Section J Case Study series: Ductwork

New construction and the design implications of the envelope line and ceiling space

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INTRODUCTION

For the NCC 2019 the new fan performance requirements are based around the design of the total fan and ductwork system. The 2019 NCC Section J became mandatory on May 1, 2020, with the ductwork Deemed-to-Satisfy (DtS) provisions covered under Part J5.4 as part of the fan and ductwork system, and ductwork has additional requirements under Part J5.5 and J5.6. The code is a performance-based code, and the DtS provisions are just one way of complying with it. A Performance Solution that demonstrates compliance with the performance requirements of the code by using other methods of assessing the total duct and fan system can also be used.

Determining the ductwork pressure drops is dependent on other factors in the design and construction of a building. Duct pressure drop allowances of 1Pa/m for straight duct can be exceeded due to these and other constraints. Ductwork aspect ratios can affect efficiency of the ductwork, resulting in significant pressure losses that are not always accounted for. This opens an opportunity for ductwork component designs to be improved and innovation to occur in the area of duct design.

This case study will investigate some of the complexities in the application of the DtS provisions and the impacts it has on ductwork sizing and overall efficiency of the ductwork. The NCC 2019 provisions apply to additions, alterations and new construction; in this instance we are looking at new construction and the design implications of the envelope line and ceiling space. The ductwork aspect ratio and insulation thickness for each type of ductwork (supply and return) will be investigated to understand what impacts on the overall efficiency of the ductwork and hence fan and ductwork system.

APPLICABLE NCC 2019 CLAUSES

The applicable clauses in the NCC 2019 are for compliance assessment for the ductwork performance, based on a DtS solution using Parts J5.4, J5.5 and J5.6. The ductwork must comply with clauses in all of these parts, and hence the following summarises the key aspects covered in this case study.

To meet the performance requirements using the DtS solution in Part J5.4, there are two ways to comply:

- Component-based compliance: fan efficiency complies with minimum required system static efficiency, and meets pressure-drop requirements along the index run, for the straight duct and ductwork fittings.
- Whole-of-system-based compliance: fan motor power per unit of flowrate (W per L/s) of the proposed system is lower than the reference fan system W per L/s.

To meet the DtS provisions for the ductwork insulation, Part J5.5 requirements are:

- Ductwork and fittings in an air conditioning system must be provided with insulation –
  - (i) Complying with AS/NZS 4859.1; and
  - (ii) Having an insulation R-Value greater than or equal to –
    - (A) for flexible ductwork, 1.0; or
    - (B) for cushion boxes, that of the connecting ductwork; or
    - (C) that specified in Table J5.5.

Location of ductwork and fittings	Climate zone 1, 2, 3, 4, 5, 6 or 7	Climate zone 8
Within a conditioned space	1.2	2.0
Where exposed to direct sunlight	3.0	3.0
All other locations	2.0	3.0

Table J5.5: Ductwork and fittings – Minimum insulation R-Value

There are other clauses in Part J5.5 that have additional details and exclusions that need to be reviewed by the designer; however, these are not the focus of this case study so have been left for readers to follow up themselves.

To meet the DtS provisions for the ductwork sealing, Part J5.6 Ductwork sealing requires:

- Ductwork in an air conditioning system with a capacity of 3000L/s or greater, not located within the only or last room served by the system, must be sealed against air loss in accordance with the duct-sealing requirements of AS 4254.1 and AS 4254.2 for the static pressure in the system.

DEFINING THE BUILDING ENVELOPE

The building envelope is defined by the application of Part J1 Building Fabric, and Part J3 Building Sealing. Where the building fabric insulation and vapour barriers are applied as per the design documentation defines the building envelope line, and hence impacts on the air conditioning system requirements. Part J1 is applied to the building fabric as per the clause J1.1.

J1.1 Application of Part

The DtS provisions of this Part apply to building elements forming the envelope of a Class 2 to 9 building other than J1.2(e), J1.3, J1.4, J1.5 and J1.6(a), which do not apply to a Class 2 sole-occupancy unit or a Class 4 part of a building.

The definition of the building envelope and conditioned space are provided in schedule 3 of the NCC, and is a link within the NCC.

Envelope, for the purposes of Section J in Volume One, means the parts of a building's fabric that separate a conditioned space or habitable room from –

(a) the exterior of the building; or

(b) a non-conditioned space including –

(i) the floor of a rooftop plant room, lift-machine room or the like; and

(ii) the floor above a carpark or warehouse; and

(iii) the common wall with a carpark, warehouse or the like.

Conditioned space, for the purposes of Volume One, means a space within a building, including a ceiling or under-floor supply-air plenum or return-air plenum, where the environment is likely, by the intended use of the space, to have its temperature controlled by air conditioning.

The application of the building sealing requirements of the NCC DtS provisions also requires the envelope line to be sealed to limit air movement across the thermal barrier. This is applied as per Part J3 Building sealing.

J3.1 Application of Part

The DtS Provisions of this Part apply to elements forming the envelope of a Class 2 to 9 building.

There are situations where exemptions apply which are covered in the code.

The location of the envelope line, i.e., position of where the insulation and sarking are installed, must be determined by the architect, construction designer or environmentally sustainable design (ESD) professional. It can be influenced by the mechanical HVAC designer who has the right level of training and professional understanding of construction methods, heat transfer and insulation and materials properties.

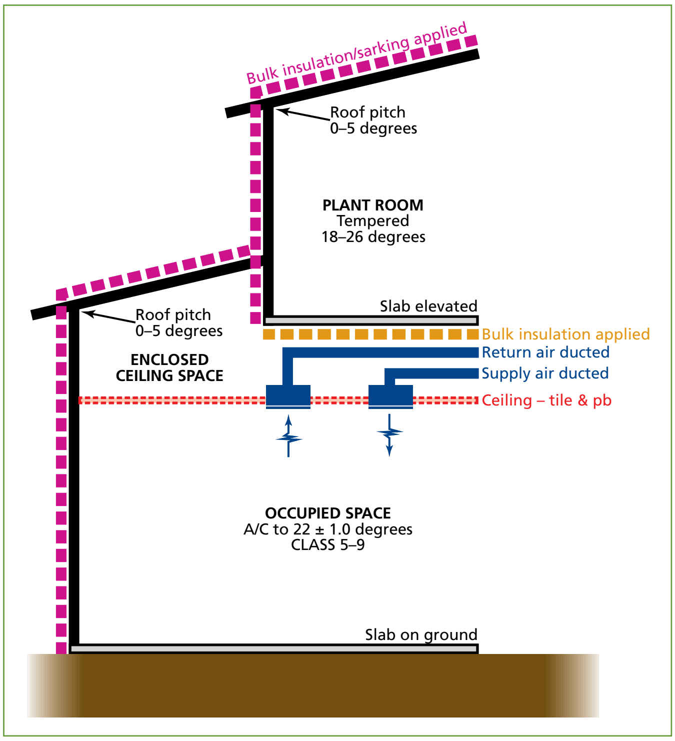


Figure 1: Building envelope diagram

Figure 1 shows an example situation where the defining position for the envelope line and hence the requirements of the ductwork insulation are not easily determined. Depending on the construction methods of the builder and cost implications in the build process, the location of the building fabric insulation and sarking system can positively or negatively impact the ductwork efficiency.

In this instance the envelope line is located at the roof line, and hence the enclosed ceiling space as noted is considered to be part of the conditioned zone. The ductwork insulation required will be for ductwork located in the conditioned zone and hence an R1.2 insulation wrap is to be used. In this situation the ceiling space under the plant room will be quite restricted. Ductwork into this area will be restricted in available sizing and hence air volume capacity.

If the envelope line was moved to the ceiling line and the enclosed ceiling space became a non-conditioned zone, the required insulation on the ductwork becomes R2.0. In addition, the insulation for the roof/ceiling would then need to be located at the ceiling line, further reducing the space available for ductwork. An R2.0 duct wrap insulation is typically 75mm in thickness. Providing 75mm insulation within a 250mm available space results in the free duct depth to be 100mm. Fact: 100mm is only sufficient for toilet exhaust and kitchenette exhausts or outside air supply for units and apartments. It could be argued it is not even enough depth for that application.

Therefore, the envelope line location and the impact that has on the ductwork air path is a critical design step that must be considered in any ductwork design.

REVIEW THE DESIGN AND CEILING SPACE

The envelope line shown in Figure 1 provides for the entire ceiling plenum space to be within the conditioned zone even though the return and supply air are both ducted into the occupied space below. This makes sense in this situation because otherwise the tile and plasterboard ceiling would become the envelope line and then create some significant issues in construction, trying to seal against air movement between the ceiling plenum and the occupied space. Light fittings, fire services, and other ceiling penetrations are very difficult to seal up. Also, the seal would be broken and not repaired the first time any maintenance is performed. A typical ceiling plenum cross-section can look like the detail in Figure 2.

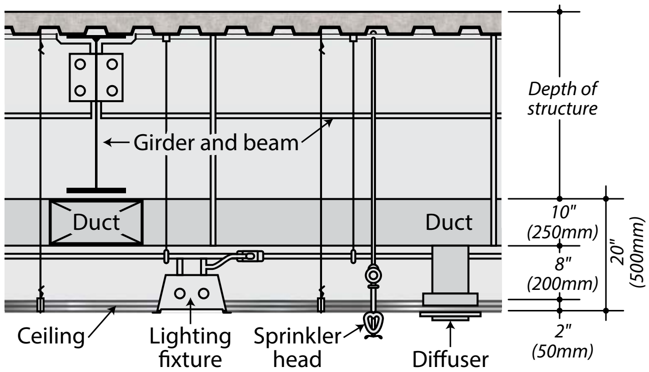


Figure 2: Typical Ceiling Plenum Space

Calculation of the allowable void for HVAC ductwork in the typical case shown in Figure 2 means only a 250mm deep section of duct can fit within the ceiling space where it traverses under the structural support girder. The resultant calculations for the open-air path allowable for the ductwork if insulated are:

	dimensions		
Duct depth available space	250	250	mm
Internal lined top	40	50	mm
Internal lined bottom	40	50	mm
Air path depth	170	150	mm
Air velocity in duct	4.44	4.44	m/s
Width based on standard ratio	680	600	mm
Maximum air volume	513.264	399.6	L/s
NCC pressure drop allowance	1	1	Pa/m

Table 1: Duct sizing calculations 4:1 aspect ratio.

The above calculations are based on maintaining a recommended duct width to depth ratio of 4:1, however, as noted in DA03 page 3-90 a duct width to depth ratio of 8:1 still allows for the equivalent diameter method to be used for duct pressure drop calculations. Using 8:1 aspect ratios, the absolute maximum allowance for this ductwork is given in the following calculations:

	dimensions		
Duct depth available space	250	250	mm
Internal lined top	40	50	mm
Internal lined bottom	40	50	mm
Air path depth	170	150	mm
Air velocity in duct	5.36	4.94	m/s
Width based on standard ratio	1360	1200	mm
Maximum air volume	1239.232	889.2	L/s
NCC pressure drop allowance	1	1	Pa/m

Table 2: Duct sizing calculations 8:1 aspect ratio.

DETERMINE DUCT PRESSURE DROPS

To achieve the DtS provisions for straight duct, the 1Pa/m maximum static value reached with the airflow velocities as noted in Table 1 and Table 2 average at about 5m/s. For a given system serving an office, the ductwork sizing is dependent on the available ceiling space and the required airflow to service the area with adequate airflow. To investigate the impact of this on the ductwork design and system performance, an example system is presented below.

Given a system with the following details:

Total office area served	499	m^2
Supply air	2400	L/s
Return air	1600	L/s
Outside air	800	L/s
System description: Floor-mounted AHU with supply air and return air ducted through ceiling space.		

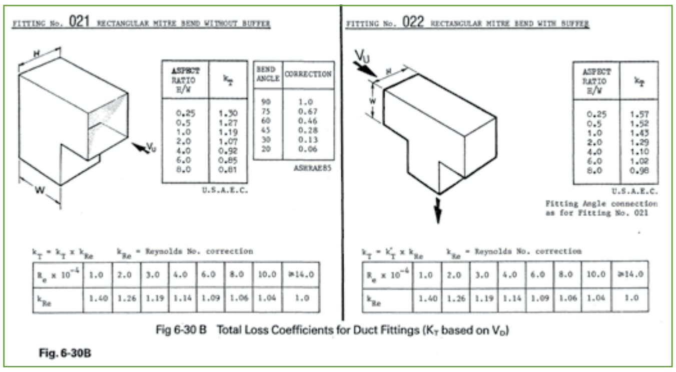
Table 3: Air conditioning system characteristics.

The ductwork sizing for the given ceiling space and internal clear air path dimensions noted in Table 1 and Table 2 will result in an impractical solution, and a solution where the aspect ratios of the ductwork exceed the maximum recommended. The main supply air (SA) duct branch from the AHU needs to provide 2,400L/s. To achieve the 150mm duct depth and 5m/s air velocity, a duct approximately 2,650mm wide is required. The aspect ratio for this ductwork would then be a width to depth ratio of 15.5:1. The practical issues with duct of this design are:

- 2,650mm width ductwork requires additional structural support and higher cost hanger arrangements
- 2,650mm width ductwork is likely to sag in the middle and can result in moisture sitting in the low spots, resulting in dust build-up, contamination and potential health risks
- 2,650mm width ductwork that is only 170mm depth is very difficult to handle onsite for installation
- The duct sizing is costlier to manufacture and will use more metal than ductwork of a more reasonable width-to-depth ratio

- Airflow through ductwork of such extreme aspect ratios is not always even across the entire width of the ductwork, resulting in stagnant areas, or potential for take-off branches to be starved of air.

The sizing of the ductwork and hence the available airflow that can be delivered through the ductwork affects the total static pressure losses for the fittings within the system. Unless the aspect ratio is reduced, the k_T factors for the fittings can be significantly higher and hence result in much larger pressure drops through the fittings.



FITTING No. 021 RECTANGULAR MITRE BEND WITHOUT BUFFER

ASPECT RATIO H/W	k_T
0.25	1.30
0.5	1.27
1.0	1.19
2.0	1.07
4.0	0.92
6.0	0.85
8.0	0.81

U.S.A.E.C.

BEND ANGLE	CORRECTION
90	1.0
75	0.67
60	0.46
45	0.28
30	0.13
20	0.06

ASHRAE85

$k_T = k_T \times k_{Re}$ k_{Re} = Reynolds No. correction

$R_e \times 10^{-4}$	1.0	2.0	3.0	4.0	6.0	8.0	10.0	≥14.0
k_{Re}	1.40	1.26	1.19	1.14	1.09	1.06	1.04	1.0

FITTING No. 022 RECTANGULAR MITRE BEND WITH BUFFER

ASPECT RATIO H/W	k_T
0.25	1.57
0.5	1.52
1.0	1.43
2.0	1.29
4.0	1.10
6.0	1.02
8.0	0.98

U.S.A.E.C.

Fitting Angle connection as for Fitting No. 021

$k_T = k'_T \times k_{Re}$ k_{Re} = Reynolds No. correction

$R_e \times 10^{-4}$	1.0	2.0	3.0	4.0	6.0	8.0	10.0	≥14.0
k_{Re}	1.40	1.26	1.19	1.14	1.09	1.06	1.04	1.0

Fig 6-30 B Total Loss Coefficients for Duct Fittings (K_T based on V_D)

Fig. 6-30B

Figure 3: DA03 Fitting 021 and Fitting 022 Rectangular bends.

Rectangular duct design is typical in most systems due to cost of manufacture and ease of installation. The table only has 0.25 as the lowest height-to-width (H/W) value. As such, the k_T factors for these bends with aspect ratio 8:1 would not be found in the table because the case study duct (wide but shallow) H/W value is 1/8 or 0.125. The k_T factors for H/W at 0.25 are 1.3 and 1.57, respectively for the fittings 021 and 022, for an H/W ratio of 0.125 an interpolation using a best-fit curve to determine the k_T factor is required.

The calculation of the total pressure loss through fittings is based on the square of the velocity in the ductwork. Therefore, a high velocity will result in a high loss through fittings with high aspect ratios.

$$\Delta P = 0.6 * k_T * V^2$$

The pressure drop through fittings is therefore highly dependent on the velocity in the ductwork, and if ductwork is reduced in size due to practical considerations associated with the ceiling space, there is no option but to run ductwork with higher velocities.

RE-CONFIGURE THE DUCTWORK DESIGN

The calculations above show that the ductwork will need to be redesigned for this system. Ductwork with an aspect ratio of 15.5:1 cannot be used and a different solution is required. Things to consider in the redesign of the system ductwork and also the Air Handling Unit are:

- Consider if the plant room can be relocated so the girder beam is not near the AHU and hence the main duct branch has more ceiling space
- Review the architectural design and other services to determine the ductwork path that works parallel to the girder beam and only crosses under the girder beam for smaller branch ducts
- Have localised duct sections that pass under the girder beam, with ductwork either side being in a more reasonable aspect ratio of 4:1
- Consider localised reduction of the insulation where ductwork passes under the girder beam; compensate with thicker insulation in other areas
- Consider a performance-based solution and energy assessment to provide a performance solution using comparison to the DtS provisions.

CONCLUSION

Ductwork sizing is important in the determination of the pressure drop within a system that the fan must overcome. The fan power is proportional to the total pressure drop in the system. For the energy efficiency of the air conditioning system, it is very important that the envelope line, location of the building insulation and available ceiling space are all taken into consideration.

The size of ductwork and the aspect ratio of the duct impacts on the buildability of the HVAC system and also on construction costs. It is important to make sure aspect ratios greater than 4:1 are not exceeded because the impact on the pressure loss in a system at fittings will be more significant with a high aspect ratio.

Duct insulation thickness impacts on the air path available within a ductwork system, and the insulation applied to ductwork is linked to the location of the envelope line for the building. Making sure the insulation applied to the ductwork is appropriate to the installation and ensuring the insulation requirements are balanced against the fan power consumption affects the system's overall efficiency.

ABOUT THE AUTHOR

Ken Thomson, M.AIRAH, has more than 25 years' experience in the building industry, and has completed numerous projects in ESD and mechanical design. These projects include HVAC system design, documentation and commissioning (including undertaking CFD analysis, façade design and analysis, and daylight and glare assessments), as well as post-occupancy inspections, energy audits and building condition audits.

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