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Analysis of Specific Energy Consumption for the Residential Ventilation Units as per European Standards

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Analysis of Specific Energy Consumption for the Residential Ventilation Units as per European Standards

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“Education is the manifestation of the perfection already in man”

--Swamy Vivekananda

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Resumo

Na década atual, escolher a melhor maneira de aquecer o ambiente interior das residências é um grande desafio. A maioria dos países usa aquecedores convencionais para aquecer o ambiente interior ou aparelhos de ar condicionado para arrefecer o ambiente interior. O problema com esses métodos é o maior consumo de energia e o efeito estufa causado pela libertação de CFC ou HFC dos aparelhos de ar condicionado. De acordo com a pesquisa de Washington, o mundo está prestes a instalar 700 milhões de unidades de ar condicionado em todo o mundo, o que significa uma grande quantidade de emissão de gases de efeito estufa. Isso é prejudicial porque os gases de efeito estufa são a principal causa do esgotamento da camada de ozono e do aquecimento global. Assim, para reduzir este efeito, o que podemos fazer é utilizar técnicas passivas de arrefecimento através de telhados reflexivos e radiativos em casas tropicais e tambem, utilizar unidades de ventilação residencial como aquecedores de ambiente interior em regiões mais frias.

À medida que se caminha para que venha a existir um parque de edifícios com consumo quase nulo, e tendo em conta os métodos de ventilação utilizados nas habitações mais antigas, em que nao se verificam as taxas de ventilação sugeridas na ASHRAE, cria-se uma oportunidade para a utilizaçao de unidades de ventilação com sistemas de recuperação de calor.

Muitos dos países europeus passaram do método de ventilação natural para outros métodos de ventilação nos últimos anos, mas ainda há espaço para o crescimento de unidades de ventilação com instalação de permutadores de calor.

Este estudo trata sobre as Unidades de Ventilação Residencial na região europeia. Na Europa, a instalação de RVUs deve obrigar ao "REGULAMENTO DELEGADO DA COMISSÃO (UE) n. ° 1254/2014» que completa a Diretiva 2010/30 / UE do Parlamento Europeu e do Conselho no que diz respeito à rotulagem energética das Unidades de Ventilação Residencial. De acordo com esta diretiva, os valores da SEC, AEC e AHS para os produtos de diferentes regiões do mundo são calculados e comparados com aquecedores convencionais que são usados em regiões mais frias para verificar se as RVUs com permutadores de calor valem a pena investir e substituir a ventilação convencional e meios convencionais de aquecimento ambiente, como aquecedores de gás e energia elétrica, para que possamos reduzir o impacto ambiental causado por meios convencionais de aquecimento ambiente que usam enorme quantidade de combustível para aquecer a mesma área residencial.

Palavras-Chave

Consumo anual de energia elétrica, Consumo de energia específico, Poupança de energia para aquecimento, Unidade de ventilação residencial.

Abstract

In the current decade choosing the best way to heat or cool interiors of a house is the biggest challenge. Majority of the world uses conventional heaters to heat interiors or air conditioners to cool the interiors. Problem with these methods is higher energy consumptions and greenhouse effect caused by the release of CFCs or HFC's from air conditioners. According to Washington post-survey, the world is about to install 700 million air-conditioning units around the world, that means a whole lot of greenhouse gas emission. This is bad because greenhouse gases are the main cause of the ozone layer depletion and global warming. So, to reduce these what we can do is passive cooling techniques through reflective and radiative roofs in tropical houses and use of residential ventilation units as space heaters for the house in colder regions.

As more and more buildings are constructed with zero energy consumption in mind and old ventilation methods used in old homes which are not met with the ASHRAE standards, so there is only one way with which above problems can be tackled and that is by using ventilation units with heat recovery systems.

Many of the European countries transitioned from natural ventilation method to other ventilation methods in recent years, but there is still space for the growth of ventilation units with heat exchangers installation.

This study is about the Residential Ventilation Units in the European region. In Europe, installation of RVUs must oblige to the "COMMISSION DELEGATED REGULATION (EU) No 1254/2014" supplementing Directive 2010/30/EU of the European Parliament and of the Council with regards to energy labeling of Residential Ventilation Units. As per this Directive, SEC,AEC and AHS values for the products from different regions of the world are calculated and compared with conventional space heaters which are used in colder regions in order to check if RVUs with heat exchangers are worth investing and replacing conventional ventilation and conventional means of space heating like gas and electrical space heaters, so that we can reduce environmental impact caused by conventional means of space heating which uses enormous amount of fuel to heat up same space area.

Keywords

Annual Heating Saved, Annual Electricity Consumption, Residential Ventilation Units, Specific Energy Consumption.

Declaration

Anoop Jayadevaswamy Matada declares, under a commitment of honor, that this work is original and that all non-original contributions were duly referenced, with identification of the source.

16th November 2017

Signature

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Nomenclature

AEC	–	Annual Electricity Consumption (electric power per year)	($kWha^{-1}$)
AHS	–	Annual Heating Saved (fuel gross calorific value per year)	($kWha^{-1}$)
Cair	–	Specific heat capacity of air at constant pressure and density	($kWhm^{-3}K^{-1}$)
CTRL	–	Ventilation control factor	
MISC	–	Aggregated general typology factor	
Pef	–	Primary energy factor for electric power generation and distribution	
Q_{defr}	–	Annual heating energy per m^2 heated floor area for defrosting, based on a variable eletric resistance heating	
q_{net}	–	Net ventilation rate demand per m^2 heated floor area	($m^3h^{-1}m^{-2}$)
q_{ref}	–	Reference natural ventilation rate per m^2 heated floor area	($m^3h^{-1}m^{-2}$)
SEC	–	Specific Energy Consumption	($kWhm^{-2}a^{-1}$)
SPI	–	Specific Power Input	($kWhm^{-3}$)
t_a	–	Annual operating hours	(ha^{-1})
t_{defr}	–	Duration of the defrosting period, i.e. when outdoor temperature is below -4’c	(ha^{-1})
t_h	–	Total heating hours	(h)

X – Exponent that takes into account non-linearity between thermal energy and electric saving, depeneding on motor and drive characteristics

ΔT_{defr} – Average difference in K between the outdoor temperature and -4'c during defrosting period

Δt_h – Average difference in indoor and outdoor temperature (K) over a heating season, -3 K correction for solar and internal gains

η_h – Average space heating efficiency

η_t – Thermal efficiency of heat recovery

Abbreviations

AEC – *Annual Electricity Consumption*

AHS – *Annual Heating Saved*

ASHRAE – *American Society of Heating, Refrigeration and Air-conditioning Engineering*

BVU – *Bidirectional Ventilation Unit*

HRS – *Heat Recovery System*

HRV – *Heat Recovery Ventilation*

MSD – *Multi-Speed Drive*

MVHR – *Mechanical Ventilation Heat Recovery*

NRVU – *Non-Residential Ventilation Unit*

REHVA – *Federation of European Heating, Ventilation and Air-Conditioning Association*

RVU – *Residential Ventilation Unit*

SEC – *Specific Energy Consumption*

SPI – *Specific Power Input*

UVU – *Unidirectional Ventilation Unit*

VSD – *Variable Speed Drive*

VU – *Ventilation Unit*

Glossary of terms

BVU	–	*Ventilation unit producing na air flow between indoors and outdoors and which is equipped with both exhaust and supply fans.*
Central demand control	–	*A demand control of a ducted ventilation unit that continuously regulates the fan speed(s) and flow rate based on one sensor for the whole ventilated building or part of the building at central level.*
Clock control	–	*A clocked (daytime-controlled) human interface to control the fan speed/flow rate of the ventilation unit, with at least seven weekday manual settings of the adjustable flow rate for at least two setback periods, i.e. periods in which a reduced or no flow rate applies.*
Control factor (CTRL)	–	*A correction factor for the SEC calculation depending on the type of control that is part of the ventilation unit.*
Demand control	–	*A device or set of devices, integrated or as a separate delivery, that measures a control parameter and uses the result to regulate automatically the flow rate of the unit and/or the flow rates of the ducts.*
Demand controlled ventilaiton	–	*A ventilation unit that uses demand control.*
Ducted unit	–	*A ventilation unit intended to ventilate one or more rooms or enclosed space in a building through the use of air ducts, intended to be equipped with duct connections.*
Effective power input	–	*electric power input at reference flow rate and corresponding external total pressure difference and includes the electrical demand for fans, controls (including remote controls) and the heat pump (if integrated).*

HRS	–	*Part of a BVU equipped with a heat exchanger designed to trasnfer the heat contained in the (contaminated)exhaust air to the (fresh)supply air.*
Local demand control	–	*A demand control for a ventilation unit that continuously regulates the fan speed(s) and flow rates based on more than one sensor for a ducted ventilation unit or one sensor for a non-ducted unit.*
Manual control	–	*Any control type that does not use demand control.*
Maximum flow rate	–	*Maximum air volume flow rate of a ventilation unit ahta can be achieved with intefrated or separatly co-supplied controls at standard air conditions (20'c and 101 325 Pa).*
Multi speed drive	–	*Fan motor that can be operated at three or more fixed speeds plus zero (off).*
Non-ducted unit	–	*A single room ventilation unit intended to ventilate a single room or enclosed space in a building, and not intended to be equipped with duct connections.*
Recuperative heat exchanger	–	*A heat exchanger intended to transfer thermal energy from one air stream to another without moving parts, such as a plate or tubular heat exchanger with parallel flow, cross flow or counter flow, or a combination of these, or a plate or tubular heat exchanger with vapour diffusion.*
Regenerative heat exchanger	–	*A rotary heat exchanger incorporating a rotating wheel for the purpose of transferring thermal energy from one air stream to the other, including material allowing latent heat transfer, a drive mechanism, a casing or frame, and seals to reduce bypassing and leakage of air from one stream or another; such heat exchangers have varying degrees of moisture recovery depending on the material used.*

RVU	–	*Ventilation unit where maximum flow rate does not exceed 250 m^3/h or flow rate between 250 and 1000 m^3/h and the manufacturer declares its intended use as being exclusively for a residential ventilation application.*
SEC	–	*Coefficient to express the energy consumed for ventilation per m^2 heated floor area of a dwelling or building.*
Sound power level	–	*Casing-radiated A-weighted sound power level expressed in dB with reference to the sound power of one pW. Transmitted by air at reference airflow.*
SPI	–	*Specific power input means the ratio between the effective power input (in W) and the reference flow rate (in m3/h).*
Thermal efficiency of a residential HRS	–	*Ratio between supply air temperature gain and exhaust air temerature lossboth relative to the outdoor temperature, measured under dry condition of HRS, and standard air conditions, with balanced mass flow at reference flow ratem na indoor-outdoor temperature difference of 13K, no correction for thermal heat gain from fan motor.*
UVU	–	*Ventialtion unit producing na air flow in one direction only, where the mechanically produced air flow is balaced by natural air supply or exhaust.*
VU	–	*Electricty driven appliance equipped with at least one impeller, one motor and a casing and intended to replace utilised air by outdoor air in a building or a part of a building.*
VSD	–	*Electric controller, integrated or functioning as one system or as a seperate delivery with the motor and the fan, which continuosly adapts the electrical power suppied to the motor in order to control the flow rate.*

1. Introduction

The building industry is one of the biggest consumers among other energy usage sectors in the modern world [1]. Roughly 25% of EU final energy consumption is by residential buildings and space heating consumes almost 60% of that energy [2]. Therefore, there is great potential to save energy by minimizing the demand for space heating and cooling of the building [3].

Among all building services, HVAC systems play a significantly important role in building energy consumption [4].

Main benefits of residential ventilation units are [5]

1. Increase comfort and satisfaction of the occupants
2. Reduces greenhouse gas emission
3. Reduces energy consumption and costs associated with space heating

The use of furnaces, space heaters, and boilers as a method of indoor heating could result in incomplete combustion and the emission of carbon monoxide, nitrogen oxides, formaldehyde, volatile organic compounds and other combustion byproducts. Incomplete combustion occurs when there is insufficient oxygen; the inputs are fuels containing various contaminants and the outputs are harmful byproducts, most dangerously carbon monoxide, which is a tasteless and odorless gas with serious adverse health effects. [6]

In the housing stock main role for a ventilation unit is to provide fresh air and to dilute internally generated pollutants in order to assure adequate indoor air quality. Energy is required for the functioning of this unit, which can be either by directly moving air or indirectly for conditioning the outdoor air for thermal comfort. [7]

As ventilation unit in the current century is essential, most of the green building have low levels of air leakage as most green builders include some type of mechanical ventilation system in every home they build.

Building ventilation has three basic elements

- Ventilation rate – the amount of outdoor air provided into space
- Airflow direction – should be the overall airflow direction based on the better ventilation strategies like mixed or displacement ventilation, related to physical dimensions of the houses.
- Airflow pattern – the external air should be delivered to space in an efficient manner and the airborne pollutant produced in that space should be removed in an efficient manner.

1.1 Why should we ventilate homes?

Life inside home generates both pollutants and moisture. The moisture comes mainly from cooking, washing and showers. If moisture level exceeds in certain area it may farm molds, fungi and bacteria. Mold spores and dust becomes airborne and circulates freely throughout the house which may lead to variety of symptoms and allergic reactions.

In addition to excessive moisture and biological contaminants, there may be appliances for example water heaters, leaky chimneys and wood burning appliances which utilizing combustion may have potential for carbon monoxide and other pollutants to escape into air can create stale air.

And if home is new, then the vary product which it is made can give off gases that might not agreeable to human comfort and for the sake of good health.

There are three methods which can be used to ventilate a building

- Natural ventilation – natural forces drives outdoor air though purpose built opening in the building i.e. windows, doors and air leaks through them when they are closed.
- Mechanical ventilation – fans can be installed either in windows or air ducts for supplying air into building or exhaust air from the building. Type of mechanical unit depends on climate, for warm climate to prevent infiltration and interstitial condensation, a positive pressure mechanical ventilation is used. Similarly, for cold climate, exfiltration interstitial condensation a negative pressure mechanical ventilation is used.
- Hybrid ventilation – it relies on both natural and mechanical drive forces to provide desired flow rates.

1.2 Why can't we open windows like we used to do in olden days?

ASHRAE sets standards for residential ventilation at a minimum of 0.35 air change per hour and not less than 15 cmf per person. Homes which are built in previous decades may execute these values especially during windy day. However, it may not be the case during calm winter day as it may fall below minimum recommended levels set by ASHRAE.

1.3 What is ASHRAE?

American Society of Heating, Refrigerating and Air-Conditioning Engineers, in short, its known as ASHRAE which was founded in 1894, it is a global society advancing human well-being through sustainable technology for the built environment. The ASHRAE and its members focus mainly on building systems, energy efficiency, indoor air quality, refrigeration and sustainability through research, standards writing publishing and continuous educating.

ASHRAE with a mission to advance the arts and science of heating, ventilating, air conditioning and refrigerating to serve and promote humanity towards sustainable world and with a vision to lead the world with foremost source of technical and educational information and provide an opportunity for professional growth of art and science in the fields of heating, ventilating, air conditioning and refrigerating.

1.4 ASHRAE and its standards

The ASHRAE had a residential ventilation standard since 2003 when ASHRAE 62.2 ("Ventilation and Acceptance Indoor Air Quality in Low-rise Residential Buildings") was first approved for publication. ASHRAE established the basic ventilation formula in 2003 which was unchanged until recently i.e. 7.5 cmf per person + 1 cmf per 100 square feet. When a newer version of 62.2 released in 2013, it had a significant change in the ventilation formula. As per the new formula, high-performance homes need to be ventilated at a higher rate, i.e. 7.5 cmf per person + 3 cmf per 100 square feet [8].

1.5 What is the Main reason to use ventilation unit?

A well-planned air ventilation system filters and suitably warmed supply air which is brought into the cleanest rooms like bedrooms and living rooms in order to boost air transfer and the air is removed from the places where more humidity and impurities are born like bathroom, utility room and kitchen. Even if the kitchen has a cooker hood or a roof fan and hood, there should be a place where air can be extracted from the ceiling of the kitchen.

1.6 What are the options for ventilation and Why should we use Heat Recovery Ventilation?

Other than the natural ventilation system we can use the following methods for ventilation

a. Extractor fans

Pros: easy installation and remove pollutants.

Cons: they waste heat, noisy and they create draughts.

b. Passive stack ventilation

Pros: avoids use of electric fans by using stack effect to draw warm air from wet rooms like kitchen and bathrooms through ducts

cons: lack of indoor pressure for air circulation, wastes heat and causes droughts.

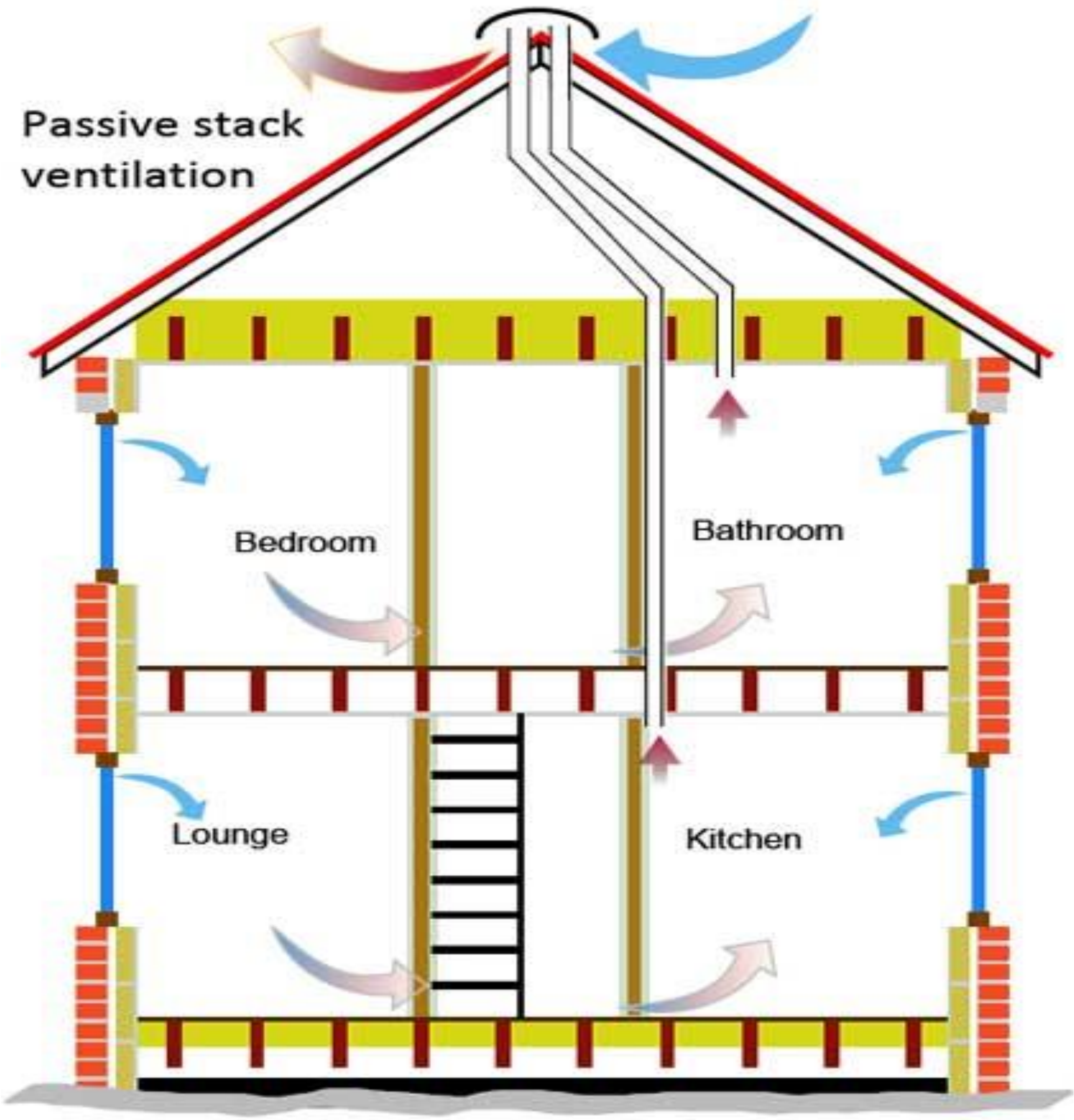


Figure 1 Pictorial representation of passive stack ventilation [9]

c. Central extract ventilation

Pros: contaminated air from wet room is replaced with the fresh air

Cons: it wastes heat and it creates drafts

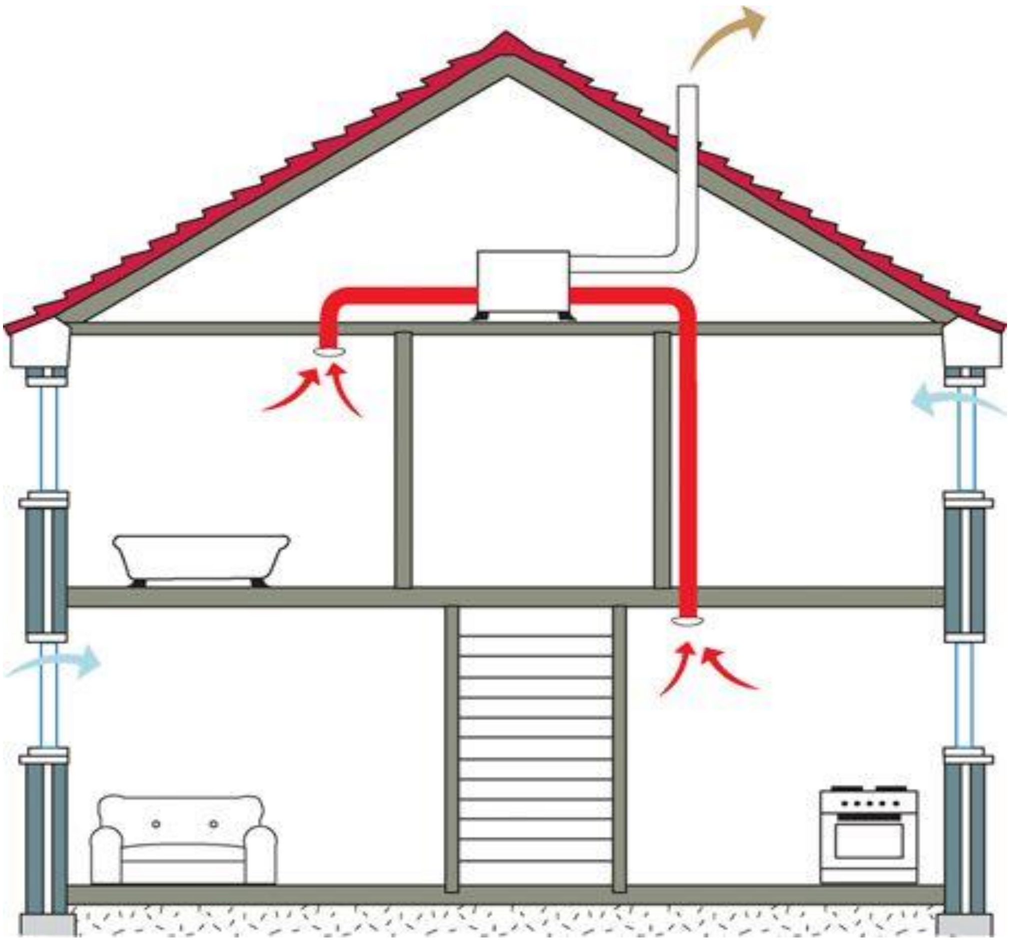


Figure 2 Pictorial representation of central extract ventilation [10]

d. Mechanical ventilation with heat recovery systems

Pros: removes contaminated stale air and it is continuously replaced by warm fresh air

So mechanical ventilation system with heat recovery is the most efficient way to ventilate as more than 80% of the heat from the stale air is recovered when stale air passes through heat exchanger and it is transferred to the fresh air.

A heat recovery ventilation uses the heat in the outgoing stale air to warm up the fresh air. A typical unit features two fans, one to take out household air and another one is used to bringing fresh air in.

HRVs are ideal for tight, moisture prone homes as they replace the humid air with dry fresh air.

Depending on the model, HRVs can recover up to 85% of the heat from outgoing airstream. And, an HRV contains filters that keep dust from entering the house. A typical HRV for residential use might move as much as 200 cfm of air which is more than enough of the quantity that an ASHRAE is set. [11]

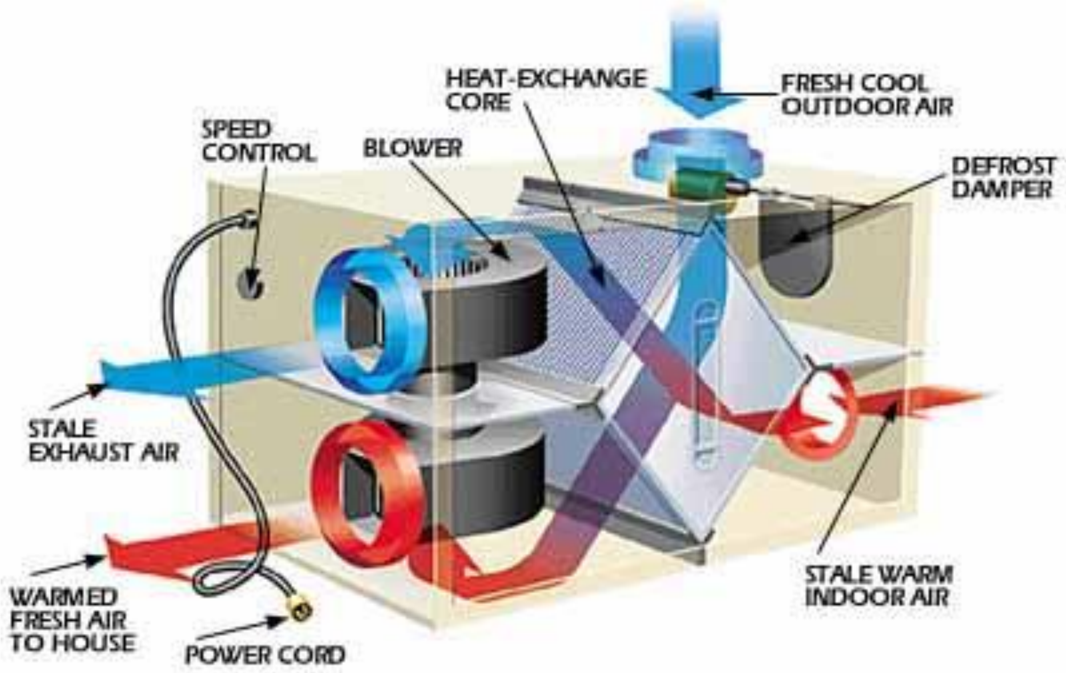


Figure 3 Typical heat recovery ventilation unit [11]

1.7 Basic working principle behind HRV

A HRV is similar to a balanced ventilation system, except in this it uses the heat which is present in the outgoing stale air (for example, heat producted in kitchen, bathrooms and other house hold appliances) to warm up the fresh air. A typical HRV system consists of two fans, one is used to remove household air and another one is used for bringing fresh air. Heat exchanger core which is present in HRV transfers heat from outgoing stream to the incoming stream in the same as the car radiator works. And HRV contains filters which keep smaller particles like pollen and dust from entering the house.

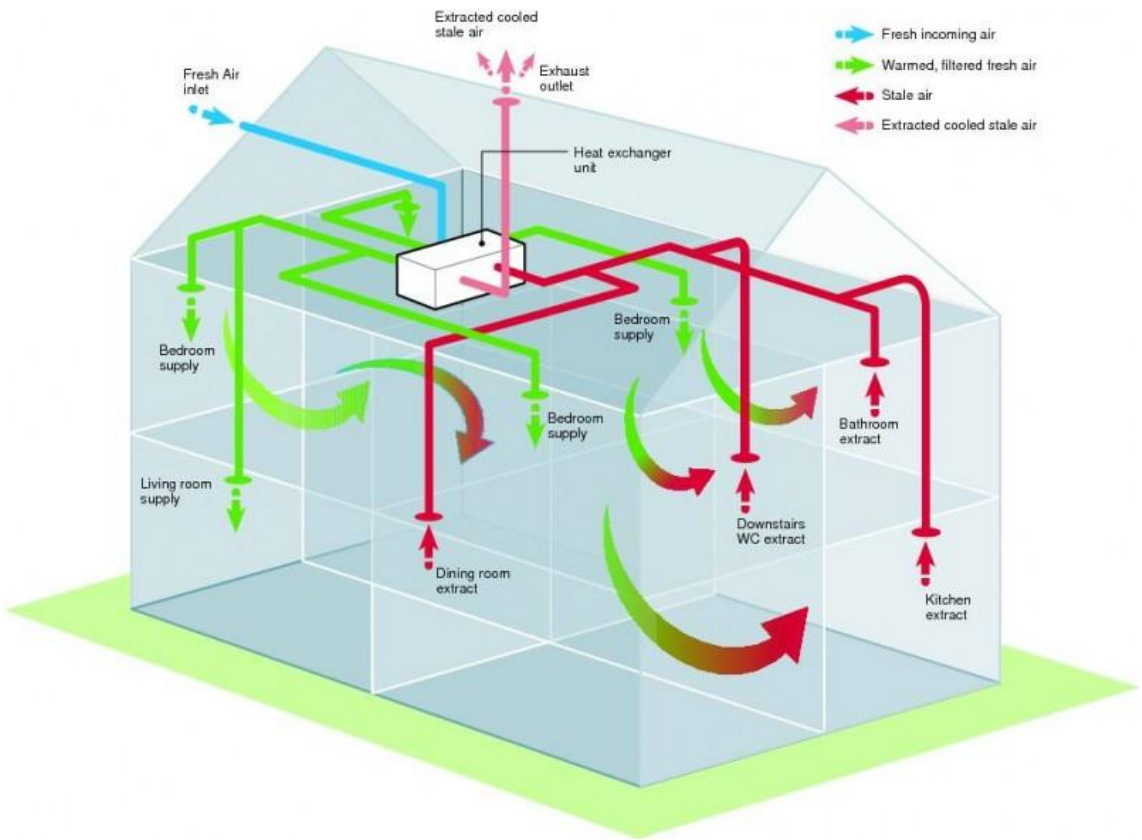


Figure 4 Pictorial representation of stale air removal and fresh air introduction to the house [12]

1.8 What is Heat recovery system and what are its types?

Heat Recovery Ventilation(HRV) which is also known as Mechanical Ventilation Heat Recovery (MVHR) is an energy recovery ventilation system which uses heat recovery ventilator, heat exchanger, air exchanger or air to air heat exchanger for employing a cross-flow or counter flow heat exchange between the inbound and outbound air flow.

MVHR also transfers the humidity level from the exhaust stale air to the fresh intake air.

Mainly there are two types of heat recovery systems which we are using for our calculation purpose are listed below

- Recuperative heat exchanger – Heat transfers continuously from hot fluid to the cold fluid through a dividing wall. There is no direct mixing of the fluids. Some examples are tubular, plate type and extended surface exchanger. [13]

- Regenerative heat exchanger – Operation involves the temporary storage of heat from the hot fluid which is transferred in a packing which possesses the necessary thermal capacity to the cold fluid. This is accomplished by bringing hot fluid in contact with the heat storage medium and then introducing cold fluid which absorbs the heat. Some examples are rotary, fixed bed heat exchanger. [14]

1.9 Schedule

The pursuit of the objectives which are set to achieve for the completion of this thesis is calendarized and same is shown in the below figure.

Task Name	Duration	Start	Finish	Predecess
Document study	2 wks	Tue 28-03-17	Mon 10-04-17	
Data collecting for calculation	3 wks	Tue 11-04-17	Mon 01-05-17	1
Preparing microsoft xl sheet for calculation purpose	2 wks	Tue 02-05-17	Mon 15-05-17	2
Calculations are made and compared with document	2 wks	Tue 16-05-17	Mon 29-05-17	3
Discussing and finalising calculation document	1 wk	Tue 30-05-17	Mon 05-06-17	4
Thesis writing - Thesis development part	4 wks	Tue 06-06-17	Mon 04-09-17	5
Gathering more information for introduction and bibilographic work	1 wk	Tue 05-09-17	Mon 11-09-17	6
Thesis writing - Conclusion and Future work	1 wk	Tue 12-09-17	Mon 18-09-17	7
Thesis writing - Introduction and Bibilography	1 wk	Tue 19-09-17	Mon 25-09-17	8
Thesis writing - Annex	0.5 wks	Tue 26-09-17	Thu 28-09-17	9
Thesis writing as per template	4 wks	Thu 28-09-17	Thu 26-10-17	10
Changes are made as per guides instructions and finalizing thesis document	1.5 wks	Thu 26-10-17	Mon 06-11-17	11

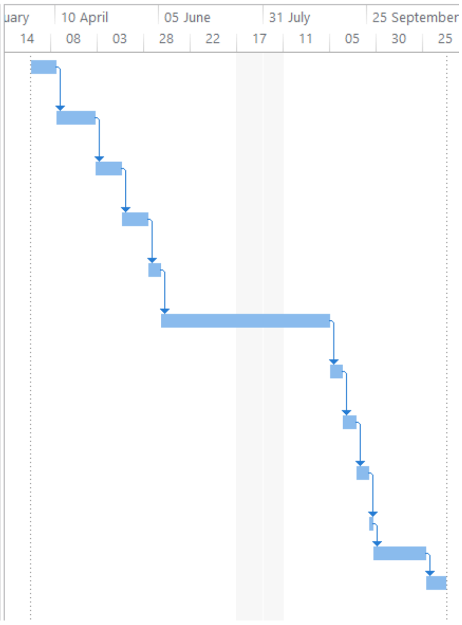


Figure 5 Project schedule

1.10 Organization of the report

In chapter 1 Introduction, few questions concerning the ventilation and ventilation units have been answered along with the mentioning of what is ASHRAE and how it is connected with ventilation. In the next chapter 2 Bibliography work, supporting data which are already available, and which are backbone to this thesis are mentioned. In chapter 3 Thesis development, it contains elaborate plans of methodology and formulas used in calculation part and values which are obtained from this calculation part are compared with each other in the results heading to give a clear picture about the obtained values. In the next chapter 4 Conclusion and Future work, contains points which summarize what is this thesis trying to tell us by comparing calculation results with the current trend in ventilation field and what can be achieved or improved in future is written here. In the final chapter 5 Annexes, which contains the supporting data for this thesis work which are parts of bibliography documents.

2. Bibilographic Work

2.1 Commision Regulated Delegated Regulation (EU) NO 1254/2014 [15]

"COMMISSION DELEGATED REGULATION (EU) No 1254/2014 of 11 July 2014" supplementing Directive 2010/30/EU of the European Parliament and of the Council with regards to energy labelling of Residential Ventilation Units states the following points

1. Products with significant potential for energy saving and performance levels having equivalent functionality and it must oblige with Directive 2010/30/EU in matters of achieving the policy objectives more quickly or at lesser expenses than the mandatory requirements.

2. Assessment of the technical, environmental and economic aspects of residential ventilation units from the commission with improvements have already achieved in energy efficiency but there is scope for further reduction in energy consumptions and a wide disparity in performance levels and found no self-regulation or voluntary agreement which could achieve the policy objectives.

3. Regulations also say that ventilation units with electric power input less than 30 W per air stream should be exempted, also non-residential ventilation units (NRVU's) should be

excluded from labelling as they are chosen by planners and architects. Exceptions that should be excluded also includes multifunction units which heat or cool and kitchen hoods.

4. The label should include sound levels of the residential ventilation units as it is an important consideration for the consumers.

5. Information provided on the label should contain data obtained from reliable, accurate and reproducible methods which include measurement and calculation methods based on the procedures laid down in regulations (EU) No 1025/2012 of the European Parliament and of the Council.

6. In case of distant selling, this regulation should specify requirements as to the uniform design and content for the label, the technical documentation, and the fiche, as the importance of information displayed to end-user is increasing on the internet.

This article concentrates on the following subject matters and scopes

1. Requirements for residential ventilation unit's energy labelling is established by this regulation.
2. This regulation shall not be applicable to the ventilation units which
   (a) Are unidirectional (exhaust or supply) with an electrical input of 30 W or below.
   (b) Are potential working in the explosive atmosphere as stated in Directive 94/9/EC of the European Parliament and of the Council.
   (c) Are operating for emergency use I.e. for the short period of time regards to safety in case of fire as set out in regulation (EU) No 305/2011 of the European Parliament and of the Council.
   (d) Including additional unit for heat exchanger and heat pump for heat recovery other than that of heat recovery system which is in the unit, except heat transfer for frost protection or defrosting.
   (e) Are classified as range hoods covered by Commission Delegated Regulation (EU) No 65/2014.
   (f) Are exclusively specified as operating
      (i) Temperature of air being moved exceed 100 ‘c
      (ii) If the unit is located outside the air stream, operating ambient temperature for the motor exceeds 65’c or lower than -40’c.
      (iii) Where supply voltage exceeds 1000 V AC or 1500 V DC.

(iv) In the environment with abrasive substances or the corrosive environment or the flammable environment, and toxic environment.

Also, this article gives the measurement methods information to calculate specific energy consumption and classify based on SEC value. And this article gives necessary formulas for calculation methods and state of art measurement for annual energy consumption and annual heating saved calculation.

They also mentioned that the commission will review this regulation in the light of technological progress and present the results to the consultation forum no less than January 1st of 2020.

2.2 Evolution of ventilation system types in some EU countries [16]

REHVA is the Federation of European Heating, Ventilation and Air-Conditioning Associations which represents a network of more than 100,000 engineers from 27 countries who dedicate their work to the improvement of health, comfort, and energy efficiency in all buildings and communities.

An article which was written and published by REHVA states the following facts. Across EU contries, all the countries don't follow the same ventilation practices. This is mainly because of the different climatic conditions and building construction tradition. It is important to know ventilation systems in current building stocks in Europe for the future development of energy efficient ventilation for a good indoor condition. Ventilation system categorized as shown below for explaining things which are present in this bibilography.

For each of the 15 different systems which are shown in the figure 6 is represented by the different colors which are shown below. The article says that the colors used are chosen based on accurate visual distinction and on the system and adjacent subsystems identification.

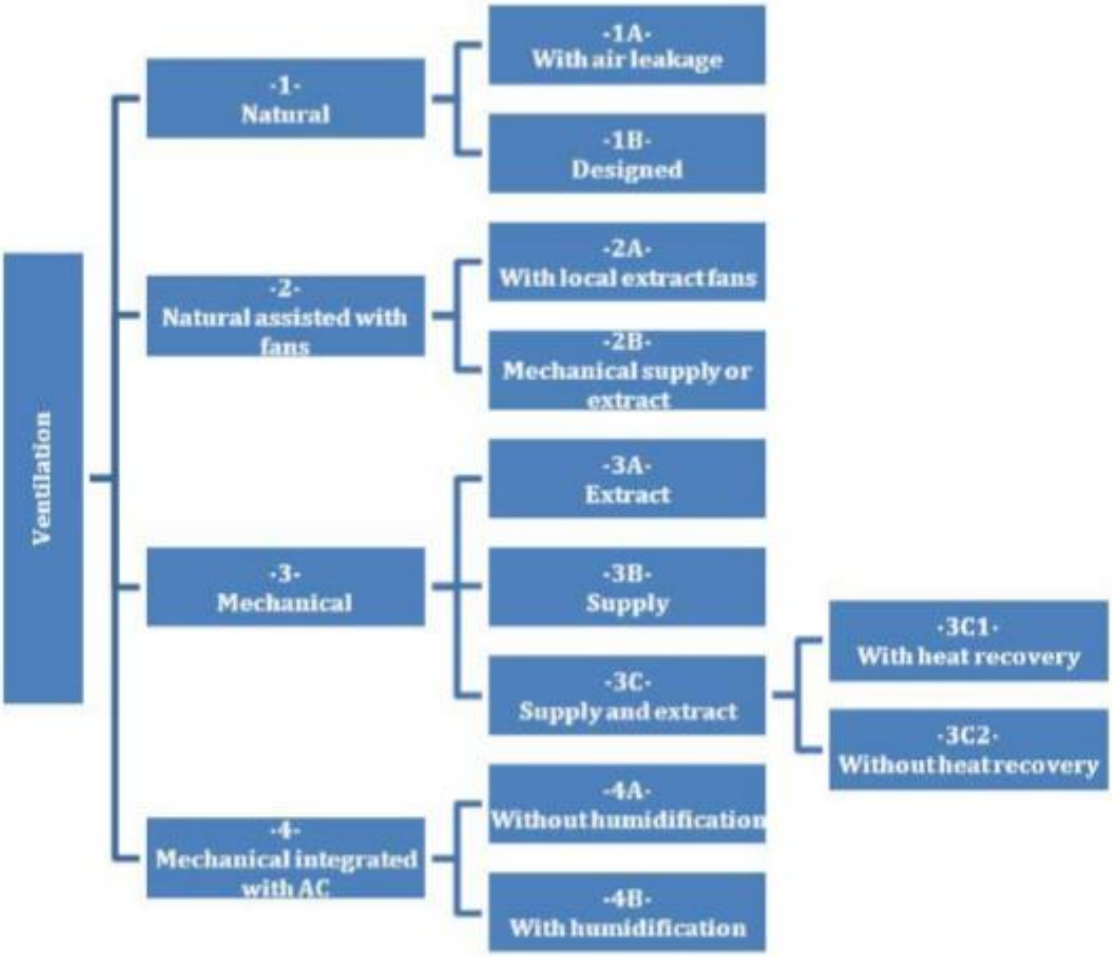


Figure 6 Ventilation system categories based on the REHVA article [16]

In this case study, they showed the evolution of the ventilation system used in some European countries. As the country regulations and construction practice of a country changes and it influence type of ventilation systems used in that country. Even though the evolution of ventilation unit in all countries is different but the trend is similar.

As per the data present in this article, we can tell that before the year 1980 all countries mainly used natural ventilation.

Finland was one of the first countries to make a change i.e. before 1959 by introducing mechanical supply or extract ventilation systems. Gradually the situation changed to a point that all constructed building after 2004 has only mechanical ventilation systems.

	1A	Natural ventilation with air leakage
	1B	Designed natural ventilation
	1A, 1B	Natural ventilation
	2A	Natural ventilation with local extract fans
	2B	Hybrid ventilation (1A or 1B + intermittent 3A or 3B)
	2A, 2B	Natural assisted with fans
	1A, 1B, 2A, 2B	Natural ventilation with or without assisting fans
	3A	Mechanical extract ventilation
	3B	Mechanical supply ventilation
	3A, 3B	Mechanical ventilation
	3C1	Mechanical extract and supply ventilation with heat recovery
	3C2	Mechanical extract and supply ventilation without heat recovery
	3C1, 3C2	Mechanical with or without heat recovery
	4A	Ventilation integrated with AC without humidification
	4B	Ventilation integrated with AC with humidification

Figure 7 Color code for the ventilation system categories used in this bibliography [16]

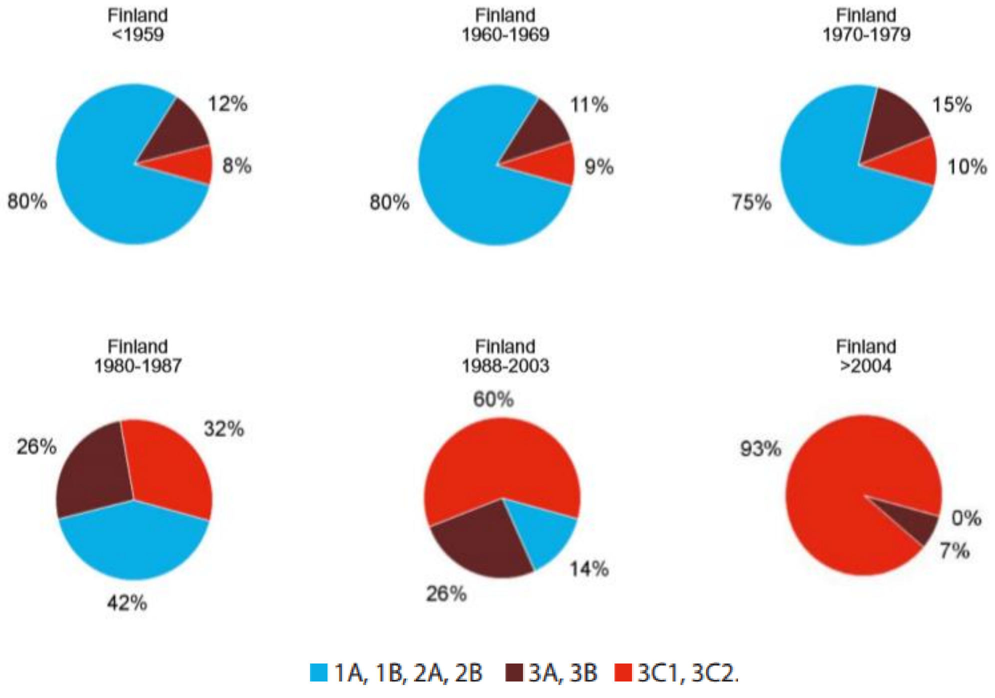


Figure 8 Distribution of ventilation systems n houses by construction year in Finland [16]

In case of United Kingdom, main changes took place between 1980 to 2010 during which constructed buildings had mostly fan assisted natural ventilation. Only after 2011 mechanical ventilation system accounts for half of the systems in constructed houses.

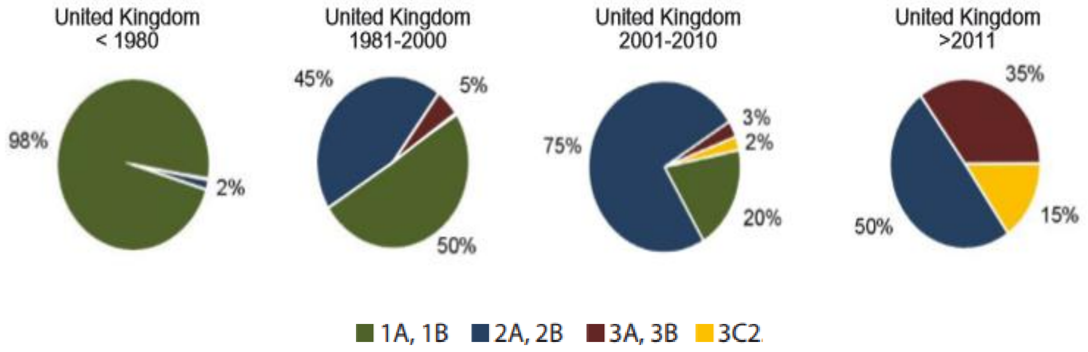


Figure 9 Distribution of ventilation systems in houses by construction year in United Kingdom [16]

Although Portugal favored fan assisted natural ventilation over natural ventilation they introduced mechanical system as hybrid ventilation.

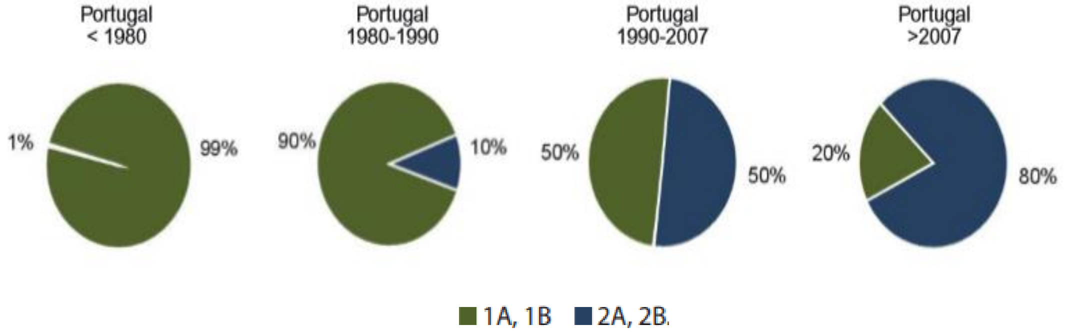


Figure 10 Distribution of ventilation systems in houses by construction year in Portugal [16]

This article concludes that the distribution of ventilation system had a similar evolution from natural ventilation system towards mechanical ventilation system. Only notable difference is that evolution occurred sooner in some countries compared to others. But still, as most of the houses from the building stock are old which uses natural ventilation system and they contribute towards overall ventilation systems allocates.

3. Thesis Development

3.1 Methodology

As per the COMMISSION DELEGATED REGULATION (EU) No 1254/2014 of july 2014, for calculating SEC, AEC and AHS values we are using the formulas which are given in that document. Formulas which are from the document are mentioned in the formulas used section.

These formulas basically consists of 4 group of parameters, which are

a. Default values which doesnt affected by climatic change or type of machine used, which are specific heat capacity(C_{air}), net ventilation(q_{net}), natural ventilation rate(q_{ref}), annual operating hours(t_a), primary energy factor electric power generation and distribution(pef) and space heating efficiency(η_h).
b. Values which are mentioned by the manufactures for that particular product, which are specific power input(SPI) and thermal efficiency of the heat exchanger(η_t).
c. Values which are selected based on the data provided by the manufacturer for that product, which are general typology ventilation system, type of control system used by that ventilation unit, type and drive characteristics of the motor used by that product, type of heat exchanger used by that product.

d. Values which bound to external climatic condition when they are working i.e. like if machine is working during cold, average or warm temperature.

Additional data which are provided for that machine like sound power level(L_{WA}) and maximum airflow rate are used in the labelling of that prodcut along with the product classification.

3.1.1 Formulas used

1. Specific energy consumption [$kWhm^{-2}a^{-1}$]:

$$SEC = [t_a \times pef \times q_{net} \times MISC \times CTRL^x \times SPI] - [t_h \times \Delta T_h \times \eta^{-1}_h \times c_{air} \times \{q_{ref} - (q_{net} \times CTRL \times MISC \times (1 - \eta_{t\_})\}] + Q_{defr}. \quad \textbf{(1)}$$

2. Annual heating energy [kWhm-2a-1]:

$$Qdefr = t_{defr} \times \Delta T_{defr} \times c_{air} \times q_{net} \times pef. \quad \textbf{(2)}$$

3. Annual electricity consumption [$kWha^{-1}$ electricity]:

$$AEC = (t_a \times q_{net} \times MISC \times CTRL^x \times SPI) + Q_{defr}. \quad \textbf{(3)}$$

4. Annual heating saved [$kWha^{-1}$ gross calorific value]:

$$AHS = t_h \times \Delta T_h \times \eta^{-1}{}_h \times c_{air} \times (q_{ref} - (q_{net} \times CTRL \times MISC \times (1 - \eta_t)). \quad \textbf{(4)}$$

3.1.2 Calculation parameters

1. MISC value which is used in the formula 1, 3 and 4 for the given RVU is chosen based on whether if its ducted system or non-ducted system.

Table 1 General typology and MISC values for RVUs [15]

General typology	MISC
Ducted ventilation unit	1.1
Non-ducted ventilation unit	1.21

2. CTRL value which is used in the formula 1, 3 and 4 for the given RVU is chosen based on the ventilation control factor.

Table 2 Ventilation control factor values based on type of control unit used in RVUs [15]

Ventilation control	CTRL
Manual control (no DCV)	1
Clock control (no DCV)	0.95
Central demand control	0.85
Local demand control	0.65

3. X-value which is used in the formula 1 and 3 for the given RVUs is chosen based on the motor and drive speeds.

Table 3 Motor and drive speed and corresponding x-values for RVUs [15]

Motor and drive	X-value
On/off and single speed	1
2-speed	1.2
3-speed	1.5
Variable speed	2

4. Values which are depend solely on the working climatic condition which are used in the formula 1, 2, 3 and 4 are chosen from the table 4.

Table 4 Climate constant values which are used for calculating SEC, AEC and AHS [15]

Climate	**T_h in h**	**ΔT_h in k**	**T_{defr} in h**	**ΔT_{defr} in k**	**Q_{defr} (*) in kWh/a.m^2**
Cold	6552	14.5	1003	5.2	5.82
Average	5112	9.5	168	2.4	0.45
Warm	4392	5	-	-	-

* Bidirectional unit with recuperative heat exchanger,

$Q_{defr}=t_{defr}*\Delta T_{defr}*c_{air}*q_{net}*pef$

* unidirectional units with regenerative heat exchanger, $Q_{defr}=0$

5. Default values which are used in the formulas 1, 2 3 and 4 are taken from the table 5.

Table 5 Default values which are used in calculating SEC, AEC and AHS [15]

Defaults	**Values**
C_{air}	0.000344
q_{net}	1.3
q_{ref}	2.2
t_a	8760
pef	2.5
η_h	75%

3.2 SEC, AEC AND AHS Calculation

A. Manufacturer 1

A.1 Specifications [17]

General typology: Ducted ventilation unit

Ventilation control: Local demand

Motor and drive characteristics: Variable speed

SPI: 0.26 W/(m^3/h)

Heat exchanger type: Rotary (belongs to Regenerative heat exchanger)

Thermal efficiency of heat exchanger: 88

Sound power level: 44 dB(A)

Maximum airflow: 993 m^3/h

A.2 Selecting calculating parameters

MISC = 1.1

CTRL = 0.65

x-value = 2

Q_{defr} = 0

A.3 SEC calculation

The SEC value which is calculated in fig 11 was obtained from the equation 1 and the data which are present in the table 4 and 5, and also with the calculation parameters from the manufacturer 1 specification are used.

	Climate	SEC	MISC	$CTRL^x$	SPI	t_h	ΔT_h	CTRL	η_t	Q_{defr}
Manufacturer 1	Cold	-87.5648	1.1	0.4225	0.00026	6552	14.5	0.65	0.88	0
	Average	-43.0796	1.1	0.4225	0.00026	5112	9.5	0.65	0.88	0
	Warm	-17.5955	1.1	0.4225	0.00026	4392	5	0.65	0.88	0

Figure 11 Calculated SEC value for the manufacturer 1

A.4 AEC & AHS calculation

The AEC and AHS value which is calculated in fig 12 was obtained from the equation 3 and 4 respectively and the data which are present in the table 4 and 5, and also with the calculation parameters from the manufacturer 1 specification are used.

	Climate	MISC	$CTRL^x$	SPI	t_h	ΔT_h	CTRL	η_t	Q_{defr}	AEC	AHS
Manufacturer 1	Cold	1.1	0.4225	0.00026	6552	14.5	0.65	0.88	0	137.6069	9100.497
	Average	1.1	0.4225	0.00026	5112	9.5	0.65	0.88	0	137.6069	4651.978
	Warm	1.1	0.4225	0.00026	4392	5	0.65	0.88	0	137.6069	2103.563

Figure 12 Calculated AEC and AHS value for the manufacturer 1

A.5 SEC classification

As per annex 1 SEC should be classified based on the average temperature value, that is approximately -43 so, manufacturer 1 product falls under A+ classification.

B. Manufacturer 2

B.1 Specifications [18]

General typology: Ducted ventilation unit

Ventilation control: Local demand

Motor and drive characteristics: Variable speed

Air volume: 500 m^3/h

Rated power: 360 W

Heat exchanger type: Aluminium (belongs to Recuperative heat exchanger)

Thermal efficiency of heat exchanger: 90

Sound power level: 35 dB(A)

SPI= rated power/air volume

= 360/500

= 0.072 $W/(m^3/h)$

B.2 Selecting calculating parameters

MISC = 1.1

CTRL = 0.65

x-value = 2

B.3 SEC calculation

The SEC value which is calculated in fig 13 was obtained from the equation 1 and the data which are present in the table 4 and 5, and also with the calculation parameters from the manufacturer 2 specification are used.

	Climate	SEC	MISC	CTRL^x	SPI	t_h	ΔT_h	CTRL	η_t	Q_{defr}
Manufacturer 2	Cold	-76.4684	1.1	0.4225	0.00072	6552	14.5	0.65	0.9	5.82
	Average	-36.9572	1.1	0.4225	0.00072	5112	9.5	0.65	0.9	0.45
	Warm	-11.6962	1.1	0.4225	0.00072	4392	5	0.65	0.9	0

Figure 13 Calculated SEC value for the manufacturer 2

B.4 AEC & AHS calculation

The AEC and AHS value which is calculated in fig 14 was obtained from the equation 3 and 4 respectively and the data which are present in the table 4 and 5, and also with the calculation parameters from the manufacturer 2 specification are used.

	Climate	MISC	CTRL^x	SPI	t_h	ΔT_h	CTRL	η_t	Q_{defr}	AEC	AHS
Manufacturer 2	Cold	1.1	0.4225	0.00072	6552	14.5	0.65	0.9	5.82	963.0653	9181.503
	Average	1.1	0.4225	0.00072	5112	9.5	0.65	0.9	0.45	426.0653	4693.387
	Warm	1.1	0.4225	0.00072	4392	5	0.65	0.9	0	381.0653	2122.288

Figure 14 Calculated AEC and AHS value for the manufacturer 2

B.5 SEC classification

As per annex 1 SEC should be classified based on the average temperature value, that is approximately -36 so, manufacturer 1 product falls under A classification.

C. Manufacturer 3

C.1 Specifications [19]

General typology: Ducted ventilation unit

Ventilation control: Manual control

Motor and drive characteristics: Variable speed

Maximum airflow: 490 m^3/h

SPI: 0.44 $W/(m^3/h)$

Heat exchanger type: Rotary (belongs to Regenerative heat exchanger)

Thermal efficiency of heat exchanger: 78.9%

Sound power level: 56 dB(A)

C.2 Selecting calculating parameters

MISC = 1.1

CTRL = 1

x-value = 2

Q_{defr} = 0

C.3 SEC calculation

The SEC value which is calculated in fig 15 was obtained from the equation 1 and the data which are present in the table 4 and 5, and also with the calculation parameters from the manufacturer 3 specification.

	Climate	SEC	MISC	$CTRL^x$	SPI	t_h	ΔT_h	CTRL	η_t	Q_{defr}
Manufacturer 3	Cold	-68.4394	1.1	1	0.00044	6552	14.5	1	0.781	0
	Average	-28.2491	1.1	1	0.00044	5112	9.5	1	0.781	0
	Warm	-5.22527	1.1	1	0.00044	4392	5	1	0.781	0

Figure 15 Calculated SEC value for the manufacturer 3

C.4 AEC & AHS calculation

The AEC and AHS value which is calculated in fig 16 was obtained from the equation 3 and 4 respectively and the data which are present in the table 4 and 5, and also with the calculation parameters from the manufacturer 3 specification are used.

	Climate	MISC	$CTRL^x$	SPI	t_h	ΔT_h	CTRL	η_t	Q_{defr}	AEC	AHS
Manufacturer 3	Cold	1.1	1	0.00044	6552	14.5	1	0.781	0	551.1792	8221.891
	Average	1.1	1	0.00044	5112	9.5	1	0.781	0	551.1792	4202.854
	Warm	1.1	1	0.00044	4392	5	1	0.781	0	551.1792	1900.475

Figure 16 Calculated AEC and AHS value for the manufacturer 3

C.5 SEC classification

As per annex 1 SEC should be classified based on the average temperature value, that is approximately -28 so, manufacturer 1 product falls under B classification.

D. Manufacturer 4

D.1 Specifications [20]

General typology: Ducted ventilation unit

Ventilation control: Manual control

Motor and drive characteristics: Variable speed

Maximum airflow: 120 l/s= 432 m^3/h

SPI: 0.745 W/(m^3/h)

Heat exchanger type: Rotary (belongs to Regenerative heat exchanger)

Thermal efficiency of heat exchanger: 80%

Sound power level: dB(A)

D.2 Selecting calculating parameters

MISC = 1.1

CTRL = 1

x-value = 2

Q_{defr} = 0

D.3 SEC calculation

The SEC value which is calculated in fig 17 was obtained from the equation 1 and the data which are present in the table 4 and 5, and also with the calculation parameters from the manufacturer 4 specification.

	Climate	SEC	MISC	$CTRL^x$	SPI	t_h	ΔT_h	CTRL	η_t	Q_{defr}
Manufacturer 4	Cold	-63.1873	1.1	1	0.000745	6552	14.5	1	0.85	0
	Average	-20.8952	1.1	1	0.000745	5112	9.5	1	0.85	0
	Warm	3.332579	1.1	1	0.000745	4392	5	1	0.85	0

Figure 17 Calculated SEC value for the manufacture 4

D.4 AEC & AHS calculation

The AEC and AHS value which is calculated in fig 18 was obtained from the equation 3 and 4 respectively and the data which are present in the table 4 and 5, and also with the calculation parameters from the manufacturer 4 specification are used.

	Climate	MISC	$CTRL^x$	SPI	t_h	ΔT_h	CTRL	η_t	Q_{defr}	AEC	AHS
Manufacturer 4	Cold	1.1	1	0.000745	6552	14.5	1	0.85	0	933.2466	8651.847
	Average	1.1	1	0.000745	5112	9.5	1	0.85	0	933.2466	4422.638
	Warm	1.1	1	0.000745	4392	5	1	0.85	0	933.2466	1999.859

Figure 18 Calculated AEC and AHS value for the manufacturer 4

D.5 SEC classification

As per annex 1 SEC should be classified based on the average temperature value, that is approximately -20 so, manufacturer 1 product falls under classification D.

E. Manufacturer 5

E.1 Specifications [21]

General typology: Ducted ventilation unit

Ventilation control: Manual control

Motor and drive characteristics: Variable speed

Maximum airflow: 352 m^3/h

SPI: 0.2572 $W/(m^3/h)$

Heat exchanger type: Recuperative heat exchanger

Thermal efficiency of heat exchanger: 85%

Sound power level: 50dB(A)

E.2 Selecting calculating parameters

MISC = 1.1

CTRL = 1

x-value = 2

E.3 SEC calculation

The SEC value which is calculated in fig 19 was obtained from the equation 1 and the data which are present in the table 4 and 5, and also with the calculation parameters from the manufacturer 5 specification.

Manufacturer 5	Climate	SEC	MISC	$CTRL^x$	SPI	t_h	ΔT_h	CTRL	η_t	Q_{defr}
	Cold	-72.65	1.1	1	0.000257	6552	14.5	1	0.85	5.82
	Average	-35.7279	1.1	1	0.000257	5112	9.5	1	0.85	0.45
	Warm	-11.9501	1.1	1	0.000257	4392	5	1	0.85	0

Figure 19 Calculated SEC value for the manufacturer 5

E.4 AEC & AHS calculation

The AEC and AHS value which is calculated in fig 20 was obtained from the equation 3 and 4 respectively and the data which are present in the table 4 and 5, and also with the calculation parameters from the manufacturer 5 specification are used.

Manufacturer 5	Climate	MISC	$CTRL^x$	SPI	t_h	ΔT_h	CTRL	η_t	Q_{defr}	AEC	AHS
	Cold	1.1	1	0.000257	6552	14.5	1	0.85	5.82	903.9388	8651.847
	Average	1.1	1	0.000257	5112	9.5	1	0.85	0.45	366.9388	4422.638
	Warm	1.1	1	0.000257	4392	5	1	0.85	0	321.9388	1999.859

Figure 20 Calculated AEC and AHS value for the manufacturer 5

E.5 SEC classification

As per annex 1 SEC should be classified based on the average temperature value, that is approximately -35 so, manufacturer 1 product falls under A classification.

F. Manufacturer 6

F.1 Specifications [22]

General typology: Ducted ventilation unit

Ventilation control: Manual control

Motor and drive characteristics: Variable speed

Maximum airflow: 351cmf=396 m^3/h

SPI: 0.29 $W/(m^3/h)$

Heat exchanger type: Recuperative heat exchanger

Thermal efficiency of heat exchanger: 90%

Sound power level: 54.1dB(A)

F.2 Selecting calculating parameters

MISC = 1.1

CTRL = 1

x-value = 2

F.3 SEC calculation

The SEC value which is calculated in fig 21 was obtained from the equation 1 and the data which are present in the table 4 and 5, and also with the calculation parameters from the manufacturer 6 specification.

	Climate	SEC	MISC	$CTRL^x$	SPI	t_h	ΔT_h	CTRL	η_t	Q_{defr}
Manufacturer 5	Cold	-72.65	1.1	1	0.000257	6552	14.5	1	0.85	5.82
	Average	-35.7279	1.1	1	0.000257	5112	9.5	1	0.85	0.45
	Warm	-11.9501	1.1	1	0.000257	4392	5	1	0.85	0

Figure 21 Calculated SEC value for the manufacturer 6

F.4 AEC & AHS calculation

The AEC and AHS value which is calculated in fig 22 was obtained from the equation 3 and 4 respectively and the data which are present in the table 4 and 5, and also with the calculation parameters from the manufacturer 6 specification are used.

	Climate	MISC	$CTRL^x$	SPI	t_h	ΔT_h	CTRL	η_t	Q_{defr}	AEC	AHS
Manufacturer 5	Cold	1.1	1	0.000257	6552	14.5	1	0.85	5.82	903.9388	8651.847
	Average	1.1	1	0.000257	5112	9.5	1	0.85	0.45	366.9388	4422.638
	Warm	1.1	1	0.000257	4392	5	1	0.85	0	321.9388	1999.859

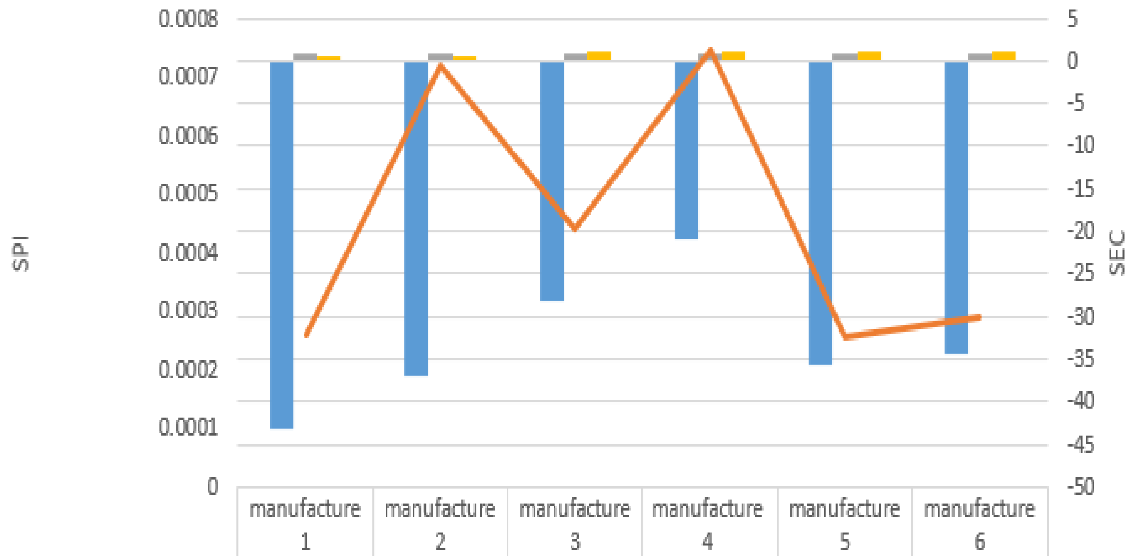
Figure 22 Calculated AEC and AHS value for the manufacturer 6

F.5 SEC classification

As per annex 1 SEC should be classified based on the average temperature value, that is approximately -35 so, manufacturer 1 product falls under A classification.

3.3 Results

3.3.1 Comparison between SEC and SPI of different manufacturers for the average temperature condition



	manufacture 1	manufacture 2	manufacture 3	manufacture 4	manufacture 5	manufacture 6
SEC	-43.07961082	-36.95723822	-28.24905905	-20.89521697	-35.72791297	-34.37592401
thermal efficiency	88%	90%	78%	85%	85%	84%
CTRL	0.65	0.65	1	1	1	1
SPI	0.00026	0.00072	0.00044	0.000745	0.000257	0.00029

Figure 23 Comparison of SEC and SPI values

a. The objective of this graph is mainly to compare and see how SPI, thermal efficiency, and CTRL value affects SEC value.

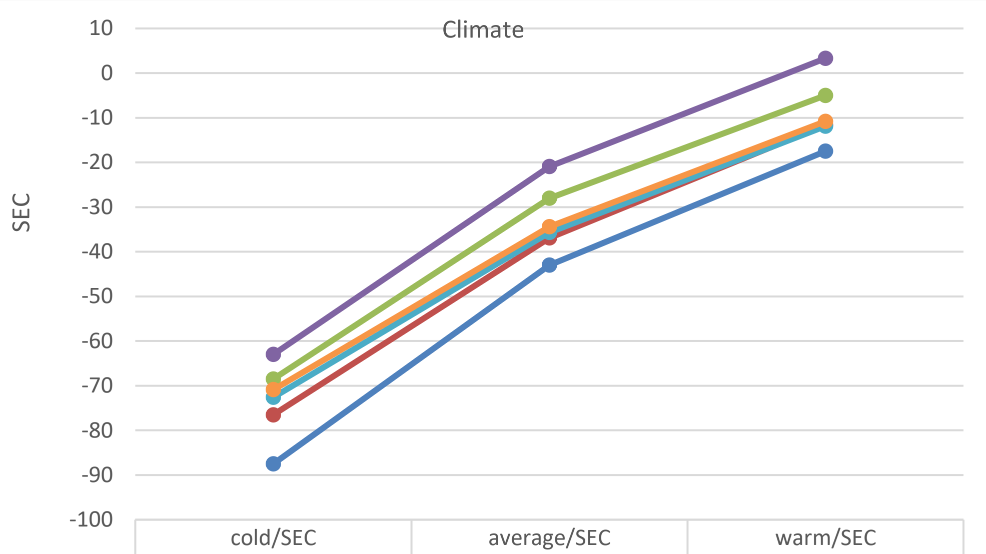
b. In this graph, we are mainly comparing SEC and SPI values of different manufacturers for average climate condition using clustered column-line graph.

c. Firstly, let's see for lowest SPI values i.e. manufacture 5 with 0.257 W/(m^3/h) and manufacture 1 with 0.26 W/(m^3/h), which are almost equal to one another have SEC values approximately -36 and -43 respectively. Reason for this large difference in SEC values is mainly because of the two factors, the thermal efficiency of manufacture 1 one is slightly higher than lowest SPI value one and CTRL factor of lowest SPI value is slightly more than that of the other. Because of these two factors even with lowest SPI value has lower SEC value compared to that of other manufacture.

d. In case of the almost best and worst SEC values, main impacting factor between them is because of the large difference in SPI value. SEC value decreases significantly with increase in SPI value as shown in the graph. This can be clearly seen in the manufacture 5 and 4 which have similar thermal efficiency and CRTL values.
e. In case of manufacture 2 and 4 which have almost similar SPI values, and both of those values significantly higher values compared to other manufactures SPI values, even with higher SPI value manufacture 3 has the second lowest SEC value. It's because of the thermal efficiency and CRTL values favouring the manufacture 2.
f. Now let's see for manufacture 3 which has lowest thermal efficiency compared to others and manufacturer 4 which has worst SEC score compared to others, both manufactures have similar CRTL value. Even with lowest thermal efficiency manufacture 3 has better SEC score that is because of the lower SPI compared to manufacture 4.
g. From all above interpretation, we can conclude from this graph is that SPI and CTRL values play a huge role in decreasing SEC value, lower SEC value means better classification that machine has and thermal efficiency may not be the main game-changing factor in SEC calculation.

3.3.2 Comparison of SEC values of different manufacturers for different climate conditions

a. The objective of this graph is mainly to see how SEC value behaves in different climatic condition.
b. In this graph, we are comparing SEC values of different manufacturers for different climatic condition using a line graph.
c. We can clearly see that manufacture 1 has consistently better SEC values in different climates compared to others.
d. SEC values of manufactures 2,5 and 6 behave almost similar to one another for all climatic conditions.
e. Even though manufacture 2 is slightly better than manufacture 5 in cold and average climatic condition, manufacture 5 has slightly better SEC value in warm climate compared to manufacture 2.



	cold/SEC	average/SEC	warm/SEC
manufacture 1	-87.5	-43	-17.5
manufacture 2	-76.5	-36.9	-11.6
manufacture 3	-68.5	-28	-5
manufacture 4	-63	-20.9	3.3
manufacture 5	-72.6	-35.7	-11.9
manufacture 6	-70.9	-34.4	-10.8

Figure 24 Comparison of SEC values of different manufacturers for different climate conditions

f. We can clearly see that manufacture 4 has consistently worst SEC values in different climates Compared to others.

g. From all above interpretation, we can conclude from this graph is that SEC and climatic condition are strongly connected with each other and SEC value increases with increasing climatic changes.

3.3.3 Comparison between AEC, AHS and SEC of different manufacturers

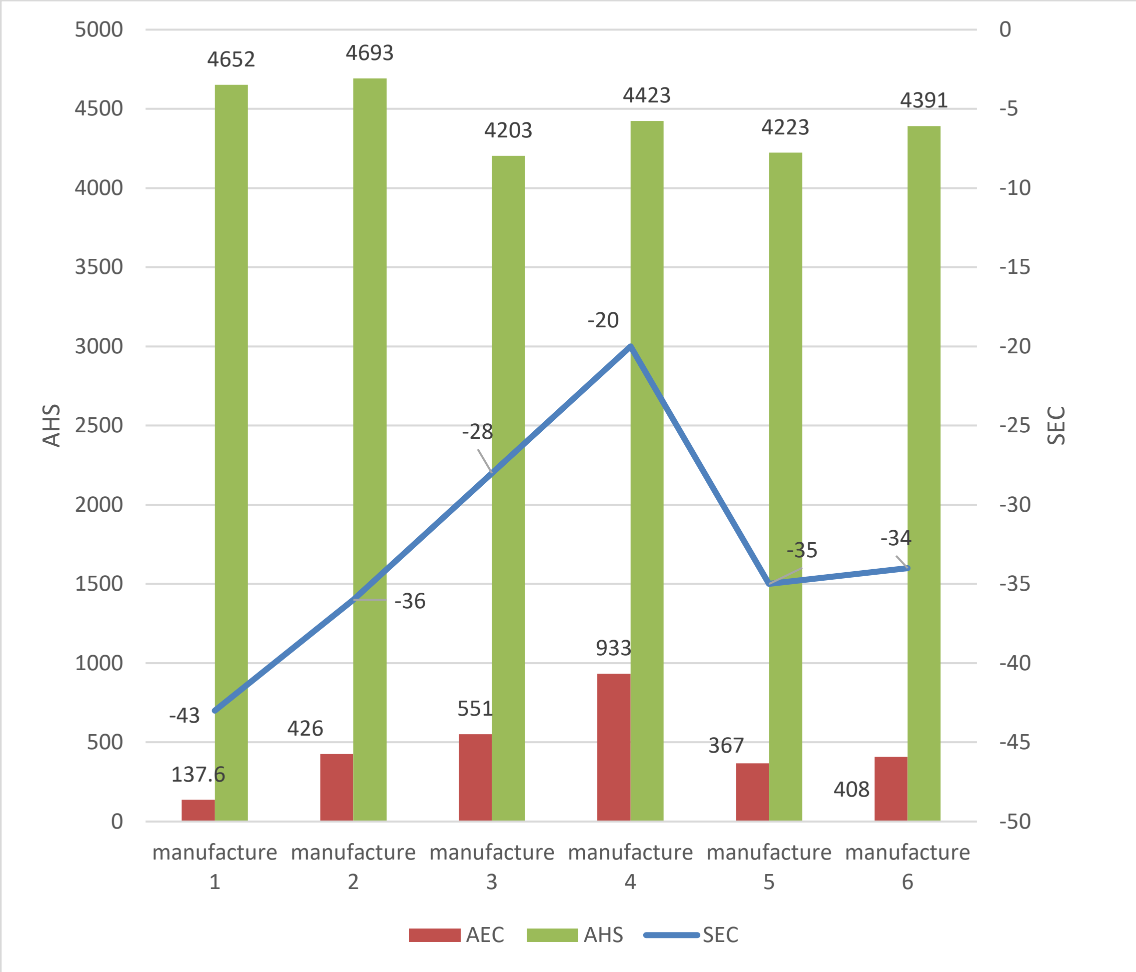


Figure 25 Comparison between AEC, AHS and SEC of different manufacturers

a. The objective of this graph is mainly to see how SEC value affects AEC and AHS of RVUs.
b. In this graph, we are mainly comparing SEC with AHS and AEC values of different manufacturers for average climatic condition using clustered column-line graph.
c. Although all manufacturers have almost similar AHS, their AEC and SEC values vary with one another.

d. Manufacture 1 has the best SEC value among others with lowest AEC, which indicates it has the ideal condition for the best RVU.
e. Manufacture 4 with worst SEC value has highest AEC compared to others, which makes it worst RVU compared to others.
f. Manufactures 2, 5 and 6 with almost similar SEC values have almost similar AEC.
g. Manufacture 5 with SEC value of -35 has better AEC compared to the manufacture 6 which has lower SEC value of -34.
h. From all above interpretation, we can conclude from this graph is that lower the SEC values yield lower AEC as those machines are better energy rated in terms of classification and AHS for almost all the machines are almost similar.

3.3.4 Comparison between AEC of different manufacturers

a. The objective of this graph is mainly to see how AEC value behaves for climatic changes.
b. In this graph we are mainly comparing AEC of different manufacturers for different climatic condition using a clustered line graph.
c. Manufactures 1, 3 and 4 ‘s AEC values doesn’t alter even when there a change in climatic condition this is because these RVUs use a regenerative heat exchanger. As regenerative heat exchanger has the annual heating energy for defrosting is zero.
d. Manufactures 2, 5 and 6 ‘s AEC values almost parallel to each other even when their values alter along with a change in climatic condition. This is because these RVUs use a recuperative heat exchanger.
e. Manufacture 1 has the lowest AEC compared to other manufacturer which indicates it’s the best among all other manufacturers.

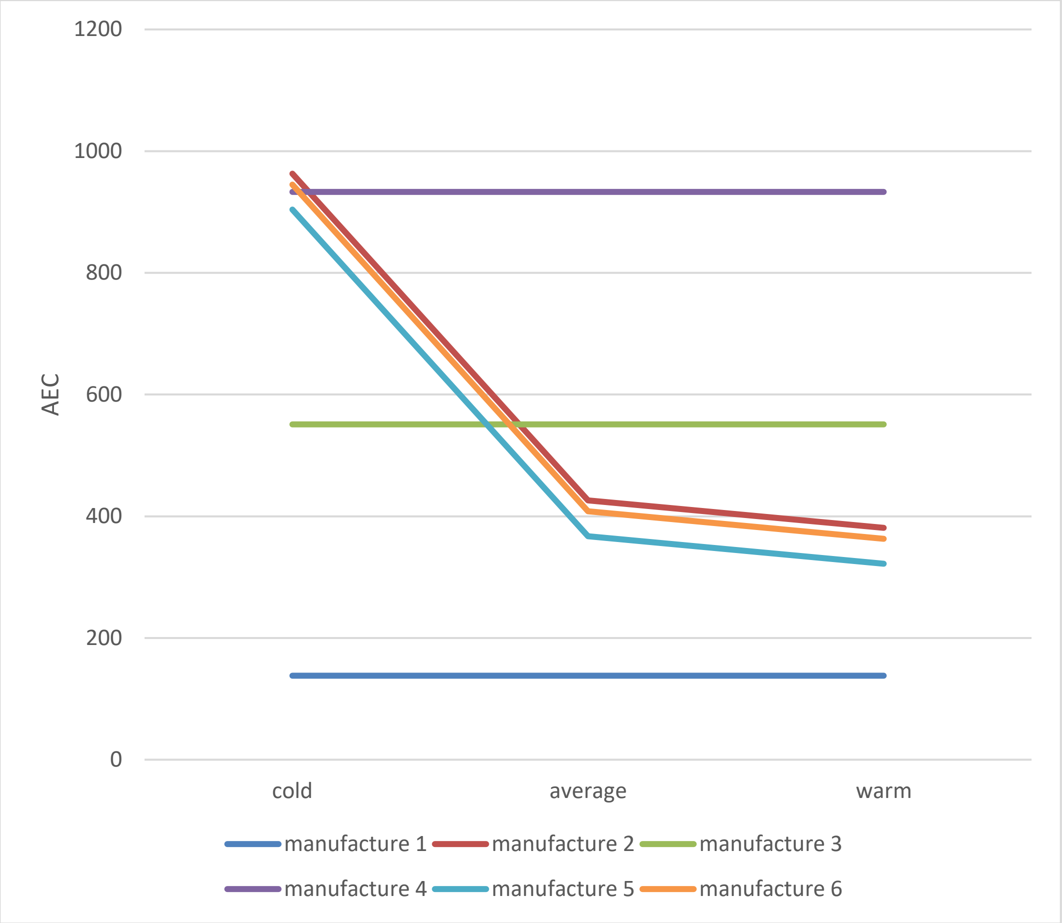


Figure 26 Comparison between AEC of different manufacturers

f. Even though manufacture 2 and 6 have the higher AEC compared to manufacture 1 at cold climatic condition but it takes lead for average and warm climate in AEC values which indicates even with early AEC value advantage, manufacture 4 is worst among other manufacturers.

g. From all above interpretation, we can conclude from this graph is that AEC doesn't change with climatic condition changes if it has regenerative heat exchangers and climatic condition are one of the strong influencing factor if it has recuperative heat exchanger as AEC value changes along with the climatic condition changing.

4. Conclusion and Future Work

4.1 Conclusion

The main question we have to ask ourselves in a sustainable point of view is that whether RVU is it worth replacing conventional heating means in colder regions. If we look at conventional gas space heaters, their price ranges from 500 to 1200 euros. For comparison purpose let us consider a gas heater worth 800 euros one which has an input of 65000 BTU/hr [23] which is approximately 19 kWh. And if we look at conventional electric space heaters, which has cheap price pool compared to both gas space heaters and RVUs which have a starting from 100 – 600 euros. For comparison purpose let us consider an electric heater worth 500 euro one which has an input of 9.2 kWh [24] and RVUs with heat exchanger price varies from 1000 – 2000 euros. When it comes to rating which is best among these, the price of investment alone cant be the main factor as we have to consider their annual working cost also.

Let us consider cold climate as the working condition, for which working hours will be 6552 per year as per the data provided in the document "COMMISSION DELEGATED REGULATION (EU) No 1254/2014 of supplementing Directive 2010/30/EU", so we will use approximately 124488 kWh/a if it's a gas space heater[16] and 60278 kWh/a if its an electric space heater[17]. If we compare these results with the worst RVU product which is used in our calculation i.e product of manufacture D which got the classification of D which is with worst classification compared to other manufacturers which are in our study has an AEC of 933 kWh/a. So it's safe to say that even the worst RVU has the lower Annual Energy Consumption compared to the gas and electric space heaters which are mentioned above.

Now let us compare those units for average climate condition as the working condition with working hours of 5112 per year as per the data provided in the document "COMMISSION DELEGATED REGULATION (EU) No 1254/2014 of supplementing Directive 2010/30/EU", conventional gas heater consumes around 97128 kWh/a worth of energy and conventional electrical heater consumes around 47030 kWh/a worth of energy. If we check Annual Energy Consumption of the same worst RVU which we considered for the last comparison, it consumes 933kWh/a worth of energy. So we can tell that when it comes to AEC, RVUs energy consumption is considerably less when compared to typical gas and electric space heaters.

Even though RVUs initial investment is high, their AEC compared to conventional means of space heating is quite less and if we go for a unit which is rated higher in the classification with regenerative heat exchangers like product from manufacturer A, will have AEC of 137 kWh/a. RVUs will have lower investment and working cost combined compared to conventional means of space heating.

SPI and CTRL values play a huge role in decreasing SEC value, lower SEC value means better classification of RVUs and thermal efficiency may not be the main game-changing factor in SEC calculation. So we can say that RVU with regenerative heat exchanger and lower SEC values are worth investing.

When it comes to the chosing the best method for space heating, by chosing RVUs with heat exchangers we can help reduce environmental impact caused by the conventional means of space heating which uses enormous amount of fuel. At the same time RVUs with heat recovery uses a small quantity of energy to heat up the same space area.

4.2 Future work

As we saw in the article from REHVA which was in bibliography, there is a lot of hope for RVUs with heat exchangers as more and more building which are constructed in the recent year contains provisions for these units and standard regulations for building constructions are changing. And building which is constructed in mind as nearly zero energy, ventilation with heat recovery is necessary.

As implementing of RVU with heat exchangers in a house is a booming field, as world tends to move towards renewable energy. we will see more research in this field as they can use solar panels to generate energy required by the RVU or they can use geothermal energy to heat up the air which is supplied to the house during winter seasons.

As per the article which was published by REHVA which was mentioned in bibliography if we consider Portugal, there is a lot of growth space for implementing RVUs with heat exchangers, that is because till 2004 they were still using natural ventilation with fan assistance.

Documentory References and Other Sources of Information

[1] CHENARI, Behrang; DIAS CARRILHO, João; GAMEIRO DA SILVA, Manuel – '*Towards sustainable, energy-efficient and healthy ventilation strategies in buildings: A review', Renewable and Sustainable Energy Reviews*, 2016.

[2] A, Vallati; S, Grignaffinia; M, Romagnaa; L, Maurib; C, Coluccia. – *Influence of Street Canyon's Microclimate on the Energy demand for space cooling and heating of buildings,* Turin, Italy, 2016.

[3] LIDDAMENT, M W – '*A review of ventilation and the quality of ventilation air.', Indoor air*, United Kingdom, Volume 10, Issue 3, 2000, pages 193-199.

[4] PÉREZ-LOMBARD, Luis; ORTIZ, José; POUT, Christine – *'A review on buildings energy consumption information', Energy and Buildings*, Volume 40, Issue 3, 2008, pages 394-398.

[5] MAITNIYAZI Bake; ASHISH Shukla; SHULI Liu – *'Performance study of low-energy solar ventilation unit for residential application*'. Bologna, 2017.

[6] BEARG W, David – *Indoor Air Quality and HVAC Systems.* New York: Lewis Publishers,1993.

[7] MAX Sherman; NANCE Matson – *Residential Ventilation and Energy Characteristics.* California,*1997.*

[8] MARTIN Holladay – *BLOG ARTICLE: How Much Fresh Air Does Your Home Need?*, 2013.

[9] Passive stock ventilation figure, Available online: https://www.practicaldiy.com/self-build/ventilation/passive-stack-ventilation.php

[10] Central extract ventilation figure, Available online: https://www.pinterest.pt/pin/273171533620369891/

[11] KLENCK, Thomas – *How it* Works*: Heat Recovery Ventilation*, Online article, 2000.

[12] Pictorial representation of how stale air is removed, and fresh air is transferred in a House, Available online:http://www.thompsonellis.co.uk/products/mvhr/

[13] K SHAH, Ramesh; P SEKULIC, Dusan – *Fundamentals of Heat Exchanger Design*, 2003.

[14] A J, Willmott – Regenerative Heat Exchangers,2011

[15] “COMMISSION DELEGATED REGULATION (EU) No 1254/2014” *supplementing Directive 2010/30/EU of the European Parliament and of the Council with regards to energy labelling of Residential Ventilation Units,* Official Journal C 416, 2016, pages 16–30.

[16] ANDREI, Litiu – *Ventilation system types in some EU countries*, 2012

[17] Manufacturer 1 product specifications, Available online: http://www.komfovent.com/residential-ventilation-units/domekt-r/468

[18] Manufacturer 2 product specifications, Available online: http://us.klingenburg.de/knowledge/regeneration-recuperation/

[19] Manufacturer 3 product specifications, Available online: http://thomosventilation.en.made-in-china.com/product/rKlmIVRLXZkb/China-High-Quality-Central-Ventilator-Air-Conditioning-with-Heat-Recovery-THB500-.html

[20] Manufacturer 4 product specifications, Available online: http://www.flaktwoods.com/products/air-treatment/air-handling-unit-residential/rdas/

[21] Manufacturer 5 product specifications, Available online: http://www.swegon.com/en/Products/Home-Ventilation/Ventilation-Units/Rotary-heat-exchanger-R-series/CASA-R120-Premium/

[22] Manufacturer 6 product specifications, Available online: http://www.titon.co.uk/pages/ventilation-systems/mvhr/hrv-2.85-q-plus.php

[23] Manufacturer product specifications, Available online: http://www.homedepot.com/p/Williams-65-000-BTU-hr-Enclosed-Front-Console-Propane-Gas-Room-Heater-6501521A/202906983

[24] Manufacturer product specifications, Available online: http://www.homedepot.com/p/Williams-31-400-BTU-Hr-9-2-kW-Forsaire-Counterflow-Electric-Wall-Furnace-3144030/202903164

ANNEX 1 Specific Energy Consumption Classes[15]

SEC classes of residential ventilation units calculated for average climate.

Classification from 1 January 2016 of commission delegated regulation (EU) No 1254/2014

Table 6 SEC classification [15]

SEC Class	**SEC in kWh/a.m^2**
A+	SEC < -42
A	-42 ≤ SEC < -34
B	-34 ≤ SEC < -26
C	-26 ≤ SEC < -23
D	-23 ≤ SEC < -20
E	-20 ≤ SEC < -10
F	-10 ≤ SEC < 0
G	0 ≤ SEC

As per the document presented by the commission delegated regulations (EU) No 1254/2014 of 2016 states that products with a SEC values less than “-42” during its average temperature working time is graded with “A+” classification which is the highest classification rating which can be obtained. And a SEC values of zero and the positive number gets the lowest classification i.e. “G”.

ANNEX 2 The Label[15]

a. From 1 January 2016, afterward marketing for UVUs labelling started.

The label shall provide the following information.

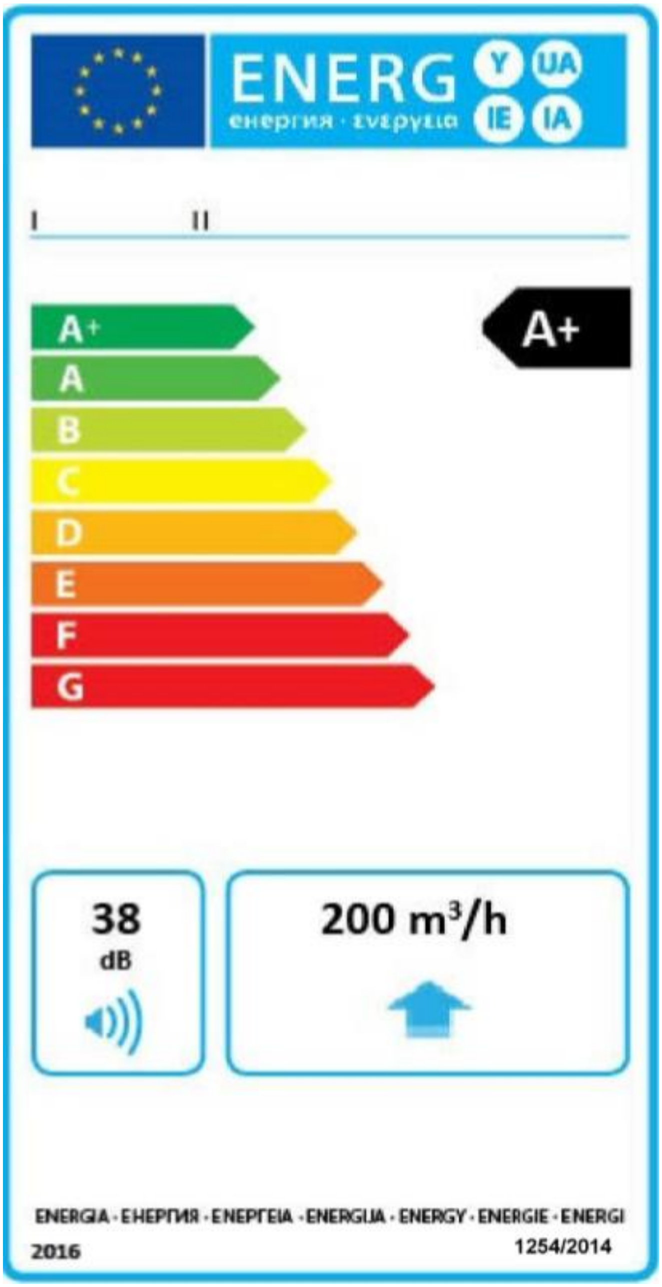


Figure 27 Label for UVUs [15]

1. Suppliers name or trademark
2. Suppliers model identifier

3. Energy efficiency, head of the arrow containing both of the energy efficiency class of the appliance and relevant energy efficiency class should be at same height.
4. Sound power level rounded to the nearest integer (dB).
5. For representing UVUs, maximum flow rate (m^3/h) is rounded to the nearest integer and it should be accompanied by one arrow.

b. From 1 January 2016, afterward marketing for BVUs labelling started.

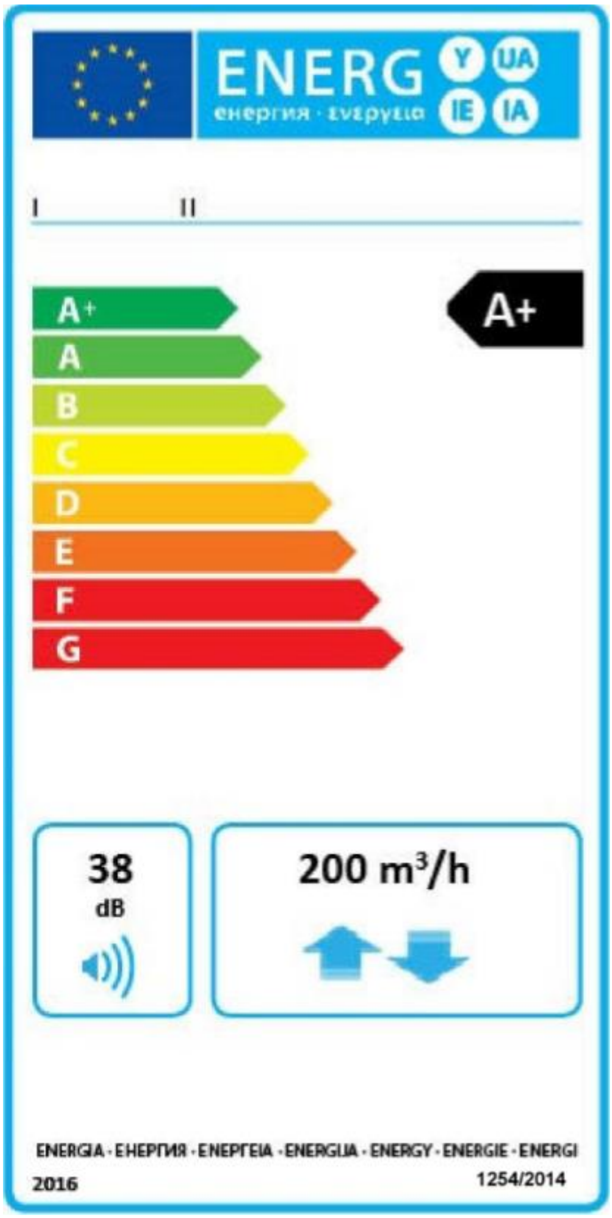


Figure 28 Label for BUVs [15]

The label shall provide the following information.

1. Supplier's name or trademark.
2. Suppliers model identifier.
3. Energy efficiency, head of the arrow containing both of the energy efficiency class of the appliance and relevant energy efficiency class should be at same height.
4. Sound power level rounded to the nearest integer (dB).
5. For representing UVUs, maximum flow rate (m^3/h) is rounded to the nearest integer and it should be accompanied by one arrow.

c. The design of the labels for residential ventilation units shown in points 6.1 and 6.2 shall be as constructed as shown below.

Whereby,

(a) The label dimensions should be at least 75 mm wide and 150 mm high and printed in a larger format.
(b) The background should be white.
(c) Colours used are CMYK- cyan, magenta, yellow and black.
For example, 00-20-00-X: 0% cyan, 20% magenta ,0% yellow and 100 % black.

Following requirements should be fulfilled by the above-shown label (numbers refer to the figure above)

1. **EU label border stroke:** 3.5 pt – Colour: X-00-00-00,
round corners: 2.5mm.
2. EU LOGO: colour: X-80-00-00 and 00-00-X-00.
3. Energy logo: Colour: X-00-00-00.
Pictogram as depicted: EU logo+energy logo: width 62 mm, height 12 mm.
4. Sub-logo border: 1 pt- colour: X-00-00-00, length:62 mm.
5. A+ - G Scales:
- Arrow: height: 6mm, gap 1mm
Colours: A+ class: X-00-X-00
A class: 70-00-X-00
B class: 30-00-X-00

C class: 00-00-X-00

D class: 00-30-X-00

E class: 00-70-X-00

F class: 00-X-X-00

G class: 00-X-X-00

- text: Calibri bold 13 pt, paitals , white

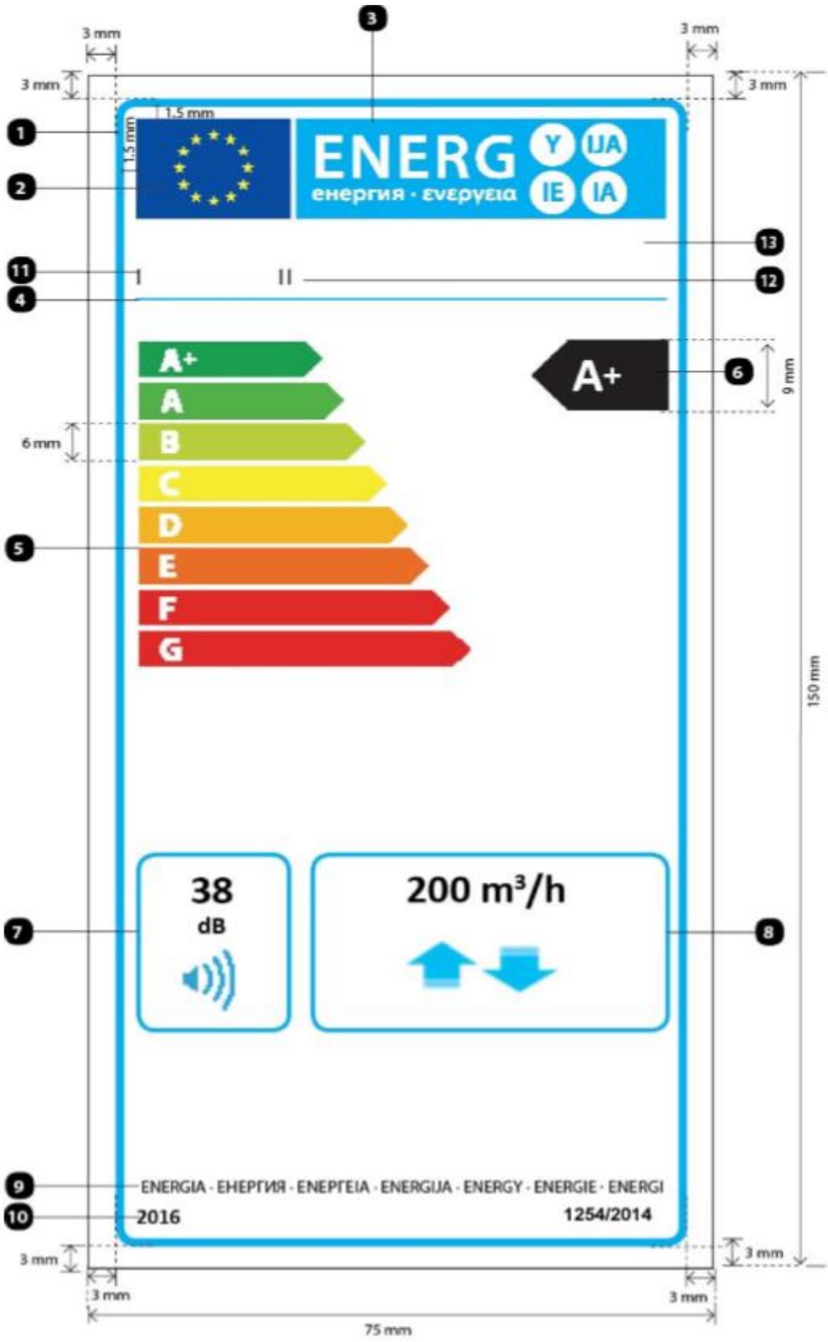


Figure 29 Design of the label for RVUs [15]

6. **SEC class**
   - Arrow: width 17 mm, height: 9 mm, colour: 00-00-00-X
   - text: Calibri bold 18.5 pt, capitals, white, ‘+’ symbols: Calibri bold 11 pt, white aligned on a single row.

7. **Sound power level (dB)**
   -border:1.5 pt, colour:X-00-00-00, round corners: 2.5 mm.
   -value: Calibri bold 16 pt, colour: 00-00-00-X.
   -‘dB’: Calibri regular 10 pt, colour : 00-00-00-X.
8. **Maximum flow rate (m^3/h)**
   -Border: 1.5pt, colour:X-00-00-00, round corners: 2.5mm.
   -Value: Calibri bold 16 pt, colour: 00-00-00-X.
   -‘m^3/h’: Calibri bold 16 pt, colour: 00-00-00-X.

   -One or two arrows
   - each width:10mm, each height: 10mm.
   - Colour: X-00-00-00.
9. **Energy**
   - Text: Calibri regular 6pt, capitals, colour:00-00-00-X
10. **Reference period**
    -Text: Calibri bold 8 pt
11. **Supplier’s name or trademark**
12. **Supplier’s model identifier**
13. Suppliers’ name or trademark and model identifier shall fit in a space of 62x10 mm.

ANNEX 3 Technical Documentation[15]

The technical documentation provided with the product should include the following things,

[1] Name and address of the suppliers.

[2] Suppliers model identifiers.

[3] Where appropriate, reference to the standards applied.

[4] Where appropriate, calculation methods, measurement standards, specifications used and technical parameters for measurements.

[5] Overall dimensions and specification of the type of RVU.

[6] SEC class of that model as stated in Annex 2 and Sec for each applicable climate zone.

[7] Sound power level in L_{WA}.

[8] Results of the calculations.