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Measured field performance of aluminium windows in Kuwait

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Abstract

The air infiltration rate is determined for 154 aluminium windows installed in 25 buildings in Kuwait. The influence of window characteristics such as type, dimensions, source of profile, source of workmanship, building function, cost and age has been studied. Air-tightness is determined using portable equipment to pressurize a chamber created on each window and to measure the air flow and pressure increase. The results show that aluminium windows in Kuwait have a mean infiltration rate of 13.48 $m^3/h/m$ at 75 Pa, about 3.4 times higher than the ANSI/AAMA maximum limit. The type of window is the main factor influencing performance, with horizontally hinged windows leaking the most, and tilt-and-turn and fixed windows the least. Newly installed windows and those installed in low-cost projects show marginally greater mean air-infiltration values than those in old or prestigious projects; however, the standard deviation is noticeably greater, indicating lower quality control. Windows installed in residential buildings produce lower leakage rates than those in office or public buildings. The volume of air leakage remains the same for sliding windows with different areas, indicating that leakage occurs mostly at the corners; however, leakage increases with area for vertically hinged windows, showing that leakage occurs at the sash/window joint.

Introduction

Aluminium windows have gained popularity in the Arabian Gulf region in the past 15 years because of their relatively low cost compared to timber or steel ones. Aluminium billets are locally produced in one factory in Bahrain. Imported billets from neighbouring countries are also available at competitive prices. In Kuwait, aluminium profiles are extruded in two factories, whereas aluminium windows and doors are fabricated using local and imported profiles in 45 workshops. Most of the windows fabricated are double sliders; since these do not occupy space when they are open. Other types, such as tilt-and-turn and vertically or horizontally hinged windows, are gaining acceptance. However, the choice of window type does not follow any functional or performance criteria, but depends mainly on cost.

A serious drawback in fenestration works in Kuwait arises from the windows' lack of air- and water-tightness. The consequent high energy consumption for cooling systems is a burden on the total national consumption. These shortcomings in window performance are attributed to the following factors:

(1) No code of practice or national standard for window performance is applied. Designers and contractors follow owners' requests for minimum profile thickness and anodization colour only. No performance criteria are provided in most design documents.

(2) In those rare cases where performance criteria are specified, they are generally ignored, since no testing facilities are available to verify compliance.

(3) There is little interest among building owners in the energy savings they can achieve from tighter windows, since the government

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subsidizes up to 90% of the cost of electricity. Thus, owners are more interested in cutting down on initial costs by using inferior cheap windows.

Consequently, many design, fabrication, installation and maintenance defects are observed in fenestration works [1]. Not only are air and heat allowed to penetrate into the interior, causing a temperature increase and high consumption of energy to operate the cooling systems, but also dust particles can enter, creating a nuisance for tenants. Fine dust is common in Kuwait during high winds, especially in the summer; the annual dust fall-out is 119 t/km^2 [2]. This dust is a health hazard, and can shorten the life of electrical equipment. Carruthers [3] reported that imported windows from Europe and North America failed to prevent dust infiltration in newly constructed buildings in Saudi Arabia.

The impact of visible defects observed in aluminium windows on air infiltration has previously been studied by us [4]. Windows without defects had an air infiltration rate 46% lower than the overall average. However, the rate of deterioration in performance with increasing number of defects varied from one window type to another. Vertically hinged windows had a higher rate than double sliders. The increase in air infiltration reached a plateau when the number of defects equalled six. Simple maintenance, such as replacing missing or faulty weatherstrips, was found to improve the air-infiltration rate by 10–30%.

Weidt and Weidt [5] conducted a field survey on 197 windows made of different materials installed in newly built residential houses. They reported that window type was a dominant factor controlling air leakage, and recommended further field studies to isolate the areas of greatest leakage, to study commercial buildings and to study the effect of time on window performance. Their study was a valuable contribution to research on window field performance, and resulted in the AAMA [6] and ANSI/AAMA [7] voluntary specifications adopting new air-infiltration acceptance limits that vary with window type. They reported the air infiltration per unit area for fixed windows, and recognized the difference between field and laboratory results by allowing an extra 50% for the field infiltration rate.

Nevander [8] encouraged those involved in window performance studies to correlate laboratory results with practical field experience. Furthermore, he stressed the need for information on the performance of windows subjected to natural weathering conditions.

Literature, however, is scarce on the performance of aluminium windows installed in old buildings in a harsh climate, such as that of the Arabian Gulf States. Quality and performance criteria for these elements have not been well defined. Many contractors import windows either ready-assembled or knocked-down, without giving much consideration to their suitability. Imported materials vary widely in quality, and, in the absence of controls, low grades are used.

It is generally accepted that the quality of workmanship greatly influences window performance. Daoud *et al.* [4] found that defects due to fabrication and installation processes are the most influential in degrading the performance of aluminium windows installed in buildings of different ages in Kuwait. The quality of workmanship in the Gulf states is normally related to the size of contractor. Large contractors have the resources to control quality in order to maintain their reputations. Small contractors, on the other hand, do not pay much attention to this area. They often depend on newly hired personnel with little or no experience, in order to minimize the cost. Also, small contractors are involved in small projects according to governmental categorization. This applies to general contractors; however, its application to specialized contractors, such as those involved in fenestration works, is not clear. Weidt and Weidt [5] found the contractor's experience can greatly influence the air infiltration rate through newly installed windows. This, however, was deduced from a limited number of field tests.

This study was directed towards evaluating the effect of window type, source of material and workmanship, and the age, dimensions, function and cost of the building on air infiltration through aluminium windows. The data were based on field air-infiltration tests of windows installed in 25 buildings in Kuwait. The aim was to initiate national awareness of the need for national specifications for window performance, and to study the effect of different window characteristics on performance.

Sample selection

The field survey was carried out on 154 windows installed in 25 buildings located around Kuwait City. Eight operational types were included: horizontal double slider, vertical single slider, vertically hinged single and double leaf, horizontally hinged single and double leaf, tilt-and-turn and fixed (Fig. 1(a)). Horizontal double sliders dominated the sample, representing 45% of the total; this is in line with the fact that double sliders are the most common type of window in Kuwait. Vertically hinged windows, at 29%, are the second most common type. Tilt-and-turn, vertical sliders and fixed windows are rare, and hence were the least numerous in the sample.

The sample included windows installed in buildings with three different functions: residential, office and public. The total number of windows within each type was kept almost constant (Fig. 1(b)), however, the number of residential buildings was almost double that of office or public buildings. This is consistent with their actual distribution. The care and maintenance of windows of each type is expected to vary noticeably. Windows in residential buildings are used by a limited number of people, and are cleaned and checked on a more regular basis than those in office or public buildings. Since public buildings have many more users, their windows are subjected to more abuse.

Windows ranging in age from newly installed to more than 10 years old were tested (Fig. 1(c)). Newly installed windows (less than or equal to two years old) dominated the sample, since they represent the most recent practice in Kuwait, which theoretically should represent the highest quality. Notably, half of these have been installed in national housing projects that are currently under construction and are the highest quality governmental housing projects, since they benefit from the cumulative expe-

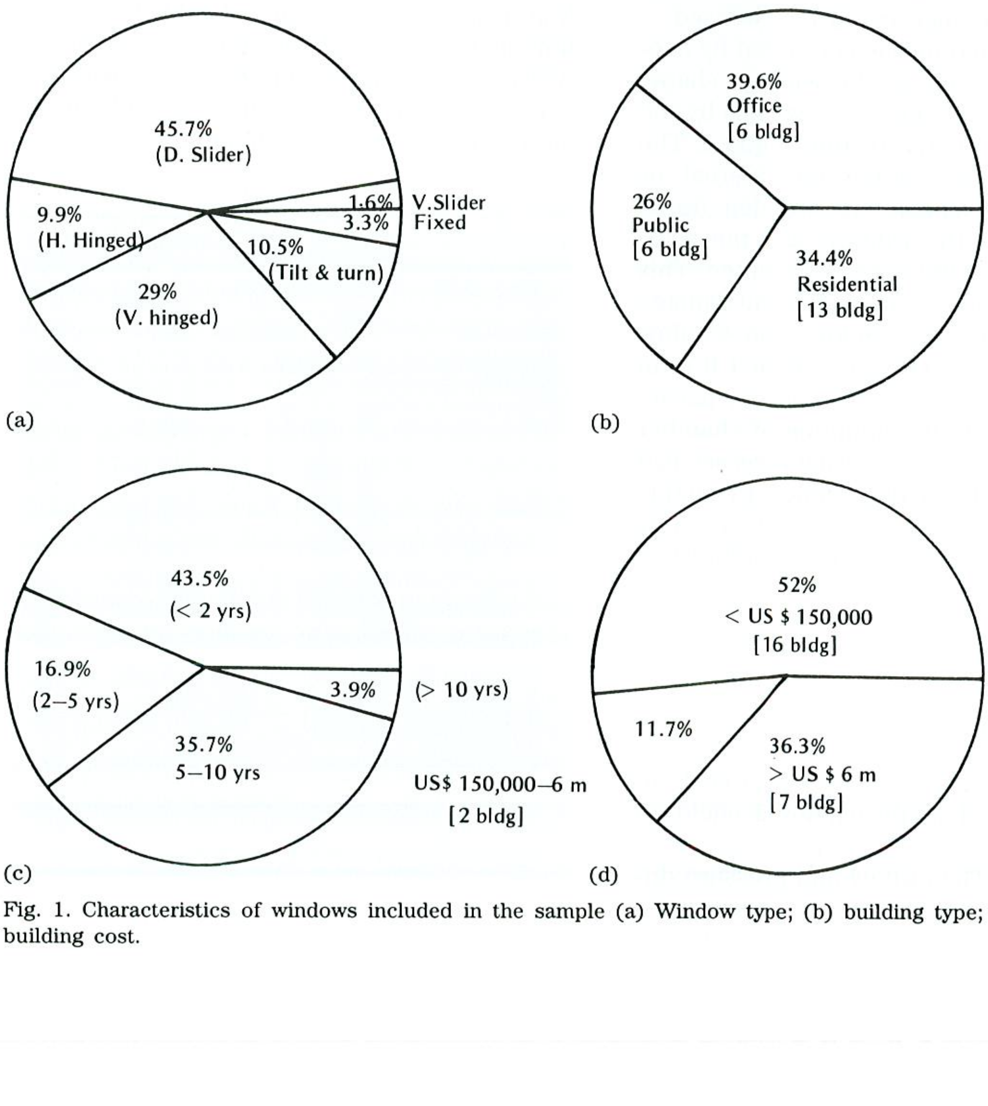

Fig. 1. Characteristics of windows included in the sample (a) Window type; (b) building type; (c) window age; (d) building cost.

rience of the past 10 years. The other age groups were included to compare old with new practice and to determine the impact of age on performance.

The cost of the building reflects the size of the contractor involved in its construction. Figure 1(d) shows the percentage of windows tested within each cost group. Three groups were defined, representing the wide range of buildings in Kuwait. The sample included buildings ranging in cost between US$ 150 000 and US$ 25 000 000. Sixteen small villas, such as those built in the national housing scheme, represented the low-cost buildings, and were more numerous in the sample; seven commercial complexes or large public facilities represented the other end of the scale. The windows in the low-cost buildings numerically dominated the sample, which reflects the actual distribution that exists.

Since a large share of the market in Kuwait depends on imported materials and labour, the sources of aluminium profiles and workmanship were included as two parameters so that their impact on performance could be assessed.

The sample selection was controlled by geometrical factors, such as the window shape, dimensions and accessibility, as well as by the tenants' response to the testing request. The window had to have either an external or internal recess to enable the wooden frame that formed (with the window and the wall) the test pressure chamber to be mounted. This arrangement eliminated any permanent damage to the wall finish near the window. Also, window dimensions were limited to less than 1.8 m in either direction for practical reasons, particularly the transport and mounting of chamber elements. Windows with external recesses had to be accessible from the outside to enable the frame to be mounted. Therefore, only ground-floor windows or those overlooking terraces could be tested.

Field test set-up

Air-infiltration tests are normally carried out in the laboratory, where the window is enclosed in a pressure chamber and exposed to differential pressures. The airflow and pressure difference across the window are used to calculate the infiltration rate per unit of crack length under a particular pressure, as specified in the ASTM E283 standard. In this case, the air is infiltrating the window through the joint between the sash and the frame, whose length is defined as the crack length.

In the field test, the chamber is built around the window. In the current study, this was achieved by installing a wooden frame with plexiglass sheet on either the interior or exterior of the window to form the chamber (Fig. 2). The wooden frame's joint with the wall was sealed with silicon paste, as was the plexiglass/frame joint. The test is standardized in ASTM E783. In the field test, air could infiltrate the window through the sash/frame joint and/or the window/wall joint. The main concern was the volume of air infiltrating the window, regardless of the route it took. The infiltration rate was reported per unit of crack length to facilitate comparison with other windows and with laboratory results.

The field-test equipment consisted of an air blower, an airflow meter and a manometer. The blower was capable of delivering 75 m^3/h at a maximum pressure of 600 Pa. The airflow meter complied with the requirements of ASTM E783. The pressure difference was measured using a micromanometer with an accuracy up to 0.01 mm of liquid column height;

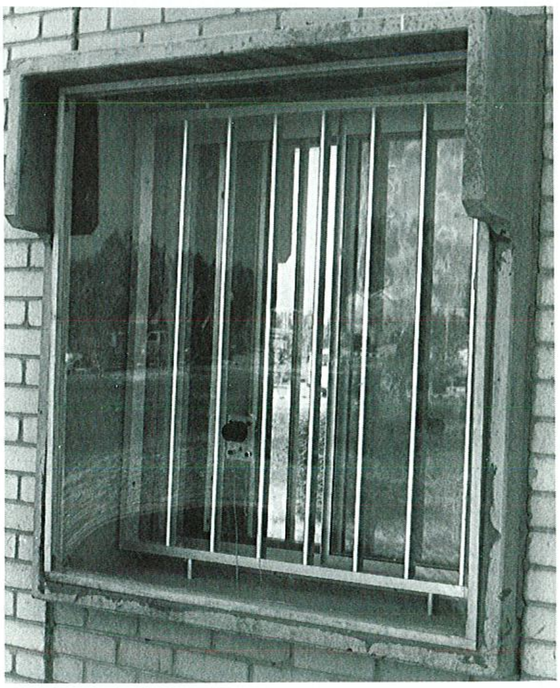

Fig. 2. General arrangement of the pressure chamber on a double sliding window installed at a ground floor.

the liquid had a specific gravity of 0.793 at 20 °C.

The test was carried out 24 hours after the frame was installed, to give enough time for the silicon to set. The window was locked prior to the test. The airflow meter and the micrometer were set to zero, and the liquid was checked to ensure that it was free of air bubbles. The air-supply hose and the pressure tubes were connected to nozzles fixed to the plexiglass sheet (Fig. 3). The window was exposed to a pressure of 150 Pa to check for air leaks through the frame joints or the connections between the chamber and the testing apparatus. Once the apparatus was secured, the test was carried out by incremental increases in the air flow in steps of 2 cm. The corresponding pressure was recorded. At least one reading was taken close to a chamber pressure of 75 Pa, which is the standard pressure required by the ANSI/AAMA 101-85 voluntary specifications. In cases where this pressure was not achievable, e.g., badly leaking windows, the airflow at 75 Pa was extrapolated by

$$Q_{75} = (75/\Delta P)^{1/2} Q$$

where Q = air loss at standard atmospheric temperature and pressure conditions (STP) (m^3/h); Q_{75} = air loss at STP at chamber pressure of 75 Pa (m^3/h) and ΔP = pressure loss across the orifice measured in meters of water (Pa).

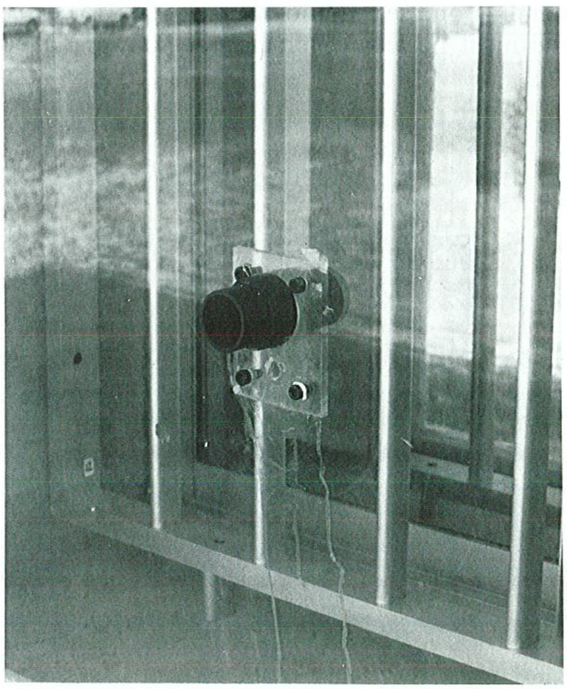

Fig. 3. Attachment connection between air hose and test chamber.

The results were reported in the following ways:

Total volume of air loss (Q) in m^3/h.

Air infiltration rate per unit crack length in m^3/h/m.

Air infiltration rate per unit daylight area in m^3/h/m^2.

Air infiltration rate per unit ventilation area in m^3/h/m^2.

Discussion of results

The mean air infiltration rate per unit of crack length over the entire sample was 13.48 m^3/h/m, which is 340% higher than the maximum allowed by ANSI/AAMA 101-85 for field tests. The frequency of occurrence for the results is plotted against the upper limit of the air-infiltration rate within each strip in Fig. 4. Nine windows (five fixed and four tilt-and-turn) satisfied the ANSI/AAMA limit, representing 6% of the total sample. In contrast, Weidt and Weidt [5] reported that 60% of newly installed windows in the U.S.A. have satisfactory air-infiltration rates. Fifteen windows had air infiltration rates ranging from 3.07 to 6.14 m^3/h/m (100–200% of the limit). This increased to 30 for the next group, where the air-leakage rate ranged from 200 to 300% of the ANSI/AAMA limit. Accordingly, 54 windows, i.e., 35% of the total sample, allowed an amount of air infiltration less than or equal

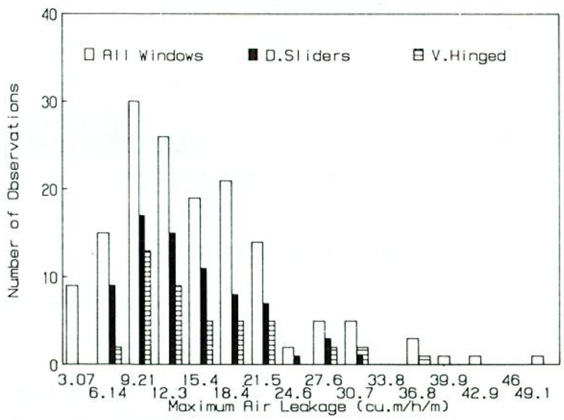

Fig. 4. Frequency distribution for air infiltration rates of all windows, double sliders and vertically hinged windows.

to three times the ANSI/AAMA limit. The remaining 65% had an air-infiltration rate higher than 9.27 $m^3/h/m$.

Plotting the same diagram for the double sliders (Fig. 4) indicates that nine of the 72 in the sample had air-leakage rates ranging from 3.07 and 6.14 $m^3/h/m$, and 17 had rates between 6.14 and 9.27 $m^3/h/m$. Thus, 36% of sliding windows had air-leakage rates below 9.27 $m^3/h/m$, almost the same ratio as in the entire population. The frequency diagram for vertically hinged windows (single and double leaves combined) indicates that 15 windows out of 44 had air-leakage rates below 9.27 $m^3/h/m$. This represents the same percentage as for the entire population.

Effect of window type on performance

The effect of window operational type was studied by evaluating the air-infiltration rate per unit of crack length, unit area of daylight and unit area of ventilation opening. Figure 5 shows the variation in air-infiltration rate per unit of crack length with different window types. Vertical sliders were not plotted due to lack of results. All types of openable windows had mean air-infiltration rates per unit of crack length exceeding the ANSI/AAMA limit. Horizontally hinged single-leaf (hopper) windows produced the highest mean (33.16 $m^3/h/m$), and the vertically hinged double-leaf the lowest (11.10 $m^3/h/m$). The means for tilt-and-turn and double sliders were close to the lower limit, and those for double hopper and single-leaf vertically hinged windows came in mid-range. Only four tilt-and-turn windows rated below the limit for the entire population of openable windows. Five fixed windows complied with the ANSI/AAMA limit for fixed windows (4.06 $m^3/h/m^2$).

Weidt and Weidt [5] found that window type is a dominant factor controlling air leakage. Their mean values for casement, double sliders, vertically hinged double-leaf, single slider and vertically hinged single-leaf windows were 1.28, 3.41, 4.02, 4.41 and 5.36 $m^3/h/m$, respectively. These are 30–40% of the values obtained for corresponding windows (double sliders and vertically hinged) in this study. It must be noted that Weidt and Weidt's sample contained wood, wood-cladded and aluminium windows.

The method of reporting air-infiltration rate can slightly modify the position of each type with respect to the others. Figure 6 shows the types in descending order for each method of reporting, starting with the most airtight. The hopper and double hopper windows performed badly, regardless of the method of reporting the air-leakage rate. Tilt-and-turn and fixed windows consistently ranked among the types with least leakage. Double sliders and vertically hinged windows interchanged positions, depending on the method of reporting. However, the most noticeable change in rank occurred

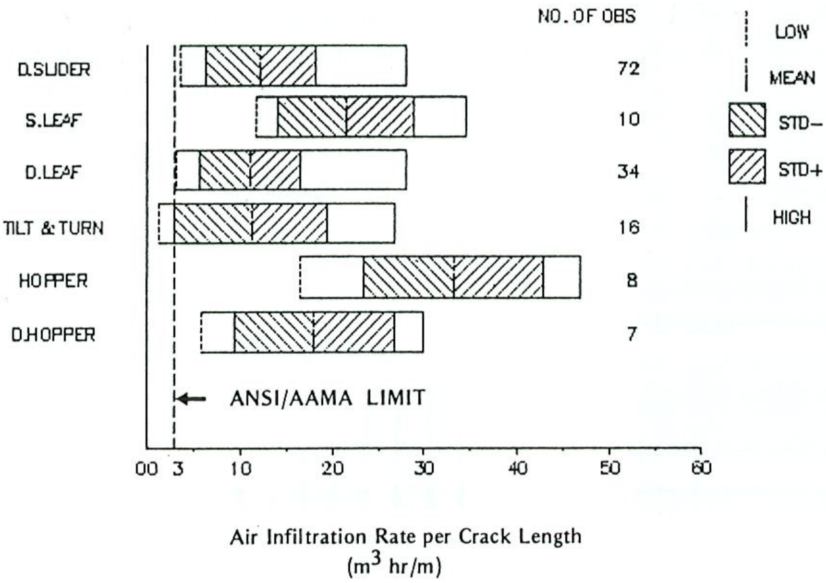

Fig. 5. Air infiltration rates per crack length for openable window types.

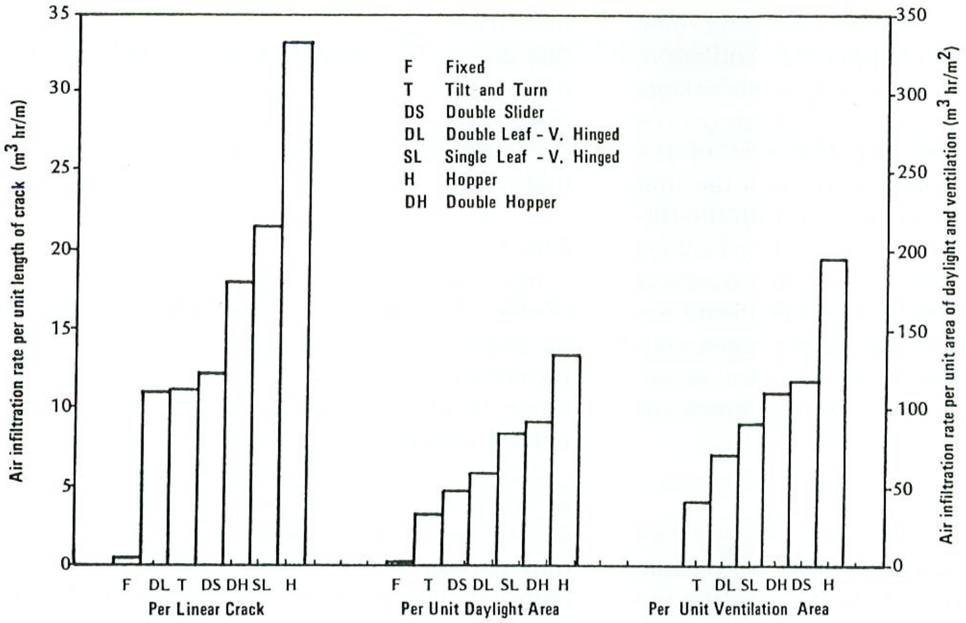

Fig. 6. Air infiltration rates of various window types.

when the double slider was reported per unit area of ventilation. This is mainly because the ventilation area of such windows is almost half the daylight area, thus doubling the deduced rate. Clearly, the method of reporting air infiltration does not play an important role in judging window performance in Kuwait, possibly because the types of window tested are not sensitive to the method of reporting air-leakage rates. Weidt and Weidt [5], however, observed that the method of reporting significantly affected the performance evaluation of their sample, which included single and double sliders and single- and double-hung windows. In single-slider and single-hung types, the crack length is almost half that of the double-slider and double-hung ones, whereas the ventilation area and daylight area remain almost the same for both types. As a result, double sliders and double-hung windows always produced lower rates when the air infiltration was reported per linear crack length. When air leakage was reported by either unit area of daylight or of ventilation, the single-slider and single-hung types performed better than the double windows.

In this study, the areas and crack lengths of vertically hinged double-leaf and double-hopper windows were almost double those of single-leaf windows. Thus, the double-leaf type always performed better than the single-leaf, regardless of reporting method. One exception is the vertically hinged group reported by daylight area, where the double-leaf type produced slightly higher rates than the single-leaf. This was attributed to the fixed daylight area in some double-leaf windows, which did not contribute to either the crack length or ventilation area data, being unopenable. However, this effect showed only when the rate was reported per daylight area.

The standard deviation and range were more consistent than the mean values of air infiltration for different types. Eliminating fixed windows and vertical sliders, the standard deviation ranged from 5.48 to 9.69 for double-leaf windows and hoppers, respectively, whereas the mean value of air infiltration per unit crack length varied from 11.10 to 33.16 $m^3/h/m$ (i.e., threefold). The range of results for all windows except fixed and vertical sliders was also consistent, indicating that the quality of workmanship was consistent regardless of window type. However, the high standard deviation and range indicate that quality control over fabrication activities was poor. It is important to improve quality control to reduce the variability, and hence the standard deviation, in the results. This should be in parallel to reducing the mean value, in order to upgrade performance.

Tilt-and-turn windows performed better than the single-leaf vertically hinged ones. Both types have essentially the same function, except that the tilt-and-turn windows can swing open horizontally to act as a hopper for ventilation. The tilt-and-turn type produced an air-leakage rate per unit crack length approximately 50% that of the single-leaf and 33% that of the hopper. These ratios improved when the unit areas of daylight were compared, with the tilt-and-turn producing 40% and 25% of the leakage rates for vertically hinged single-leaf windows and hoppers, respectively. This significant superiority may be due to the more rugged construction and superior materials used to accommodate the sophisticated mechanism for the dual operation.

Effect of window age

For windows up to 10 years old, age had no effect on the mean values of air infiltration, whereas older windows showed a 20–40% improvement in performance. The standard deviation for newly installed windows was more than double that for older windows, indicating that the level of quality control has declined in the past five to ten years. Deterioration of weather strips and other elements over time appeared to have little or no effect on window performance. This may reflect the very high air-infiltration rates obtained in this study, whereby the effects of aging were masked by serious defects in window construction. Weidt and Weidt [5] found that windows 25–50 years old produced higher air-leakage rates than newly installed windows. Their sample was limited (6–9 cases), but they attributed this decline in performance to the loss of weather strips in old windows.

Effect of building type

Slight variations in performance were obtained among windows installed in residential, office or public buildings.

Residential buildings yielded air-infiltration rates 28% and 17% lower than those for office and public buildings, respectively. This may reflect the extra care taken in selecting and maintaining windows in residential buildings. Since all three types had air-infiltration rates more than three times the ANSI/AAMA limit, this comparison is spurious.

Effect of building cost

The cost factor had no influence on the mean value for air infiltration. However, the standard deviation for low-cost buildings was the highest, indicating that quality control was poor for this group. The most expensive buildings produced the lowest standard deviation, indicating better quality control. For all categories, however, both the standard deviation and the air-infiltration rates were quite high.

Effect of source of material

Most of the windows had locally produced profiles, but the source of profile had little or no effect on the results. The imported profiles produced an air-infiltration rate 13% below those locally produced, and 9% below the overall average (13.48 $m^3/h/m$).

The double-slider windows yielded consistent air-infiltration rates regardless of the material source. Among horizontally hinged (hopper and double-hopper combined) windows, the local material allowed about 50% higher infiltration than imported materials installed by foreign contractors. Although both significantly exceeded the standard limit, the windows that were manufactured and installed by local contractors were of significantly lower quality. This may have resulted from a lack of local experience with aluminium hopper and double-hopper windows, since these types are relatively new.

Effect of source of workmanship

Since only 24 of the 154 windows tested involved imported workmanship, it would be statistically unsound to compare them with the entire sample. However, since the imported group consisted mainly of two types of window, double sliders and double hoppers, a reasonable comparison could be made with the corresponding local groups. Since no double hoppers were manufactured locally, they were replaced by locally produced hoppers. The sliders installed using imported workmanship produced slightly higher infiltration rates than local windows. This may be because they were mainly installed in public buildings, which generally yielded higher rates than other buildings. Nevertheless, both groups were well above the ANSI/AAMA limit.

Effect of window dimensions

The effect of window width (L) and area (A) was studied to determine if there are optimum dimensions at which air infiltration is minimized. Table 1 presents the air infiltration by total volume, volume per linear crack length

TABLE 1. Air infiltration rates for different window widths

Window width (m)	Number	Mean value	Standard deviation	Lower limit	Upper limit
	Total volume of air infiltration (m^3/h)				
$L<1.0$	75	66.09	34.64	0.00	164.73
$1.0<L<1.5$	58	68.57	33.36	18.68	155.70
$L>1.5$	21	68.90	44.33	0.00	166.47
	Air infiltration per unit crack length ($m^3/h/m$)				
$L<1.0$	75	14.77	10.02	0.00	46.75
$1.0<L<1.5$	58	12.51	6.28	3.56	28.11
$L>1.5$	21	11.59	8.04	0.00	29.94
	Air infiltration per unit daylight area ($m^3/h/m^2$)				
$L<1.0$	75	65.25	43.56	0.00	191.89
$1.0<L<1.5$	58	47.65	26.27	12.00	116.00
$L>1.5$	21	46.36	42.50	0.00	149.55

and volume per unit daylight area for different window widths across the total sample. Table 2 presents the same data for different window areas. The results show the following:

(1) Whereas the air-infiltration rate per unit crack length or daylight area decreases with increasing L and A, the total volume of air infiltration remains almost unchanged. This is explained by the increased crack length and daylight area in larger windows, which result in decreased infiltration rates. However, the air-infiltration volume depends on the size and location of the defects. Since most of the defects found in the sample were basically independent of size, e.g., gaps between the vertical sections of double sliders, missing hardware or missing hole caps, the insensitivity of total volume of air to window size is explicable.

(2) Infiltration rates for double sliders and double-leaf windows in different width and area

TABLE 2. Air infiltration for different window areas

Area (m^2)	Number	Mean value	Standard deviation	Mean value	Standard deviation
		Total volume (m^3/h)		Per crack length ($m^3/h/m$)	
$A<1.0$	45	69.60	35.38	17.64	10.73
$1.0<A<1.5$	59	72.59	40.57	13.24	7.78
$1.5<A<1.8$	22	63.67	34.63	11.70	6.35
$1.8<A<2.0$	23	53.93	19.77	8.65	3.57
$A>2.0$	5	64.91	16.79	8.95	2.53
		Per daylight area ($m^3/h/m^2$)		Per vent. area ($m^3/h/m^2$)	
$A<1.0$	45	82.47	44.90	126.76	63.66
$1.0<A<1.5$	59	55.18	33.87	106.08	64.72
$1.5<A<1.8$	22	40.26	23.27	92.84	67.16
$1.8<A<2.0$	23	28.62	10.12	62.67	27.74
$A>2.0$	5	24.17	6.29	66.76	32.94

groups were analysed separately. For the same length or area group, most double sliders leaked less air than vertically hinged windows. In terms of total volume, the larger the area of the vertically hinged windows, the lower the volume of air leakage. This indicates that performance was influenced by factors other than dimensions, since this result was not expected. For double sliders, the air volume was independent of window size. This may be because double sliders leak mainly from corners and gaps, which are independent of window size, whereas hinged windows leak along the sash perimeter, which depends on the dimensions. It is therefore expected that, the larger the window, the larger the perimeter and the higher the volume of air infiltration.

Conclusions

The study showed that only 6% of windows in the sample complied with the ANSI/AAMA 101-85 limit. The majority yielded air-infiltration rates well above this limit, indicating grave shortcomings in window construction in Kuwait when judged by American or European standards. Furthermore, the deviation in the results was high, showing poor quality control over production activities.

Horizontally hinged windows produced the highest air-infiltration rate, whereas fixed windows and tilt-and-turn windows allowed the least leakage. Double sliders and vertically hinged windows were midway between the extremes. Tilt-and-turn windows provided air leakage rates approximately one-half those of vertically hinged windows.

Age had a negligible effect on window performance. Old windows performed better than the new ones, mainly due to a decline in construction practice and quality control in the local market.

Windows in residential buildings yielded air-infiltration rates 28% and 17% lower than those in office and public buildings, respectively.

Building cost, and hence contractor grade, seemed to have no influence on the mean values of air infiltration; however, low-cost buildings yielded higher standard deviations, indicating poor quality control among small contractors.

The source of the aluminium profile had little or no effect on the air-infiltration rate. Windows made from imported profiles produced an air-leakage rate 9% below the overall average, and 11% below that of the locally produced profiles. Similarly, the source of workmanship (i.e., local or imported) had only a minor effect on performance. This, however, may change when performance limits are imposed by the national code of practice.

The total volume of air infiltration seemed to be independent of window size, since size is largely irrelevant to those defects allowing air leakage. However, double sliders leaked mostly from corners, whereas vertically hinged windows leaked from the sash/window joint.

These conclusions are greatly influenced by the poor performance of windows in Kuwait, and may not necessarily be applicable to windows installed in regions where performance criteria are imposed on window production. Hence the output of the study has created public concern about the need to impose such limitations on window fabrication in Kuwait. A revised Kuwaiti specification incorporating performance requirements is currently under preparation.

Acknowledgements

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References

1 O. Daoud, H. Al-Shami and G. Maheshwari, Field survey and performance assessment of aluminium windows in Kuwait, *Kuwait Institute for Scientific Research, Rep. No. KISR3072*, Kuwait, 1989.
2 *Annual Statistical Abstract*, Central Statistical Office, Ministry of Planning, Kuwait, 1985.
3 J. F. S. Carruthers, The performance assessment of windows, *Proc. Windows in Building Design and Maintenance, Gothenburg, Sweden*, Swedish Council of Building Research, 1987, pp. 34–40.
4 O. Daoud, G. Maheshwari and H. Al-Shami, Defects in aluminum windows and their impact on dust and air infiltration, in preparation.

5 J. Weidt and J. Weidt, Air leakage of newly installed residential windows, *Lawrence Berkeley Laboratories, Rep. LBL 11111*, National Technical Information Service, Springfield, VA, U.S.A., 1980.
6 AAMA, *Voluntary Specifications for Aluminum Architectural Windows, GS-001*, American Architectural Manufacturers Association, IL, U.S.A., 1984.
7 ANSI/AAMA, *Voluntary Specifications for Aluminum Prime Windows and Sliding Doors, ANSI/AAMA 101-85*, American Architectural Manufacturers Association, IL, U.S.A., 1985.
8 J. Nevander, Closing remarks, *Proc. Windows in Building Design and Maintenance, Gothenburg, Sweden*, Swedish Council of Building Research, 1987, pp. 133–134.