Indoor Environments in Hong Kong's High-rise Residential Buildings

John Burnett

The Hong Kong Polytechnic University
HKSAR

Introduction

Hong Kong has belatedly joined the ranks of many developed countries in embracing the concept of sustainable building. A raft of new initiatives has sprung up in recent years to join some others that were forerunners, such as the Hong Kong Building Environmental Assessment Method (HK-BEAM) [1] which has already shaped improvements through the labelling of building performance. Whilst the concept of sustainability takes into account social, economic and environmental aspects, ASTM [2] describes a sustainable building or 'green building' as a building that provides the specified performance requirements while minimizing disturbance to and improving the functioning of local, regional, and global ecosystems, both during and after construction and service life. A green building optimizes efficiencies in resource management and operational performance and minimizes risks to human health and the environment. The recent SARs outbreak has certainly highlighted the fact that a 'green building' should not be unhealthy, nor should it be unsafe!

The goal of design and operation is to ensure a building is safe, healthy and efficient. Given that on average person in Hong Kong spends more than 85% of their time indoors [3], healthy and comfortable indoor environments are essential in sustaining the quality of life. Any concerns about the external environment must be balanced against the need for an indoor environment that is sustainable. Indoor environmental quality (IEQ) depends on many interrelating factors, not least the physical parameters that define thermal comfort, indoor air quality (IAQ), lighting quality, noise aspects, etc. The environmental performance of a building is good only if IEQ is maintained no less than the minimum levels of acceptability. The objective is provide good IEQ and others services whilst minimising consumption of non-renewable natural resources and minimising emissions, effluent, and waste.

HK-BEAM is a voluntary scheme in which a holistic view is taken of building environmental performance, not least IEQ. The assessment of various criteria is preferably performance based, that is by reference to a detailed design calculation or, preferably, a measurement in the completed building. Otherwise, inclusion of certain 'features' that contribute to improved performance is used, e.g. use of materials. The assessment criteria should be as transparent as possible, and the assessment method practicable. Preference is given to the use of established standards and guides to define the criteria. With the HK-BEAM scheme being upgraded (to reflect the gradually improving performance standards) and expanded (to cover a greater variety of buildings) it has been opportune to re-examine the assessment criteria for high-rise residential buildings [4], in particular to see if the performance-based criteria and assessment methods for IEQ should be strengthened. If a HK-BEAM certificate means that the major performance criteria relevant to safeguarding the health and comfort of occupants have been met, it can enhance the public perception that certification under HK-BEAM is a marker of quality.

Both internationally and locally there has been a great deal of focus on indoor environments in air-conditioned buildings, where the prevailing concept is to 'build tight and ventilate right'. Specifications, standards and guidelines for thermal comfort and IAQ are available in abundance for such buildings. In Hong Kong, professionals usually consider ASHRAE standards for thermal comfort [5] and IAQ [6], CIBSE codes for interior lighting, and other international references for acoustics, noise and vibration issues. However, even in well designed and operated air-conditioned buildings maintaining indoor environmental conditions that satisfies all occupants is often problematic. When in comes to buildings which utilise natural ventilation IEQ criteria are much more difficult to prescribe because of the variability of circumstances when a building is 'open'. In a typical residence IEQ and in particularly IAQ is as much dependent on occupant activities as on building design quality. Nonetheless, the IEQ issue remains pertinent to the quality of residential buildings and some serious considerations should be given to demonstrating that a building is not unhealthy when utilising natural ventilation, mechanical ventilation or air-conditioning.

To limit the discussion the focus here is on high-rise residential buildings in Hong Kong where individual units utilise window units or split-units when air conditioning is used. In such circumstances we should consider the 'worst case' scenarios affecting the various physical parameters by which we largely define IEQ:

- thermal comfort parameters – temperature, relative humidity (RH), air movement;
- indoor air quality parameters – 'freshness' as defined by carbon dioxide (CO_2) level, and 'cleanliness' as defined by absence of harmful substances (air pollution);
- lighting – mainly daylighting provisions; and
- acoustics, noise and vibration.

Thermal Comfort

Thermal comfort in high-rise residential buildings is a design issue, where the focus should be to mitigate solar heat gains, particularly on upper floors and solar-facing facades that are not shaded by adjacent structures. ASHRAE 55 [5] and ISO 7730 [7] provide design criteria for thermal comfort conditions in air-conditioned buildings. Derived from laboratory studies they specify combinations of personal (clothing, activity) and environmental factors (air temperature, RH, air movement, etc) acceptable to at least 80% of a building's occupants. However, the heat balance model underlying the standards does not account for the complex ways that individuals interact with their environment, modify their behaviour, or adapt their expectations to match the prevailing conditions. Residents have greater control of the indoor environment, and behavioural adjustments provide an opportunity to maintain thermal comfort. As reported by Brager and de Dear [8] people in naturally ventilated buildings seem to demonstrate a preference for a wider range of thermal conditions, perhaps due to their ability to exert control over the environment, by opening windows, operating fans and adjusting clothing, or because of changed expectations. They also tend to prefer conditions that more closely reflect outdoor conditions.

Taking into account behavioural adaptation, acclimatisation and psychological aspects of adaptation under naturally ventilated conditions Brager and de Dear proposed an adaptive standard, as illustrated in Fig. 1. This comfort standard given in terms of outdoor temperature applies to buildings in which occupants control operable windows and where activity levels are 'sedentary' (less than 1.2 met). The criterion given by Fig. 1 seems to be supported by evidence from several field studies in S. E Asia. For example, Feriadi *et al* [9] show that for residents in naturally ventilated housing in Singapore non-physiological factors and adaptive actions contribute in a positive way to a higher level of thermal comfort acceptability. The study also revealed occupant's tendency to modify the hot and humid living environment by creating a higher air movement (using fans, opening windows). In residential buildings people adapt to (or tolerate) the thermal conditions that they can afford.

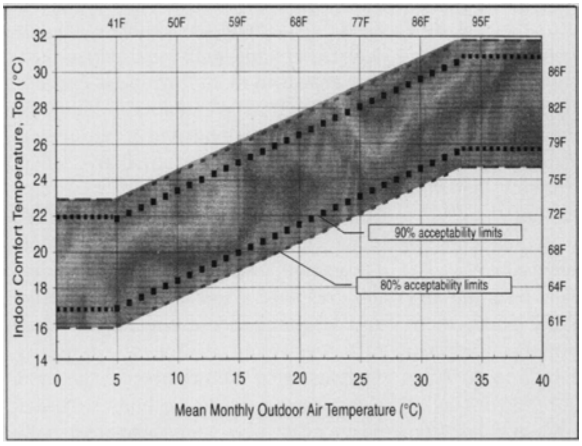

Fig. 1. Adaptive standard for naturally ventilated buildings (from Brager & de Dear)

Using Fig. 1 designers would calculate the average of the mean minimum and maximum air temperature and determine the acceptable range of indoor operative temperatures. At the design stage the use of a thermal simulation model such as HTB2 [10] could determine whether the predicted indoor temperature is likely to be comfortable using natural ventilation Fig 2 provides an illustration of using HTB2 for temperature and cooling load estimation in high-rise residential units.. Design options could be investigated to determine the extent to which natural ventilation (cooling) could be employed during the year to reduce reliance on mechanical cooling. When air-conditioning is employed the performance criteria can revert to Table 1, although much depends on the sizing of the installed unit in relation to room size. Criteria are given in HK-BEAM [4] for the best positioning of units to achieve efficient cooling and to improve energy efficiency to some degree.

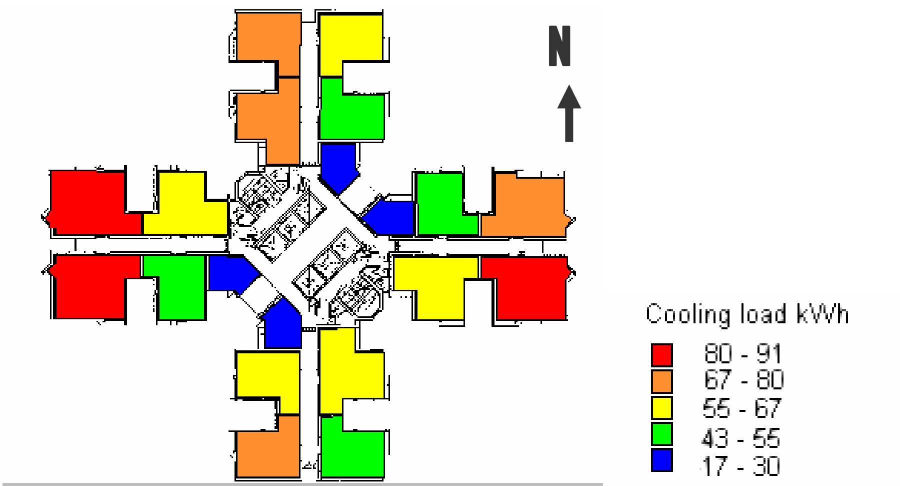

Fig. 2. Annual cooling load calculation (Floor 5 : solar control glass)

Indoor Air Quality

Acceptable IAQ is defined as air toward which the substantial majority of occupants express no dissatisfaction with respect to odour and sensory irritation and in which there are not likely to be contaminants at concentrations that are known to pose a health risk. The sources of air pollution are either mainly from outdoors (including neighbouring premises), or mainly from indoors. Proximity to outdoor 'point' sources such as industrial or commercial buildings, or 'line' sources such as vehicular traffic on adjacent roads, need to be assessed for potential impact. The indoor sources are both the building materials (over which designers have some control) and furnishings (mostly controlled by occupants), or from the activities of occupants (cooking, smoking, incense burning, etc).

Given the dearth of reliable information on the health effects resulting from exposure to low levels and mixtures of contaminants the pragmatic solution is to define limits of exposure (dose = level x time) that are not likely to be harmful. Owing to the uncertainties authorities use safety factors for daily and annual exposure to air pollutants, and set limits for short term (15-min) exposure. For most carcinogenic substances (e.g. formaldehyde, radon) threshold levels may not be specified, so the lowest levels considered practicable are used. Ambient air quality standards in Hong Kong, as elsewhere, target only a few pollutants known to affect the general population, including susceptible persons (HKAQO, Table I). Under its IAQ management programme the HKSAR Government has established provided guidelines for IAQ in Public Transport Interchanges and enclosed car parks, with criteria for public transport facilities due for publication. The major initiative however is the IAQ Certification Scheme for air-conditioned buildings [11] which provides health related criteria for eight pollutants, carbon dioxide (CO_2), and 3 thermal comfort parameters (IAQ, Table I).

Table I: Indoor and outdoor air quality standards

Parameter	**IAQ Certification Scheme**			**Hong Kong Ambient Air Quality Objectives**				
		Excellent	Good					
	Unit	8-hour average		1-hour	8-hour	24-hour	3-month	1-year
Room temp.	^oC	20<25.5	<25.5					
Relative humidity	%	40-70	<70					
Air movement	ms^{-1}	<0.2	<0.3					
Carbon dioxide (CO_2)	ppmv	<800	1000					
Carbon monoxide (CO)	μgm^{-3} ppmv	<2000 <1.7	<10000 <8.7	30000	10000			
Respirable Suspended Particulate (PM_{10})	μgm^{-3}	<20	<180			180		55
Nitrogen dioxide (NO_2)	μgm^{-3} ppmv	<40 <21	<150 <80	300		150		80
Ozone (O_3)	μgm^{-3} ppmv	<50 <25	<120 <61	240				
Formaldehyde (HCHO)	μgm^{-3} ppmv	<30 <24	<100 <81					
Total Volatile Organic Compounds (TVOC)	μgm^{-3} ppmv	<200 <87	<600 <261					
Radon (Rn)	Bqm^{-3}	<150	<200					
Airborne bacteria	$cfum^{-3}$	<500	<1000					
Lead	μgm^{-3}						1.5	

Air Pollution in Hong Kong Homes

A number of studies have measured indoor air pollution in residential buildings in Hong Kong, including assessment of contributions from indoor and outdoor sources. Usually it is the pollutants listed under IAQ in Table I that have been measured but, unfortunately a key parameter, the prevailing ventilation rate, has often been omitted. Chao [12] compared indoor and outdoor levels of NO, NO_2, SO_2 and O_3 in ten units and concluded that outdoor levels were higher than indoor levels, and based on the IAQ criteria (Table I) that NO_x levels may be a cause for concern. Airborne particulate is a major problem for homes near roads, industrial sources and construction sites. Tung *et al* [13] reported TSP levels in the public and private housing surveyed varied from 37.5 to 227.1 $\mu g\ m^{-3}$, with PM_{10} levels between 35.1 and 161.6 $\mu g\ m^{-3}$, with a high proportion of PM_{10} from indoor activities. If the 24 h measurements are extrapolated to HKAQO annual figures only 8 out of the 50 sites fell within the PM_{10} guidelines. Besides PM_{10} Lee *et al* [14] also found that bacteria levels were relatively high when compared to the IAQ criteria. VOCs and formaldehyde are generally found to be indoor sources from finishes, fittings, furnishings and user activities.

Radon has long been recognised as an important indoor air pollutant at all levels due to the type of construction materials used. According to various studies concentrations found in homes are generally well below 150 Bqm^{-3}, but only if rooms are provided with sufficient background ventilation of the order of 0.5 to 1 ach^{-1} [15]. This is achieved in 'leaky' rooms, but with improved tightness of building envelopes and the absence of provisions for ventilation, levels can be significantly higher. The catch-22 for residential units near to outside sources of pollution is that air exchange is needed to dilute indoor pollutants but it brings in outdoor contaminants.

Whilst the focus is invariably on the listed contaminants, there are others that may have greater significance. For example, Leung *et al* [16] found that at least one major inhaled allergen of mite, cat and cockroach were present in varying quantities in 85% of the HK homes studied, as well as NO_2, and exposure could be important in the development of asthma and allergic diseases in susceptible individuals. Temperatures and RH exceeding 26^oC and 80%, respectively, provide an ideal climate for dust mite growth. Improving hygiene in buildings is as important as improving IAQ!

IAQ (Ventilation) Criteria for Residential Premises

Given the variability of circumstances, establishing IAQ criteria for residential premises is more problematic since both natural ventilation and air-conditioning will be used it is the occupants who have a major impact on IAQ. Notwithstanding, recommendations can be found in the literature, for example the exposure guidelines published by Health Canada [17], although assessment for compliance is not covered. When it comes to more practical design guidance IAQ is usually addressed by specifying ventilation rates to which designers can more easily respond. Practically, ventilation strategy for residential buildings is threefold:

- local exhaust (operable windows, mechanical extract, etc) to remove pollutants (and water vapour) from specific rooms (kitchens, bathrooms, etc) before they enter habitable rooms;
- ventilation of habitable rooms for respiration and to dilute unavoidable contaminant emissions from people, materials, etc; and

- rapid ventilation (operable windows) to cater for episodic occupant controlled events such as smoking, painting, etc.

Extract ventilation rates are given in various standards, such as 50 Ls^{-1} [5] for kitchens with about half these rates in bathrooms. Detailed design guidance is available based on number of bedrooms [18, 19], as is the prescribed size of operable windows under building regulations. However, contamination of inside air by outside sources tends not to be covered by standards and guides.

The fresh air requirement for human respiration depends on the level to which CO_2 is to be maintained. CO_2 should be regarded an indicator of ‘comfort’ [20]. In offices and similar workplaces a CO_2 level of 1000 ppm (650 ppm from occupants plus 350 ppm ambient, achieved with around 7.5 Ls^{-1} per person) is generally prescribed as being suitable for unadapted persons (visitors to a space). It can be argued that for persons who have adapted to a space, such as occupants of a residential bedroom, CO_2 (from occupants) can be up to 3 times higher, suggesting that odour comfort being maintained at around 2300 ppm (3 x 650 + 350) for adapted persons.

The Canadian criterion for dwellings is 3500 ppm [16], and there are no known serious health effects at 5000 ppm, the occupational health exposure limit. Measurements in a dozen high-rise bedrooms in Hong Kong [21] with one or two occupants found levels between 450 and 1800 ppm, with the lower figures achieved using window type air-conditioners and, as to be expected, the higher levels arising when split type air-conditioners are used. Given that the air flow rates with dampers open was typically only 20-25% greater than with dampers closed (also reported in other studies), it is clear that air-change through infiltration often dominates. The relationship between room size, ventilation rates and estimated CO_2 level can be calculated [20], and 1-2 ach^{-1} is acceptable as far as odour comfort of adapted persons (residents) if other pollutant sources are controlled.

With the activities of users critical to residential IAQ much can be done to alert residents about the IAQ problems they themselves create through smoking, incense burning, cooking, hobbies, cleaning, decorating, etc., and how to reduce the problem by choice. EPD’s WEB site and IAQ information Centre is a good source laypersons to use, but more active involvement of building managers may prove fruitful in spreading the word. Designers contribute through choice of materials and finishes to reduce VOCs etc, by giving consideration to breezeways, outside and neighbouring sources, etc., to allow natural ventilation without excessive pollution, and by ensuring sufficient ventilation when rooms are ‘closed’ so that internal sources are adequately diluted.

A performance based assessment of IAQ in new buildings could be based on the ventilation rates provided (background, source control by extract fans), or use the approach adopted in the IAQ Certification Scheme through measurement of the pollutants. The ‘worst case’ scenarios should be covered, with measurement of indoor sources (e.g. radon, VOCs) carried out with rooms ‘closed’, and outdoor sources (e.g. particulate, CO) with rooms (windows or ventilators) ‘open’.

Lighting (Daylighting)

Artificial lighting in residences is matter of user preference and perhaps the major design issue is flexibility to allow adaptation to user preferences. Daylighting provisions are an important design issue given the benefits to comfort and health (as well as energy savings). Sunlight, provided it is not excessive, gives a sense of brightness and cheerfulness and has a therapeutic effect. For unobstructed buildings the target is to provide as much daylight as possible without excessive glare and solar gains. Hong Kong Building (Planning) Regulations uses obstruction angles for defining access to natural light, and non-legislative guidelines are available for designing for access to daylight and sunlight, with ample technical advice as to how this may be achieved.

For densely packed high-rise residential buildings the challenge is to get daylight into rooms on lower floors that are heavily overshadowed by adjacent structures. The amount of daylight in a room at any depth can be estimated using the Daylight Factor (DF) approach which is well documented in design guides. An appendix to a draft practice note [22] by the Buildings Department describes a method of estimating Vertical Daylight Factor (VDF – illuminance ration onto the external facade) from the geometry of an external window and the visible sky (Fig. 3 provides an insight to the approach adopted). Whilst there is some concern that the criteria of VDF of 8% in habitable rooms will translate into a significant value of DF (interior daylighting), the approach offers an alternative design criteria to the Building Regulations. However, as discussed in another paper in the conference proceedings [23] aspects of daylight and sunlight availability can be examined much more comprehensively using total annual incident radiation or total annual illumination (TAI). Assessment of daylight performance can focus on DF for unobstructed windows, VDF for heavily obstructed facades, or TAI when a protocol and criteria for assessment for Hong Kong is developed.

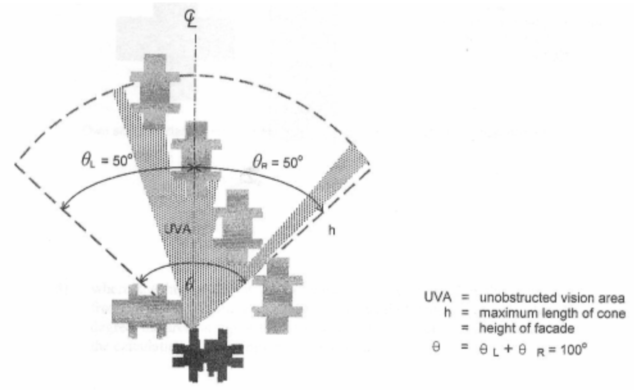

Fig. 3. Measurement of height of façade and unobstructed vision area (from ref: 22)

Noise and Vibration

Whilst it may not be a significant health issue noise, and to a lesser extent vibration, can certainly detract from the quality living. Noise from outside sources is a design issue, as is noise and vibration from building services equipment. The Hong Kong Planning and Standards Guidelines provide criteria for maximum permissible noise levels at the external façade of residential buildings for various outside noise sources (e.g. 70 dB(A) L10(1 hour) for road traffic noise). The Guidelines also indicate the likely noise attenuation by the building envelop for each type of noise, with well-gasketted double glazed windows achieving up to 15 dB(A) for road traffic noise. However, the existence of gaps such as in window units reduces their effectiveness. This suggests that further effort can be made if sleep is not to be disturbed.

Equally relevant is the noise transmission between apartments on the same floor, and between floors. The latter has not received much attention by designers. There are well established design criteria for airborne noise attenuation through party walls, and for impact noise through floors [e.g 24]. Given that the use of floor coverings such as carpets are not generally preferred by homeowners designing floors/ceilings to reduce impact noise is an important quality feature for which some homeowners may pay a premium. Noise and from vibration building services plant is also a design issue, but one that should be satisfactorily addressed by acoustic enclosures and vibration dampers. In the event that vibration is perceived to be a problem ISO 2631 [25] provides criteria whereby the impact on people can be assessed.

HK-BEAM Criteria

Table II lists the criteria currently included in HK-BEAM 4-03 'pilot version' [26] that can be applied to high-rise residential buildings, but as they remain under review further changes are likely, especially to clarify targets such buildings. It should be noted that the assessment covers those aspects of performance that can be regarded as the outcome of good design, it does not take into account the impacts of residents and their activities.

With many flats in one block it is not practicable to assess all units under all circumstances, so the approach is to consider 'worst case' scenarios. For thermal comfort under naturally ventilated conditions it is the most exposed units that should be assessed and where breeze is limited. When air-conditioning is used the units with the highest solar gains should be checked. For IAQ we can consider both the 'windows open' and 'windows closed' scenarios, the former to consider whether outdoor sources are a problem, and the later to determine the relevance of indoor sources. In reality maybe only CO, PM_{10}, and radon are good enough indicators. Both design and measurement of DF or VDF is relatively easy. Noise measurements are more difficult but can be assessed by calculation if measurement is too problematic. An important aspect of the HK-BEAM framework is that designers can submit alternative performance criteria and methods for assessment, so that a submission regarding daylight using ICUE [23] or other more sophisticated means, for example, would be accepted as an alternative.

Conclusions

This paper is the outcome of a further review of IEQ criteria that is included in the pilot version of HK-BEAM for assessing new building developments [26]. It has become clear that an assessment method covering all types of buildings raises various issues such as the relative weightings of the environmental aspects included, the performance criteria and the assessment method to be used. Defining comprehensive indoor environmental performance criteria in buildings that utilise natural ventilation, yet allows for unambiguous assessments that can be undertaken without excessive cost and effort, is fraught with difficulty.

An overriding consideration is that the assessment of high-rise residential buildings be practicable; else take-up under this voluntary scheme would be limited. The key is to demonstrate that the assessment of appropriate IEQ criteria provides a sound indication of building quality, in terms of comfort and health. By undertaking measurements on an appropriate sample of residential units it is reasonable to label a whole building or even a whole estate.

Table II: Indoor environmental quality criteria in HK-BEAM 4-03 likely to be applicable to high-rise residential buildings (see ref: 26)

Thermal Comfort in Air-conditioned/Naturally Ventilated Premises	Credit
for demonstrating worse case peak temperatures without mechanical cooling does not exceed 30°C in any occupied/habitable rooms	1
for sustaining the air temperature at the design value within ±1°C when the air-conditioning unit is operating at steady state under conditions of zero occupancy	1
Background Ventilation in Air-conditioned/Naturally Ventilated Premises	
for demonstrating through appropriate modelling or commissioning tests that a minimum air change rate of 1 per hour is provided in occupied or habitable rooms under conditions of natural ventilation	1
Uncontrolled Ventilation in Air-conditioned/Naturally Ventilated Premises	
for undertaking tests on a representative sample of units, to demonstrate that the air tightness is less than 2.0 $ac.h^{-1}$ at 50 Pa	1
Localised Ventilation	
for provision of: an adequate ventilation system for rooms/areas where significant indoor pollution sources are generated; and a system of local exhaust of premises undergoing fit-out and redecoration	1
Natural Ventilation in Public Areas	
for undertaking an analysis of building and adjacent building forms to assess wind pressures on ventilation openings in public/circulation areas	1
for demonstrating that each common area has ventilation openings capable, under prevailing wind conditions, of providing adequate ventilation	1
Outdoor Sources of Air Pollution (*for residential buildings this would be specified for 'open' conditions)*	
for demonstrating compliance with the appropriate IAQ criteria for CO, NO_2, ozone, RSP for each type of occupied premises in the building development	1+1+1+1
Indoor Sources of Air Pollution (*for residential buildings this would be specified for 'open' conditions)*	
for compliance with the appropriate standards for VOCs, formaldehyde, radon specified for each type of occupied premises in the building development	1+1+1
Odours and Hygiene	
for adequacy of plumbing and drainage installations to limit odours	1
for the provision of a hygienic refuse collection system	1
Daylighting Windows and Views *(residential)*	
for demonstrating that at least 80% of windows in occupied/habitable rooms achieve a VDF of 12%, and the remainder achieve a VDF of 8% or	1
Alternatively, for windows not subject to significant obstruction: for demonstrating that at least 80% of occupied/habitable rooms achieve an average DF of 2.5%, and the remainder an average DF of 1.5%	
for demonstrating that 80% of all occupied/habitable rooms with windows have a window to floor area ratio of 35% or more, and the remainder 25% or more	1
Noise Isolation *(residential)*	
for demonstrating noise isolation between rooms, premises and/or floors: bedroom to living room : STC46 (same unit), bedroom to bedroom : STC52, IIC52 (between units); STC44 (same unit), living room to living room : STC52, IIC52 (between units)	1
Background Noise *(residential)*	
for demonstrating background noise levels in bedrooms under window closed conditions at or below 30dB $L_{Aeq,T}$=8 hr, and < 45 dB between 23:00 to 07:00.In habitable rooms (other than kitchens) under closed window conditions < 55dB $L_{Aeq,T}$=16 hr between 07:00 to 23:00.	1
Indoor Vibration *(residential)*	
for demonstrating vibration levels shall not exceed the given in ISO 2631-2	1

References

[1] Burnett J and Yik F W H. Framework of Building Environmental Assessment Methods. HKIE Transactions, Vol. 8, No. 3, pp 1-7.
[2] ASTM E 2114-01. Standard Terminology for Sustainability Relative to the Performance of Buildings.
[3] Chau C K, Tu E Y, Chan D W T and Burnett J. Estimating the total exposure to air pollutants for different population age groups in Hong Kong. Environment International, Vol. 27, pp 617-630, 2002.
[4] Centre of Environmental Technology. HK-BEAM 3/99 (Residential). An environmental assessment for new residential buildings. http://www.bse.polyu.edu.hk/Research_Centre/BEP/hkbeam/main.html
[5] ANSI/ASHRAE 55-1995. Thermal Environmental Conditions for Human Occupancy.
[6] ANSI/ASHRAE 62-2001. Ventilation for Acceptable Indoor Air Quality.
[7] International Organization for Standardization. ISO 7730-1994. Moderate thermal environments – Determination of the PMV and PPD indices and specifications of the conditions for thermal comfort.
[8] Brager G S and de Dear R. A Standard for Natural Ventilation. ASHRAE Journal, October 2000, pp 21-28.
[9] Feriadi H, Wong N H, Chandra S and Cheong K W. Adaptive behaviour and thermal comfort in Singapore's naturally ventilated housing. Building Research & Information, 2003, Vol. 31(1), pp 13–23.
[10] Jones P and Yik F W H. Sustainable high-rise residential housing in Hong Kong. Proc. International Housing Conference, Hong Kong 2004.
[11] Environmental Protection Department, HKSAR Government IAQ Certification Scheme for Offices and Public Places. http://www.iaq.gov.hk/second.asp?page=scheme&sub=download
[12] Chao C Y H. Comparison between indoor and outdoor air contaminant levels in residential buildings from passive sampler study. Building and Environment, Vol. 36, 2001, pp999-1007.
[13] Tung T C W, Chao C Y H, Burnett J, Pang S W and Lee R Y M. A territory wide survey on indoor particulate level in Hong Kong. Building and Environment. Vol. 34, 1999, pp 213-220.
[14] Lee S C, Chang M and Chan K Y. Indoor and Outdoor Investigation at six Residential Buildings in Hong Kong. Environment International, Vol. 25, No. 4, pp 489-496, 1999.
[15] Chao C Y H, Tung C W T, Chan D W T and Burnett J. Detailed measurement of indoor radon level in 5 residential premises and the effect of ventilation. Indoor + Built Environment, Vol. 6, No. 5, 1997, pp. 277-281.
[16] Leung R, Lam C W K, Chan A, Lee M, Chan I H S, Pang S W and Lai C K W. Indoor environment of residential homes in Hong Kong – relevance to asthma and allergic disease. Clinical and Experimental Allergy. Vol. 28, pp 585-590, 1998.
[17] Ministry of Supply and Services Canada. Exposure Guidelines for residential Indoor Air Quality. April 1987 (Rev. July 1989).
[18] BSR/ASHRAE Standard 62.2P. Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings. April 2002.
[19] British Standards Institution, BS 5925: 1991. Code of practice for Ventilation principles and designing for natural ventilation.
[20] ASTM D 6245-98 (Re approved 2002). Standard Guide for Using Indoor Carbon Dioxide Concentrations to Evaluate Indoor Air Quality and Ventilation.
[21] Lin Z and Deng S. The outdoor air ventilation rate in high-rise residences employing room air conditioners. Building and Environment Vol. 38, 2003, pp 1389-1399.
[22] Buildings Department. Practice Note for Authorized Persons and Registered Structural Engineers 241 Draft. Lighting and Ventilation Requirements. Announced November 2002.
[23] Chung T M and Mardaljevic J. Quantifying solar access and daylight availability in dense urban settings. Proc. International Housing Conference, Hong Kong 2004.
[24] Department of Environment, Transport & Regions UK. Approved Document E. Resistance to the passage of sound.
[25] ISO 2631-1: 1997. Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration. Part 1 General requirements.
[26] HK-BEAM Society (2003). Hong Kong Building Environmental Assessment Method – New Building Developments. HK-BEAM 4/03. http://www.bse.polyu.edu.hk/Research_Centre/BEP/hkbeam/main.html