

COMPUTATIONAL ANALYSIS OF REFLECTIVE AIR SPACES

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SUMMARY

The space shuttle does it, and now conventional bulk insulations are doing it. Reflective foil provides significant and economic insulation enhancement from adjacent empty space.

The power of modern personal computers has enabled rapid prediction of the thermal performance of new building sections incorporating reflective insulation. Selected research findings are presented. The traps and tricks of reflective insulation are also discussed.

1 INTRODUCTION

The insulation rating of practically all materials is sensitive to insulation mean temperature. Typically, the higher the temperature, the lower the insulation rating. For most materials, this effect is relatively small. In contrast, the insulation rating of reflective air spaces is particularly sensitive to boundary conditions, and so values can rarely be generalised. As a consequence, insulation manufacturers, building accrediting authorities and designers have had occasional misunderstandings and headaches when reflective insulation is concerned. This paper will firstly discuss general properties of reflective insulating cavities, then discuss their application as an adjunct to conventional insulation and building materials.

2 THE BEHAVIOUR OF REFLECTIVE INSULATING CAVITIES

The heat flow across an unventilated cavity having parallel reflective surfaces results from:

- Radiation,
- Convection, and
- Conduction.

The surface heat transfer by radiation is minimised by using as bright a Reflective Foil Laminate (RFL) as possible. If sun-glare from reflections is likely to be a problem to installers or others; aluminium foil with a dull, "anti-glare" surface treatment can be used.

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U.S.A. Division of Housing Research Paper 32 [1] (HR32) provides detailed procedures for evaluating the **radiation** heat transfer which depends on the emittances and temperatures of the surfaces facing the air spaces, and the **convection** and **conduction** heat transfer which does not depend on the surface emittances but does vary with the cavity gap, orientation and direction of heat flow, and the temperatures of the surfaces.

Robinson and Powlitch in HR32 provide graphical methods for determining the reflective cavity insulation rating based upon extensive testing and theoretical modelling.

Calculation of the total thermal resistance through reflective spaces involves an iterative procedure. The air space mean temperature and temperature drop are estimated using an initial assumed space resistance; then the resistance of the air space is determined by the Robinson and Powlitch method. This enables improved estimation of the air space mean temperature and temperature drop, and further calculations.

This Robinson and Powlitch HR32 method has been almost universally accepted and has been the original source for data found in ASHRAE, AIRAH and other handbooks. Although complex to apply manually, the original equations and graphs are amenable to computational analysis which Enersonics has undertaken. The HR32 graphs have been curve fitted with Visual Basic functions. The iterative calculations required are then speedily completed by a modern personal computer.

3 SUMMARY OF THE PROPERTIES OF REFLECTIVE CAVITIES

Graphs 1 to 4 in Appendix 1 are based upon the HR32 equations (1)--(5), and Figure 8.

These illustrate:

- **Graph 1**. The brighter the surfaces, the greater the thermal resistance (however a bright surface facing a dull surface is nearly as effective as for both surfaces bright).
- **Graph 2**. Generally, the greater the air gap, the greater the thermal resistance (particularly for heat flow down).
- **Graph 3**. The greater the temperature difference across the cavity, the greater are any convection currents, leading to reduced thermal resistance (particularly for heat flow up).
- **Graph 4**. Generally, the greater the cavity mean temperature, the lower the thermal resistance (particularly for heat flow down).
- Any convection currents generated by the buoyancy effects of heated air reduce thermal resistance. Within horizontal cavities, this effect is greatest for heat flow up, and least for heat flow down. Sloping and vertical cavities have intermediate levels of convection currents and thermal resistance.

Thus reflective cavities have maximum thermal resistance when they are designed to have minimum temperature drop across the reflective cavity, i.e., when they are combined with other resistive elements, e.g. polystyrene, fibreglass, or other reflective cavities.

4 EMITTANCE

The following table lists typical surface emittances and the combined emittance (E) calculated by $E=1/(1/e_1+1/e_2-1)$ where e_1 and e_2 are the emittances of the parallel facing surfaces.

		COMBINED EMITTANCE OF AIR SPACE calculated by $E=1/(1/e_1+1/e_2-1)$					
Surface	e_1 \ e_2	0.03	0.05	0.11	0.20	0.28	0.87
Bright RFL [4]	0.03	0.015	0.019	0.024	0.027	0.028	0.030
Bright RFL [3]	0.05	0.019	0.026	0.036	0.042	0.044	0.050
Aluminium	0.11	0.024	0.036	0.058	0.076	0.086	0.108
Anti-glare RFL	0.20	0.027	0.042	0.076	0.111	0.132	0.194
Galvanised Iron	0.28	0.028	0.044	0.086	0.132	0.163	0.269
Building materials: wood, brick etc	0.87	0.030	0.050	0.108	0.194	0.269	0.770

Table 1 (Data from Table E2 [2], Table 3 pg 22.3 [3], and [4])

Modern foils typically have emittances of 0.03 [4]. A conservative value often still used is 0.05. If an upward facing reflective surface collects dust, its emittance will reduce, however the layer of dust formed will, in itself, become a thin layer of bulk insulation. There is a trade-off that requires further research. Anti-glare reflective foil laminate surfaces typically have emittances of 0.2, however there are recent reports that some are as poor as 0.35 [6].

ASHRAE Fundamentals [3] states "Polluted environments may cause rapid and severe material degradation. However, site inspections show a predominance of well-preserved installations and only a small number of cases in which rapid and severe degradation has occurred." Based upon the application and environment, appropriate emittances must be selected for reflective cavity thermal resistance calculations.

5 SELECTED APPLICATIONS OF REFLECTIVE INSULATION

This section shows some results of our research in optimising application of reflective insulating cavities. The method used is our computerised version of the HR32 method, allied with thermal resistance data in the AIRAH Handbook [5]. The results discussed are the final, converged results of many iterations.

Appendix 2 shows calculations for the overall thermal resistance of a 150mm slab concrete roof having asphalt roll roofing above and a single 50mm reflective cavity beneath, for summer. Similar calculations (not shown) reveal the significant thermal resistance improvement if the single 50mm reflective cavity is replaced with double 25mm reflective cavities.

Similar calculations were performed for a tilt slab wall, with and without a reflective cavity between an R0.6 sheet of polystyrene and a 150mm tilted concrete slab. (10mm plasterboard was adjacent the polystyrene sheet.)

OVERALL THERMAL RESISTANCES OF SOME BUILDING SECTIONS ($m^2.K/W$)		
Flat concrete slab roof	Winter	Summer
with no insulation:	0.3	0.3
with single 50mm reflective cavity beneath:	0.9	2.0
with double 25mm reflective cavity beneath:	1.5	2.3
Concrete tilt-slab wall with R0.6 Polystyrene	Winter	Summer
with no cavity:	0.9	0.9
with single 25mm reflective cavity:	1.7	1.6

Table 2. Note: All cavities are unventilated.

For the **roof** results, it is evident that the thermal resistance contribution of the extra reflective cavity is greater in winter (67% c.f. 15%), and that the summer heat-flow-down thermal resistance is substantially larger than for the winter heat-flow-up situation.

The roof example also shows that for the same total building section thickness, multiple smaller reflective cavities have greater thermal resistance than a single larger cavity, especially in winter. The roof results also illustrate that roof summer thermal resistance is normally substantially greater than the winter's.

For the **wall** results, inclusion of a single (affordable) reflective cavity nearly doubles the overall thermal resistance. The summer value is slightly less than the winter overall value because of the particular cavity temperature differences used (4.6K summer c.f. 2.8K winter). However, calculated summer and winter thermal resistances are similar, showing that normally only one wall calculation set is required.

6 THE TRAPS

Once it is clearly understood that the thermal resistance of reflective cavities is very dependent on temperature boundary conditions (mean temperature, and temperature difference), and that any convection currents reduce thermal resistance, it is easy to avoid the following traps:

- doing a single first-guess calculation instead of converged iterations;
- applying a flat roof system R-value to a sloping roof;
- applying a mild winter R-value to a severe climate application, e.g. in the alps;
- applying a shaded roof summer R-value to a sunlit roof;
- ignoring the derating required when using anti-glare foils instead of bright foils;
- ignoring dust collection in ventilated roof spaces on upward facing foil surfaces;
- failing to maintain a uniform separation between cavity opposing surfaces. (Having non-parallel surfaces in reflective cavities might exacerbate convection currents and thermal short-circuits, so HR32 evaluation methods may not apply.)

7 THE TRICKS

There are no tricks apart from:

- the requirement to perform rigorous iterative calculations based upon HR32 [1] for the specific boundary conditions, and
- prevent dust degrading foils by facing bright foils down instead of up.

8 CONCLUSION

By the use of today's fast and friendly personal computers and programming languages, the work of Robinson and Powlitch [1] has been extended to allow thermal performance evaluation of new building sections incorporating reflective insulation. In particular, reflective unventilated cavities can be used to economically boost the overall thermal performance of various bulk insulations.

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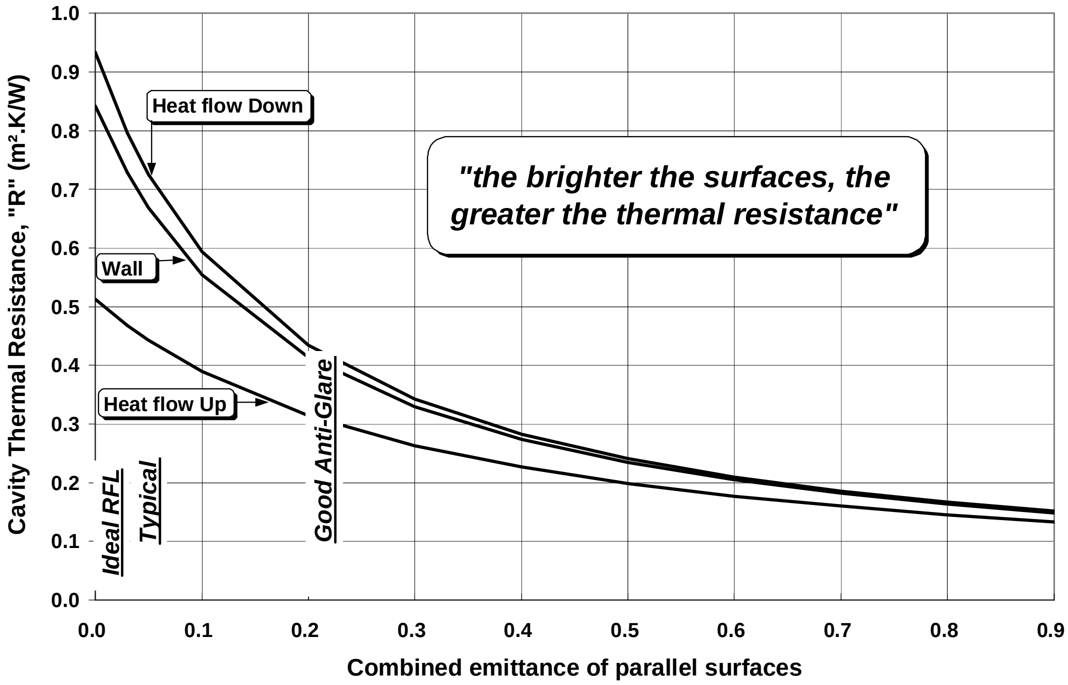
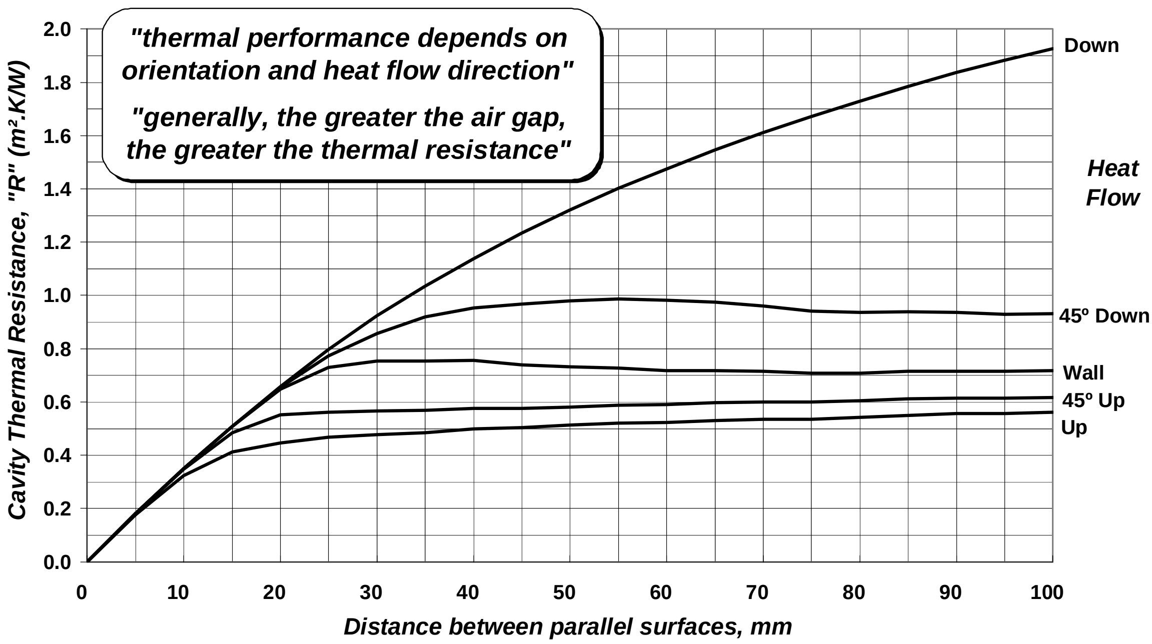
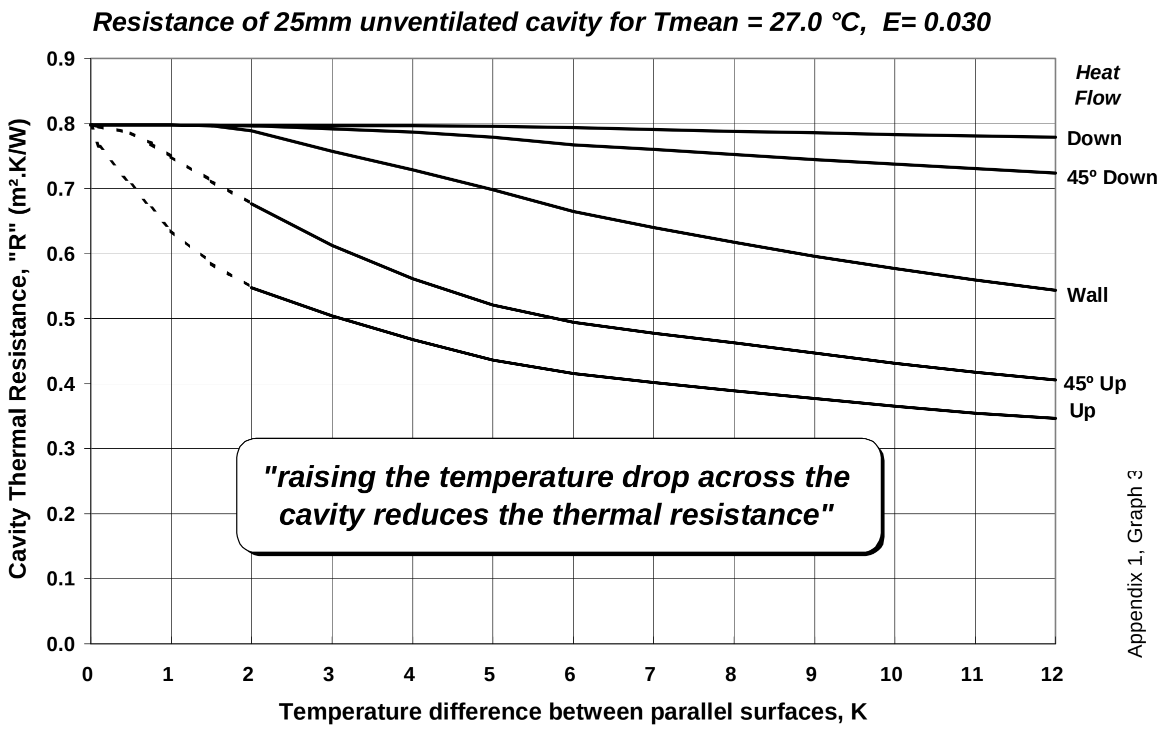
Resistance of 25mm unventilated cavity for Tmean = 27.0 °C, dT= 4.0 K

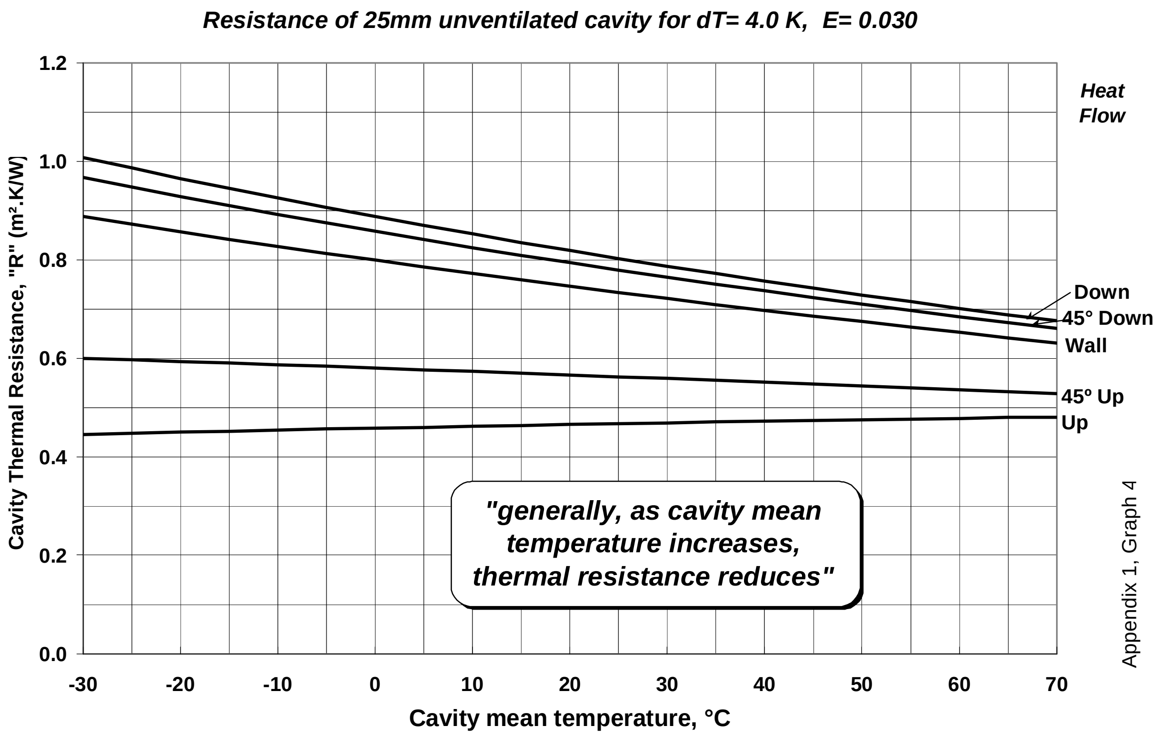


Appendix 1, Graph 1

Resistance of unventilated cavity for Tmean = 27.0 °C, dT= 4.0 K, E= 0.030




Resistance of 25mm unventilated cavity for Tmean = 27.0 °C, E= 0.030
Cavity Thermal Resistance, "R" (m².K/W)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
6
7
8
9
10
11
12
Temperature difference between parallel surfaces, K
Heat Flow
Down
45° Down
Wall
45° Up
Up
"raising the temperature drop across the cavity reduces the thermal resistance"
Appendix 1, Graph 3


Resistance of 25mm unventilated cavity for dT= 4.0 K, E= 0.030
Cavity Thermal Resistance, "R" (m².K/W)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-30
-20
-10
0
10
20
30
40
50
60
70
Cavity mean temperature, °C
Heat Flow
Down
45° Down
Wall
45° Up
Up
"generally, as cavity mean temperature increases, thermal resistance reduces"
Appendix 1, Graph 4