Achieving Acceptable Indoor Air Quality with Unitary Air Conditioning Units in Hot and Humid Climates

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Abstract

The use of unitary air conditioning units is expanding rapidly throughout the world, especially in hot and humid climates. Such units comprise predominantly of direct expansion refrigerant systems with wall mounted, ceiling mounted and floor mounted indoor units coupled to an external air-cooled condensing unit with refrigerant piping. They are robust and reliable units, readily available, economical to procure and simple to install. In Asia, many establishments including hotels, offices, restaurants and schools are solely relying on such units to provide cooling either whole year round or during the summer season. In relation to the cooling of an enclosed building, indoor air quality is now a major concern for building designers and engineers specifying air conditioning systems. It is not just enough to cool an enclosed space. The resultant quality of air must be of acceptable quality with respect to odour, suspended particles, chemical contaminants, bacteria, moisture and mould. Achieving acceptable indoor air quality with unitary air conditioning units poses a major challenge to the specifiers, the manufacturers and to the end-users of such systems. This is because the very simplicity and relatively low cost of such systems does not allow for elaborate fresh air intake and exhaust systems that are commonly part of large air conditioning systems employing air handling units with ducting and diffusers. Nonetheless the continued use of unitary air conditioning units globally necessitates that measures be taken to ensure that acceptable indoor air quality can be achieved. The engineers who specify such units need to incorporate fresh air intake whenever possible and duct the fresh air into the indoor units. Exhaust can be localised through ceiling or wall fans. The manufacturers need to increase R&D for the indoor units to produce better filtration with chemical filters and normal dust filters to eliminate odours and dust. In addition manufacturers can incorporate other techniques into the indoor units such as ionization or ozonisation and even additional fans to exhaust room air and bring in fresh air. Academics and researchers need to conduct research into the indoor air quality typically achieved using unitary air conditioning units. Prolonged measurements of various air quality indicators in establishments using such units will reveal useful data for designers and manufacturers. End-users should be aware of the limitations of unitary air conditioning units with respect to indoor air quality and practice good space management such as banning smoking and other activities that release undesirable odours and chemicals. Last but not least local authorities need to re-examine building codes especially with regard to space and ventilation and ensure sufficient legislation to protect the health of occupants of indoor spaces cooled by such units. Unitary air conditioning units will not go away. Fortunately, achieving acceptable indoor air quality with such units is not a task insurmountable. The team effort of all key industry players can and will provide the necessary solutions and ASHRAE is well poised to be the leader in this endeavour.

Keywords: Unitary Air Conditioning Units

1. Introduction

Air conditioning is now almost mandatory in any indoor commercial, educational and residential space especially in the hot and humid climates of Asia. It is no longer considered a luxury to work, shop, study, eat or even sleep in an air conditioned environment. Indeed, without the comfort of air conditioning it would not be possible for the occupants of countries or regions with hot and humid climates to raise their productivity level whether in the office, classroom or specialized manufacturing facility and compete globally with those in the temperate countries.

The rapidly developing economies or economic regions in Asia are located mainly in hot and humid climatic zones. Most businesses are housed in smaller premises, factories and warehouses. Air conditioning for these premises are practically synonymous with unitary air conditioning units. Typically, the business operator will install several of these units in their premises to provide the necessary air conditioning. To most of them this is deemed sufficient. Rarely would they think about the resultant indoor air quality unless there is some major health issue or complaint. Most of the occupants or customers who patronize these businesses also do not think about indoor air quality especially where smoking

is allowed. Table 1 lists the major businesses that are typically served by unitary air conditioners.

Table 1. Businesses with unitary air conditioners

Business	Typical unit
Office	Wall mounted
Retail shop	Ceiling Cassette
Restaurant	Ceiling Cassette and floor unit
Hairdresser	Ceiling cassette and wall mounted
Clinic	Wall mounted
Classrooms	Ceiling cassette and wall mounted
Coffee shop	Ceiling Cassette
Hotel room	Wall mounted

The HVAC engineer almost never ever contributes any input to these air conditioning installations. The business operators will just buy the units from a retail shop and get them installed with minimum fuss. Various measures therefore need to be taken to ensure that the air quality in these premises will meet acceptable standards and everybody concerned has a part to play.

2. Unitary air conditioners

2.1 Definition

Unitary air conditioners are factory-made assemblies that normally include an evaporator or cooling coil and a compressor-condenser combination [1].

Room air conditioners are encased assemblies designed primarily for mounting in a window or through a wall and are sometimes called window air conditioners. A unitary air conditioner with more than one factory-made assembly is commonly called a split system [1]. It basically comprises an indoor unit with the evaporator and blower and an outdoor unit with the compressor and condenser coil and fan coupled with refrigeration piping.

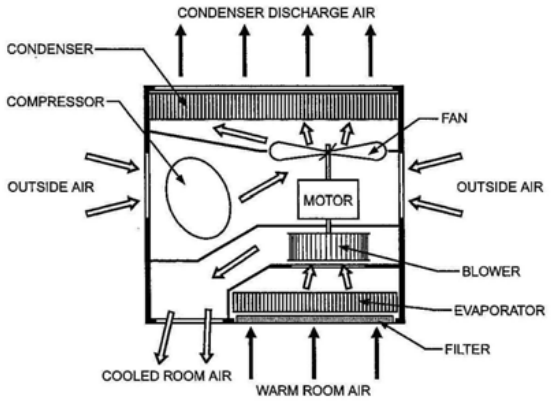

Fig. 1. Schematic view of typical room air conditioner[1]

Figure 1 shows a typical room air conditioner while Figures 2 and 3 show typical split systems that are commonly used and these include wall mounted, floor mounted, under ceiling mounted and ceiling cassettes.

Room air conditioners incorporate a lever marked “ventilation” and this opens or close a flap in the casing and allow the unit to draw in some outdoor air. However they require a large hole to be knocked in the wall and is also noisy as the compressor noise is audible in conditioned space. Room air conditioners are there uncommon in Asia except perhaps for Hong Kong.

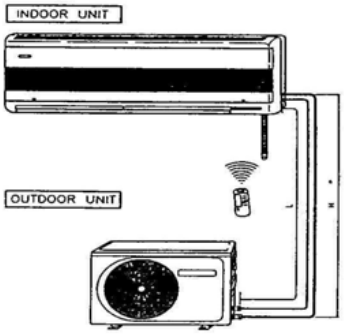

Fig. 2. Typical split system air conditioners (wall mounted)

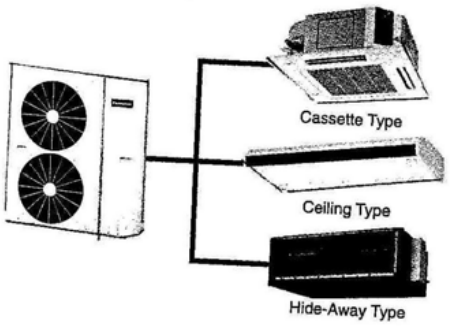

Fig. 3. Typical split system air conditioners (cassette under ceiling and concealed)

Split systems are most commonly used as they easy to install requiring only a small hole in the wall are also less noisy as the compressor is in the out unit which can be located away from the conditi space (to the limits of the refrigeration piping len Split systems can incorporate a ducted air distribu system with diffusers and grilles where the ductwo connected to the indoor unit which is usually conce inside the ceiling space. However they are less com and are only used in larger premises and new build The rest of this paper will focus only on split syster conditioners without ducting.

2.2 Construction of units

The split system air conditioner comprises the in unit and the outdoor unit coupled with suction and li line refrigerating piping. The indoor unit is made u the evaporator coil, blower fan, filters and elect components while the outdoor unit comprises compressor, the air cooled condenser coil, the conde fan and electrical components.

Both indoor and outdoor units are housed in rc casings. The outdoor unit is basically the s construction for all the various types of indoor units. difference lies in the type of indoor unit. Table 2 list common indoor unit construction which varies basi

due to the cooling capacity of the unit and also the aesthetics. Note that for a certain cooling capacity the indoor unit is available in all the construction types and the choice will then largely be based on aesthetics, space available for installation and pricing.

Table 2. Common split system indoor unit construction

Type	Typical cooling capacity (kw)	Remark
Wall mounted	2.64 – 7.03	Most common
Ceiling Cassette	5.26 – 14.65	Most aesthetic
Tall floor mounted	7.03 – 14.65	Used in China
Under ceiling	5.26 – 17.60	Can be floor mounted

2.3 Application and installation

Wall mounted units are the most commonly used split system. Due to mass production and almost mandatory installation in residences, their price has dropped significantly over the last ten years. In the minds of the general public, air conditioning is almost synonymous with the ubiquitous wall mounted split system. Their availability in many capacities and relatively low cost also make them the first choice in small offices and retail outlets.

Ceiling cassette and under ceiling units are generally used when larger capacities are required for larger premises. Ceiling cassettes can be installed more evenly over a large air conditioned space and provide more even air distribution. In contrast, under ceiling units need to be located near walls to conceal the refrigerant piping and drain outlet and therefore may not provide sufficient air distribution for large open spaces.

Tall floor mounted units are more common in China especially in restaurants. They are less common in South East Asia where most restaurants use cassettes or under ceiling units.

Figure 4 shows a typical split system installation with one outdoor unit coupled to one indoor wall mounted unit. The installation is basically the same for the other types of indoor units with perhaps the ceiling cassette as the most different as the indoor unit is concealed inside the ceiling with its fascia flushed with the ceiling. In addition the ceiling cassette comes with an in-built drain pump for the condensate to be pumped away.

Most manufacturers recommend a maximum refrigeration piping length of 7 to 15 metres with a maximum elevation between indoor and outdoor units of 5 to 7 metres depending on the capacity of the split system. These constraints severely limit the application of split systems to small premises or where the outdoor unit is installed on a wall bracket immediately outside the conditioned space.

To overcome these constraints manufacturers have come up with variable refrigerant flow (VRF) split systems using inverter control of the traditional compressor or the more recent digital scroll compressor technology. VRF systems not only allow much longer refrigerant piping of up to 100 metres but also allow up to 30 indoor units to be connected to one outdoor unit.

The issue of indoor air quality largely involves indoor unit which is the same type regardless of wh it is a simple single split system or multiple unit system.

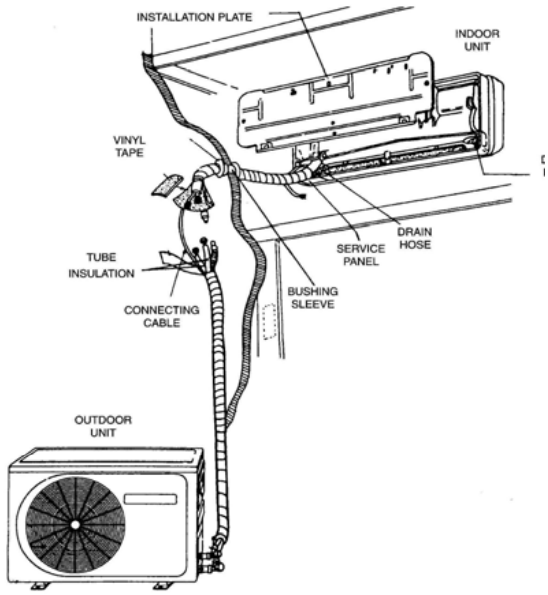

Fig. 4. Typical split system installation

2.4 Worldwide usage

The sale of unitary air conditioning units world is growing at a tremendous pace. Table 3 shows estimates of world demand for room air conditio which cover the room or window unit and the simple system. It is estimated that over 56 million of these will be sold in 2008 with Asia accounting for nearly of the total.

The HVAC industry and all its players espec those in North America cannot ignore these statistics mentioned above, the HVAC engineer is seldom invo in the selection and installation of these units and per this is the reason there is little technical literature o subject even from ASHRAE.

At the Region XIII Chapters Regional Conferen Hong Kong in 2005 the Malaysia Chapter of ASH submitted a motion that ASHRAE develop and a Chapter on Split Unit Air Conditioners in the upco 2008 ASHRAE HVAC Systems and Equip Handbook under the section on Unitary Equipment. Split Unit Air Conditioners shall include wall mou under ceiling mounted and ceiling cassette units consideration for air filtration and ventilation. ASH society has responded positively to this motion a technical committee has been set up to look into it.

3. Indoor air quality

3.1 Definition

Indoor air quality (IAQ) is all about creating indoor environment that is conducive to the com health and safety of the occupants leading to sustained well-being and productivity. Comfo basically dependant on the indoor dry bulb tempera

Table 3. World demand for room and split system air conditioners (in thousands of units) [2]

	2001 Actual	2002 Actual	2003 Actual	2004 Projected	2005 Forecast	2006 Forecast	2007 Forecast	20 Fore
World total	**34,695**	**36,212**	**43,352**	**46,559**	**48,655**	**50,967**	**53,409**	**56**
Japan	7,638	6,898	6,633	6,931	6,800	6,800	6,800	6
Asia (excl Japan)	14,593	15,558	21,187	23,733	25,448	27,295	29,284	31
Middle East	1,394	1,475	1,878	2,001	2,130	2,212	2,259	2
Europe	2,477	2,958	3,930	4,324	4,592	4,861	5,149	5
North America	5,581	6,235	6,300	5,945	5,945	5,947	5,949	5
Central & South America	1,793	1,864	2,054	2,135	2,218	2,269	2,323	2
Africa	714	651	763	795	827	854	881	
Oceania	506	572	607	696	696	730	765	

(*Source: Japan Refrigeration and Air Conditioning Industry Association*)

and relative humidity while health and safety is dependant on the level of indoor air pollution. Table 4 shows the common contributors to indoor air pollution in typical modern indoor environments. These airborne contaminants are either due to infiltration from outside or released indoors by building materials, furnishings, equipment, industrial and biological processes and the occupants themselves.

Table 4. Common indoor air contaminants

Type	Examples	Source
Biological particles	Viruses, bacteria, mould, spores, fungi, algae, dust mites	Plants, moisture, people, animals
Dust particles	Synthetic fibres, asbestos, smoke, diesel,	Cigarettes, work activities, building materials
Chemicals	Inorganic gases such as CO_2, CO, SO_2, NH_3, O_3, NO, volatile organic compounds (VOC) such as CFCs, HCHCs and formaldehyde & radon	Furnishings, equipment, people, work activities

3.2 The indoor environment

Acceptable IAQ is a desirable feature of any indoor environment and while some aspects like level of contaminants are measurable, others like comfort can be subjective. Ultimately the occupant is the final judge. The indoor environment is either naturally ventilated based on open able windows and prevailing winds, mechanically ventilated with fans or air conditioned (with or without accompanying ventilation). The air conditioned indoor environment is the subject of our study.

Unitary air conditioners of the right capacity can easily produce comfort conditions with respect to dry bulb temperature and relative humidity but most, if not all of them, will struggle to handle indoor air pollution. reason is that cooling is readily achieved with refrigerating effect of the air conditioner while indoc pollution is complex and requires very efficient filtra and also other techniques to mostly mitigate the lev contaminants and not entirely eliminate them. S contaminants may even be termed as ultrafine part that are hard to measure and track but yet contribu indoor pollution [3].

3.3 Legislation, standards and guidelines

Sick building syndrome (SBS) is now com everyday terminology and most occupants of in environment will be quick to quote this term the inst they feel unwell. Local authorities are there cognizant of the need to ensure buildings are desi and constructed to result in acceptable IAQ. Legisla is usually built into local building codes such as Malaysia Uniform Building By-Laws (UBBL) [4]. In Third Schedule (By-law 41) clause 11, it states "*Where room, window or wall air-conditioning units provided as means of air-conditioning, such units s be capable of continuously introducing fresh air.*" system air conditioners such as wall mounted and u ceiling mounted units are generally incapable of function.

There are numerous standards and guide pertaining to IAQ and ASHRAE lead the way *ASHRAE Standard 62-1999, Ventilation for Accepı Indoor Air Quality* [5]. This standard is quoted in n local authorities' legislation including the Mala UBBL. The title of the standard also clearly implies the main factor to acceptable IAQ is ventilation w basically deals with removal of the contaminants thr introduction of outdoor air for dilution and exhaus stale indoor air. There are three methods to determin amount of outdoor air as shown in Table 5.

Table 5. Ventilation methods per ASHRAE Std 62-19

Method	Example
Flow rate per person	Dining – 10 l/s per person
Flow rate per unit area	Garage – 7.5 l/s per m2
Air change per hour	Living room – 0.35 air change per hour

Some other bodies that issue standards and guidelines include the World Health Organization, the International Standards Organization and the United States Environmental Protection Agency.

3.3 Achieving acceptable IAQ

The key to achieving acceptable IAQ lies in controlling the source strength and the rate of removal of the contaminants. The source of contaminants may or may not be known to the occupants but they remain largely within his control if the level of IAQ awareness is raised and the occupants exercise control on their activities, the choice of furnishing, materials, equipment etc. The rate of removal of the contaminants however requires artificial intervention with mechanical equipment such as air conditioners, air cleaners and ventilation fans. The aim is to limit the level of contamination in the indoor air to acceptable levels through filtration, dilution and direct exhaust of the air.

4. Unitary units and IAQ

4.1 Challenges faced

Split system air conditioners face major challenges when called upon to manage indoor air pollution to achieve acceptable IAQ. Due to their construction they are mostly unable to exhaust room air, inject outdoor air or filter and treat the indoor air to the extent required. The indoor unit is basically designed to just re-circulate the indoor air through the filter and evaporator coil to continually cool the air.

4.2 Problems to introduce outdoor air

The split system air conditioner evolved from the room or window air conditioner where it seems common sense to split the indoor and outdoor units thereby removing the main source of noise (the compressor) from the cooled space and also avoid knocking a large hole in the wall. A search of the web could not reveal who or which company first introduced the split system but it is likely to be the Japanese around the end of the seventies.

Without the common casing sticking out of the wall the split system lost the most direct means of introducing outdoor air into the cooled space. As a result, all of these units are installed without any direct ventilation air introduced into the unit. Any outdoor air to be introduced into the cooled space either required a separate fan or merely by leaving a window partially opened. The amount of outdoor air cannot be controlled in the latter case. In addition, the outdoor air introduced into the cooled space is not pre-cooled and filtered which will result in discomfort and may add contaminants to the cooled space.

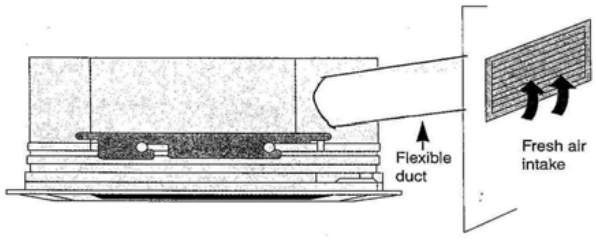

Fig. 5. Outdoor air connection to ceiling cassette

The ceiling cassette unit however has a knocko its casing which allows outdoor air to be introd direct into the unit (see Figure 5). This air can be filt and if the duct is too long a fan can be added (see Se 5.1 below).

4.3 Problems to filter or treat the room air

With or without introduction of outdoor air the system needs to filter the air entering the indoor un remove pollutants and also to keep the cooling coil blower fan clean. The compact size of the wall mou indoor unit resulted in the design of simple wash plastic filters and a metal scroll as the blower fan. filter's capability is basic while the blower fan deve very minimal static pressure. The other indoor especially the ceiling cassette, have more pow blower fans but the filters are basically the same type

Large air handling units typically have pre-filters secondary filters and even High Efficiency Particulate (HEPA) filters for special applications such as rooms. Typical commercial air purifiers or air clea have several stages in filtration and purification Figure 6). In comparison, the split system is unab handle the level of filtration required and at most, s manufacturers have added a small deodorizing filte addition to the basic filter or improved the basic (see Section 5.2 below).

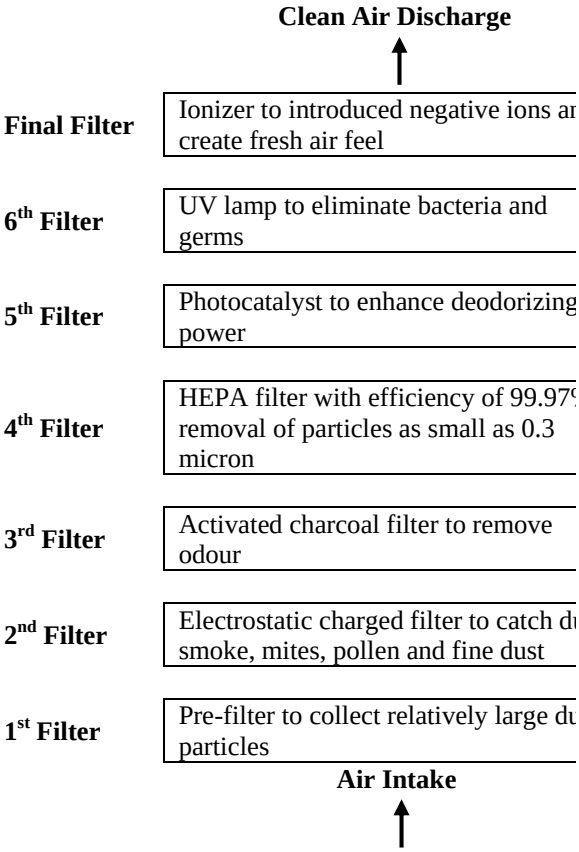

Fig. 6. Typical commercial air purifier filtration proc

5. Remedial measures

The split system air conditioner is here to stay fo foreseeable future. The subject of IAQ will also gro importance with a better educated population deman

improved living and working conditions and with consequent threat of litigation and insurance claims hanging over building owners and business operators.

There are five major players who can work together to collectively address the issue from all angles as follows:

- Specifying engineers
- Manufacturers
- Academia and researchers
- End-users
- Local authorities

5.1 Specifying engineers

HVAC engineers who are entrusted to design and specify a split system must incorporate outdoor air intake whenever possible and duct the air into the indoor units. Exhaust can be localised through ceiling or wall fans. The exhaust and air intake points must be kept as far apart as practicable. The amount of outdoor air can be based on ASHRAE Std 62-1999 and flow rate per person (method 1 in Table 5 above) is usually used.

For cassette units this can be achieved easily by connecting the outdoor air direct to the casing as shown in Figure 5 above. If the duct is long or one duct is supplying to several cassettes a fan may have to be added as the cassette blower fan may not develop enough static pressure to pull in the required air. A filter is also added to the outdoor grille with balancing dampers in the ducting if several cassettes are served by one outdoor air system. Figure 7 shows a typical design layout of a ducted outdoor air system with fan and filter supplying outdoor air to 6 cassette units.

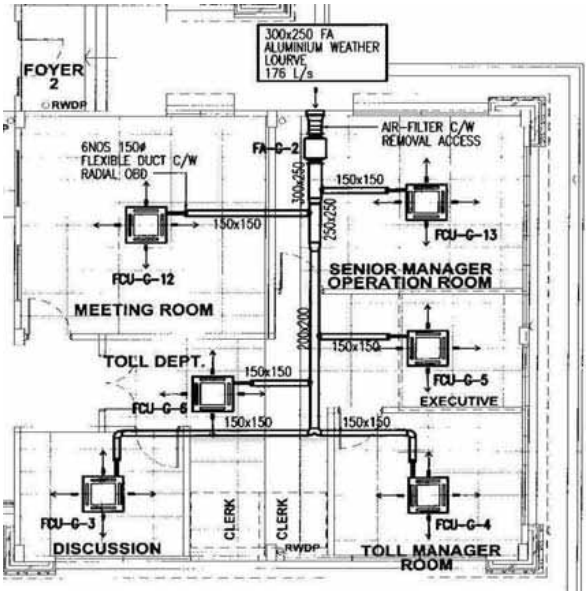

Fig. 7. Typical outdoor air supply system to cassettes

Wall mounted and under ceiling units have casings that do not have fresh air intake points. The best that the specifying engineer can do is to specify latest models with enhanced filtration and locate exhaust fans sized to the required ventilation air flow rate. Figure 8 shows such a typical installation. Make-up air will usually be by infiltration through windows, doors and the building structure. For this reason wall mounted and under ce units are not recommended for interior zones.

Fig. 8. Under ceiling unit installation with exhaust fa

5.2 Manufacturers

Manufacturers of split system air conditioners mostly aware of IAQ issues. Latest models are offe improved filtration with a minimum of basic filter activated carbon or deodorizing filter. One manufac introduced an oxygen membrane in the outdoor un pump oxygen into the cooled space but the model been removed lately for unknown reasons. And manufacturer claimed their unit can exhaust stale r air and then introduce fresh outdoor air (see Figur Whether these features really work or are just mark gimmicks can only be determined through prolo survey and research (see next subsection).

Fig. 9. Advertisement for air exchange wall mounted

Manufacturers need to continually improve R&D efforts and explore additional air clea techniques such as UV lamps, ionization and ozonisa It should be noted that even commercial air purifiers extended filtration processes are not certain to compl remove all indoor pollutants. The US Food and I Administration does not regulate the units, and standards exist to give consumers a clear indicatio their effectiveness [6]. Manufacturers of split syster conditioners therefore need to invest in R&D be

these filtration processes.

Effort must be made to improve the performance of the split system blower fan especially for wall mounted units such that they can develop higher static pressure to allow more elaborate filtration but still maintain low noise levels. Separate fans for exhaust or intake of outdoor air can also be considered and one possible technique is to incorporate this separate fan into the outdoor unit with a separate duct to the indoor unit.

5.3 Academia and researchers

Academia and researchers need to conduct research into the indoor air quality typically achieved using split system air conditioners. Prolonged measurements of various air quality indicators in establishments using such units will reveal useful data for designers and manufacturers. Research can also be conducted on the effectiveness of the filters employed by these units. Existing premises such as apartments, small restaurants, offices and retail shops are the best locations for such research.

The easiest measuring indicator is the level of carbon dioxide (CO_2). The gas itself is not considered a direct contaminant or health risk but the CO_2 concentration in the indoor space will indirectly indicate presence of more harmful gases or the reduction of oxygen (O_2) content. Most standards recommend a maximum CO_2 indoor concentration of 1000 parts per million (ppm). Figure 10 show a typical hand held IAQ measuring instrument.

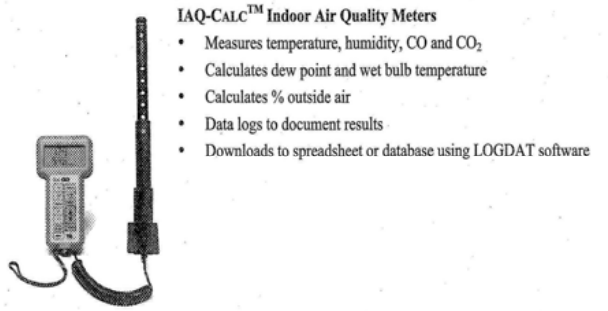

Fig. 10. Typical IAQ measuring instrument

Hiroshi Yoshino et al conducted a long term survey on IAQ and health hazard in sick houses in Japan over summer from 2000 to 2002 [7]. It is not mentioned whether any split system air conditioners were used especially when windows were closed or when no mechanical ventilation was operated. SC Lee et al conducted a study on IAQ characteristics in ten hair dressing salons in Hong Kong [8]. The study attributed high levels of CO_2 to poor ventilation but again there was no mention of the type of ventilation and it is also highly likely that these salons were installed with split system air conditioners.

In premises using split system air conditioners without any exhaust fans the only ventilation will come from infiltration through doors, windows and the building structure. It is suggested that research be conducted on the long term IAQ of such premises under controlled conditions of all windows closed, windows partially opened and with exhaust fans installed and running. The effect of ventilation on comfort conditions must be t into consideration. To achieve acceptable IAQ expected that exhaust fans must be installed as we larger capacity units specified to cater for the ventila thermal load.

5.4 End-users

End-users should be aware of the limitations of system air conditioners with respect to indoor air qua They have to maintain the units in tip-top condition regularly clean the cooling coil, blower fan and clea replace filters. They should seek expert advice on air conditioning installations and not just depend electrical appliances retailers who may not have necessary knowledge and training in HVAC.

In addition, end users must practice good s management when their premises are installed with system air conditioners. Table 6 lists some recommer practices and suggestions. It is important to purge indoor air on a daily basis for all retail shops and cl by opening all windows for natural purging or portable fans to assist. Purging is best done in the e morning before the premises open for business.

Table 6. Recommended space management practices premises with split system air conditioners

Premises	Activity	Recommendation
Residence	Smoking	Restrict to outdoors
	Cooking	Use exhaust hood
Office	Smoking	Ban all smoking
	Eating	Restrict to tea room
	Equipment operation (photocopy, printers, etc.)	Install spot exhaust
Retail shop	Smoking	Ban all smoking
	Hairdressing	Install spot exhaust
		Purge indoor air daily
Restaurant	Smoking	Ban all smoking
	Cooking	Restrict to kitchen wit exhaust hood
		Purge indoor air daily
Clinic	Consultation	Install exhaust fan
	Procedural	Locate near windows
		Purge indoor air daily

5.5 Local authorities

Local authorities need to re-examine building c especially with regard to space and ventilation and en sufficient legislation to protect the health of occupan indoor spaces cooled by split system air conditioners.

It is not much use to have legislation that stipu minimum outdoor air quantities for ventilation v there is no means to enforce especially for small busi premises that install the air conditioning without expert advice. The operators of such businesses are likely to be ignorant of any ventilation requirem Local authorities need to train their enforcement staf the requirements, and periodically visit these premis monitor the IAQ. Simple air quality measurements

be taken or a simple survey of the customers in the premises can be conducted to determine the state of the indoor air. Perhaps the issue and renewal of business licenses can be made subject to compliance to the legislated IAQ.

6. Conclusion

The use of unitary air conditioning units especially split system air conditioners are already widespread worldwide and more so in the hot and humid climatic regions of Asia. In tandem with the increasing use of these units is the emergence of the important issue of indoor air quality with respect to the comfort and health of the occupants of the indoor environment.

There is no doubt that the split system air conditioner does a good job in cooling the indoor space but does a very marginal one in terms of IAQ. The general inability to introduce and treat outdoor air and the lack of effective filtration combine to make these units appear incompatible with maintaining acceptable IAQ. Yet these units are essential, especially for the emerging economies in Asia, as they represent an affordable and readily available means of cooling the indoor space whether commercial, residential or even industrial.

The task of achieving acceptable IAQ with these units is daunting but not insurmountable. It requires the collective time, effort and skill of the specifying engineer, manufacturers, academia and researchers, end-users and the local authorities to diligently pursue their individual agenda and deliver the solutions. All these players can be united as members of ASHRAE, who can lead in the issue of standards, guidelines, handbooks and continu research for the betterment of all

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