Estimating the heat flux on walls from fires in adjacent lower roofs

There is no specific method for calculating the thermal impact of fires from roofs in New Zealand Building Code Verification Method C/VM2 or in the scientific literature. BRANZ investigated adapting related published research and modelling approaches for this purpose, validated by limited small-scale experimental fires. The initial modelling suggests that New Zealand's general and specific Building Code requirements to mitigate fire spread from lower roofs are conservative in some, but not all, realistic fire situations. The recommended one-size-fits-all approach may not be appropriate for some building configurations.

Fire spread between adjacent buildings can occur when a fire plume develops above a roof and impacts adjacent taller buildings (Figure 1). A fire plume above a roof can be caused by:

- a fire within the building penetrating through the roof through an opening caused by heat failure of roof elements or an intentional opening in the building design
- ignition within the roof itself or on the external surface of the roof
- flames from a large fire exiting windows or gaps in the external walls and reaching above the roof.

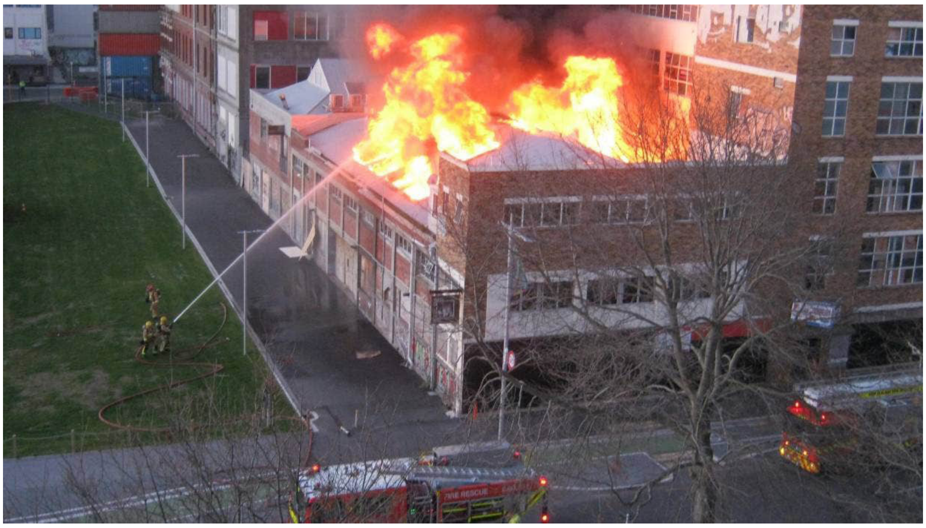


Figure 1. Roof fire and adjacent taller buildings at risk (Sol Square, Christchurch, July 2016). Photo: Brian Dimbleby. Reproduced with permission.

Weather conditions, especially wind, may also influence the size and shape of the flame plume and the amount of heat reaching adjacent buildings.

The risk of fire spreading from a lower roof to adjacent buildings is mitigated in the New Zealand Building Code through general performance-based and specific prescriptive requirements. Verification Method C/VM2 includes limits for radiant heat flux at certain distances across property boundaries and requires that buildings are designed to limit external fire spread. Acceptable Solutions C/AS1 and 2019 C/AS2 (previously C/AS2 to C/AS7) address fire spread from lower roofs directly through requirements for building fire resistance into adjacent roofs and walls. Fire resistance in lower roofs will protect against fire plumes penetrating through roofs, whereas fire resistance in adjacent walls will shield against all three causes of fire plumes listed above. See box for more details.

The physical effects of fires from roofs are not fully understood. BRANZ undertook this research because a better understanding of the thermal impact of fires from roofs on adjacent external walls could determine whether the present rules are appropriate and potentially refine these requirements in the New Zealand building regulations.

Available models and small-scale validation

BRANZ undertook a literature review on methods to evaluate the thermal impact from lower roofs. Although no specific published methodology was found, there were related radiation and flame geometry models available that could be applied to the problem.

Previous work had investigated the heat exposure on external walls from nearby unprotected wall areas or openings in adjacent

Building Code requirements relating to fire spread from lower roofs to adjacent buildings

The intention of the building regulations is to restrict the further spread of a fire by limiting the heat exposure of potentially ignitable objects on the exterior of buildings or inside unprotected areas such as windows.

Building Code general performance-related requirements

Clause C3.5 requires buildings to be designed and built so that fire does not spread more than 3.5 m vertically from the fire source over the external cladding of multi-level buildings (see also Verification Method C/VM2 design scenario 4.6 *VS External vertical fire spread* Part C).

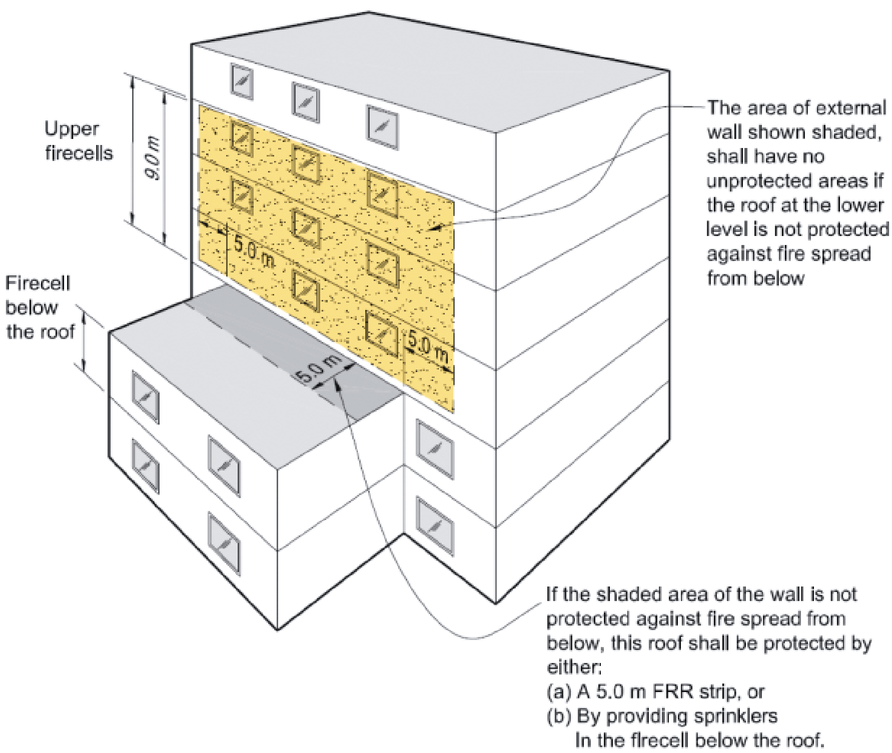
Clause C3.6 requires that buildings are designed so that heat radiation from fire does not exceed 30 kW/m² at a relevant boundary or 16 kW/m² to 1 m beyond the relevant boundary.

Clause 3.7 states that external walls of adjacent buildings closer than 1 m from the boundary must either:

- be non-combustible
- for buildings defined in the Building Code as Importance Level 3 and 4, not ignite for 30 minutes when subjected to 30 kW/m² radiant flux
- for Importance Level 1 and 2 buildings, not ignite for 15 minutes when subjected to 30 kW/m² radiant flux.

Specific prescriptive requirements in Acceptable Solutions C/AS1 and 2019 C/AS 2 (previously C/AS2 to C/AS7)

Figure 5.2: **External walls and roof, vertical fire spread**
New Zealand Building Code Acceptable Solution C/AS3



buildings or pool fires (a fire burning over a pool of liquid, vaporising fuel). Models were developed to estimate the heat emanating from fire sources and the effect on a nearby target (in this case, an external wall). These were based on point source, vertical cylinder and tilted cylinder configurations.

The point source model is widely used and is considered relatively accurate compared to other models for estimating the effect of heat from fire on targets in compartments (fire compartments are discrete areas within buildings designed to limit the spread of fires). This type of model assumes the fire is a sphere radiating heat in all directions. The sphere's location is based on flame height and tilt.

Modelling the fire as a vertical cylinder is an alternative approach and gives the model another dimension. A tilted cylinder model can then represent flame under wind conditions. Other models were identified to estimate fire heat release rate and flame geometry as necessary inputs.

None of these models had been validated for fire spread from lower roofs. BRANZ undertook a series of small-scale fire experiments to provide an initial basis to validate them, including:

- experiments in the open air and in compartments with ceiling openings
- propane, heptane and wood fuels (with a range of surface areas for the propane and heptane)
- moving the ceiling openings and fuel location relative to a vertical wall panel containing sensors to measure heat flux.

These experiments provided some indication of how these models perform, but fire experiments at larger scales will be necessary to improve confidence in the modelling.

Modelling heat flux from a lower roof on adjacent buildings

The models were applied to fires in hypothetical building geometries (an 8 m square compartment with an unrated roof and varying fire size, flame heights, roof vent size and flame tilt) so that their output could be compared with the current prescriptive requirements in the regulations.

The potential heat flux was calculated using maximum flame height estimates (including tilted scenarios) from NFPA 80A *Recommended practice for protection of buildings from fire exposure*. Heat release rates from roof fires were estimated from these maximum flame heights.

A comparison of the different types of model showed that the point source and cylindrical models provided similar estimations of heat flux, particularly at lower flux levels. The cylindrical modelling is slightly more conservative and predicted higher heat fluxes for a given position.

Using these modelling approaches and validated by the experimental data, BRANZ calculated values for the maximum vertical and horizontal extent of heat flux levels ranging from 12.5 kW/m² to 50 kW/m² for 1 to 4 storeys contributing to the fire for plumes with no tilt (Table 1) and fire plumes with a 45° tilt (Table 2). Percentages shown are relative to the current New Zealand fire resistance

Table 1. Modelled extent of heat flux (left column) received on roof and adjacent wall from different sizes of square roof vent with no flame tilt. [From SR409 page 74 table 13 and 16]

FH = 3 M/STOREY X 1.4 STOREYS FLAME HEIGHT (1 STOREY INVOLVED)

ALLOWABLE HEAT FLUX (KW/M²)	PROTECTED WALL HEIGHT/HORIZONTAL SEPARATION	ROOF VENT SIZE/HRR* 5 M 12 MW	10 M 39 MW	15 M 84 MW	20 M 152 MW
12.5	Wall	5.9 / 66%	7.8 / 86%	10.4 / 116%	13.3 / 148%
	Roof	3.6 / 71%	4.3 / 85%	6.2 / 124%	8.4 / 168%
16	Wall	5.4 / 60%	6.9 / 77%	9.2 / 102%	11.7 / 130%
	Roof	2.9 / 58%	3.4 / 69%	4.6 / 92%	6.3 / 126%
20	Wall	4.8 / 54%	6.2 / 69%	8.1 / 90%	10.2 / 113%
	Roof	2.3 / 46%	2.7 / 55%	3.3 / 66%	4.6 / 91%
25	Wall	4.3 / 48%	5.4 / 60%	6.9 / 76%	8.6 / 96%
	Roof	1.8 / 36%	2.1 / 42%	2.2 / 44%	3.0 / 61%
30	Wall	4.2 / 47%	4.7 / 52%	5.8 / 65%	7.2 / 80%
	Roof	1.4 / 27%	1.6 / 31%	1.5 / 29%	1.9 / 38%
50	Wall	4.0 / 45%	0.0 / 0%	0.0 / 0%	0.0 / 0%
	Roof	0.1 / 2%	0.0 / 0%	0.0 / 0%	0.0 / 0%

FH = 3 M/STOREY X 2.6 STOREYS FLAME HEIGHT (4 STOREYS INVOLVED)

ALLOWABLE HEAT FLUX (KW/M²)	PROTECTED WALL HEIGHT/HORIZONTAL SEPARATION	ROOF VENT SIZE/HRR* 5 M 27 MW	10 M 65 MW	15 M 124 MW	20 M 208 MW
12.5	Wall	9.5 106%	11.3 126%	14.2 158%	17.2 192%
	Roof	5.2 104%	7.0 140%	9.1 182%	11.5 230%
16	Wall	9.0 100%	10.5 116%	12.9 144%	15.5 173%
	Roof	4.3 86%	5.6 112%	7.2 144%	9.0 180%
20	Wall	8.4 94%	9.7 108%	11.8 131%	14.1 156%
	Roof	3.6 72%	4.5 90%	5.6 113%	7.0 140%
25	Wall	8.0 89%	9.0 100%	10.7 119%	12.6 140%
	Roof	2.9 59%	3.5 70%	4.3 85%	5.2 104%
30	Wall	7.9 88%	8.4 93%	9.8 109%	11.3 126%
	Roof	2.5 49%	2.7 55%	3.2 65%	3.9 78%
50	Wall	7.8 86%	6.5 72%	6.8 75%	7.1 79%
	Roof	1.4 27%	1.0 20%	0.8 16%	0.8 15%

Table 2. How a 45º tilt in the flame plume towards the adjacent wall could influence the fire-plume envelope and the extent of heat flux received on adjacent wall (left column).

FH = 3 M/STOREY X 1.4 STOREYS FLAME HEIGHT (1 STOREY INVOLVED)									
ALLOWABLE HEAT FLUX (KW/M²)	HORIZONTAL SEPARATION	ROOF VENT SIZE/HRR 5 M 12 MW		10 M 39 MW		15 M 84 MW		20 M 152 MW	
12.5	No tilt / 45º tilt	3.6 /	4.9	4.3 /	5.8	6.2 /	7.7	8.4 /	9.9
	% increase / % relative to 5 m	38%	98%	35%	115%	24%	154%	18%	198%
16	No tilt / 45º tilt	2.9 /	4.3	3.4 /	4.7	4.6 /	6.1	6.3 /	7.8
	% increase / % relative to 5 m	51%	87%	37%	94%	32%	122%	24%	155%
20	No tilt / 45º tilt	2.3 /	3.9	2.7 /	4.1	3.3 /	4.8	4.6 /	6.1
	% increase / % relative to 5 m	69%	78%	51%	83%	45%	96%	33%	121%
25	No tilt / 45º tilt	1.8 /	3.5	2.1 /	3.6	2.2 /	3.7	3.0 /	4.5
	% increase / % relative to 5 m	98%	71%	74%	73%	68%	73%	49%	90%
30	No tilt / 45º tilt	1.4 /	3.3	1.6 /	3.3	1.5 /	3.2	1.9 /	3.4
	% increase / % relative to 5 m	141%	66%	109%	66%	117%	63%	78%	68%
50	No tilt / 45º tilt	0.1 /	2.7	0.0 /	1.1	0.0 /	0.8	0.0 /	0.7
	% increase / % relative to 5 m	2124%	54%	N/A	22%	N/A	17%	N/A	14%

FH = 3 M/STOREY X 2.6 STOREYS FLAME HEIGHT (4 STOREYS INVOLVED)									
ALLOWABLE HEAT FLUX (KW/M²)	PROTECTED WALL HEIGHT/ HORIZONTAL SEPARATION	ROOF VENT SIZE/HRR 5 M 27 MW		10 M 65 MW		15 M 124 MW		20 M 208 MW	
12.5	No tilt / 45º tilt	5.2 /	8.0	7.0 /	9.8	9.1 /	11.9	11.5 /	14.3
	% increase / % relative to 5 m	53%	159%	39%	195%	30%	238%	24%	286%
16	No tilt / 45º tilt	4.3 /	7.1	5.6 /	8.4	7.2 /	9.9	9.0 /	11.8
	% increase / % relative to 5 m	66%	143%	49%	167%	38%	199%	31%	236%
20	No tilt / 45º tilt	3.6 /	6.6	4.5 /	7.2	5.6 /	8.4	7.0 /	9.8
	% increase / % relative to 5 m	84%	132%	62%	145%	49%	168%	39%	195%
25	No tilt / 45º tilt	2.9 /	6.1	3.5 /	6.3	4.3 /	7.0	5.2 /	8.0
	% increase / % relative to 5 m	108%	123%	82%	127%	65%	140%	53%	159%
30	No tilt / 45º tilt	2.5 /	5.8	2.7 /	5.9	3.2 /	6.0	3.9 /	6.6
	% increase / % relative to 5 m	136%	117%	115%	118%	85%	120%	71%	133%
50	No tilt / 45º tilt	1.4 /	5.5	1.0 /	3.8	0.8 /	3.6	0.8 /	3.5
	% increase / % relative to 5 m	304%	109%	N/A	75%	N/A	71%	N/A	70%

requirements - 9 m vertical (adjacent wall) and 5 m horizontal (lower roof) - with green shading meeting the current Acceptable Solution requirements and red shading exceeding them.

Separate modelling showed that the wind velocity needed to produce a 45° tilt is relatively low (less than 15 km/hr) - well within conditions that can be expected in most of New Zealand.

Discussion

The preliminary modelling presented here shows how the flame height and the size of the roof vent can influence the degree of heat flux received on adjacent surfaces and its horizontal or vertical extent. The results show that having a single one-size-fits-all requirement does not do a good job of representing the potential risk for a range of typical building configurations.

There are situations, particularly for smaller single-storey buildings, where reducing the requirements may be justified. At the opposite end of the spectrum, additional horizontal separation distance may be warranted if a roof fire in a building with a large multi-storey fire compartment could result in prevailing winds tilting a flame plume in the direction of a higher external wall.

Requiring ignition-resistant external wall materials with wall fire resistance ratings that are based on the expected incident heat flux would be more justifiable than the present fire resistance rating requirements. It is also not certain whether an intermediate combination of fire protection requirements in roofs and adjacent walls (for example, 7 m vertical and 3 m horizontal) could provide an equivalent level of safety.

Further experiments at intermediate or full scale are needed to provide a more certain validation of the modelling.

Recommendations

- Future work to develop experimental validation data of the flame height, tilt and heat radiation at larger scales is necessary to improve confidence in model performance.
- Modelling the effect of non-square roof vents would be useful.
- Analysing fire incident data may improve the understanding of this risk for typical building configurations in New Zealand, including the probability of full roof collapse.
- Any future changes to prescribed Building Code requirements should be made in context with general roof and wall fire protection requirements.

Further reading

Study Report SR409 *Fire spread from lower roofs*

BRANZ Research Now: Fire safety design #5 *Estimating the heat flux on walls from fires in adjacent lower roofs*