Heat-losss through transparent honeycomb insulation

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ABSTRACT

The use of a transparent honeycomb structure for insulation is viable because it suppresses convective and radiative losses while increasing passive solar gains. The development of reliable methods for calculating the overall heat transfer through honeycomb materials helps predicting and optimising the thermal performance of honeycomb insulated buildings. Mathematical models have been created which yield design parameters for optimal geometry, material selection and application of honeycomb transparent insulation. The effects of these parameters on the U value is discussed.

MATERIAL DESIGN

A honeycomb structure divides the air-filled enclosure into a large number of cells. Due to the reduced dimensions of each cell in comparison to the single enclosure the viscous forces acting on the air in each cell are increased. If the cell is dimensioned correctly the onset of natural convection can be shifted to larger temperature differences. This also gives the opportunity to increase the distance bewteen plates which improves the insulating contribution of the air layer trapped in the cells.

The honeycomb walls should be made thin so that the loss of radiation and the conductive heat loss through the material could be kept very small compared to the benefit which is reached by the suppression of natural convection. The selection of the material used for making the honeycomb is also important from an optical point of view: the refractive index has to be chosen correctly.

SIMULATION

Hollands (1984) showed a strong coupling between the radiation and conduction modes of heat transfer. In our work a coupled mode heat transfer model adjusted with an air gap between the absober and transparent insulaton has been used to determine the dependence of U-value of honeycomb insulation on different dimensional and material characteristics. Selected parameters such as cover plate emissivity (e_c), absorber plate emissivity (e_a) and air gap in four assumed and near limit configurations are listed below.

Configuration	*Cover emissivity*	*Absorber emissivity*	*Airgap*
1	0.9	0.9	no
2	0.9	0.1	no
3	0.1	0.1	no
4	0.9	0.	yes

For sample calculations a honeycomb structure similar to AREL's Thermode has been chosen with an average cell size of 3.5 by 3.5 mm, cell length of 100 mm, and wall thickness of 0.03 mm, made of polycarbonate . All the calculations have been made at constant average temperature of 15 °C and at a temperature difference of 10 °C between the end plates.

The overall U-value has been calculated as a function of the emissivity of the sidewalls and conductivity of honeycomb shown in Fig. 1. The nature of the curves can be best understood by considering separately the dependence of radiation and conduction heat transfer as a function of sidewall emissivity (Fig. 2).

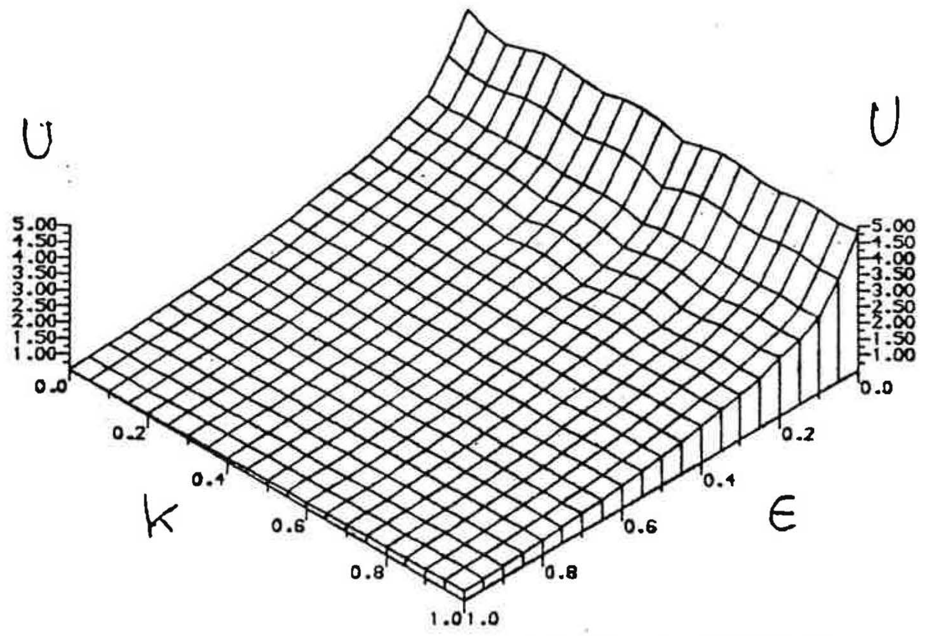

Fig. 1 U-value as a function of conductivity (k) and emissivity (e)

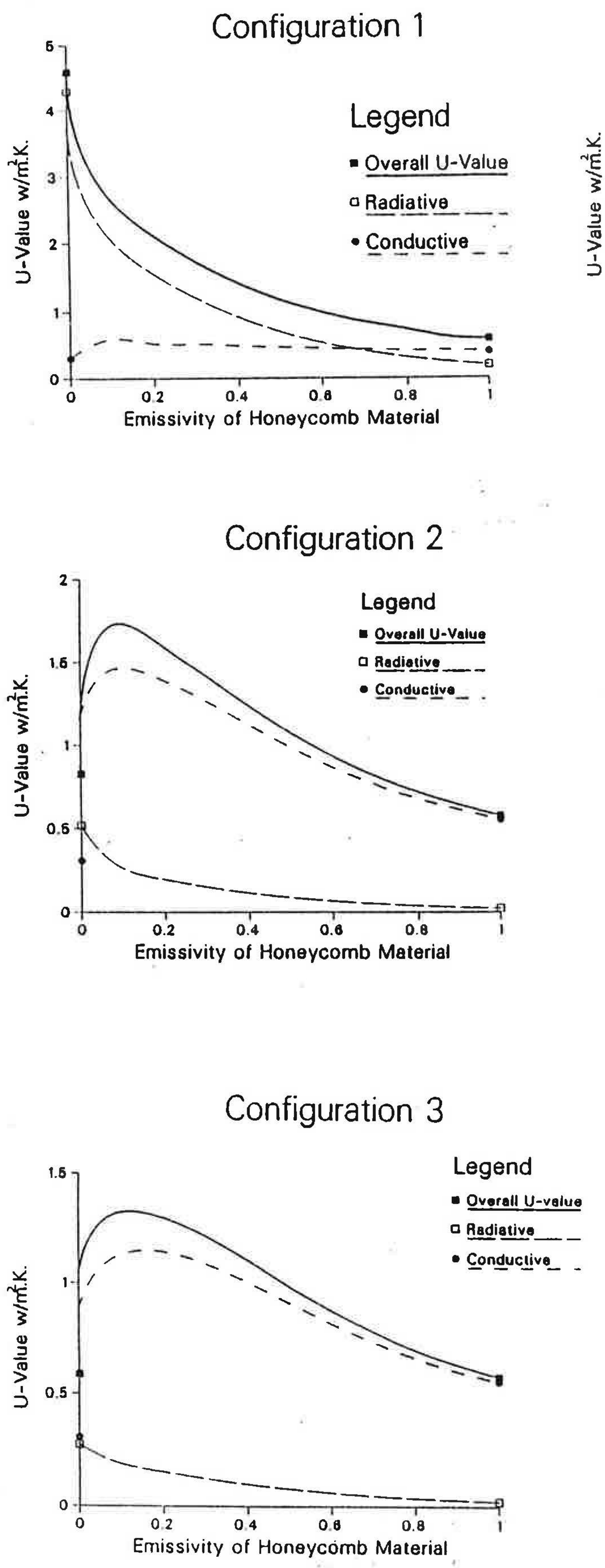

Fig. 2 U-value as a function of emissivity for configurations 1, 2, 3

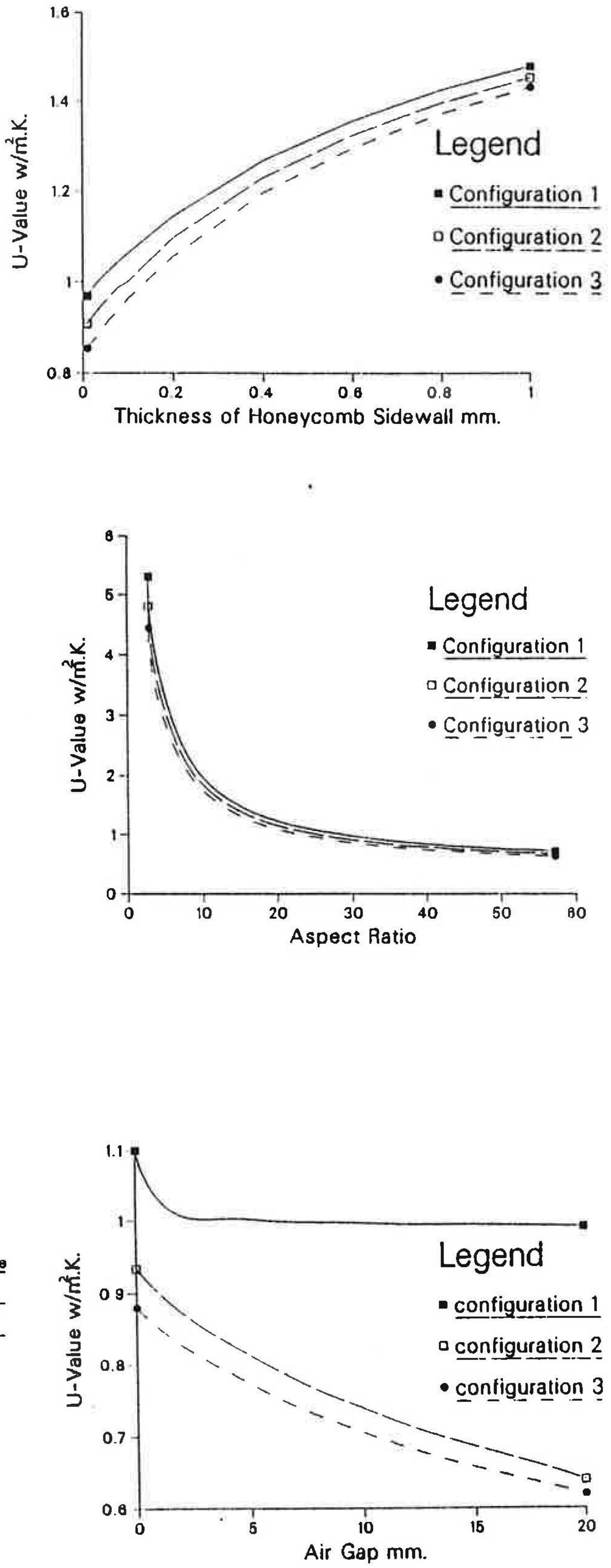

Fig. 3 U value as a function of structural geometry for configurations 1,2,3

COUPLED MODE HEAT TRANSFER

Radiation heat transfer through the honeycomb decreases with an increase in sidewall emissivity as a result of an increase in radiation shielding by the sidewall. No radiation shielding occurs when the sidewall emissivity is zero and the maximum shielding occurs when the sidewall emissivity is one.

Conduction heat transfer through the absorber surface, when the sidewall emissivity is zero, is equal to the independent mode conduction heat transfer since no radiative-conductive coupling exists. When the sidewall emissivity is increased from zero: the radiative-conductive coupling causes the heat conducted through the absorber surface first to increase to a maximum value and then to decrease as the sidewall emissivity increases.

The initial increase at low sidewall emissivities is a result of an increase in radiation assisted conduction coupling. As the sidewall emissivity is further increased the increase in resistance to radiation transmission becomes stronger resulting in decreased conduction heat transfer as the sidewall emissivity increases.

As seen in Figure 2 for configurations 2 and 3 the overall U-value for low emissivity sidewalls increases with an increase in emissivity. This increase in overal U-value results from the greater increase in conduction with increase in emissivity compared to the reduction in radiation as a result of the increase in radiation shielding. For configuration 1 it can be seen from Figure 2 that the heat transfer due to radiation is more dominant thus the increased conduction with increase in emissivity has a weaker effect on the overall heat transfer. Hence it can be concluded that there will always be a decrease in over all U-value with an increase in sidewall emissivity for high emissivity honeycombs since both conduction and radiation heat transfer decreases with an increase in sidewall emissivity.

It can also be concluded that if a honeycomb has plates such as black paint or glass then the greater the honeycomb emissivity the lower the heat losses will be. If however one or both of the bounding sufaces have a reduced emissivity then design curves similar to the ones shown for configuration 2 and 3 should be studied before selecting a cell emissivity configuration.

The size of the cell was fixed at 3.5 mm and the aspect ratio has been varied by changing the cell length of honeycomb. It is noted from Figure 3 that the U value of honeycomb decreases with an increase of aspect ratio. This effect has been expected since both the conductive and radiative heat transfer decreases with increase of the cell length.

The thickness of the sidewall has been varied from 0.01 to 1.0 mm keeping all other parameters constant. The first three configurations show qualitatively the same dependence of U-value on sidewall thickness. The conclusion is that overall U-value will be lower with thinner sidewalls.

THE INFLUENCE OF AN AIR GAP

The large effect that the mechanism of coupled heat transfer has on the total heat transfer can be reduced by the introduction of a gap between the honeycomb structure and the absorber wall i.e. at the place where the largest temperature gradients are expected. For a selective surface absorber large temperature gradients exist in the air and the honeycomb structure wall near the absorber. This induces large conductive heat transfer. Application of a gap shall decrease coupling between the heat transfer mechanisms locally and reduce overall heat transfer. Moreover the gap introduces an air layer which has a smaller thermal conductivity than the thermal conductivity of honeycomb structure wall. Figure 3 shows the effect of air gap thickness on U-value for configurations 1, 2 and 3. It is important however that the air gap thickness be restricted to prevent convection heat transfer to take place.

CONCLUSIONS

The best transparent insulation has high emissivity and thin walled honeycomb material with high aspect ratio and an air gap of about 20 mm thickness in front of a selectively absorbant mass wall.

REFERENCES

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