant improvement in bed sore prevention [9]. To monitor the sleep of patients, a differential measurement technique was applied [10].

The use of rubber tubes for the flow of air creates a great advantage in reducing pressure [11]. The operation of air ventilated air bed is also dependent on the patient's weight, as it is also a factor affecting to the prevention of bed sore [12]. As prolonged bed rest is one of the reasons for bedsores, the air mattress provides a good alternative to normal beds, as the air bed is designed for prolonged use for hospitalized patients [13]. The standard hospital mattress is less effective for avoiding bed sores, whereas air ventilated air bed is specially designed for such cases [14]. Also, the use of air-ventilated air beds can be done in surgeries, as the noise produced by air beds is low as well as it is flexible which helps in operations [15].

Air mattresses can also be designed to inflate and deflate at certain intervals of time. This helps the patients to change their positions on bed automatically when the patient is not able to change the sleeping position due to critical physical condition [16]. Few researchers also focused on the effectiveness of static air mattress overlays to prevent pressure ulcers and proved that mattress overlays are more effective in preventing pressure ulcers compared with the use of a standard mattress [17]. The study shows that the main areas of starting the skin ulcers are pressure points. The pressure points are close to the bone areas. The mattresses are designed according to the bone positions and pressure points [18]. Support surfaces can be created for the patients to provide relief and reduce the chances of pressure ulcers [19]. Along with the support surfaces, bed-integrated local exhaust ventilation system in combination with air cleaning fabric also found to be a very effective solution [20]. Even after various approaches used in bed or mattress design, individual patient care with holistic treatment approach proved to be very effective. It includes dressings of the ulcers, customised beds, individualised pressure conditions of the beds and critical observations [21].

## OBJECTIVES

The following are the objectives of the present research work:

1. To design and develop of air ventilated air bed for hospitalized patients.
2. To improve the conventional hospital bed system by applying engineering principles and concepts.
3. To ventilate the air around the patient's body.
4. To prevent the patient from bedsores and other skin diseases caused by sweating while resting.

5. To give more comfort to the patient's bed rested for a longer duration.
6. To maintain the good health of patients by providing a clean and healthy environment.

## RESEARCH CHALLENGES

The research work has provided a unique solution for bedridden patients to provide them comfort. At the same time, during the design and implementation phase following challenges were observed.

1. Unwanted airflow was observed through the pipe junctions. The pipe joints were manually made and did have minor air leakage.
2. Laying the air tubes on the air bed to ventilate the air bed was initially challenging, as it caused discomfort to the patients. The laying pattern and tube size kept on changing initially to make it comfortable for the patients.
3. At the first stage it was challenging to maintain the airflow uniform throughout the mattress. The proposed solution has two compressors to keep the airflow separate for the bed and tubes.

## METHODOLOGY

### Identification of Problem

In the medical field, there are various serious diseases like paralysis, brain hemorrhage, or recent disease like Covid -19. Due to these diseases, patients may suffer from coma, i.e., a condition that limits their ability to change positions or continuous laying in bed without movement of the body. When a patient's body continuously comes in contact with the bed, due to pressure and temperature difference body tends to sweat on the back side. If sweated body and bed come in contact regularly, then friction between the outer parts of the skin epidermis ruptures, and the inner layer dermis is open. After some time, it may completely damage the patient's outer skin. In Covid 19 conditions, patients are generally on a ventilator support system to breathe, but some patients are not able to get up from the bed due to the severity of the infection. Hence the body of the patient remains always in contact with the bed. This leads to bed sores. If bed sores happen simultaneously with the other disease, then the body of the patient becomes weak and the percentage of patients surviving decreases. In certain cases, the patient may die.

### Define Parameters

**a. Moisture Control**

Moisture plays a vital role in bedsores. It is very important to control moisture for achieving the goal of reducing bedsores. The main reason behind the bedsore is moisture. It will happen due to the body resting continuously on the bed. Variations in temperature happen according to the state of body condition. This leads to sweat from the body. It may cause cracking of tissue and bedsores to happen.

**b. Air Ventilation**

Generating moisture is controlled by proper air ventilation. When a patient is laying on the bed, the gap between the body and the bed is very negligible and if the air is not properly circulated around the patient's body it causes moisture generation around the patient's body. Proper ventilation is provided artificially by using compressed air from the bottom side of the body.

**c. Air Flow Uniformity**

It is very necessary to flow the air over the human body. This is possible by providing a rubber tube at the back side of the body. But in some cases, this rubber tube gets pressed and blocked if the patient occupies the bed completely. The back pressure is generated on the system so there is a need for such provision where the tube is not getting pressed and air flows uniformly.

### Working

The two compressors used in setup C1 and C2 as shown in Figure 2, have the same pressure range of 70 – 130 mmHg. The first compressor was connected to the bed for inflation or blowing, and the second compressor was connected to a rubber tube circuit for ventilation. When the C1 compressor is switched on, the pressure regulating valve adjusts the pressure as per the requirements of the patient.

The air flows through the compressor to the inlet port of the bed. Two ports are available for the compressor, which works on a cycle having a cycle time of 6 min. In the first 6 min, one layer of the bed inflates, whereas in the next 6 min, the other layer of the bed inflates. To make the system stabilize, 30 to 40 minutes are required. After the complete filling of the air in the bed, the pressure is regulated by the pressure regulating valve. A rubber tube is provided with a small hole on its periphery having a diameter of 2 mm from which the circulation of air takes place. This results in continuous impingement of air in the patient's body.

When the patient is resting on the bed, there is a compression of a rubber tube due to body weight. To avoid this issue, a rubber tube is placed in the gap between two layers, as shown in Figure 1. It will not generate back pressure on the system and air flows uniformly around the body of the patient.

### Model Designing

Figure 1 represents a block diagram utilizing a single compressor for inflating the air bed and for ventilation around the patient's body. The basic components are the air compressor, Tee connectors, pressure control valve, tube mesh, and air bed.

The air compressor is connected to the inlet port of Tee-Connector (T1) which one outlet port connection is given to the air bed and another port connection is given to the inlet port of tube mesh. Tee- Connector (T2) is connecting with the air bed from one outlet port and the other outlet

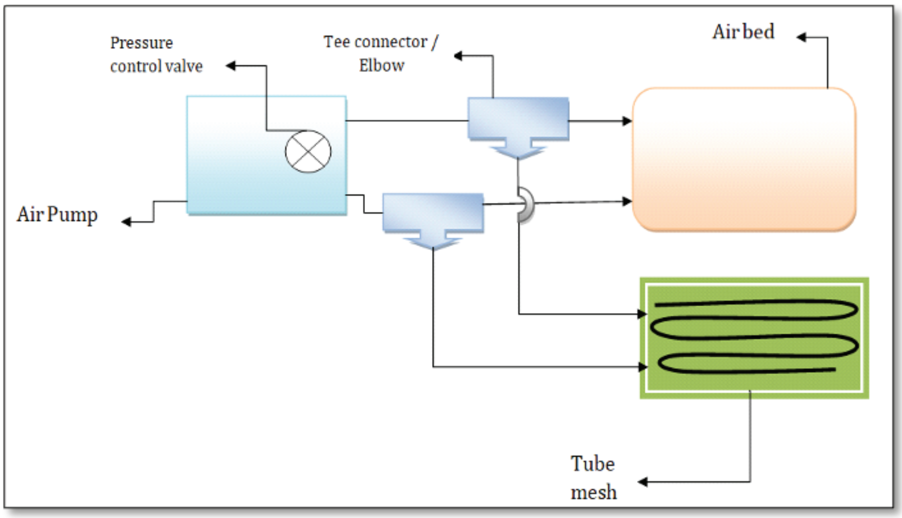


**Figure 1.** Initial design block diagram - single compressor system.

port is connected to the inlet of tube mesh. Tube mesh is made up of rubber material which is placed in the gap between the air bed layers which contains capillary holes over it. This is a basic structure used for trials to find out whether a single compressor is sufficient for inflating air beds and providing ventilation.

Figure 2 represents the block diagram of the complete construction of the air-ventilated air bed system. The basic components that are shown in Figure 2 are air pumps/compressors, pressure control valves, air beds, tube mesh, and connection lines. Here in this block diagram, a separate compressor is utilized for inflation and ventilation purpose. Compressor C1 is connected to the air bed, the pressure is controlled by a pressure control valve 1 for inflating the air bed. Compressor C2 is connected with tube mesh, the pressure is controlled by a pressure control valve 2 for ventilation around the patient's body. The tube mesh is also made from a rubber material to avoid any kind of discomfort to the patient. The tube mesh is arranged on an air bed in such a manner that it perfectly fits in the groves of the air bed. As the compressor operates in a cycle, every portion of the tube mesh and air bed is supplied with a sufficient amount of air.

### Capillary Tube

Figure 3 represents the capillary tube that is used for tube mesh: The capillary tube has an inner diameter of 2 mm and an outer diameter of 4 mm. The material used for the capillary tube is rubber. Holes of diameter 1 mm are

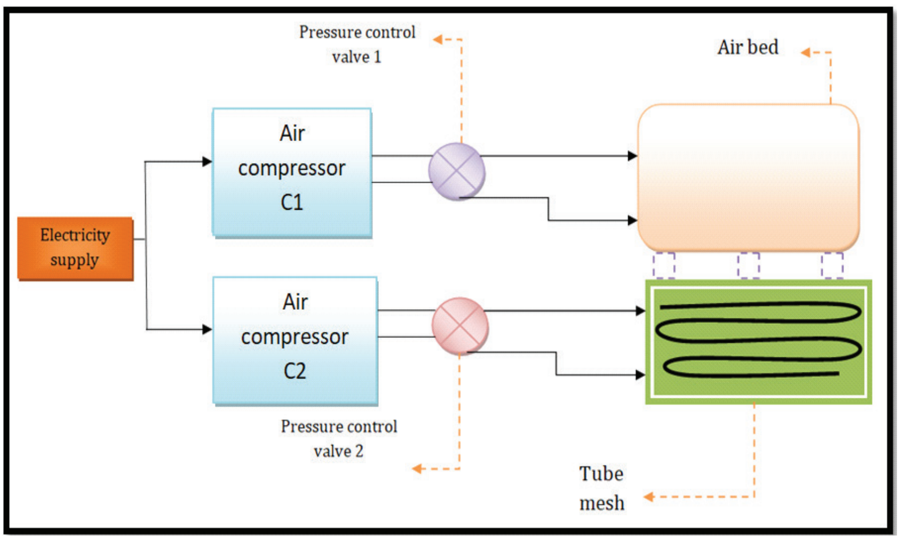


**Figure 2.** Block diagram of system with double compressor-Final design.

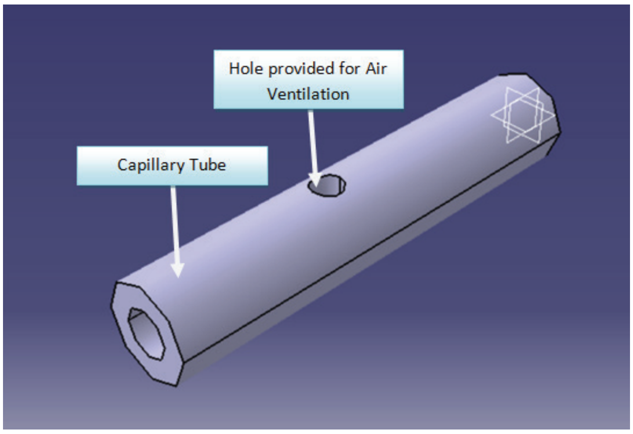


**Figure 3.** Rubber tube provided with holes.

provided on the tube through which air is ventilated around the patient's body. The tube is flexible and avoids any kind of discomfort for the patient.

## Tube Connections

Figure 4 shows the tube connections made to form complete airflow lines as well as tube mesh. The connections consist of three different tubes of different dimensions fitted inside each other to avoid any air leakage. The first tube is a compressor tube, directly connected to a compressor outlet, made from a rubber material, and having an 8 mm outer diameter and an inner diameter is 6 mm. The second tube is a PVC material tube mostly used as a reducer having an outer diameter of 6 mm and an inner diameter of 4 mm. The last tube is a capillary tube made from rubber material which avoids discomfort to the patient.

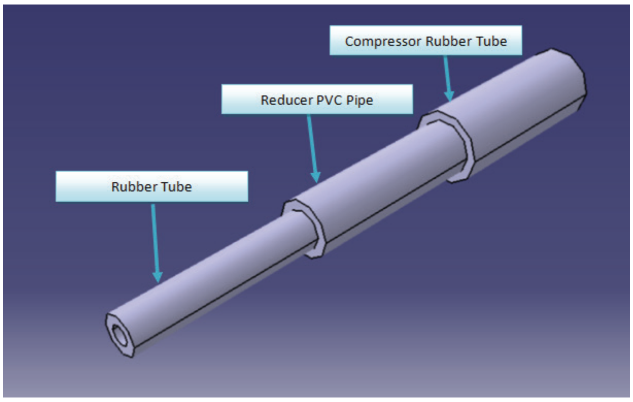


**Figure 4.** Tube connections.

## Selection of Material

**a. Air Compressor**

To maintain silence in the hospital, the compressor should be noise free. Also, air pressure is the main parameter for proper ventilation. The medical compressor should meet all specific requirement characteristics.

**b. Mattress**

The alternative solution to reduce bedsores is anti-decubitus mattresses which are widely used in such situations. This ultimately provides comfort to the patient but is not much efficient. It forms a layer when it is completely filled with air.

**c. Rubber Tube**

The rubber tube should be selected in such a way that the patient should feel comfortable while lying on the bed and it should not compress by the weight of the patient.

## Project design

**Design:**

As shown in Figure 5 the rubber tubes are placed in between the gaps of the air bed curve. When the load is applied to the bed, the rubber tubes are not compressed easily and the airflow is uninterrupted. Hence the back pressure generated on the compressor reduces by using this design.

**Calculations**

**A. In this condition air is circulated for ventilation and bed inflates purpose by using a single compressor.**

Q1 amount of air flowing toward the T connector some of the air passes toward the ventilation system i.e., Q3 and some air passes toward the bed i.e., Q2.

For T connector:

According to principle of fluid mechanics,

$Q1 = Q2 + Q3$

$Q = AV$

ASSUMPTION:

Velocity of air is 5 m/s Neglecting loss in tube due to friction.

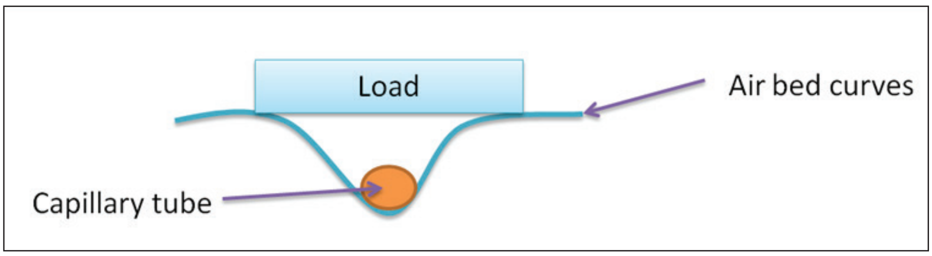


**Figure 5.** Tube Position

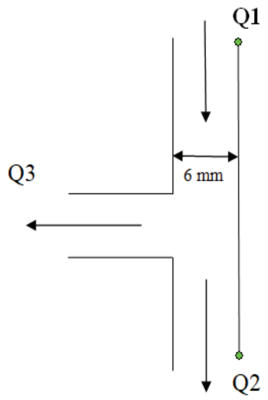


**Figure 6.** Flow rate through T connector.

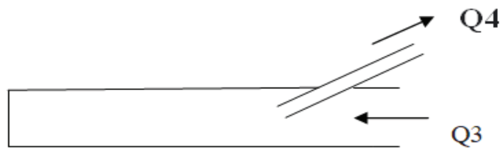


**Figure 7.** Flow rate through valve tube.

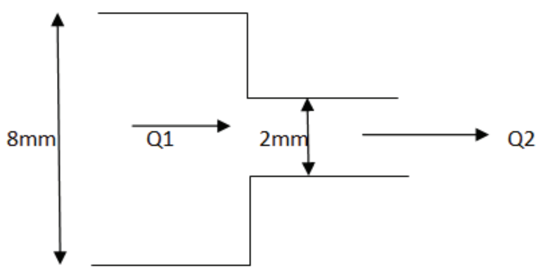


**Figure 8.** Flow rate through separate compressor.

$Q1= \pi (r1)\ 2 * V1$
$Q1 = 1.4137 * 10 - 4\ m^3/s$
But $Q2 = Q3$
$Q2 = Q3 = Q1 * 0.5$
$Q2 = Q3 = 7.068 * 10 - 5\ m3\ /s = 0.0706\ mm^3\ /s$

**B. Air flow rate and velocity of valve tube:**

This arrangement is provided reduce diameter to d3 to d4 for connection of rubber tube.

$Q3 = Q4$
$0.0706 = \pi\ (2)2 * V4$
$V4 = 0.022$ mm/s
$Q4 = \pi\ (2)2 * 0.022$
$Q4 = 0.0691\ mm^3\ /s$
For 10% loss due to eddy
Actual air flow rate = $0.9 * 0.0691 = 0.06319\ mm^3/s$

**C. Air flow rate of separate compressor for ventilation:**

After trial-and-error method concluded that single compressor is not sufficient to deliver required pressure hence two compressors are used.

$Q1 = \pi\ (r1)\ 2 * V1$
$= \pi\ (4*10\ -3\ )\ 2 * 5$
$Q1 = 2.513*10 - 4\ m^3\ /s$
$Q1 = 0.2513\ m^3\ /s$
$Q1 = Q2$
$A1V1 = A2V2$
$0.2513 = \pi\ (1)\ \text{^}2 * V2$
$V2 = 0.0799$ mm/s
Loss due to sudden contraction
$= 2.036*10 - 6$ mm
Actual Velocity = $0.0799 - 2.036*10 - 6$
$= 0.0798$ mm/s
Actual discharge = $A2 * V$ Actual
$= 0.2506\ mm^3\ /s$

## Manufacturing

### Tube meshing

The most important part of manufacturing is manufacturing the tube mesh, as tube mesh is the most important part of the construction of the air bed. The tube mesh consists of rubber tubes with holes at specific intervals for air ventilation. The rubber tubes are inserted in the gaps of the Honeycomb Structure of the air bed.

### Connections

There are some specific connections provided for manufacturing the air bed. The power supply is connected to the two compressors and the compressor tube is connected to the reducer which is connected to the rubber tube.

## Testing

The following procedure is used for testing the setup.

1. First, collect the components required for the testing. Open the mattress and spread the mattress on the floor.
2. Connect the first compressor to the mattress.

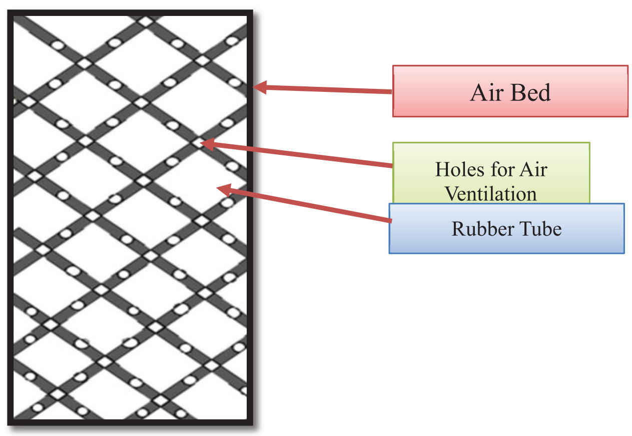


**Figure 9.** Air Bed

**Table 1.** Feedback

| Patients Feedback / Suggestion | Recommendations from Doctors |
|---|---|
| The product improves air circulation around the body while maintaining relief and relaxation. For greater ventilation, the airflow/air pressure should be raised. While changing sides, the tube mesh should not slip. | For optimal results, increase the airflow/air pressure. To avoid fungal infection and other skin problems, apply candid dusting powder. For system maintenance, cleaning, and disinfection, a simple method or way should be found. |

3. Then connect the rubber tube to the second compressor and attach the rubber tube to the surface of the mattress. A diamond shape is formed on the surface of the mattress.
4. Start the first compressor. Inflate the mattress. It takes around 15 to 20 minutes to inflate the mattress.

Start the second compressor. Check every connection for any air leakage. Inspect whether the air is properly flowing through the tubes and the holes.

Lay on the mattress for checking the ventilation, as well as use the water dipping method. Control the speed of the compressor by the push button present on the compressor. Set it according to the requirement.

After testing setup, deflates the mattress.

## PROJECT IMPLEMENTATION / TRIALS

Because the method is based on reverse engineering, various trials are conducted to arrive at final outcomes. Following a trial using a single air compressor for air beds and tube mesh, doctors and patients offered a variety of suggestions once the system was implemented in the hospital.

Taking into account the feedback another compressor is used for mesh without disturbing the original connection of the air bed. Here a temperature-measuring thermometer is used for determining the patient body temperature. The new project setup undergoes two different trials; one consists of an empty trial having only an air bed and another where two air compressors are used. Both trials were performed on alternative days in a morning time slot. The temperature readings were taken by two different ways:

1. By measuring the Body temperatures with Bodywear and
2. By body skin temperature (Core temperature).

For both trials, the patient and his bodywear are kept the same.

### Free Trial

This trial was performed in the morning secession in a time slot of 10:00 AM to 12:00 PM. The readings are recorded every 10 minutes time intervals. For the free trial only a single compressor with air bed is used. In conducting the trial, the air bed system has been on a stability condition of 10 to 15 min. Hence the proper air is inflated in the air bed. Here given the information regarding the free trial.

### Observation Table of Free Trial

The following are the observations from Table 2:

**Table 2.** Free Trial Observation Table

| Sr. No. | Time (am) | Body temperatures with Bodywear ($^0$F) | Core body temperature ($^0$F) |
|---|---|---|---|
| 1 | 10:00 | 95.8 | 97.5 |
| 2 | 10:10 | 95.8 | 97.7 |
| 3 | 10:20 | 95.9 | 97.7 |
| 4 | 10:30 | 96.0 | 97.6 |
| 5 | 10:40 | 95.9 | 97.7 |
| 6 | 10:50 | 96.1 | 97.7 |
| 7 | 11:00 | 96.3 | 97.8 |
| 8 | 11:10 | 96.5 | 97.8 |
| 9 | 11:20 | 96.6 | 97.8 |
| 10 | 11:30 | 96.8 | 97.9 |
| 11 | 11:40 | 96.9 | 97.8 |
| 12 | 11:50 | 97.1 | 98.0 |
| 13 | 12:00 noon | 97.3 | 98.1 |
| Average | | 96.38 | 97.77 |
| Standard Deviation | | 0.480843 | 0.147145 |

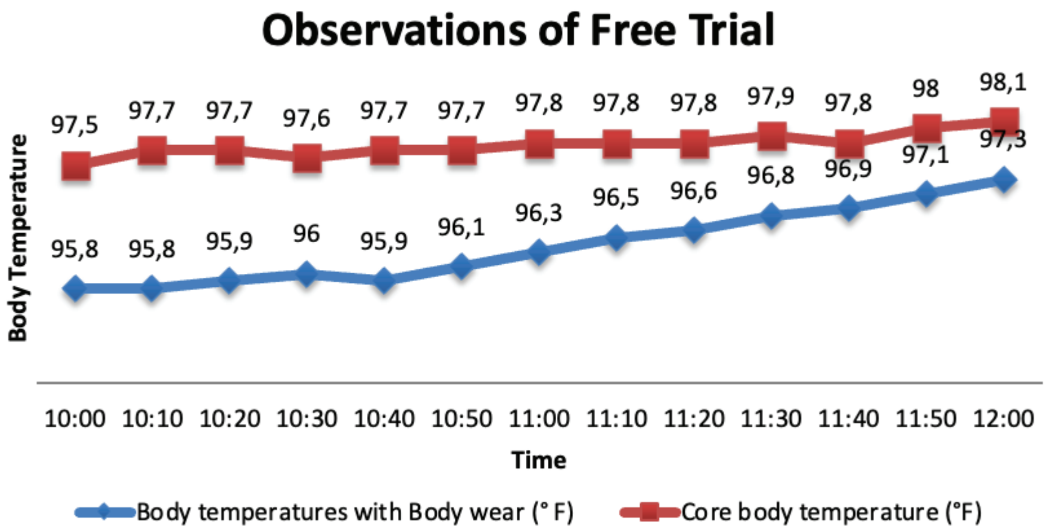


**Figure 10.** Observations of Free Trial.

1. The table shows a total of 13 readings recorded after time intervals of 10 minutes.
2. The second column of the table indicates the time at which respective readings are recorded in $^0$F. The third column shows body temperature with body wear while the last column indicates body surface temperature.
3. The temperature is measured with help of infrared thermometer. The air bed temperature is 97.1$^0$ F at the end of the trial.
4. While the average temperature of the body with clothes (body wear) is 96.38$^0$ F, the average temperature of the body surface (without body wear) is 97.77$^0$ F.
5. The standard deviations of the readings are less than 0.5 and is fairly acceptable.

**Project Trial**

This trial was performed in the morning secession in a time slot of 10:00 am to 12:00 pm. The readings are recorded every 10 min. of the time interval. For the setup trial, two compressors were used. One for the air bed and another for rubber tubes for air ventilation. The same way is used for setup trials. The system is kept for 10 to 15 min on to achieve stability condition. Before performing the trial, the tube mesh is checked for air ventilation at different intervals using the water dipping method. Here a trial setup is shown. The air bed temperature is 96.4$^0$ F at the end of

**Table 3.** Project Trail Observation Table

| Sr. No. | Time (am) | Body temperatures with Body wear ($^0$F) | Core body temperature ($^0$F) |
|---|---|---|---|
| 1 | 10:00 | 96.7 | 97.5 |
| 2 | 10:10 | 96.6 | 97.5 |
| 3 | 10:20 | 96.6 | 97.5 |
| 4 | 10:30 | 96.5 | 97.7 |
| 5 | 10:40 | 96.5 | 97.7 |
| 6 | 10:50 | 96.5 | 97.7 |
| 7 | 11:00 | 96.5 | 97.6 |
| 8 | 11:10 | 96.4 | 97.6 |
| 9 | 11:20 | 96.4 | 97.6 |
| 10 | 11:30 | 96.4 | 97.6 |
| 11 | 11:40 | 96.3 | 97.5 |
| 12 | 11:50 | 96.4 | 97.5 |
| 13 | 12:00 noon | 96.3 | 97.5 |
| Average | | 96.46 | 97.34 |

the trial. Here the given table shows observations recorded while performing the trials. Where 96.46⁰ F is the average temperature of the body with cloth and 96.34⁰ F is the average temperature of the body without cloth.

**Observation Table of Project Trial**

The following are the observations from the table:

1. The table shows a total of 13 readings recorded after time intervals of 10 minutes.
2. The second column of the table indicates the time at which respective readings are recorded in 0 F. The third column shows body temperature with body wear while the last column indicates body surface temperature.
3. The temperature is measured with the help of an infrared thermometer. The air bed temperature is 96.4⁰ F at the end of the trial.
4. While the average temperature of the body with clothes (body wear) is 96.46⁰ F, the average temperature of the body surface (without body wear) is 96.34⁰ F.

**Material Testing**

The same process is followed for validating the air ventilation effect on the system as well environment. Three different types of materials are tested for a time duration of 3 min. Its initial and final temperature is recorded for forming a conclusion and validation of the system's working.

## UNCERTAINTY ANALYSIS

This research work includes the use of a digital infrared non-contact type thermometer. Table 5 shows the specifications of this thermometer and the uncertainty of the same.

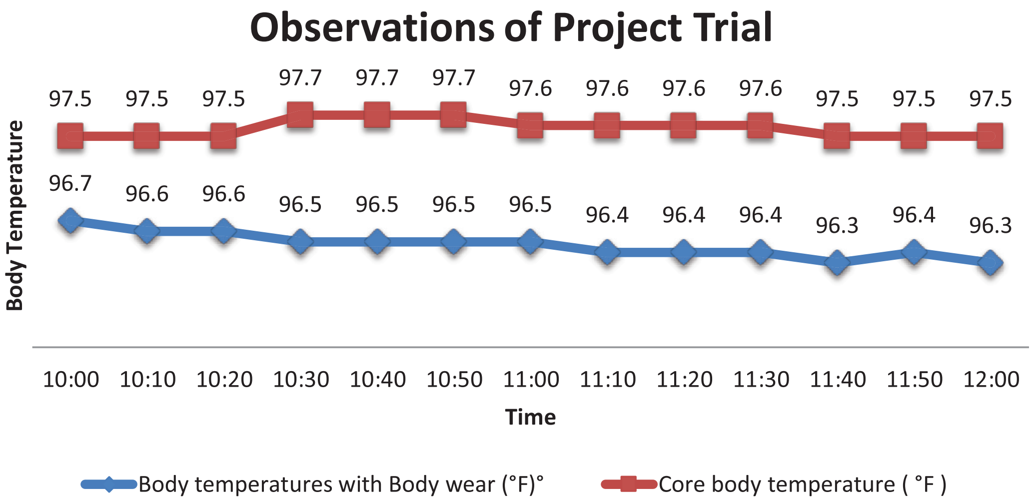


**Figure 11.** Observations of project trial

**Table 4.** Material Testing

| Sr. No. | Material | Time duration (min.) | Initial Temp. (⁰F) | Final Temp. (⁰F) |
|---|---|---|---|---|
| 1 | Wood | 3 | 84.4 | 83.8 |
| 2 | Steel | 3 | 84.9 | 83.9 |
| 3 | Ceramic | 3 | 84.9 | 84.2 |

**Table 5.** Thermometer specifications and uncertainty

| Temperature Instrument | Specifications | Range | Precision | Uncertainty |
|---|---|---|---|---|
| Infrared digital thermometer | Unit size: 155 x 100 x 40 mm (L x W x H)<br>Weight: 151g (including the batteries)<br>Temperature display resolution: 0.1°C and 0.1°F<br>Non contact type | Measuring range: - In body mode: 32°C ~ 43°C (89.6°F ~ 109.4°F) | 32.0°C ~ 34.9°C (89.6°F ~ 94.8°F) : ±0.3°C (±0.6°F)<br>35.0°C ~ 42.0°C (95°F ~ 107.6°F) : ±0.2°C (±0.4°F)<br>42.1°C ~ 43°C (107.8°F ~ 109.4°F) : ±0.3°C (±0.6°F) | ±0.3°C (±0.6°F) |

**Table 6.** Need of Two Compressors

| Sr. No. | Parameter | Use of one compressor | Use of two compressor |
|---|---|---|---|
| 1 | Connection | MORE | LESS |
| 2 | Loss Due to Leakage | MORE | LESS |
| 3 | Air Flow Rate at Outlet | 0.00691 mm^3/s | 0.2506 mm^3/s |
| 4 | Velocity At Outlet | 0.022 mm/s | 0.0798 mm/s |
| 5 | Ventilation | IMPROPER | PROPER |
| 6 | Pressure Drop | MORE | LESS |

## RESULTS AND DISCUSSION

### Need of Two Compressors

For proper ventilation, a single compressor is insufficient. By including two compressors, users get the benefit of both an air mattress and ventilation. The results are improved with compressor staging. The loss due to leakage was minimized, as well as the connection. By lowering the pressure drop, the airflow rate is boosted. The compressor staging is mainly derived from the following parameters i.e., connections in mesh, mostly including joints and bends another parameter is lost due to leakage, air flow rate improvement, controlling air velocity at the outlet, and comparing ventilation with single and double compressor.

### Analysis

As shown in Figure 12, comparative analysis shows that:

1. The time periods during which readings are obtained are shown on the X-axis. Temperature intervals in degrees Fahrenheit are shown on the Y-axis.
2. The airbed measurements are shown by the red chart line, which has a temperature range of 97.5$^0$ F minimum to 98.1$^0$ F maximum. The temperature is rising with a step after a set time interval, as shown by the chart line. After a 30-minute time delay, a step shape may be seen.
3. The blue chart line depicts the project's actual execution, with a minimum temperature range of 97.5$^0$ F and a maximum temperature range of 97.7$^0$ F. If look at the chart line, will notice that the temperature rises at first, and then settles into a steady state. After the process begins, the chart displays a spike or rise at a specific time interval, followed by a return to normal temperature.
4. The project trial yields better outcomes than the free trial; the system is effective in maintaining the patient's body temperature.

### Findings

Proper ventilation can help with bedsore therapy. Ventilation aids in the regulation of body temperature. Proper ventilation not only reduces the risk of bedsores but also improves the health of the patient. With certain changes, an air mattress may be used to treat bedsores efficiently. A refrigeration system can be added to the recommended solution to deliver cool air. Engineering ideas and understanding can help with medical difficulties and equipment development. The comfort condition of the patient is improved due to the circulation of air. It also assists in

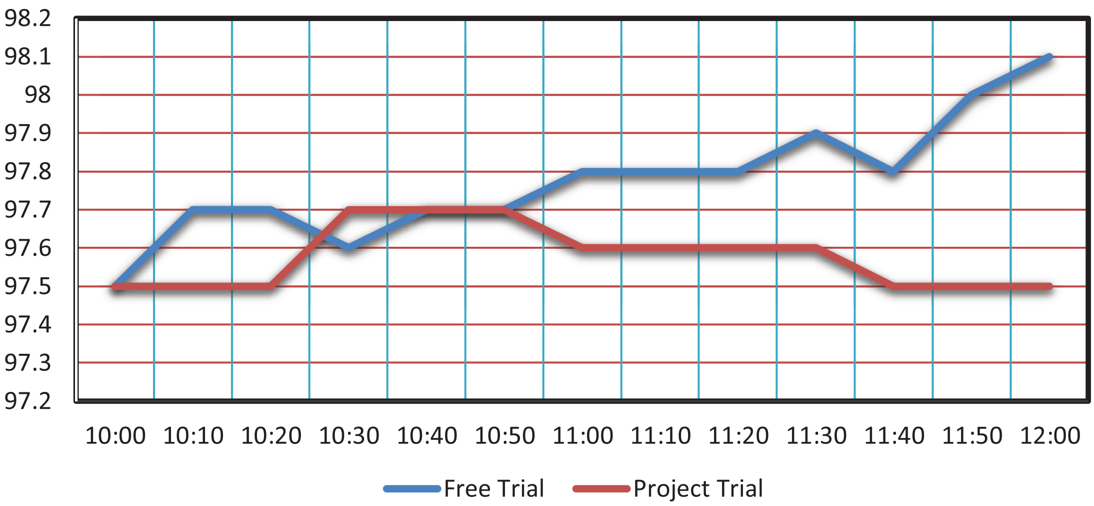


**Figure 12.** Analysis Chart of project.

evaporation of the sweat from the body and reduces the frequency of changing the clothes from the air mattress.

Thermodynamic aspects of this air bed can be observed from the perspective of evaporative cooling. The air passing over the body evaporates the sweat from the body which mainly has water contents. This evaporative cooling keeps the skin dry for a longer time and avoids bedsores.

**Costing**

The proposed solution is very simple and it can be add-on to the existing air bed. The cost estimation is done for a complete solution of a standard air bed and additional compressor with air tubes. The total cost is ₹6345.

| Sr. No. | Item | Cost in ₹ |
|---|---|---|
| 1 | Standard Air Bed | 2750 |
| 2 | Additional compressor | 2750 |
| 3 | Air tubes | 375 |
| 4 | Connectors | 420 |
| 5 | Air joint | 50 |
| | Total | 6345 |

## CONCLUSIONS

Based on the result, it is concluded that this innovation can be utilized to reduce the problem where patients are suffering from bedsores. One of the most important aspects of bedsore prevention is the control of temperature and moisture contained in the backside of the patient's skin. Providing air ventilation to the bed surface not only aids in the prevention of bed sores but also provides comfort to the patient.

1. Experiments were performed to study the effectiveness of the developed system. The solution developed served the purpose of providing the cooling effect to reducer the sweat of the patient.
2. The accuracy of the system is increased by using two separate compressors for inflation and ventilation. Ventilated air operates at a controlled pressure. As a result, venting air around the patient's body provides additional benefits for recovering from medical issues.
3. The study of implementation offers superior outcomes than previous strategies. The system is successfully maintaining the patient's body temperature at a steady level.
4. The maximum variation of body temperature is observed to be very stable and within 0.20F. The proposed solution makes the patient stable and avoids a rise in the body temperature of the patient.
5. The existing air bed can be modified simply by laying the air tubes over the standard bed and addition of one compressor. This makes the solution simple and user-friendly.
6. The proposed solution is cost-effective at only ₹6345. The cost of treatment of one day is more than the cost of this solution.
7. The air tubes are replaceable and can be fitted in any of the existing air mattresses irrespective of the brand and make of the mattress.

## FUTURE SCOPE

This system can be provided for multiple numbers of beds in hospital wards, by replacing the air compressor with a hermetically sealed compressor. It will improve the efficiency of the system. The condenser can be used for cooling of the air before entering the tube for better efficiency of the system. A new chemical composite can be developed in the form of powder which is more efficient in absorbing moisture. This powder can be spread on the mattress.

The number of tubes on the bed can be increased for patients with high weight (more than 70 Kg) to provide better comfort. A higher capacity compressor (0.5 to 1 bar pressure) may be used in single for the bed. This may reduce the size required for two compressors.

## NOMENCLATURE

| | |
|---|---|
| A | Cross-sectional area of the tube |
| Q1 | Air flow rate toward T connector |
| Q2 | Air flow rate toward air bed |
| Q3 | Air flow rate toward ventilation |
| Q4 | Bypass air flow rate |
| r | Radius of the tube |
| V | Air velocity |

## AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

## DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

## CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## ETHICS

There are no ethical issues with the publication of this manuscript.

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