Discussion on design internal pressures in AS/NZS1170.2:2021

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ABSTRACT
This paper presents the basis for a discussion on providing some simplified methods for internal pressures in buildings less than 25 m in height in the AWES handbook. It examines the internal pressure calculations based on the design examples of a warehouse in the AWES handbook following Section 5.3 of AS/NZS 1170.2. The paper discusses the sensitivity of the design pressures to various assumptions made, such as leakage, whether or not some elements are wind rated and the way the internal volume is partitioned.

Practicing design engineers indicate that the changes to internal pressure calculations in AS/NZS 1170.2:2021 have added considerably to their workload. Some have said that they do not understand them. The worked examples in the AWES handbook do not rigorously follow the method in AS/NZS 1170.:2021.

1. Introduction

Internal pressures are important in the design of enclosed buildings as they can have a substantial contribution to net pressures across the building envelope and therefore the wind loads to be resisted by the structure. AS 1170.2 (Standards Australia, 1989) in common with other national wind loading standards included simplistic recommendations for internal pressures. Internal pressure provisions in AS/NZS 1170.2, (Standards Australia 2002) became more detailed to include aspects of volume and leakage, and subsequent amendments and revisions have attempted to refine the calculation of internal pressures. Damage investigations (Boughton et al, 2021, Leitch et al, 2008, Boughton et al, 2011) have shown that if internal pressures are underestimated, the net loads on structures are significantly higher than the designer has anticipated and failures occur.

The internal pressure calculations require designers to anticipate scenarios in which the envelope has some openings. The origins of the openings observed in damage investigations (Parackal et al 2022) show six scenarios that could occur in any wind event; the last three are likely in tropical cyclones.

- Doors or windows are left open for ventilation or garage doors are open for easy access.
- Doors are opened to get people into the building just before the peak gust arrives and the wind at the time makes them difficult to close.
- Garage doors are opened to put vehicles away at the last minute before the wind event arrives.
- Failure of door or window latches, so that doors or windows blow in.
- Doors or windows are struck by wind-borne debris; trampolines, unsecured garden sheds and light outdoor furniture can become wind-borne debris at wind speeds significantly below the design wind speed. They could break windows or doors before a peak gust occurs.
- Un-rated windows and doors fail at wind speeds before the peak gust arrives.

Figure 1, Figure 2 and Figure 3 present extracts from AS/NZS 1170.2:2021 (Standards Australia, 2021).

> Pressure coefficients for internal pressure ($C_{p,i}$) shall be determined from Tables 5.1(A) or 5.1(B). Table 5.1(A) shall be used for the design case where there are no potential openings in any surface with a combined area greater than 0.5 % of the total area of that surface, and the leakage in the walls lead to internal pressures. Table 5.1(B) shall be used for the design case where there are openings in any surface greater than 0.5 % of the total area of that surface, or they can be created accidentally.

Figure 1. Extract from Clause 5.3.1.2 in AS/NZS 1170.2:2021

In general, small windows and personnel doors exceed the limit of 0.5% of a surface area, so for most enclosed buildings, Table 5.1(B) must be used.

> Subject to Clauses 5.3.2.2 and 5.3.2.3, combinations of openings and open area shall be assumed to give internal pressures, which, together with external pressures, give the most adverse wind actions.
>
> NOTE Potential openings include doors or windows that are left open or may fail, vents that are normally open and holes in cladding caused by impacts by windborne debris during a major wind event. Openings can be doors (including balcony doors) or windows that are left open, open under pressure, or open due to the failure of latches or hinges. When determining internal pressures, consideration should be given to scenarios in which large openings may develop. Openings may also be generated by debris impacts, particularly in Regions C and D (see Clause 2.5.8).

Figure 2. Extract from Clause 5.3.2.1 in AS/NZS 1170.2:2021

This indicates that in considering possible opening scenarios, designers should anticipate the combination of openings that will create the most adverse internal pressures for combining with either positive external pressures or negative external pressures.

Table 5.1(B) — Internal pressure coefficients ($C_{p,i}$) for buildings with openings greater than 0.5 % of the area of the corresponding wall or roof

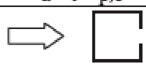
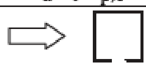
Ratio of area of openings on one surface to the sum of the total open area (including permeability) of other wall and roof surfaces	Largest opening on windward wall	Largest opening on leeward wall	Largest opening on side wall	Largest opening on roof
0.5 or less	−0.3, 0.0	−0.3, 0.0	−0.3, 0.0	−0.3, 0.0
1	−0.1, 0.2	−0.3, 0.0	−0.3, 0.0	−0.3, 0.0
2	0.7 $K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$
3	0.85 $K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$
6 or more	$K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$	$K_a K_\ell C_{p,e}$
	t5-1(b)-1			

Figure 3. Extract from Table 5.1(B) in AS/NZS 1170.2:2021

A significant change in Table 5.1(B) was the inclusion of K_a and K_l in the evaluation of $C_{p,i}$ based on the size of the opening and its location on the external surface. This work was underpinned by research (Bodhinayake, Ginger and Henderson, 2020, Estephan et al, 2021, Humphreys, Ginger and Henderson, 2019, Kopp, Oh, and Inculet, 2008, Vickery, 1986).

2. Internal pressures in a design example

The example in this paper is the third example from the AWES handbook (AWES 2022). The building is a steel portal-framed warehouse in Bunbury in the SW of Western Australia. It has a footprint of 25 x 15 m and an average roof height of 6.2 m. The potential openings include a roller door, a personnel door and a small window as shown in Figure 4.

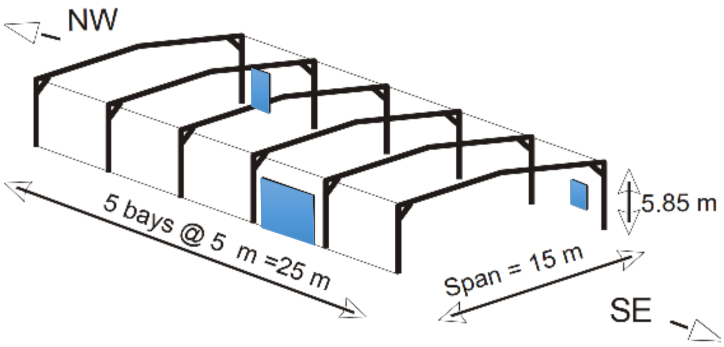


Figure 4. Example building from AWES (2022)

There are two walls with potential openings – the SW wall with the roller door (θ = 180°) and the NE wall (θ = 0°) with the personnel door and the small window. The calculations for internal pressure that follow AS/NZS 1170.2:2022 for the openings in the windward wall are shown below. It uses a value of 0.3% for the leakage of the building and a $K_{c,i}$ = 1.0. For designs of different elements in the building appropriate values of $K_{c,i}$ can be used.

Openings in wall at theta = 0 deg				
Openings wall as windward wall			wind theta =0	
	windward Cp,e	0.7	0.7	0.7
		Door	Window	Door and window
	Open area	2.5	1	3.5
	Volume (m3)	2325	2325	2325
	Ka opening	1.000	1.000	1.000
	Kl opening	1.000	1.500	1.000
	Ka used	1.000	1.000	1.000
	Kl used	1.000	1.341	1.000
	open wall area (m2)	2.965	1.465	3.965
	other surfaces area area	1.023	1.023	1.023
	True area ratio	2.898	1.432	3.876
	Used area ratio	2.898	1.432	3.876
	Cp,e factor Table 5.1(B)	0.835	0.465	0.894
	Cp,i	0.584	0.436	0.626
	100A3/2/Vol	0.170	0.043	0.282
	Kv	0.895	0.850	0.927
	Kc,i	1.000	1.000	1.000
	Cshp,i	**0.523**	**0.371**	**0.580**
	Cshp,i max			**0.580**

Openings in wall at theta = 180 deg			
Openings wall as windward wall			wind theta =180
	windward Cp,e	0.7	0.7
		Garage door	
	Open area	12	
	Volume (m3)	2325	
	Ka opening	0.993	
	Kl opening	1.000	
	Ka used	0.994	
	Kl used	1.000	
	open wall area (m2)	12.465	
	other surfaces area area	1.023	
	True area ratio	12.185	
	Used area ratio	12.185	
	Cp,e factor Table 5.1(B)	1.000	
	Cp,i	0.696	
	100A3/2/Vol	1.788	
	Kv	1.048	
	Kc,i	1.000	
	Cshp,i	**0.729**	
	Cshp,i max	**0.729**	

The calculations show that for each of the scenarios shown, $C_{p,i}$ was greater than 0.4 and that even the small window on its own gives $C_{p,i}$ = 0.436. This was partly due to the local pressure factor of 1.5 applied to the small opening. From Clause 5.3.2.1 in AS/NZS 1170.2:2021, the personnel door must be considered as a potential opening because it is difficult to purchase wind-rated personnel doors. Windows should also be considered a potential opening because they might be left open during the operation of the building or broken during a wind event.

3. Sensitivity analysis

The values for $C_{shp,i}$ were plotted against varying input parameters. Figure 5 shows the results of the sensitivity study with the default position shown with the red lines. For the volume sensitivity, the building was partitioned to give individual spaces down to 1/20th the original building volume.

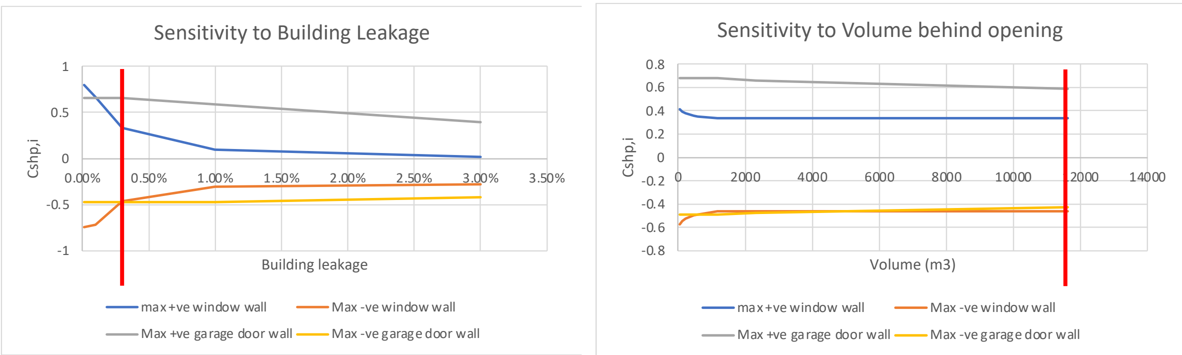


Figure 5. Variation in $C_{shp,i}$ with leakage and volume

Figure 5 shows that there is a much more significant effect of leakage for the smaller opening (window) than for the larger opening (roller door). Selecting an appropriate value for leakage is important in determining the correct internal pressure. There is little information on this to assist designers in both the standard and the AWES Handbook (AWES 2022). There is less sensitivity of the $C_{shp,i}$ to internal volume. In some cases, this will be difficult to determine at the ultimate limit state as it is a function of how internal doors are left and the strength of ceilings. However, it is conservative to assume the lowest internal volume possible. Figure 6 shows the variation in $C_{shp,i}$ with changes in the size of an opening (not its position).

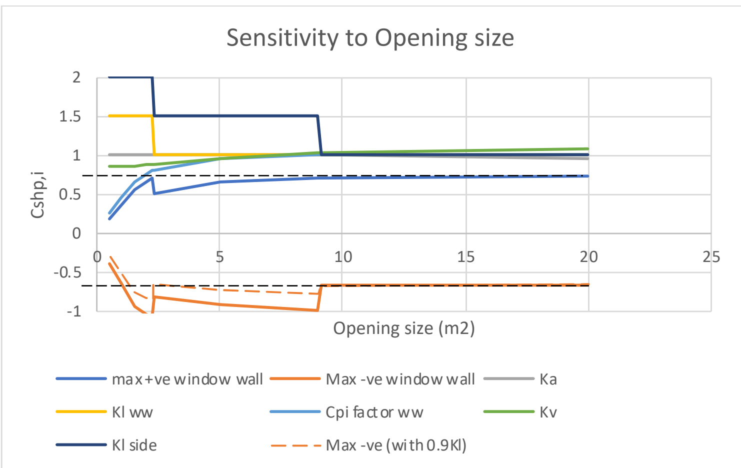


Figure 6. Variation in $C_{shp,i}$ with opening size for window only

This plot shows the K_l factors for both the side (black line) and windward (ww) wall (yellow line) stepping down as the opening size increases. Most of the other contributing factors to the equation tend to increase with the size of the opening. The $C_{p,i}$ factor is the multiplication factor drawn from Table 5.1(B) that gives the $C_{p,i}$ as a factor of the relevant $C_{p,e}$ at the location. For the windward wall (light blue line), it increases quite steeply at first then more gradually. Over the long run, these factors tend to cancel each other out, so that the $C_{shp,i}$ for windward wall (dark blue line) and for the side wall (orange line), have a few minor variations, but tend to be around values of +/– 0.7 respectively (shown be the dashed black line).

Preliminary wind tunnel studies in progress have confirmed values for peak pressures at an opening on the windward wall, but indicate that there may be a slight attenuation of instantaneous peak pressures for openings on a side wall (suction surface) for some opening configurations. If the K_l factor on the side walls only is reduced by a factor of 0.9 on the suction surface, the $C_{shp,i}$ on the side wall is given by the dashed orange line. The value of –0.7 is conservative for most parts of the dashed orange line. Completion of wind tunnel study tests will be necessary to confirm whether there is an attenuation of peak internal pressures for side walls and to define the scope of where this simplification is valid.

A large number of calculations have to be performed to deliver $C_{shp,i}$ values that are between +/– 0.6 and +/-0.7 for many buildings with intermediate leakage (between 0.2% and 0.6%).

4. Practical implications of the new calculations

The example in the AWES handbook (AWES 2022) assumes that the roller door could be blown inwards when that wall is the windward wall, but that it remains closed for all other wind directions. It assumes that the personnel door and window are not open. The resulting $C_{p,i}$ for the building is +0.695 for one direction, but otherwise (–0.3, 0.0) treating the building as having all walls equally permeable. The +0.695 is the same as the calculations in section 2, but the –0.3, +0.0 significantly underestimate the other $C_{p,i}$ values (calculated for the configuration of the example warehouse -0.76 for an open window). The assumptions in the AWES handbook, which do not reconcile with AS/NZS 1170.2, (see Figure 2) will give lower values of $C_{shp,i}$.

Discussions with practicing engineers have indicated that there is confusion in the extra work that goes into calculating $C_{shp,i}$ in AS/NZS 1170.2:2021 and some are planning to develop their own in-house processes for simplifying it. This paper has studied the rationally based methods in AS/NZS 1170.2 performed sensitivity studies to identify where simplifications can be made and proposes the form of a simplification that may lead to the intent of the Standard being adopted more widely in the design of parts of buildings less than 25 m in height.

The example followed in this paper is for a building in a non-cyclonic area and the only potential openings considered are the doors and windows. For buildings in cyclonic areas, the issue can be complicated by debris damage to the cladding. In this case, the size of opening created by debris can vary considerably and may lead to different values.

4.1 Proposed simplification

Designers could be offered an alternative to calculating $C_{shp,i}$ for buildings lower than 25 m with openings greater than 0.5% of the surface area. This could be based on the fact that most buildings lower than 25 m have unrated doors and windows that could be left open. Table 1 presents the concept of a simplification, but the final values can only be determined once the wind tunnel studies have been completed. The values in Table 1 are based on calculations using the current method of AS/NZS 1170.2:2021.

Table 1. Simplified evaluation of $C_{shp,i}$ in parts of buildings lower than 25 m

	Values multiplied by $K_{c,i}$ to give $C_{shp,i}$			
	Non-cyclonic areas		Cyclonic areas	
	+ve	-ve		
Residential, office and well-sealed commercial buildings	(+0.75)	(-0.75)	?	?
Non-air-conditioned portions of warehouses	+0.7	-0.7	?	?
Poorly sealed industrial buildings	(+0.6)	(-0.6)	?	?

Note: Only the warehouse values have been studied so far; the others will need to be confirmed later.

5. Conclusions

The complexity of the internal pressure calculations in AS/NZS 1170.2:2021 may mean that designers look up values from the wrong table and therefore under-estimate the internal pressures. The worked example in the current AWES handbook also underestimates internal pressures.

The internal pressure calculations are sensitive to the assumed leakage of the building, but little guidance is available. The factors used in the calculations are also sensitive to the size of the opening assumed, but the final $C_{shp,i}$ values obtained are less sensitive to the size of the opening. A simplified alternative based on the methods in AS/NZS 1170.2 has been proposed, which would reduce the work involved in the design of internal pressures for parts of buildings lower than 25 m and would give compatible results to the calculations in the current standard. This paper is presented to promote discussion on defining some simplified procedures for evaluating in internal pressures in low rise buildings for potential inclusion in future versions of the AWES Handbook once the wind tunnel studies that underpin it have been completed.

References

Australasian Wind Engineering Society (2022) "Wind loading handbook for Australia and New Zealand" AWES-HB-001-2022.

Bodhinayake, G., Ginger, J., and Henderson, D. (2020). "Correlation of internal and external pressures and net pressure factors for cladding design." *Wind Struct. 30 (3), 219–229.* doi:10.12989/was.2020.30.3.219

Boughton, G., Falck, D., Parackal, K., Henderson, D., and Bodhinayake, G. (2021). "Tropical cyclone Seroja - damage to buildings in the mid-west costal region of Western Australia." *Cyclone Testing Station Technical report 66*, JCU, Townsville, Q.

Boughton, G., Henderson, D., Ginger, J., Holmes, J., Walker, G., Leitch, C., et al (2011). "Tropical cyclone Yasi: Structural damage to buildings". *Cyclone Testing Station Technical report 57*, JCU, Townsville, Q.

Estephan, J., Gan Chowdhury, A., Elawady, A., and Erwin, J. (2021). "Dependence of internal pressure in low-rise buildings on aerodynamic parameters, defect features and background leakage." *J. Wind Eng. Industrial Aerodynamics 219, 104822.* doi:10.1016/j.jweia.2021.104822

Humphreys, M. T., Ginger, J. D., and Henderson, D. J. (2019). "Internal pressures in a full-scale test enclosure with windward wall openings." *J. Wind Eng. Industrial Aerodynamics 189, 118–124.* doi:10.1016/j.jweia.2019.03.024

Kopp, G., Oh, J., and Inculet, D. (2008). "Wind-induced internal pressures in houses." J. *Struct. Eng. (N. Y. N. Y). 134 (7), 1129–1138.* doi:10.1061/(asce)0733-9445(2008)134:7(1129)

Leitch, C., Ginger, J., Harper, B., Kim, P., Jayasinghe, N., and Somerville, L. (2008). "Investigation of performance of housing in Brisbane following storms on 16 and 19 November 2008"- Cyclone Testing Station Technical report 55, JCU, Townsville, Q.

Parackal, K. I., Boughton, G.N., Henderson, D.J., Falck, D,J. (2022) "Minimising damage to houses by designing for high internal pressures", *Frontiers in Built Environment*, doi 10.3389/fbuil.20222.970673

Standards Australia, (1989), "SAA Loading Code. Part 2 Wind actions", Australian Standard, AS 1170.2–1989.

Standards Australia, (2002), "Structural design actions. Part 2 Wind actions", Australian/New Zealand Standard, AS/NZS 1170.2:2002.