10.1 Major Conclusions from the Present Study

The aim of the present study was to explain the air flow pattern in a data centre scientifically and systematically. The air flow pattern within the data centre is found to depend on the operating characteristics of the perforated vent tiles. In order to explain the data centre air flow, it was essential to find a suitable methodology by which the vent tiles can be analysed scientifically. In the present study, jet theory is proposed to explain the tile flow. Data centre tiles can be modelled as multiple jet arrays and hence its characteristics can be established. This concept is successfully implemented in the present work.

In order to arrive at the multiple jet arrays, a thorough study of the basic jet theory and modelling of different jet configurations was necessary. Simple axisymmetric jets were first taken up for study. The results of this study helped to understand the behaviour of the jets with respect to the orifice diameter and the orifice thickness. Based on the results, it is concluded that orifice diameters below 10mm are not suitable for use as major orifice matrix in tiles. Orifice diameters below 10mm will result in lower area ratios of the tile. The velocity distribution of such orifices will not be suitable for application in a data centre. Orifice diameters ranging from 10mm to 14mm are found to be suitable for using as major matrix array in the standard tiles. Orifice diameters below 10mm are recommended for use as minor matrix array in combination tiles. From the study, it is observed that the orifice thickness plays an important role in the velocity distribution of the jet as well as the load bearing capacity of the tile. As the tile thickness increases, the jet quality decreases due to increased friction, whereas, the load bearing capacity of
the tile increases. Hence the decision on the tile thickness is a compromise between
the above two aspects. An orifice thickness in the range of 10mm to 12mm is found
to satisfy both the aspects.

Detailed studies on plane jets are made in the present study with different jet
configurations. This includes, single jet, twin jet, triple jet and differential triple jet.
The studies on different jet configurations showed that the jet exit velocity and the
maximum velocity are the same for any pressure difference across the orifice. The
location of maximum velocity was found to get extended as the diameter of the
orifice increases. As the jet diameter increases, the jet strength increases and the
decay is less. From this study it is concluded that, orifice diameters 10mm, 12mm
and 14mm are equally suitable to be used as major matrix array in the tile. The
selection of a particular orifice depends only on the total area ratio required by the
tile.

The studies on twin jets revealed that all the twin jet combinations show an
increase in the jet exit velocity when compared to the respective exit velocity for
single jets. This is found to be due to the creation of an additional pressure drop
between the jets resulting from the mutual entrainment of the twin jets. The
merging point of twin jet combinations are identified as the maximum velocity
point on the central merging axis.

In triple jet geometries, it is found that the jet exit velocity decreases as the
jet diameter increases. The jet exit velocity shows an increasing trend as the pitch
increases. The central jet shows higher velocities when compared with the outer
jets. The central jet is entrained by the two neighbouring jets from both sides,
thereby enabling the central jet to accelerate more. The complete merging
conditions of the triple jet geometry are established in this study. The physical
mechanism of merging of triple jets consists of two stages. In the first stage, the
neighbouring jets will merge with the central jet. This merging location can be
identified as the maximum velocity point on the merging axis. In the second stage,
the potential core of the central jet merges with the partially merged side jets. This merging location is fixed by transferring the primary merging point velocity onto the central jet velocity axis. This is further verified by obtaining the centreline velocity decay of the central jet. This plot shows a specific point where the slope of the curve changes. This point corresponds to the final merging point obtained. Hence the complete merging of the triple jet is established in this study.

The complete merging of differential triple jets is also found to follow the same trend as that for triple jets. The studies on differential triple jets established the effects of a dissimilar jet introduced between two similar jets. The introduction of a larger diameter jet between two smaller diameter jets will effectively reduce the velocities of the three jets from their corresponding triple jet velocities. However, the introduction of a smaller diameter jet between two larger diameter jets will increase all the velocities including the merging velocity. The results obtained from the study of differential triple jets have great significance in the design of combination tiles. The combination tile can be considered as a cluster of differential triple jet modules.

The studies on three dimensional jets revealed that the meshing pattern adopted for tracing the circular orifice influences the mass flow and velocity calculations through the orifice. The study resulted in the development of correction factors for mass flow and velocity. The correction factors for different mesh patterns are presented in this work. With the help of these correction factors, suitable modelling methodologies can be selected for different three dimensional jet configurations.

The studies on three dimensional single jets showed that jets of diameters 12mm and 14mm have better velocity characteristics than 10mm and 8mm jets. Merging of three dimensional twin jets is found to be different from the merging mechanism of plane twin jets. The study shows that the basic methodology adopted for plane jets cannot be applied to three dimensional twin jets. Three dimensional
twin jets will spread more in x direction and converge in y direction during merging. Hence the position of maximum velocity on the merging axis will not confirm to the actual merging point. But the merging of plane twin jets and three dimensional twin jets exhibit a unique similarity. When the merging location of a plane twin jet is transferred to a similar three dimensional twin jet, this point is found to represent the actual merging point of the three dimensional twin jet. Hence the complete merging of the three dimensional twin jet is obtained.

In the case of three dimensional triple jets, it is observed that the complete merging point can be arrived from the information obtained from similar plane triple jets. The study revealed a strong interdependence between the plane and three dimensional triple jets with respect to their merging characteristics. Whether it is a plane triple jet or three dimensional triple jet, the final merging position follows a similar pattern. This is found to be true for differential triple jets also. The merging mechanism of three dimensional 4 jet and 5 jet modules can also be explained by the procedure followed for other three dimensional jet configuration.

A scientific and systematic tile design and designation coding system is presented in this work. Presently there is no specific coding system available for data centre tiles. The coding system introduced includes all the salient features that are to be considered with respect to a tile. This coding system includes the orifice diameter, the tile thickness, the pitch and the open area ratio of the tile. Different tiles are modelled and analysed. The mass flow calibration charts and velocity distribution charts of the tiles selected for analysis have been developed. From the mass flow charts, it is possible to find the flow rate through the tile corresponding to a specific pressure difference across it. The velocity distribution chart can be used to find out the velocity at any location within the cold aisle. This will give enormous flexibility in data centre design and implementation. The tiles described in this work are defined both qualitatively and quantitatively.
Dampers are used along with the tiles for capacity control in data centre. The effect of damper in data centre tiles for capacity control is studied in the present work. The damper will change the open area ratio of the tile while closing or opening. This will change the mass flow rates through the tiles. This serves the purpose of quantitative control of the air flow. The present study identifies that the operation of a damper will introduce an additional resistance across the tile. This will create a pressure drop across the damper. The effective pressure drop across the tile will come down due to this reason. This will affect the velocity distribution from the tiles. Operation of the damper will lead to a change in the configuration of the flow geometry of the tile, which in turn will affect the development and merging of jets discharged through the orifices of the tile. Hence the study strongly proposes that dampers are not suitable for the capacity control of air flow in data centre. Custom made designer tiles must be used for capacity control in data centre.

The studies on recirculation effects showed that the recirculation of air can be controlled by proper design of vent tiles. The data centre air flow is a balance between the flow from the tile, the flow through the racks and the recirculation flow. The present study shows that the recirculation point is dependant on the rack flow and the tile flow. If the tile flow and the rack flow are balanced, there will not be any recirculation. But it is seldom possible to achieve this, as the data centre environment is dynamic in nature. It is observed that the use of dampers will increase the recirculation effect. It is concluded that well designed tiles can control the recirculation effects in a data centre. Hence the present study emphasises the need for systematic and scientific design of perforated vent tiles in data centre.

10.2 Scope for Future Work

In the present work, the feasibility of the concept of airflow management in a data centre through systematic design of the perforated vent tiles is explored. The study established the need for qualitative air flow management in data centre. The theories developed here need to be experimentally verified before being applied to
a real life data centre. But the experimental procedure is difficult and highly expensive as data centre are mission critical facilities with very limited access. Experimental investigations in a live data centre is time consuming and expensive. Major IT organizations need to be convinced about the importance of setting up research data centre to promote investigations on qualitative air flow management.

Future research in this area should also concentrate on the development of specialised software which can be used for the design and analysis of the data centre. The presently available software considers the quantitative aspects of air flow within the data centre while modelling. They do not account the air flow distribution pattern within the data centre. Most of the software consider the tiles as simple resistances placed in the airflow and calculates mass flow rates according to the resistance values assigned to the tile. This approach has its own limitations and the results obtained from the modelling will not reflect the reality. If the tile design is modified based on the findings of the present research work, there can be a qualitative change in the data centre operation. The software must be restructured to include the design aspects of the tiles and the qualitative aspects of airflow.

Present work opens up an area which needs continuous research. Any valid conclusions in this field will gain acceptance with industry and academic. Present work is only a pilot work in this field which introduces an entirely new concept.

Another area for future research may be the potential for energy conservation measures in data centre. There is a need to quantify the energy savings obtained by qualitative air flow management in data centre air conditioning.

10.3 SWOT Analysis

The present work introduces a new concept of data centre air flow management through scientific and systematic design of the vent tiles. It will be beneficial to have a
brief SWOT analysis of the entire scenario. The STRENGTH, WEAKNESS, OPPORTUNITY and THREATS related to the work are summarized below.

10.3.1 Strength

Data centre is a hot topic of discussion in IT industry for the last few decades and any work which improves the quality of performance of the data centre will be well appreciated by the industry. The present work emphasises the importance of air flow management in data centre air conditioning system and introduces a new concept of design and designation of vent tile for better performance of the data centre. A qualitative air flow management system in data centre is a new concept in energy conservation and hence must attract attention in the near future. This is the STRENGTH of the present work.

10.3.2 Weakness

The core concept of the present work does not suffer from any WEAKNESS. However, the qualitative treatment of the air flow made in the present work entirely depends on the computational results, the hence the reliability and accuracy of the results may differ from the actual situation. The experimental validation of the results presented in this work is very difficult as it has to be done in a live data centre environment. Setting up of a research data centre facility is highly expensive and not available with any of the companies who are engaged in researches in this field. The future research may focus on the experimental investigations in data centre set up for research purpose.

10.3.3 Opportunity

Any work in the data centre field opens up lot of OPPORTUNITIES since a data centre is the heart of the present IT revolution. This field demands a lot of research activities from both industry and academia. A combined effort from industry and academic experts in this field will strengthen the advancements in this direction and will result in remarkable achievements towards efficient operation of data centre.
10.4.4 Threats

“Technology delayed is technology obsolete”. Even though the core concept of this work was developed a few years back, it has not been adopted by the IT industry so far. The concept of air flow management does not suffer any THREATS as it is always beneficial to the industry.

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