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Ventilation Load Based Mapping for Indian Climatic Conditions: A Rationale for Regions to Be Industrial Hub for HVAC Industry

Amit Sharma
Mechanical Engineering Department, Deenbandhu Chhotu Ram University of Science & Technology, Murthal, Haryana-131039, India

Jag Mohan, Rajneesh Solanki
Mechanical Engineering Department, Deenbandhu Chhotu Ram University of Science & Technology, Murthal, Haryana-131039, India

Anita Kumari
Chemistry Department, Miranda house, University of Delhi, Delhi-110007, India

ABSTRACT

Addressing the ventilation load in designing of air-conditioning systems for buildings having requirement of fresh air is important information for Heating Ventilation and Air-conditioner (HVAC) consultants, architects etc. As treatment of fresh air significantly contributes in the energy requirement of air-conditioning of any building as fresh air includes both sensible and latent load. The aim of this paper is to quickly access the cooling generated by the fresh air brought from outside weather to space neutral conditions for Indian climatic conditions which assist HVAC designer for deciding of cooling equipment. Ventilation load index is the criteria adopted for addressing cooling load created by ventilation air. This work presents the comparison based on ventilation load index for different geographic locations within India. Ventilation Load based mapping of Indian region has been presented which can be served as a useful information for practicing air-conditioning (AC) engineers, consultants and architects operating in that region. These regions be for Industrial hub for moisture related systems/ equipment of HVAC industry.

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Corresponding Author Contact:

amitsharma.me@dcrustm.org

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1. Introduction

Importance of clean indoor air is undoubtedly not debatable! As we daily breathe 11000 litre (Papathanasiou,2017) of air and spend 90% of time indoors; the indoor pollutants like volatile organic compounds, nitrogen and sulphur oxides, carbon dioxide and monoxides, ozone, benzene, radon, coarse, fine and ultra fine particulates (Tran et al , 2020; World Economic Forum ,2024), dust, bacteria, viruses, pollen, fungi and molds (American Lung association,2024) exacerbates the inhaled air and thus the need of fresh outdoor air emerges. Outdoor air quality also becoming a major issue in our rapidly urbanized spaces! One needs constant influx of fresh air in our building to get the feeling of freshness; humans need about 8 litre per second (Basic need… , n.d.) fresh air to feel fresh. Fresh air, full of oxygen, gives us energy and improves our health. This is the reason for ventilating our building**s.** Ventilation may be done naturally, mechanically, and may be combination of both. If, this ventilation air carries moisture then it causes serious problem! As, if humidity persists 75% for more than 72 hours, that starts mold growth (USEPA, 2024) and this may cause sick building syndrome and also leads to serious financial implications (Krizan, 2003; Pristin, 2004).

Humidity problem may also cause degradation of electronically driven processes (Baylakoğlu et al, 2021). So, need, is to have ventilation as well as air conditioning so that outdoor air may undergo for air-conditioning (AC) processes like cooling/dehumidifying/humidifying or combination, as per need before entering into habitable area.

Geographically, India is a vast country, which is divided into five climate zones (BIS, 2005). India houses the largest population in the world. Further for this huge population, there is ever increasing demand for air-conditioned building (The Hindu Bureau,2025); need of urbanization witnesses multistory residential buildings weathering different climates (CBRE ,2023). These buildings need positive air pressure indoors. Occupants need air conditioning as well as fresh air for their health. Fresh air part be handled through ventilation; treated ventilation by natural or mechanical means to and from any space becomes necessity of AC system that involves simultaneous control of temperature, humidity, purity and movement of air, ventilation as per requirement.

Ventilation refers to the process of supplying fresh air and removing exhausted air that has accumulated contaminants by natural or mechanical means to and from any space (ASHRAE, 2022)**.** Requirement of ventilation air (ASHRAE, 2022) for high occupancy areas like school/college classrooms, theaters, restaurants, hospitals, malls etc further highlighted the importance of in-taking of fresh outdoor air. This outdoor fresh air has the sensible and latent load associated with it, and needs to be taken care of by air condition equipments/systems. Thus load associated with moister in ventilation has a substantial influence on energy consumption of building because outside air needs to be treated before it supplied to conditioned space. Treatment of air involves controlling the temperature and humidity of ventilation air. Thus handling of ventilation load leads to modification/integration of technologies with the conventional air–conditioning system like sub cooling (Park, 2015), which enhances system's capacity; air treated for moisture with air conditioning aided ventilation system using desiccant (Jani ,2023; Sahlot and Riffat ,2016), Heat pipe and heat pipe aided novel reheating (Sharma et al , 2014); along them, VAV (variable air volume) and CAV (constant air volume) (Lu and Warsinger ,2020) systems can be employed. This temperature and humidity regulated air sent to habitable space. Treatment of moisture is important.

The latent and sensible load component of fresh outdoor air varies based on geological conditions and weather prevails in that region. HVAC consultants need latent/sensible degree day (Al-Hadhrami,2013) like term for estimation ventilation load required for building that allows speedy judgment of otherwise required detailed examination. Since, buildings located in different geographical regions and air has different temperature and moisture level in that region, accordingly load associated with that prevailing outside air. HVAC consultants need quick assessment for the ventilation load for the building being erected at particular geographic location in India. Need of having topographical indicator for assessing location wise ventilation load is valuable information. Harriman et al (1997) proposed Ventilation load index (VLI) for estimation of sensible and ventilation load component associated with the outdoor fresh air. This VLI (Harriman et al, 1997) is the total load generated by one liter per second of fresh air brought from outside weather conditions to the inside design point conditions has been used and presented the ventilation load scenario for Indian cites. Components of VLI, i.e. Latent VLI and Sensible VLI, for a particular geographic location have been presented in this work. VLI for 58 cities of India spreading over 5 climate zones (BIS, 2005) is presented for comparing the dehumidification and cooling load. These cities were chosen based on population and economic activities. Climate wise comparative study on VLI of Indian Cities has been presented in this work. This paper presents the Indian perspective of the sensible and latent annual load for different regions spreading across her different climate zones. And addresses the objective of being developing the potential repository for the architects and consultants by giving them quick idea in the form of VLI map of India; and this work serve as identifying potential geographic locations for setting/expanding manufacturing of associated equipments/systems by HVAC industry. So that HVAC industry gets impetus with the information about regions needed large ventilation load treatment.

2. Methodology

In this work VLI has been estimated for 58 Indian cities spreading across India. VLI has been defined as the load generated by one litre per second of fresh air brought from outside weather conditions to the inside design conditions over the course of one year (Harriman et al, 1997). VLI separate the load into two components: latent (dehumidification) and sensible (cooling): latent kWh/(l/s) per year and sensible kWh/(l/s) per year.

VLI is the summation of latent load and sensible load (Harriman et al, 1997). Ventilation load index was calculated by comparing the temperature and humidity levels of the outside weather to temperature and humidity levels of inside design condition. So, building type, its orientation etc has not been considered. Calculations were for every hour of the year and hours that had positive values had been summed up. For calculating the VLI for different Indian cities situated in different climate zones, inside design condition was assumed to be taken as conservative value of 24°C and 50% RH (9.3 g/kg of dry air at sea level) (BIS, 2005) for comparison; and outside weather data was TMY(Typical metrological Year) data set of hourly weather observation for 58 Indian cities covering whole geography of India. Weather data for various chosen cities obtained using SAM (system advisor model) software (SAM, n.d).

Latent load in kWh/(l/s) per year is calculated as follows(Harriman et al, 1997) :

$$\text{Latent VLI} = ((\text{HR} - 9.3)\times 1.204\times 2442.5)/10^6 \tag{1}$$

Whereas outside air humidity ratio (HR) is taken in g/kg of dry air, 1.204 is the grams per second per liter of air and 2442.5 is the heat of vaporization of water at standard temperature and pressure in KJ/kg.

Similarly, sensible load in kWh/(l/s) per year is calculated as follows(Harriman et al, 1997) :

$$\text{Sensible VLI} = ((\text{DBT}^{o}\text{C} - 24^{o}\text{C})\times 1.005\times 1.204)/10^3 \tag{2}$$

Where, outside air Dry Bulb Temperature (DBT) is in degree Celsius or in Kelvin, 1.005 is specific heat of air in KJ/kg K.

To calculate the annual value of latent portion of load and annual value for Sensible VLI - separate values were calculated for each of the 8760 hours and only positive values were summed up to get the annual value.

Humidity ratio (HR) in g/kg of dry air is calculated in equation (3). This is a relation for humidity ratio between RH,P_s and Atm.Pr. As RH= P_v/P_s (Arora,2017); Partial pressure of vapor (P_v) is obtained from RH i.e. P_v= RH*P_s and this is put in expression of specific humidity(Arora,2017) or HR= 0.62198 (P_v/(Atm.Pr -P_v)) which becomes equation (3)

$$HR= 0.62198\times(RH\times P_s)/(Atm.\ Pr. - (RH\times P_s)) \quad (3)$$

Where, RH is relative humidity. P_s is saturation pressure of water vapor (MPa). Saturation pressure is calculated from dry bulb temperature using ASHRAE relations (ASHRAE, 2021)

$$\ln(P_s)=C_8/T+C_9+C_{10}T+C_{11}T^2+C_{12}T^3+C_{13}\ln T \quad (4)$$

Where

C_8=-5.8002206E+03

C_9=1.3914993E+00

C_{10}=-4.8640239E-02

C_{11}=4.1764768E-05

C_{12}=-1.4452093E-08

C_{13}=6.5459673E+00

Using equations (1), (2), (3) and (4), latent and sensible VLIs were obtained. RH and DBT for outdoor air used in this work were obtained from TMY data(SAM, n.d) for considered specific region. For calculating ventilation load indices a computer program was developed using MATLAB version 7.8.0347 (R2009a) based on following algorithm; it is here under

Step 1:Get the DBT ,RH and atmospheric pressure for particular geographical location;

Step 2: Based on outside weather parameters DBT and RH of considered location, Humidity ratio (HR) obtained using eq. (3) ;

Step 3: Saturation pressure as per eq. (4) using DBT ;

Step 4: Based on data read in first step and HR from second step , Latent VLI and Sensible VLI obtained

Step 5: Add the non negative values of latent and sensible VLI's for each of the 8760 hours of year.

Step 6: Finally annual Latent VLI as well sensible VLI obtained for particular geographical location.

3. Results and Discussion

Based on the methodology explained in previous section, Ventilation Load Index of Indian cities were estimated. Annual total ventilation load index for 58 Indian cities spreading in different Indian climate zones has been summarized in table 1.

Cities which fall under similar climate conditions have been compared in this section. Latent and Sensible ventilation load index of major Indian cities situated in their respective climate zones are shown in fig. 1 ,2 , 3 ,4 and 5.

Figure 1 compares the sensible and latent ventilation load index of cities like -Ahmedabad, Aurangabad, Bikaner, Jaisalmer, Jodhpur, Kota, Pune, Sholapur and Surat situated in hot and dry climate zone. Location that is considered to be in Hot and Dry climate zone if the monthly mean dry bulb temperature for six or more than six month is greater than 30°C and relative humidity for six or more than six month is less than 50% (BIS, 2005). All cities have latent VLI is more than Sensible VLI. Means outdoor air has inherent more latent load component. From fig. 1 it can be inferred that in hot and dry climate zone minimum ratio of latent VLI to sensible VLI is 1.3 (for Bikaner) and Maximum is 4.09 (for Surat). Ahmedabad and Surat specially have large latent load attributed to outdoor air (weather prevailing specific geographical location).

Figure 2 compares the sensible and latent ventilation load index of cities fall in warm and humid climate zone. In this zone (BIS, 2005), if the monthly mean dry bulb temperature and relative humidity for six or more than six month is greater than 30°C and 50% respectively. Cities like Bhubaneswar, Chennai, Dibrugarh, Jamnagar, Mangalore, Mumbai, Nellore, Panjim, Ramagundam and Thiruvanthapuram all are in coastal regions. From fig. 2, it is evident that ratio of latent VLI to sensible VLI is 3 (for Ramagundam) to 5 (for Chennai). Almost all have high latent load component because of proximity to the sea. Geographically Bhubaneswar, Chennai, Mangalore, Mumbai, Nellore, Panjim have very high latent load.

Figure 3 shows the latent ventilation load index for Bengaluru has higher value than sensible VLI situated in temperate climate zone. A location to be in temperate zone if the monthly mean dry bulb temperature for six or more than six month is between 25°C and 30°C and relative humidity for six or more than six month is below75%(BIS, 2005).

Figure 4 compares the sensible and latent ventilation load index for major cities of composite climate zone. In this, none of the conditions mentioned for other climate zones, is identified for six or more than six month for any location then the location is considered to be in composite climate zone(BIS, 2005). Cities considered for composite climate zone -Amritsar, Bhopal, Gwalior, Hissar, Hyderabad, Jaipur, Lucknow, New Delhi, Patna, Raipur and Ranchi, from them cities like Hissar, Hyderabad, Lucknow, New Delhi, Patna, Raipur have high ventilation load exist in the outdoor air. In composite climate zone, as from fig. 4, minimum ratio of ventilation VLI to sensible VLI is 1.77 (for Jaipur) and maximum is 4.47 (for Ranchi).

Figure 5 compares the sensible and latent ventilation load index for cities in cold climate zone and in this zone the monthly mean dry bulb temperature for six or more than six month is below 25°C for any location irrespective of relative humidity(BIS, 2005). Cities included for this comparison are considered as Dehradun and Shillong. Both reported large ventilation load index as compared to sensible but these cities require heating as their major air condition process.

Figure 6 presents the VLI mapping of India representing major Indian geographical locations whereas map lines delineate regions/study areas and do not necessarily depict accepted national boundaries. From table 1 and fig. 6 it is inferred that latent load contributes a lot in total VLI of any location within India. From table 1 it can be concluded for Indian climate that loads, i.e., latent and sensible, are never equal. This is also corroborated by reference (Harriman et al, 1997).

Table 1 Ventilation Load Index for major Indian cities in kWh/(l/s) per year

State/City	Latent VLI	Sensible VLI	Total VLI
Andhra Pradesh			
Hyderabad	103.16	37.58	140.74
Kurnool	98.02	49.24	147.26
Nellore	233.00	51.62	284.62
Ramagundam	152.68	49.41	202.09
Visakhapatnam	230.06	41.68	271.74
Assam			
Dibrugarh	145.16	16.12	161.28
Guhawati	174.91	23.41	198.32
Jorhat	158.71	21.40	180.11
Tezpur	163.58	21.38	184.96
Bihar			
Bhagalpur	181.40	42.36	223.76
Patna	151.95	37.54	189.49
Raxual	146.76	31.25	178.01
Chhattisgarh			
Raipur	116.33	41.53	157.86
Jagdalpur	114.46	25.08	139.54
Delhi			
New Delhi	100.30	40.33	140.63
Goa			
Panjim	219.09	34.81	253.90
Gujarat			
Ahmedabad	124.65	50.99	175.64
Jamnagar	150.16	33.49	183.65
Rajkot	123.23	42.98	166.21
Surat	169.01	41.25	210.26
Veraval	199.24	35.76	235.00
Haryana			
Hissar	121.48	42.08	163.56
Himachal Pradesh			
Sundernagar	55.15	11.01	66.16
Jharkhand			
Ranchi	94.07	21.26	115.33
Karnataka			
Bengaluru	80.84	15.63	96.47
Belgaum	89.68	18.21	107.89
Chitradurga	85.28	22.67	107.95
Mangalore	198.95	32.37	231.32
Kerala			
Thiruvanthapuram	123.23	42.98	166.21

State/City	Latent VLI	Sensible VLI	Total VLI
Madhya Pradesh			
Bhopal	73.65	33.20	106.85
Gwalior	91.55	46.42	137.97
Indore	65.82	30.94	96.76
Jabalpur	101.26	30.81	132.07
Akola	92.88	47.50	140.38
Aurangabad	73.28	33.80	107.08
Mumbai	189.27	38.88	228.15
Nagpur	90.17	44.65	134.82
Pune	91.50	23.57	115.07
Ratnagiri	191.48	31.33	222.81
Sholapur	80.24	40.55	120.79
Manipur			
Imphal	91.78	7.78	99.56
Meghalaya			
Shillong	35.82	0.07	35.89
Orissa			
Bhubaneswar	204.75	38.74	243.49
Punjab			
Amritsar	92.88	47.50	140.38
Rajasthan			
Barmer	88.85	55.00	143.85
Bikaner	72.55	55.21	127.76
Jaipur	77.10	43.57	120.67
Jaisalmer	87.53	50.67	138.20
Jodhpur	76.18	45.31	121.49
Kota	81.92	47.74	129.66
Tamil Nadu			
Chennai	225.35	46.96	272.31
Tiruchirapalli	180.77	54.21	234.98
Uttar Pradesh			
Allahabad	125.73	42.21	167.94
Gorakhpur	160.60	38.30	198.90
Lucknow	126.82	36.10	162.92
Saharanpur	102.61	26.70	129.31
Uttarakhand			
Dehradun	82.62	16.41	99.03
West Bengal			
Kolkata	207.22	36.71	243.93

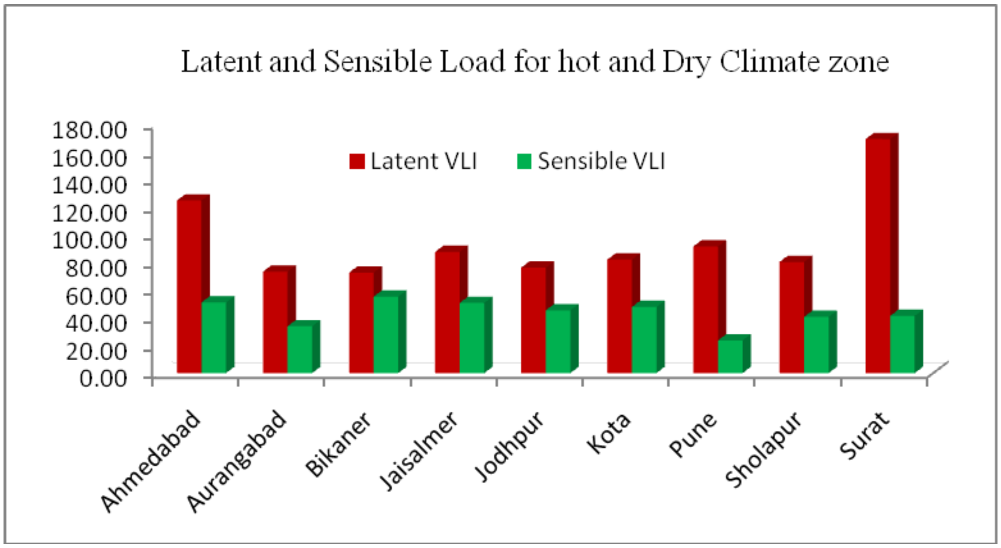

Figure 1 Study Latent and sensible VLI for major cities from hot and dry climate zone of India

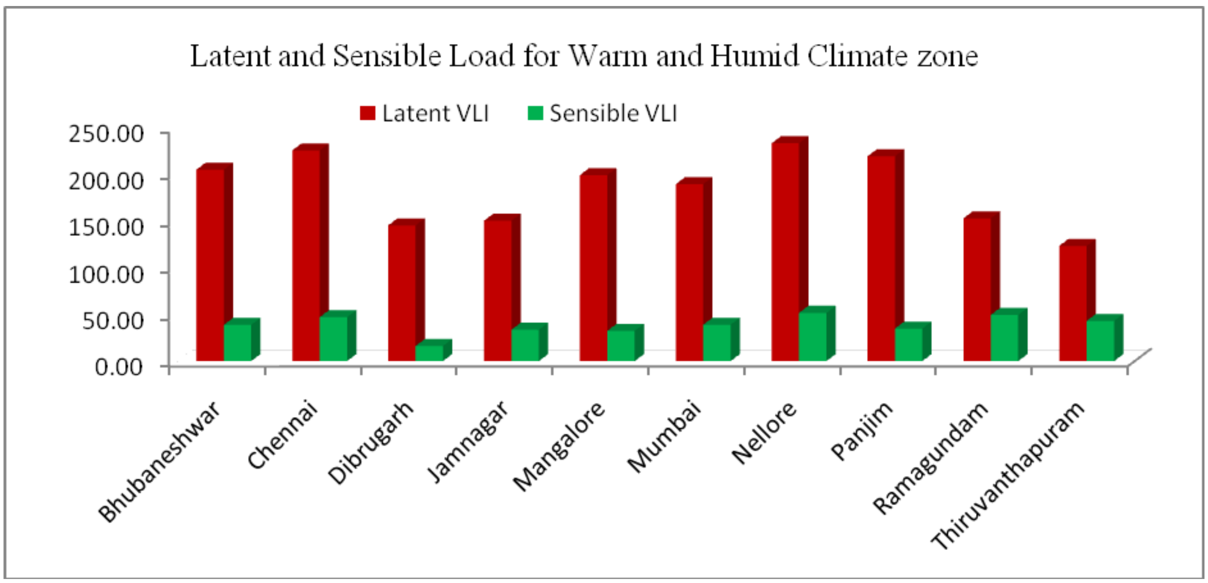

Figure 2 Latent and sensible VLI for major cities from warm and humid climate zone of India

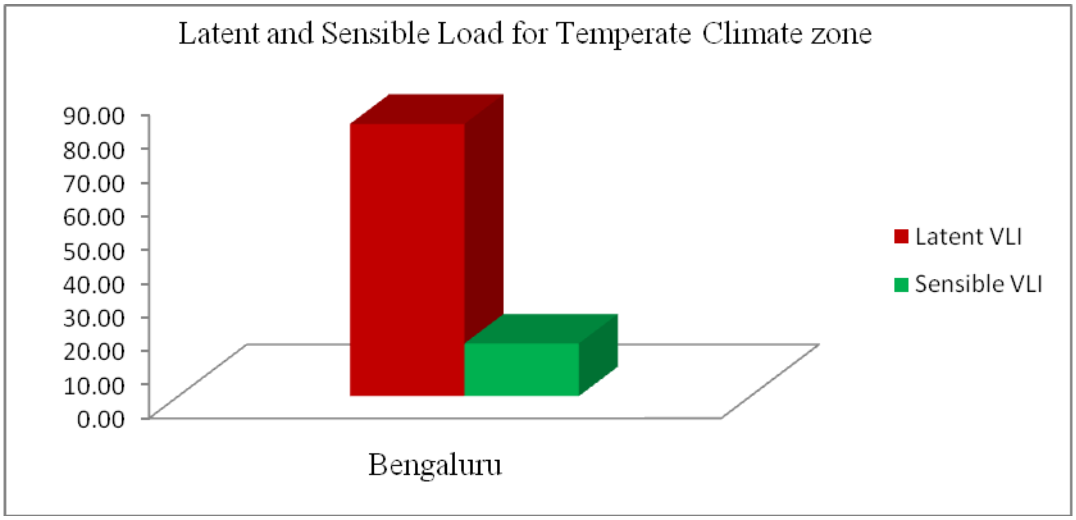

Figure 3 Latent and sensible load for Bengaluru (Temperate climate zone)

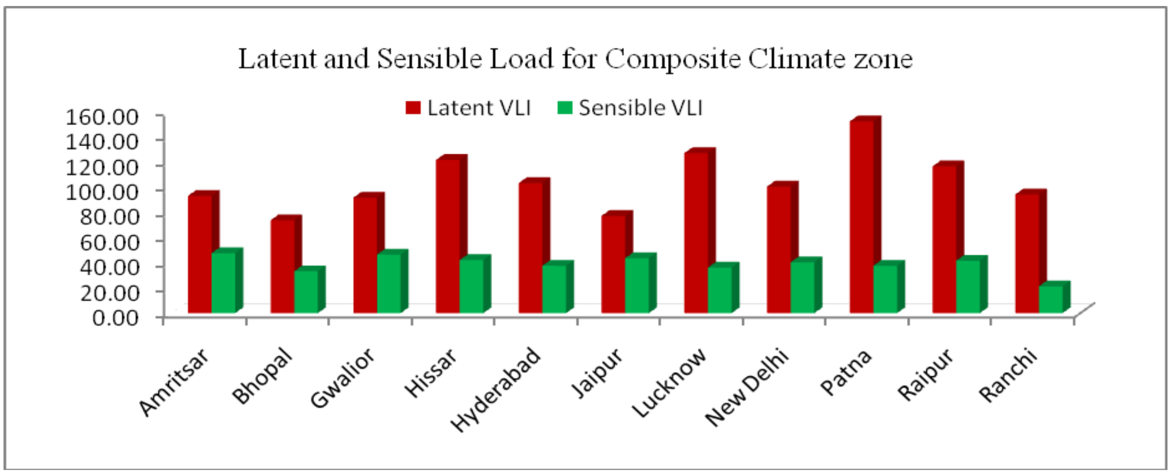

Figure 4 Latent and sensible VLI for major cities from Composite climate zone of India

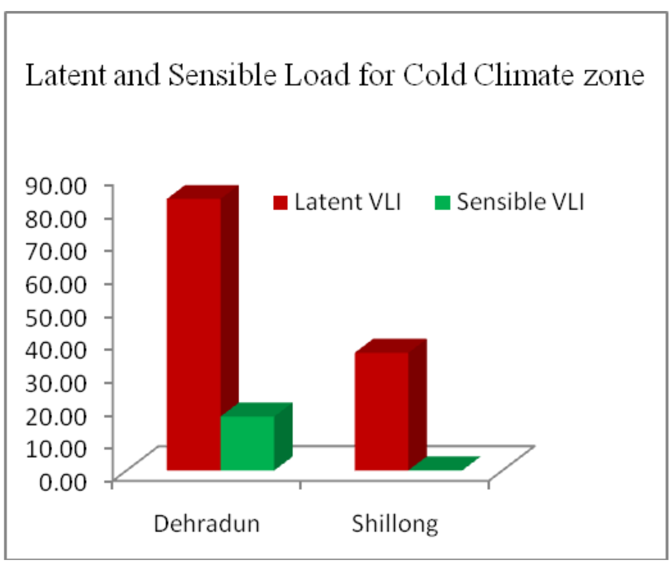

Figure 5 Latent and sensible VLI for major cities from Cold climate zone of India

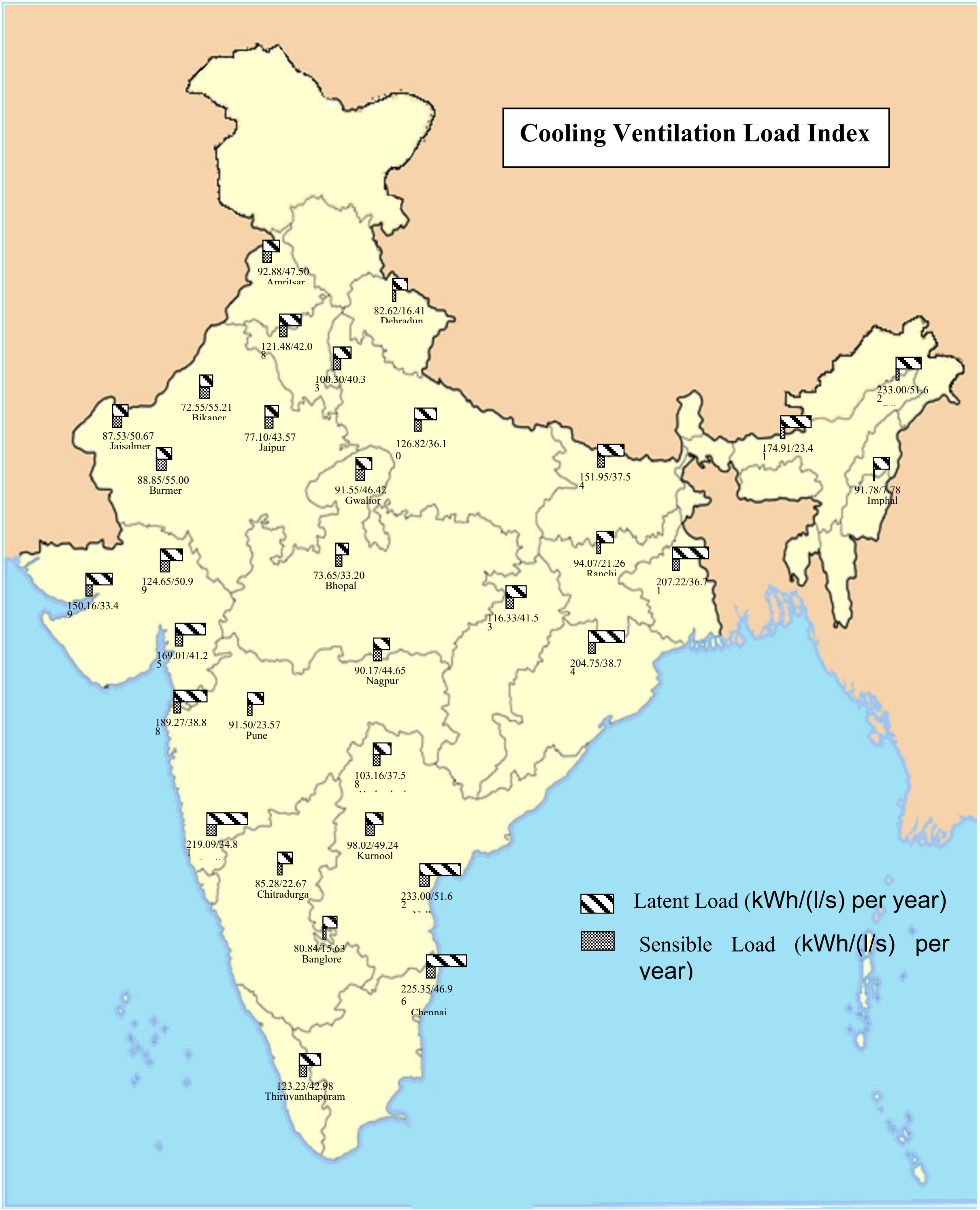

Figure 6 Map of India showing VLI of major cities

A close look on latent VLI reveals that requirement of dehumidification is more in warm and humid climate like in Mumbai, Nellore, Chennai etc. Other cities do need control of latent loads from outdoor air. The cooling requirement of New Delhi and Vishakhapatnam is almost equal but dehumidification requirement in Vishakhapatnam is more than double as compared to New Delhi. This information stress the importance of controlling moisture load for applications (buildings) with high occupancy areas such as hotels, healthcares, classrooms, restaurants, theaters libraries etc. Thus, this study emphasizes that the HVAC consultants, operating in Indian locations, need to address the issue of removing large latent loads as compared to the sensible load in treating of ventilation air for building air-conditioning.

From Figures 1,2,3,4,5, 6 and table 1 various regions/cities emerged for treating larger ventilation load under different climate zones are Surat Ahmadabad and Pune of hot and dry climate zone; all cities considered i.e. Bhubaneswar, Chennai, Dibrugarh, Jamnagar, Mangalore, Mumbai, Nellore, Panjim, Ramagundam and Thiruvanthapuram for warm and humid could be the hub; for temperate Bengulluru; and for composite climate Hisar, Lukhnow, Patna, Raipur , Ranhi , New Delhi Gwalior may be the chosen cities and Dehradun for cold climate.

VLI map of India summarizes the situation of need for tackling larger latent load across the India. HVAC consultants/ Industrialists/Entrepreneurs could see an opportunity in the issue of removing large latent loads as large latent VLI in major regions in India has economic importance too - as it stresses to have manufacturing requirement of equipment required for addressing the need of controlling humidity. Such as for handling large ventilation load which enters into building with fresh air existing rooftop air-conditioning (packaged) units need to be substantiated, with other technologies like desiccants based humidity controlling units, chilled beam for sensible cooling, heat pipe based hybrid air conditioners associated with VAV, CAV etc.

Future area of research-Study can be extended for heating loads and more cities be included; Continent wise study can be presented in future work to widen the scope if the work. Economic analysis may be done in extended work that justifies the major cooling load technologies best fit for the particular climate and thus regions.

4 Conclusions

The Table 1 and figure 6 serve as a guide for quickly assessing geographical location wise ventilation load contributed by the outdoor air for Indian climatic conditions.

Latent load appears to be major contributor in total VLI as latent load exceeds sensible load by at least 1.3:1 and often as much 11.8:1

Climate zone wise cities/regions identified which may get impetuous/economic zones for HVAC industry are-

* Hot and Dry climate zone: Surat, Ahmadabad and Pune ;
* Warm and Humid Climate zone: Bhubaneswar, Chennai, Dibrugarh, Jamnagar, Mangalore, Mumbai, Nellore, Panjim, Ramagundam and Thiruvanthapuram could be the hub for moisture controlling equipments;
* Temperate zone: Bengulluru;
* Composite climate zone: Hisar, Lukhnow, Patna, Raipur , Ranhi , New Delhi ,Gwalior and
* Cold climate zone: Dehradun.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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