

Optimization and Experimental Validation of Air Ventilation Nozzle using MATLAB

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Abstract - In the natural ventilation of building wind energy is used to drive air into building through small opening. In low velocity regime, continuity equation governs the nozzle processes. Optimization of nozzle shape is must as a requirement of large driving force as well as minimum energy losses due to stagnation and minimum air leakage from main air stream. In the present study, we are dealing with rectangular hyperbolic nozzles. Beta (β) is an angle between two asymptotes of rectangular hyperbola. This angle has a major influence on nozzle geometry. For analysis purposes β is limited in the range of 0° to 180° and Nozzle Inlet conditions of air are taken from standards as pressure 1 bar, temperature 308 K, wind velocity 3 m/s, density 1.123 kg/cubic meter in summer season for Ahmednagar city. In this case, Optimization of nozzle shapes is carried out for maximum driving force at the outlet of nozzle and minimum energy lost and minimum air leakage. Analytical results from MATLAB software for velocity, area, pressure, temperature, density distribution along the horizontal axis of the nozzle show that energy head loss and boosting of air is maximum at $\beta=0^\circ$, both continuously reducing up to $\beta=180^\circ$. Nozzle shapes when $\beta < 90^\circ$ having practical limit because of the leakage of airstream. But air leakages are maximum at $\beta=0$, then after it reduces up to $\beta=90^\circ$, then after no air leakages, Therefore unit rectangular hyperbolic nozzles (i.e. $\beta=90^\circ$) are optimum nozzle shape.

Key Words: Asymptotes¹, DBT², Natural Ventilation³, Nozzle⁴, WBT⁵

1. INTRODUCTION

An average person today spends about 90% of his time indoors. Therefore, it is important to maintain focus on a good and healthy indoor environment, but this does not exclude saving energy. To be more independent of the oil as an energy source and also to reduce the damaging outlets to the environment, an increasing use of sustainable technologies Such as solar energy, better use of daylight and use of natural ventilation is more and more often discussed when new buildings are designed. Due to complexity of building structure, rooms are not ventilated directly through windows opening. There is increasing awareness for the high energy usage in the buildings. Many buildings use mechanical air conditioning to regulate the internal environment, but even with energy efficient designs, they typically use around 230 KWh/m² of energy. However, in a number of buildings, alternative low energy systems use natural

ventilation to significantly reduce the energy consumption. Research has developed a good understanding of the basic principles of natural ventilation within simple building structures. One of the key challenges now is concerned with understanding the subtleties of such flows within more complexes multiple storey buildings. Building ventilation by natural ventilation in which openings such as windows, ventilating shafts or ventilators are used to allow outside air to enter and inside air to leave the building. Pressure difference between outside air and inside air is a driving mechanism for the air to enter and leave the building. [1] Natural ventilation is the intentional flow of outdoor air through an enclosure under the influence of wind and thermal pressures through controllable openings. It can effectively control both temperatures and contaminants, particularly in mild climate. Temperature control by natural ventilation is often the only means of providing cooling when mechanical air-conditioning is not available. The arrangement, location and control of ventilation openings should combine the driving forces of wind and temperature to achieve desired ventilation rate and good distribution of fresh air through the building. Natural ventilation occurs according to the differences of pressure across the openings. This pressure difference is caused by ambient pressure and temperature differences between different openings of a buildings. The current drive for sustainable design has led to the need to focus on natural ventilation as a factor towards the reduction of greenhouse emissions.

1.1. Ventilation

Ventilation moves outside air from surrounding into a building, and distributes the air within the building equally. The general purpose of ventilation in buildings is to provide healthy air for breathing by both diluting the pollutants originating in the building and removing the pollutants from it.

Building ventilation has three basic elements:

- (i) Ventilation rate — the amount of outdoor air that is provided into the space, and the quality of the outdoor air.
- (ii) Airflow direction — the overall airflow direction in a building, which should be from clean zones to dirty zones; and (iii) Air distribution or Airflow pattern — the external air should be delivered to each part of the space in an efficient manner and the airborne pollutants

generated in each part of the space should also be removed in an efficient manner.

1.2. Types of Ventilation

- i) Natural ventilation
- ii) Mechanical ventilation
- iii) Hybrid (mixed-mode) ventilation

2. LITERATURE REVIEW

Zahra Giabaklou et. al. had details of their work as follows, Evaporative cooling used extensively for cooling in climates with medium to low humidity. The system makes use of the evaporative effect from water falling vertically along guides to produce a reduction in the temperature of the air entering the building. [1]

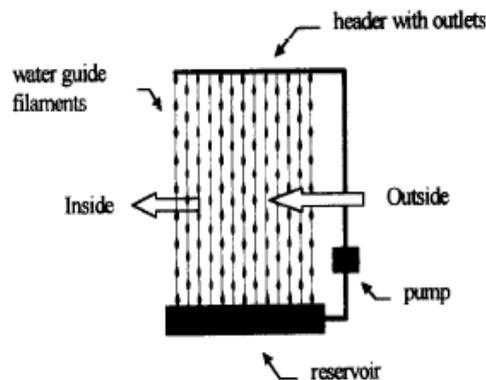


Fig-1: Natural ventilation with evaporative cooling

R. Lakshminarayanan, et.al. had details of their work as follows, the Euler-Lagrange equation was used to minimize shear stress in designing flow-metering nozzle. The test results indicated a marked increase in the value of the discharge coefficient when it is compared with that for the ASME standard nozzle. [2]

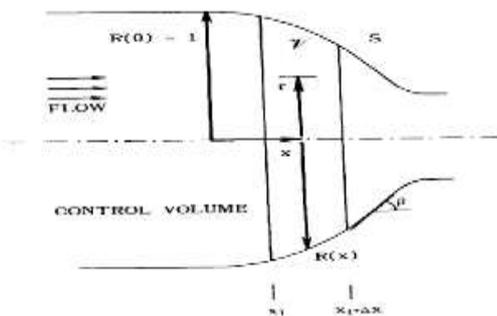


Fig-2: Schematic of nozzle and coordinate system

J.-S. Liu et.al. had done work on as follows, In this study, optimal shapes of intersecting pressure vessels are sought using a novel topology/shape optimization method, called Metamorphic Development (MD).[3]

G. Evola, et.al. had done work as follows, the design of natural ventilation in buildings is often performed by means of computational fluid dynamics (CFD) techniques, whose application is gaining popularity. According to these results, the RNG model can be considered a useful tool for the study of wind driven

natural ventilation, especially for the assessment of the ventilation rate and of the air distribution inside a room. [4] John Kaiser Calautit et. al. performed CFD Simulation of indoor air flow distribution ventilation rates, external air flow & surface pressures were generally good agreement with wind tunnel measurement.[5] Arsen K. Melikov et. al. had used chamber Size=5m*6m*2.5m, Temp, RH, Velocity were determined. Ventilation effectiveness increases with flow rate. Lowest temperature is achieved by VDG. [6] Haoru Li et. al. had used student dormitory. They have used Instruments; Co2 & Temp monitor. Indoor & outdoor temp recorder. It concluded that Mechanical ventilation should be used. Window size should increase [7]. Ivan Oropeza- Perez, Poul Alberg Ostergaard had used two room with Built area less than 45 meter square. Built area greater than 100 meter square. It concluded that natural ventilation under warm condition is affected by climate condition, window opening, material of construction, built area, no of occupants. [8] G. Anshul Singhal et. al. had optimized vent type of restrictor using CATIA V5 as modeling software and SOLID WORKS as an analysis software , they have selected boundary conditions at inlet face, total pressure=1 bar, mass flow rate=0.0703Kg/s, mass flow rate=0.0703Kg/s. The manufactured restrictor serves purpose of complying with rules of minimum compromise on power. [9] Mark R. Sippola et. al. had used two type of duct material galvanized steel and galvanized steel with internal glass insulation. It has been found that in steel duct deposition rate were much greater to floor than walls, ceilings for particles size & air speeds. Deposition in insulated ducts was nearly uniform to floor, wall & ceiling surfaces. Indicating surface roughness is dominant factor for deposition of insulated ducts. [10]

K.M. Pandey et.al. had carried out numerical study to understand the gas flow in a conical nozzle at different degree of angle. It has been found that the degree of angle for conical nozzle can be large as 12 to 18 degree maximum. So for maximum thrust we can go with 12/16 degree conical nozzle. [11] G. Hannu Koskela had done work on CFD-simulation of nozzle duct air diffuser. The geometry of a diffuser is usually complex and, therefore, it is not possible to use an exact geometrical model in practical CFD-simulations. In this study, a simplified model was developed for the nozzle duct diffuser. The model has been applied to several field studies and it has been found applicable to practical room airflow simulations [12] Haidong Wang et. al. conducted an experimental study in the engineering centre of university room of size 18m*28m. It is found that properly configured secondary airflow relay system can help improve air diffusion performance & distribution uniformity, & decrease the % dissatisfied [13].

Joanne M. Holford, Gary R. Hunt had found building geometry with opening in the floor & ceiling of storey & atrium. Experiment was performed using small scale transparent model. The salt bath technique is used. The theoretical results have been verified by salt bath experiments which shows good agreement. [14].

Torwong Chenvidyakarn et. al. used small scale laboratory model of material acrylic of dimension 15cm*15cm*15cm. Water is used as working fluid. The stability of flow regime depends not only on relative strength of heat load but also on relative height of vents. [15] S. Luo et. al. had done experimentation on given test room & then modeling & numerical simulation, then validation of experimental data with simulation data. The model is able to predict the global flow pattern in the isothermal test room with reasonable accuracy. [16]

2.1 Research Gap

Although many previous researches were made towards the understanding of natural air ventilation of nozzle, nearly no experimental data are available for the nozzle having rectangular hyperbolic shape. For this reason, the first objective of this study is to provide experimental data for rectangular hyperbolic nozzle and helpful to obtain results for the best and optimum nozzle shape for maximum air boost and minimum air bypass losses for hyperbolic nozzles.

2.2 Scope of Research

In this experiment for the construction of ventilation nozzle Galvanised iron sheet metal will be used, the inlet velocity of air will be 3m/s, ventilation of room size 25 Ft (L) × 12 Ft (B) × 12 Ft (H), we are going through following steps. Required metrological data is collected for summer season as, DBT = 41°C = 105.8 F, WBT = 22°C = 71.6F.

2.3 Objectives of Research

The objectives of this work are:

1. To construct an experimental model of nozzle.
2. To find the best and optimum nozzle shape for maximum air boost and minimum air bypass losses for hyperbolic nozzles.

3. WORKING PRINCIPLE

To maintain equal ventilation over entire building following concept is proposed as shown in fig 3.

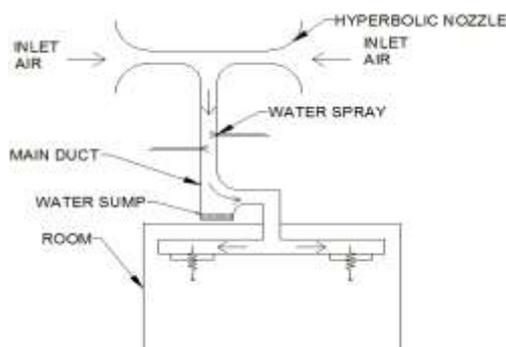


Fig-3: Natural ventilation with annulus nozzle and evaporative cooling method

As shown in fig 3 winds, which has high velocity enter in the chamber through annulus opening, provided at terrace of the building. Because of the annulus opening maximum wind can be access even though wind direction changes. This wind speed is boosted into Nozzle shape annulus duct and this boosting of wind helps to drive wind itself through duct. This wind is filtered through filtration process and cooled by evaporative cooling method.

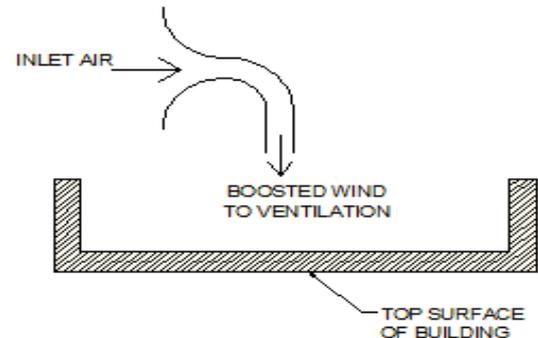


Fig-4: Model of nozzle ventilation system

Fig. 4 shows model of nozzle ventilation system. In the model, one directional hyperbolic nozzle is used in place of annulus nozzle. This nozzle can be turn as wind direction changes through rotational mechanism provided to the system. Rest of all things is similar to above explanation. Model will be designed for small residential room.

Significance of Hyperbolic profile for nozzle

- i) In mathematics hyperbola is a smooth curve that lies in a plane of hyperbola.
- ii) Hyperbolic curves meet to co-ordinate axes at infinity.
- iii) Abrupt area reduction is possible with the help of hyperbolic curve rather than other curve such as parabola, circular, elliptical.
- iv) Hyperbolic profile requires minimum material cost.

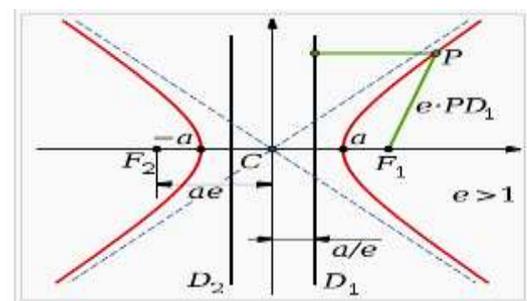


Fig-5: General hyperbolic curve

The asymptotes of the hyperbola (red curves) are shown as blue dashed lines and intersect at the center of the hyperbola, C. The two focal points are labeled F1 and F2, and the thin black line joining them is the transverse axis. The perpendicular thin black line through the center is the conjugate axis. The two thick black lines parallel to the conjugate axis (thus, perpendicular to the transverse axis) are the two

directrices, D1 and D2. The eccentricity e equals the ratio of the distances from a point P on the hyperbola to one focus and its corresponding directrix line (shown in green). The two vertices are located on the transverse axis at $\pm a$ relative to the center. Similar to a parabola, a hyperbola is an open curve, meaning that it continues indefinitely to infinity, rather than closing on itself as an ellipse does. A hyperbola consists of two disconnected curves called its arms or branches. The closest distance of the two branches connecting their vertices is called the transverse axis or major axis corresponding to the major diameter of an ellipse. The midpoint of the transverse axis is known as the hyperbola's center. The distance 'a' from the center to each vertex is sometimes called the semi-major axis.

3.1 Analytical Technique for Optimum Hyperbolic Angle of Nozzle Profile

Using analytical as well as numerical technique optimizes hyperbolic nozzle shape. Wind Data and Weather report for Ahmednagar region is collecting from Indian Metrological Department, Pune. [20] Following data is taken for inlet condition of air, where P_1 is inlet pressure condition for nozzle, V_1 is velocity at inlet of nozzle, T_1 is inlet temperature at nozzle, ρ_1 is density at inlet of nozzle & γ is constant for adiabatic process.

$P_1=1$ bar, $V_1=3$ m/s, $T_1=308$ K, $\rho_1=1.223$ kg/m³, $\gamma=1.4$. Nozzle surface must be perfectly insulated for adiabatic processes. For optimization of nozzle profile angle β is limited to, where β is is angle between two asymptotes.

$$0 < \beta < 180$$

By using mathematical models which designed in following section for different distribution such as area, velocity, pressure, temperature, density are estimated for particular angle β along the nozzle length.

3.2 Mathematical Modeling for Optimizing Hyperbolic Nozzle Shape

For the analysis of nozzle profiles for natural ventilation, it is important to know about nozzle flow processes. Generally, nozzle flow processes are adiabatic expansion processes (i.e. no heat transfer to surrounding). Governing equation for adiabatic expansion process is [18],

$$Pv^\gamma = \text{constant} \quad (1)$$

Where P is pressure in N/m² at any section in the nozzle, v is the specific volume in m³/kg at any section in the nozzle and γ is adiabatic expansion constant.

For flow analysis, continuity and navier-stroke equation are used. In our case is optimization of nozzle shape for air velocity boosting which give us maximum driving force. In low velocity region air is behave as like an incompressible fluid. In analytical solution of nozzle

processes navier-strokes equations has less importance, only continuity equation is used for our case [18].

$$\rho \times A \times V = \text{constant} \quad (2)$$

Generally, in low velocity flow regime property changes during thermodynamic processes are negligible. Density of air remain constant throughout adiabatic expansion in nozzle, therefore air is treated as incompressible fluid in low velocity regime. Continuity equation can be written as [17],

$$A \times V = \text{constant} \quad (3)$$

Only cross sectional area factor, which can affect on air velocity. Sharp area drop of the nozzle it give higher air velocity boosting. Hyperbolic nozzles are smooth curve, which used natural ventilation system. Now different hyperbolic nozzles are analyzed by using following technique,

Governing equation for hyperbola in rectangular co-ordinate system is as follows [18],

$$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1 \quad (4)$$

Moreover, polar coordinate equation for hyperbola is [19],

$$(5)$$

Where $r^2 = \frac{a^2 b^2}{b^2 \cos^2 \theta - a^2 \sin^2 \theta}$ $2a$ is the major axis length and $2b$ is the minor axis length of hyperbola.

Value of a and b can be estimated by knowing value of area at angle θ is 0° by using following formula [19],

$$a = \frac{1}{\sin(\theta_x - \beta_4)} \sqrt{\frac{A_x}{4}} \quad (6)$$

$$b = a \tan \frac{\beta}{2} \quad (7)$$

Then after for particular interval of angle θ each value of r is calculated by using polar co-ordinate equation. Value of m (distance along nozzle axis) and n (distance normal to nozzle axis) can be found by following equation for each value of r [19].

$$m = r \cos(\theta - \beta_4) \quad (8)$$

$$n = r \sin(\theta - \beta_4) \quad (9)$$

Now area of the nozzle at each interval can be calculated by using following equation as well as velocity is estimated by using continuity equation [18].

$$A = 4n^2 \quad (10)$$

$$v = \frac{m}{\rho_1 \times A} \quad (11)$$

By assuming sonic speed in air is constant and it is 340 m/s. Mach number is calculated for each interval of the angle θ as follows [18],

$$M_a = \frac{v}{340} \quad (12)$$

By using Mach number temperature, pressure and density distribution can be estimated by using the following equation [18],

$$\frac{T_0}{T} = [1 + \frac{\gamma-1}{2} M_a^2] \quad (13)$$

$$\frac{T_0}{T} = [1 + \frac{\gamma-1}{2} M_a^2] \quad (14)$$

$$\frac{\rho_0}{\rho} = (\frac{T_0}{T})^{\frac{\gamma}{\gamma-1}} \quad (15)$$

Slope of the nozzle profile at particular point and velocity head energy loss can be found by following formulae [18],

$$\text{Slope} = \frac{n_2 - n_1}{m_2 - m_1} \quad (16)$$

Where, $(n_2 - n_1)$ is perpendicular distance between inlet and outlet point of nozzle and $(m_2 - m_1)$ is axial distance between inlet and outlet point of the nozzle [19]

$$\text{Zeta} = \tan^{-1}(\text{Slope}) \quad (17)$$

$$V_{\text{normal}} = v_1(\sin(\text{zeta})) \quad (18)$$

$$V_{\text{along}} = v_1(\cos(\text{zeta})) \quad (19)$$

$$\text{Unit velocity head lost} = \frac{V_{\text{normal}}^2}{2} \quad (20)$$

3.3 Analytical Solution Technique

For the analytical solution of hyperbolic nozzles, simple continuity equation is used. In analytical solution, calculation became complicated and lengthy because of the number of parameters in flow field equation. Therefore, by mathematical solver like MATLAB we can get accurate results with minimum complication and time. A program is written in MATLAB to get analytical solution for hyperbolic nozzles. Following steps are involved in writing MATLAB program,

- (i) Mathematical In first step, all inputs are given to program.
- (ii) Modeling of hyperbolic curve is used to find out cross sectional area at each section along the nozzle length.
- (iii) Simple continuity equation for incompressible air is used to find out air velocity corresponding to cross sectional area at each section along the nozzle length. Mach number at each section along nozzle length is finding out from the relation in between velocity of air and sonic speed of air.
- (iv) Temperature profile along the nozzle length is calculated from relation in between Mach number, stagnation temperature and temperature at any point.
- (v) Similarly, pressure and density profiles are calculated from nozzle equations.

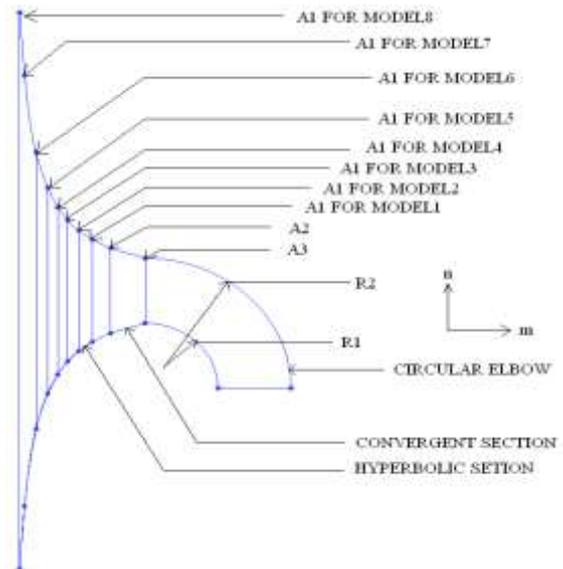


Fig-6: Model developments for optimum solution

With the help of Analytical method we are in the position to decide only optimum hyperbolic angle of nozzle profile. Analytically it is found that rectangular hyperbola is optimum hyperbolic shape. For further optimization of inlet to outlet area ratio of hyperbolic nozzle numerical analysis is required.

3.4 Optimum Hyperbolic Angle

1. For maximum mass flow rate and minimum energy loss hyperbolic angle is optimized by analytical method.
2. For analytical method we are using basic governing equations as continuity equations, mathematical hyperbolic equations for writing MATLAB program.
3. In MATLAB program each property such as velocity, pressure, temperature, density, and mass flow rate is calculated by giving mathematical background into program.
4. Results of these properties can be calculated for different hyperbolic angle such as $\beta = 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160$ and 170 .
5. By investigating these results we are approaching to final solution.

Table-1: Velocity Boost as a Function of β

Sr. No.	β (in $^\circ$)	V (m/s) at $\theta=360^\circ$	V (m/s) at $\theta=365^\circ$	Velocity boost in percent
1	20	4.4524	13.2218	296.95 %
2	30	4.4524	8.7694	196.95 %
3	40	4.4524	7.2701	163.28 %
4	50	4.4524	6.5089	146.18 %
5	60	4.4524	6.0427	135.71 %
6	70	4.4524	5.7238	128.55 %

7	80	4.4524	5.4889	123.27 %
8	90	4.4524	5.3061	119.17 %
9	100	4.4524	5.1579	115.84 %
10	110	4.4524	5.0335	113.05 %
11	120	4.4524	4.9261	110.63 %
12	130	4.4524	4.8311	108.50 %
13	140	4.4524	4.7462	106.59 %
14	150	4.4524	4.6661	104.79 %
15	160	4.4524	4.5919	103.13 %
16	170	4.4524	4.5210	101.54 %

Table-2: Air Bypass & Energy Head Loss as Function of β

Sr. No.	β (in ^o)	Slope of nozzle	Kinetic energy loss for unit mass flow rate (J/kg)	Air by passed while entered into nozzle
1	20	5.6713	4.3643	Maximum
2	30	3.7321	4.1986	Decreases from maximum to minimum
3	40	2.7475	3.9736	
4	50	2.1445	3.6963	
5	60	1.7321	3.3750	
6	70	1.4281	3.0195	
7	80	1.1918	2.6407	Minimum
8	90	1	2.25	No bypass air
9	100	0.8391	1.8593	No bypass air
10	110	0.7002	1.4805	No bypass air
11	120	0.5774	1.1250	No bypass air
12	130	0.4663	0.8037	No bypass air
13	140	0.3640	0.5264	No bypass air
14	150	0.2679	0.3014	No bypass air
15	160	0.1763	0.1357	No bypass air
16	170	0.0875	0.0342	No bypass air

3.5 Dimensions for Experimentation

For design of hyperbolic nozzle for ventilation of room size 25 Ft (L) × 12 Ft (B) × 12 Ft (H), we are going through following steps.

1. Required metrological data is collected for summer season as,

$$DBT = 41^{\circ}C = 105.8 F$$

$$WBT = 22^{\circ}C = 71.6 F$$

2. Air change rate requirement and CFM (cubic feet per minute) requirement for the given room can be calculated from the following equation as per the ASHRAE fundamental evaporative cooling chapter-2001.

$$Air\ Change\ Rate = \frac{(DBT\ in\ F - WBT\ in\ F)}{10} = \frac{(105.8 - 71.6)}{10} = 3.42$$

$$CFM = \frac{(Volume\ of\ room\ in\ cubic\ ft)}{(Air\ change\ rate\ per\ hour)} = 1052.63$$

3. Mass flow rate can be converted into m³/sec from CFM by using following equation,
 Mass Flow Rate Requirement

$$= 1052.63 \times 0.0283168 = 29.80715\ CMM = 0.49678\ m^3/sec.$$

(CMM= cubic meter per minute)

1. 20% extra mass flow rate is considered for hyperbolic nozzle design, therefore actual design mass flow rate can be estimated as follows,

$$Actual\ design\ mass\ flow\ rate\ requirement = 0.49678 \times 1.2 = 0.596136\ m^3/sec.$$

2. Using simple continuity equation dimensions of inlet, intermediate and outlet can estimate cross sections by using following equations. For the calculation point of view velocity inlet (V1) is taken as 1.5 m/s and area ratios (A1/A2), (A1/A3) are given in the above table for optimum model.

$$A1 \times V1 = A2 \times V2 = A3 \times V3 = constant$$

$$A1 = \frac{0.596136}{1.5} = 0.397424\ m^2 \quad A2 = \frac{A1}{5.85} = 0.0679357\ m^2$$

$$A3 = \frac{A1}{10} = 0.0397424\ m^2$$

3. For simplicity square ducts are designed therefore dimensions for models can be calculated from following ways,

$$Side\ length\ at\ section\ 1 = D1 = 0.630\ m = 635\ mm$$

$$Side\ length\ at\ section\ 2 = D2 = 0.260\ m = 260\ mm$$

$$Side\ length\ at\ section\ 3 = D3 = 0.199\ m = 200\ mm$$

4. Inner radius and outer radius for circular elbow duct is taken as 200 mm and 400 mm.

5. Length of straight duct is taken as 955 mm, which is suitable for stable design of hyperbolic nozzle.

6. Details about optimum designed dimensions of hyperbolic nozzle for given room condition are given in the following fig. 7.

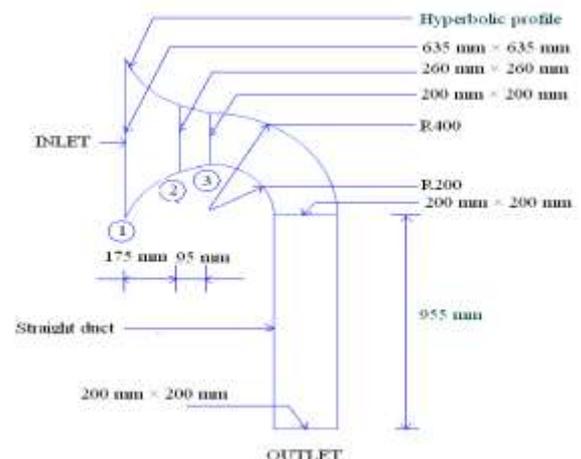


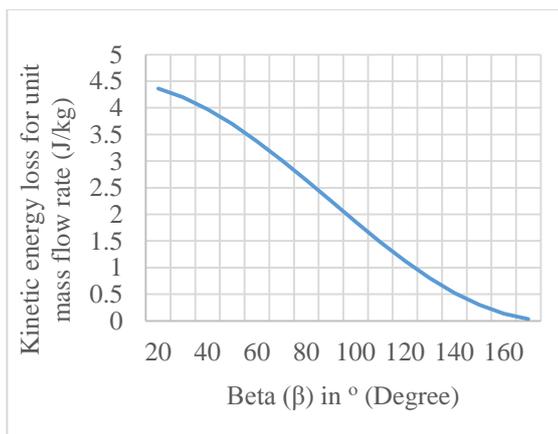
Fig-7: Final dimensions of model five for experimentation



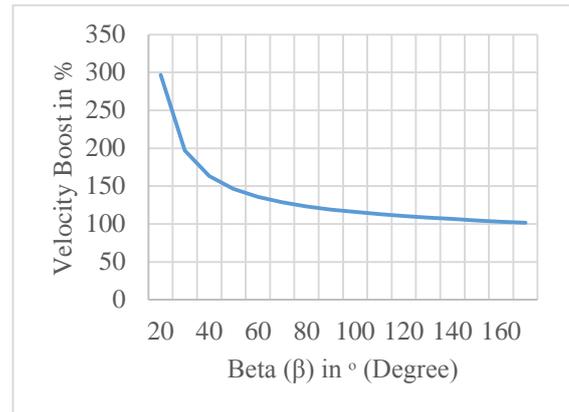
Fig-8: Hyperbolic nozzle ventilator

4. RESULTS & DISCUSSION

When $\beta=20^\circ$ high air boost is occur and it is about 296.95 % of inlet air velocity. At same time due to sharp cross sectional drop kinetic energy loss for unit mass flow rate is maximum and it is 4.3643 J/kg. As nozzle shape changes means β increases air boost decreases and finally air boost is minimum at about 101.54 % when $\beta=170^\circ$. At same way kinetic energy loss for unit mass flow rate =90 decreases when β decreases and its minimum value is about 0.0342J /kg when $\beta=170^\circ$. Nozzle profiles shows maximum air boost when angle β is minimum. However, when $\beta < 90^\circ$ leakage of air stream is maximum. After $\beta > 90^\circ$ there is no problem of flow bypass. Therefore, for maximum boosting and minimum air bypass problem. Rectangular hyperbolic nozzles ($\beta=90^\circ$) are optimum nozzles.



Graph-1: Graph of kinetic energy loss v/s Beta (β)



Graph-2: Graph of velocity boost v/s Beta (β)

5. CONCLUSION

1. From the results obtained by analytical solution the best and optimum nozzle shape for maximum air boost and minimum air bypass losses is rectangular hyperbolic nozzles ($\beta=90^\circ$). As we go incremental order from $\beta=90^\circ$ minimum air boost as well as minimum air bypass as well as minimum other energy losses. As we go decrement order from $\beta=90^\circ$ we get maximum velocity boost but air bypass is more and maximum energy loss.
2. Therefore, rectangular hyperbolic nozzle shapes are optimum, which gives better driving forces to drive air into nozzle in minimum air bypass.

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